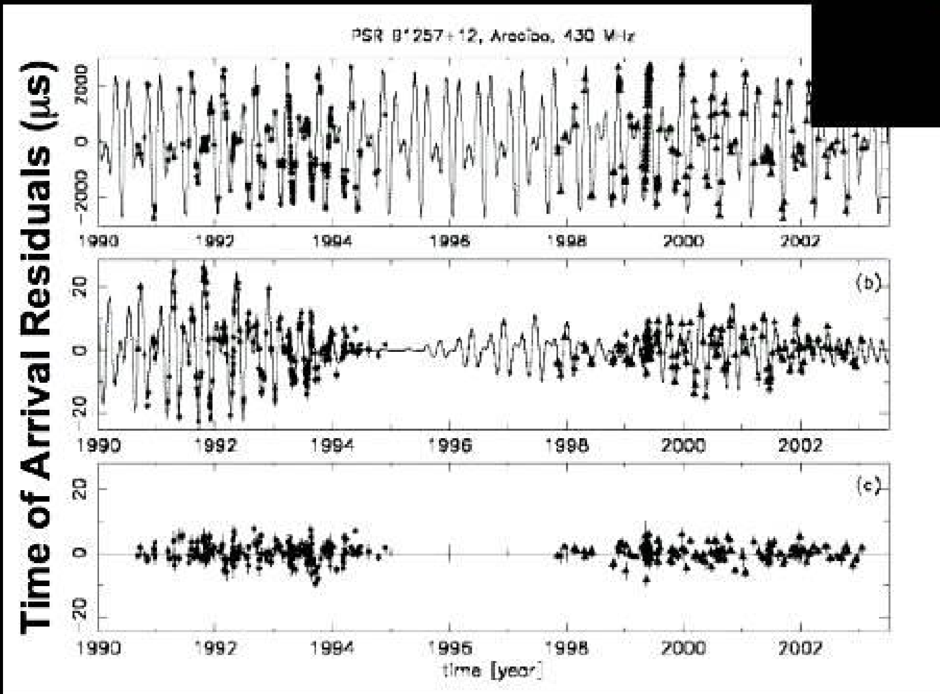
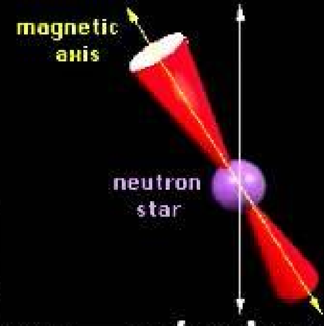
Konacki & Wolzsczan 03





w/o planets

with non-interacting planets

with real planets

1
00:00:04,670 --> 00:00:03,260
welcome to the special astrobiology

2
00:00:06,530 --> 00:00:04,680
seminar we're not holding them in

3
00:00:09,799 --> 00:00:06,540
general this quarter but we are for our

4
00:00:13,070 --> 00:00:09,809
faculty five eights and the last

5
00:00:15,049 --> 00:00:13,080
candidate will be three weeks from today

6
00:00:18,050 --> 00:00:15,059
and and you'll be getting notice about

7
00:00:19,820 --> 00:00:18,060
that we're delighted to have more today

8
00:00:21,859 --> 00:00:19,830
from broader Space Flight Center in the

9
00:00:24,650 --> 00:00:21,869
exoplanets and stellar astrophysics lab

10
00:00:27,830 --> 00:00:24,660
there on mark was an undergraduate at

11
00:00:30,259 --> 00:00:27,840
Harvard and then got his PhD under mike

12
00:00:34,910 --> 00:00:30,269
michael brown the other Mike round the

13
00:00:39,260 --> 00:00:34,920

photo fame or I should say not Pluto

14
00:00:41,479 --> 00:00:39,270
fame but it's not Pluto so much so

15
00:00:46,549 --> 00:00:41,489
what's the final name garrus garrus

16
00:00:48,950 --> 00:00:46,559
right thing and then he was a postdoc at

17
00:00:51,380 --> 00:00:48,960
at Harvard and at the center for

18
00:00:53,240 --> 00:00:51,390
astrophysics and then a Hubble fellow at

19
00:00:54,680 --> 00:00:53,250
Princeton and for the last couple years

20
00:00:58,060 --> 00:00:54,690
he's been at the Goddard Space Flight

21
00:01:00,830 --> 00:00:58,070
Center on he talked earlier today about

22
00:01:03,049 --> 00:01:00,840
optics designs that he's doing for the

23
00:01:04,100 --> 00:01:03,059
terrestrial planet finder mission but

24
00:01:05,990 --> 00:01:04,110
this afternoon he's going to be talking

25
00:01:09,080 --> 00:01:06,000
about carbon planets and water planets

26
00:01:15,860 --> 00:01:09,090
and what presto planet finder might be

27
00:01:34,250 --> 00:01:30,230
oh okay very nice now Thank You woody I

28
00:01:36,410 --> 00:01:34,260
had some trouble deciding and what the

29
00:01:39,620 --> 00:01:36,420
title of this talk should be I wasn't

30
00:01:42,980 --> 00:01:39,630
sure whether I should put an s here or

31
00:01:45,320 --> 00:01:42,990
not for compositions I decided in this

32
00:01:48,500 --> 00:01:45,330
version then instead of the composition

33
00:01:51,170 --> 00:01:48,510
of low-mass extrasolar planets I should

34
00:01:54,170 --> 00:01:51,180
be generous with the idea that there are

35
00:01:56,150 --> 00:01:54,180
lots and lots of low-mass extrasolar

36
00:01:58,430 --> 00:01:56,160
planets out there and so they deserve to

37
00:02:03,890 --> 00:01:58,440
be in the plural at least that's what I

38
00:02:13,550 --> 00:02:03,900

hope the situation is so here's where we

39
00:02:15,860 --> 00:02:13,560
are so far with our planet inventory we

40
00:02:21,229 --> 00:02:15,870
know a heck of a lot of planets around

41
00:02:23,360 --> 00:02:21,239
other stars roommate 209 and sis Tyler

42
00:02:27,199 --> 00:02:23,370
masses sort out most of them are

43
00:02:31,010 --> 00:02:27,209
jupiter-mass or larger you found a few

44
00:02:34,180 --> 00:02:31,020
recently that are approaching Neptune

45
00:02:37,760 --> 00:02:34,190
mass and even ones that are that are

46
00:02:42,440 --> 00:02:37,770
theirs we go there handful in the

47
00:02:46,010 --> 00:02:42,450
Neptune mass category but when I say a

48
00:02:48,830 --> 00:02:46,020
low-mass exoplanet I'm interested in the

49
00:02:53,479 --> 00:02:48,840
objects down here and the objects down

50
00:02:56,390 --> 00:02:53,489
here so kuro you may know is a mission

51
00:02:59,900 --> 00:02:56,400
that just launched in december and just

52
00:03:04,070 --> 00:02:59,910
saw first light last week that's French

53
00:03:08,360 --> 00:03:04,080
mission design to find extrasolar

54
00:03:10,250 --> 00:03:08,370
earth-like planets by transit survey and

55
00:03:12,380 --> 00:03:10,260
we hope that kuro will call by Kepler

56
00:03:17,710 --> 00:03:12,390
and of these two missions will shortly

57
00:03:20,990 --> 00:03:17,720
be turning in a decent inventory of real

58
00:03:21,720 --> 00:03:21,000
low mass exoplanets that we can study

59
00:03:25,290 --> 00:03:21,730
more geek

60
00:03:28,589 --> 00:03:25,300
and then my talk since afternoon which

61
00:03:34,170 --> 00:03:28,599
many poor patient enough to the 10 my

62
00:03:37,949 --> 00:03:34,180
lunch sock was about TPF which further

63
00:03:46,350 --> 00:03:37,959

ass masked extrasolar planets that we

64
00:03:50,100 --> 00:03:46,360
can study so you probably recognize this

65
00:03:54,509 --> 00:03:50,110
low mass extrasolar planet the question

66
00:03:56,759 --> 00:03:54,519
that I want to ask before we start

67
00:03:59,220 --> 00:03:56,769
finding lots more examples of low-mass

68
00:04:02,339 --> 00:03:59,230
extrasolar planets is are they all going

69
00:04:06,690 --> 00:04:02,349
to be like the earth are they all going

70
00:04:08,550 --> 00:04:06,700
to be this spectacular blue white color

71
00:04:10,229 --> 00:04:08,560
will they have different kinds of

72
00:04:13,500 --> 00:04:10,239
atmospheres will they have different

73
00:04:15,449 --> 00:04:13,510
kinds of internal compositions a lot of

74
00:04:17,629 --> 00:04:15,459
people have been thinking about this

75
00:04:22,860 --> 00:04:17,639
question what's the range of possible

76
00:04:26,279 --> 00:04:22,870
exoplanets that are out there but in

77
00:04:28,670 --> 00:04:26,289
particular I've been trying to think as

78
00:04:35,360 --> 00:04:28,680
broadly as possible about the question

79
00:04:38,250 --> 00:04:35,370
so our home planet is a silicate planet

80
00:04:43,260 --> 00:04:38,260
it's mostly made out of silicon and

81
00:04:47,969 --> 00:04:43,270
oxygen with a metal core and of course

82
00:04:51,060 --> 00:04:47,979
we live here in this thin biosphere at

83
00:04:53,700 --> 00:04:51,070
surface but is it possible that there

84
00:04:54,930 --> 00:04:53,710
are other planets that have internal

85
00:04:57,450 --> 00:04:54,940
compositions that are radically

86
00:04:59,279 --> 00:04:57,460
different than this how weird can it get

87
00:05:05,400 --> 00:04:59,289
can you have a planet that's made

88
00:05:09,870 --> 00:05:05,410

entirely out of nougat or peanut butter

89
00:05:14,770 --> 00:05:09,880
or some other exotic thing and that's

90
00:05:21,070 --> 00:05:18,170
so and here's the story for what we

91
00:05:25,460 --> 00:05:21,080
think has determined the composition of

92
00:05:30,410 --> 00:05:25,470
our earth in fact the rest of the solar

93
00:05:31,850 --> 00:05:30,420
system the broad picture that keep in

94
00:05:34,640 --> 00:05:31,860
the back of our mind spoiling that's

95
00:05:37,670 --> 00:05:34,650
Louis introduced in the 70s which is

96
00:05:42,500 --> 00:05:37,680
that the solar system swirling gas disk

97
00:05:45,140 --> 00:05:42,510
and the gas disk had a range of

98
00:05:47,510 --> 00:05:45,150
temperatures the interior the gas test

99
00:05:50,180 --> 00:05:47,520
was hot and the outer reaches of the gas

100
00:05:52,420 --> 00:05:50,190
discs were cold and that the

101
00:05:56,480 --> 00:05:52,430
planetesimals that formed in the disk

102
00:05:59,210 --> 00:05:56,490
represented the chemistry appropriate to

103
00:06:02,600 --> 00:05:59,220
the local temperature and there have

104
00:06:05,410 --> 00:06:02,610
been many people who did calculations of

105
00:06:10,400 --> 00:06:05,420
the chemical equilibrium composition of

106
00:06:12,110 --> 00:06:10,410
solar nebula material and you learn when

107
00:06:14,630 --> 00:06:12,120
you do these kinds of studies that

108
00:06:17,320 --> 00:06:14,640
material is that condensed in the hot

109
00:06:22,090 --> 00:06:17,330
part of a protoplanetary discs are

110
00:06:25,280 --> 00:06:22,100
dominantly metals metal oxides the

111
00:06:26,800 --> 00:06:25,290
equilibrium composition the equilibrium

112
00:06:30,170 --> 00:06:26,810
chemistry farther out in the disk

113
00:06:35,660 --> 00:06:30,180

incorporates lots look it's and farther

114
00:06:37,610 --> 00:06:35,670
out in the disk Isis other volatile

115
00:06:39,860 --> 00:06:37,620
counter so the earth of course

116
00:06:41,930 --> 00:06:39,870
represents saw a mix of things may be

117
00:06:44,120 --> 00:06:41,940
dominated by silicates metals that's why

118
00:06:48,020 --> 00:06:44,130
we have a planet made out of silicates

119
00:06:49,730 --> 00:06:48,030
and metals the outer parts of the solar

120
00:06:54,640 --> 00:06:49,740
system of course have planets that

121
00:07:00,129 --> 00:06:54,650
incorporate more ices water ammonia ice

122
00:07:07,769 --> 00:07:05,429
okay so here is a diagram that

123
00:07:10,179 --> 00:07:07,779
laughter's and clegg we put together

124
00:07:14,649 --> 00:07:10,189
illustrating some of the condensates

125
00:07:18,189 --> 00:07:14,659
that rain out as you cool a disc of

126
00:07:20,439 --> 00:07:18,199
material so imagine that you had solar

127
00:07:23,290 --> 00:07:20,449
composition material which sits here on

128
00:07:26,050 --> 00:07:23,300
this line in this diagram and you

129
00:07:28,980 --> 00:07:26,060
started at high temperatures the diagram

130
00:07:34,809 --> 00:07:28,990
shows some of the solids that would

131
00:07:37,800 --> 00:07:34,819
condense out material at solar carbon to

132
00:07:40,570 --> 00:07:37,810
oxygen ratio in this diagram the first

133
00:07:44,830 --> 00:07:40,580
materials that condense out our metal

134
00:07:46,779 --> 00:07:44,840
oxides in this calculation at 1,600

135
00:07:50,890 --> 00:07:46,789
polymer so then as you work your way

136
00:07:55,179 --> 00:07:50,900
down can start condensing silicates in

137
00:07:57,760 --> 00:07:55,189
water and that's an example of what you

138
00:08:00,879 --> 00:07:57,770

listen others had mind with this picture

139
00:08:04,209 --> 00:08:00,889
of condensation temperature appropriate

140
00:08:06,939 --> 00:08:04,219
conversation determining the composition

141
00:08:08,860 --> 00:08:06,949
of planets in the solar system but of

142
00:08:11,379 --> 00:08:08,870
course this diagram doesn't stop at

143
00:08:13,929 --> 00:08:11,389
solar composition lotteries in Phegley

144
00:08:19,119 --> 00:08:13,939
were modeling the concession of us in

145
00:08:21,670 --> 00:08:19,129
the envelope of a giant star where the

146
00:08:24,129 --> 00:08:21,680
carbon to oxygen ratio is not

147
00:08:27,100 --> 00:08:24,139
necessarily the same as the solar carbon

148
00:08:30,579 --> 00:08:27,110
oxygen ratio in the Sun there's about

149
00:08:33,219 --> 00:08:30,589
twice as much oxygen as there is carbon

150
00:08:36,990 --> 00:08:33,229
but in the envelope of a giant star

151
00:08:40,420 --> 00:08:37,000
which is undergoing lots of nuclear

152
00:08:42,370 --> 00:08:40,430
processing the carbon to oxygen ratio

153
00:08:45,730 --> 00:08:42,380
can be quite a bit different can be

154
00:08:50,889 --> 00:08:45,740
higher than the value of a half and we

155
00:08:54,079 --> 00:08:50,899
see in the Sun so

156
00:08:55,970 --> 00:08:54,089
many giant stars will form condensates

157
00:08:57,920 --> 00:08:55,980
on the right side of the diagram right

158
00:09:00,340 --> 00:08:57,930
here and at higher carbon to oxygen

159
00:09:03,350 --> 00:09:00,350
ratios and you can see from this diagram

160
00:09:06,290 --> 00:09:03,360
that if you move to the right and you

161
00:09:09,610 --> 00:09:06,300
pass this magical number of carbon

162
00:09:12,050 --> 00:09:09,620
equals oxygen carbon oxygen levels that

163
00:09:16,660 --> 00:09:12,060

equilibrium cannock chemistry changes

164
00:09:19,129 --> 00:09:16,670
dramatic and for higher carbon

165
00:09:21,819 --> 00:09:19,139
abundances the high temperature

166
00:09:25,780 --> 00:09:21,829
condensates that you expect to form dust

167
00:09:28,280 --> 00:09:25,790
and by extension planetesimals perhaps

168
00:09:31,370 --> 00:09:28,290
are very different the high temperature

169
00:09:36,189 --> 00:09:31,380
condensates our carbon rich materials

170
00:09:40,730 --> 00:09:36,199
graphite carbides and other reduced

171
00:09:49,829 --> 00:09:46,230
so that was a calculation for the

172
00:09:53,150 --> 00:09:49,839
envelopes of bread Giants but do we ever

173
00:09:55,470 --> 00:09:53,160
see carbon rich chemistry in

174
00:10:00,389 --> 00:09:55,480
protoplanetary discs that we see around

175
00:10:05,610 --> 00:10:00,399
other stars do we ever see carbonaceous

176
00:10:08,009 --> 00:10:05,620
materials in evidence for carbon rich

177
00:10:11,250 --> 00:10:08,019
materials surrounding young stars young

178
00:10:12,900 --> 00:10:11,260
planetary systems we sure do here are

179
00:10:15,420 --> 00:10:12,910
some recent spectra of key tourist

180
00:10:20,670 --> 00:10:15,430
dollars taken with the Spitzer Space

181
00:10:25,650 --> 00:10:20,680
Telescope showing you the spectra of

182
00:10:29,100 --> 00:10:25,660
these young stars are full of emission

183
00:10:33,500 --> 00:10:29,110
from polycyclic aromatic aromatic

184
00:10:39,019 --> 00:10:33,510
hydrocarbons Oh polycyclic aromatic

185
00:10:43,319 --> 00:10:39,029
hydrocarbons course are also called hook

186
00:10:47,670 --> 00:10:43,329
the if you look at the spectrum of a lot

187
00:10:52,379 --> 00:10:47,680
of different a critical thing kinds of

188
00:10:53,879 --> 00:10:52,389

competence someone showed one sponge

189
00:10:57,210 --> 00:10:53,889
would talk for someone compared

190
00:11:00,290 --> 00:10:57,220
inspection of a distant galaxy to the

191
00:11:03,240 --> 00:11:00,300
spectrum of the exhaust from a

192
00:11:06,420 --> 00:11:03,250
Volkswagen Beetle and they remarkably

193
00:11:10,019 --> 00:11:06,430
similar so all kinds of Astrophysical

194
00:11:15,120 --> 00:11:10,029
objects have a PHS these very

195
00:11:17,100 --> 00:11:15,130
carbon-rich compounds so t-tauri stars

196
00:11:20,960 --> 00:11:17,110
which are thought to be analogs of the

197
00:11:23,250 --> 00:11:20,970
young son show signs of carbon

198
00:11:25,650 --> 00:11:23,260
carbonaceous dust just like that

199
00:11:31,110 --> 00:11:25,660
produced

200
00:11:32,820 --> 00:11:31,120
yeah employment now stars now what

201
00:11:37,760 --> 00:11:32,830
happens if you take a protoplanetary

202
00:11:40,770 --> 00:11:37,770
disk and you sprinkle dust on the disk

203
00:11:42,930 --> 00:11:40,780
the dust doesn't just sit there the dust

204
00:11:47,340 --> 00:11:42,940
spirals inwards under the influence of

205
00:11:48,990 --> 00:11:47,350
gas train and as time goes by the dust

206
00:11:51,450 --> 00:11:49,000
has to pile up on this in the center of

207
00:11:54,030 --> 00:11:51,460
the disk and that's what this model

208
00:11:57,510 --> 00:11:54,040
wooten in Chiang illustrates they

209
00:12:01,650 --> 00:11:57,520
started out their experiment with this

210
00:12:02,970 --> 00:12:01,660
surface density profile of dust grains

211
00:12:04,230 --> 00:12:02,980
they weren't thinking about the

212
00:12:06,600 --> 00:12:04,240
competition especially we'll just

213
00:12:09,930 --> 00:12:06,610

sprinkled some tests particles on their

214
00:12:13,520 --> 00:12:09,940
gas discs and they saw that as time went

215
00:12:15,780 --> 00:12:13,530
by the surface density profile change

216
00:12:19,500 --> 00:12:15,790
material that was out here moved in

217
00:12:21,450 --> 00:12:19,510
words and eventually service that's the

218
00:12:23,430 --> 00:12:21,460
profile look like this it was an

219
00:12:25,530 --> 00:12:23,440
enhancement of salt in the center of the

220
00:12:28,410 --> 00:12:25,540
disk to look down below in this diagram

221
00:12:34,140 --> 00:12:28,420
as an illustration of little particles

222
00:12:36,740 --> 00:12:34,150
of dust moving into the center of the

223
00:12:44,230 --> 00:12:41,080
so we see t-tauri stars with evidence of

224
00:12:48,140 --> 00:12:44,240
carbonaceous grains and we know

225
00:12:53,810 --> 00:12:48,150
physically that grains tend to pile up

226
00:12:58,490 --> 00:12:53,820
in the Senators of planetary disc this

227
00:13:01,100 --> 00:12:58,500
model was invoked 93 but I wouldn't

228
00:13:02,960 --> 00:13:01,110
hashim oh no other people as an

229
00:13:08,560 --> 00:13:02,970
explanation for the formation were

230
00:13:12,860 --> 00:13:08,570
particular kind of meteorite dreams so

231
00:13:18,880 --> 00:13:12,870
wooden Hashimoto calculated the chemical

232
00:13:22,700 --> 00:13:18,890
equilibrium state of material that was

233
00:13:25,480 --> 00:13:22,710
solar nebula solar composition with on

234
00:13:28,870 --> 00:13:25,490
difference that they added an

235
00:13:31,250 --> 00:13:28,880
overabundance of carbonaceous cranes

236
00:13:33,260 --> 00:13:31,260
just like what you would expect in the

237
00:13:36,020 --> 00:13:33,270
center of a protoplanetary disk where

238
00:13:39,260 --> 00:13:36,030

who had carbon-rich grains produced by

239
00:13:41,030 --> 00:13:39,270
all stars that have been transported to

240
00:13:43,040 --> 00:13:41,040
the center of the disk to create a

241
00:13:46,460 --> 00:13:43,050
region of the disc that's enriched in

242
00:13:49,760 --> 00:13:46,470
carbon material carbon rich material

243
00:13:52,010 --> 00:13:49,770
right so they made this diagram showing

244
00:13:54,260 --> 00:13:52,020
the compositions that you would expect

245
00:13:55,910 --> 00:13:54,270
the equilibrium compositions that you

246
00:14:02,770 --> 00:13:55,920
would expect as a function of

247
00:14:07,210 --> 00:14:04,930
if you think that the appropriate

248
00:14:10,420 --> 00:14:07,220
temperature for compensation is here

249
00:14:14,440 --> 00:14:10,430
around 1100 degrees you get a bulk

250
00:14:17,050 --> 00:14:14,450
composition dominated by exit light and

251
00:14:19,450 --> 00:14:17,060
iron which is a pretty good match for

252
00:14:22,060 --> 00:14:19,460
the composition of esta tight Congress

253
00:14:23,320 --> 00:14:22,070
this particular kind of meteorite rare

254
00:14:28,510 --> 00:14:23,330
cottonseed right that they were trying

255
00:14:32,050 --> 00:14:28,520
to explain other people have taken this

256
00:14:36,870 --> 00:14:32,060
in the left step farther what if we look

257
00:14:39,370 --> 00:14:36,880
elsewhere on this diagram we see that

258
00:14:43,300 --> 00:14:39,380
depending on the temperature that you

259
00:14:46,540 --> 00:14:43,310
think that represents for equilibrium

260
00:14:48,550 --> 00:14:46,550
chemistry you can get a variety of

261
00:14:51,340 --> 00:14:48,560
compositions ranging from those of mr.

262
00:14:55,180 --> 00:14:51,350
decon droids to even more carbon rich

263
00:14:59,170 --> 00:14:55,190

bodies like you could get planetesimals

264
00:15:04,030 --> 00:14:59,180
forming substantially out of graphite

265
00:15:09,560 --> 00:15:04,040
silicon carbon and carbon enriched

266
00:15:18,750 --> 00:15:13,220
so imagine the giant instant I contract

267
00:15:21,420 --> 00:15:18,760
or a giant a planet formed out of even

268
00:15:23,390 --> 00:15:21,430
more rich carbon-rich planetesimals like

269
00:15:26,310 --> 00:15:23,400
those predicted by wooden Hashimoto

270
00:15:31,440 --> 00:15:26,320
right this planet might have the iron

271
00:15:33,630 --> 00:15:31,450
core like the earth and it could have a

272
00:15:37,740 --> 00:15:33,640
mantle made out of carbides and other

273
00:15:42,420 --> 00:15:37,750
reduced minerals the surface is probably

274
00:15:44,630 --> 00:15:42,430
alive by extension materials that have

275
00:15:47,690 --> 00:15:44,640
been delivered to the surface think that

276
00:15:50,220 --> 00:15:47,700
volatile is on the surface of the earth

277
00:15:51,840 --> 00:15:50,230
represent materials that have been

278
00:15:54,690 --> 00:15:51,850
delivered from else wearing the in the

279
00:15:55,980 --> 00:15:54,700
solar system but the bulk composition of

280
00:16:02,190 --> 00:15:55,990
this planet could be extremely different

281
00:16:05,880 --> 00:16:02,200
than that of the earth so Phegley and

282
00:16:09,620 --> 00:16:05,890
Cameron we're trying to understand the

283
00:16:11,550 --> 00:16:09,630
bulk composition of mercury in Hades and

284
00:16:15,960 --> 00:16:11,560
this is one of the directions they

285
00:16:19,100 --> 00:16:15,970
considered perhaps mercury formed in a

286
00:16:21,360 --> 00:16:19,110
very reduced the chemical setting oh

287
00:16:25,320 --> 00:16:21,370
they gave up on that idea because they

288
00:16:27,630 --> 00:16:25,330

couldn't get the density hina but since

289
00:16:30,600 --> 00:16:27,640
then other people have thought about

290
00:16:32,930 --> 00:16:30,610
this possibility Catherine Wheel on

291
00:16:36,150 --> 00:16:32,940
catharina laughter's suggested this

292
00:16:39,870 --> 00:16:36,160
model as a possibility for the core of

293
00:16:43,860 --> 00:16:39,880
Jupiter our guy dose thought about this

294
00:16:45,480 --> 00:16:43,870
concept he was worrying about which

295
00:16:47,610 --> 00:16:45,490
parts of the galaxy might be suitable

296
00:16:50,640 --> 00:16:47,620
for life thinking about galactic

297
00:16:54,060 --> 00:16:50,650
habitable zone and then recently Sara

298
00:16:59,540 --> 00:16:54,070
Seager and I did some calculations about

299
00:17:07,170 --> 00:17:04,710
so I was telling you that the chemistry

300
00:17:10,470 --> 00:17:07,180
of planet formation is all about the

301
00:17:14,610 --> 00:17:10,480
chemistry of the protoplanetary disk to

302
00:17:17,550 --> 00:17:14,620
first approximation one reason I've

303
00:17:19,680 --> 00:17:17,560
gotten excited about the possibility of

304
00:17:22,350 --> 00:17:19,690
carbon planets recently is related to

305
00:17:28,140 --> 00:17:22,360
this protoplanetary disk right here who

306
00:17:30,000 --> 00:17:28,150
is part of this object okay most of you

307
00:17:32,700 --> 00:17:30,010
have heard of a Victorian I'm glad I

308
00:17:36,000 --> 00:17:32,710
lady Victoria courses a nearby debris

309
00:17:39,150 --> 00:17:36,010
disk it's an a-star so it's a little

310
00:17:43,830 --> 00:17:39,160
more massive than the Sun but it's a

311
00:17:46,500 --> 00:17:43,840
spectacular example of what is probably

312
00:17:50,100 --> 00:17:46,510
a protoplanetary disk in the epic of

313
00:17:51,780 --> 00:17:50,110

terrestrial planet formation and here's

314
00:17:56,760 --> 00:17:51,790
this beautiful image of a David course

315
00:17:58,440 --> 00:17:56,770
with the advanced camera for surveys on

316
00:18:01,290 --> 00:17:58,450
the Hubble Space Telescope which just

317
00:18:03,030 --> 00:18:01,300
broke yesterday and I really hope they

318
00:18:05,250 --> 00:18:03,040
get it fixed so it can make more

319
00:18:07,460 --> 00:18:05,260
beautiful pictures like this so beta

320
00:18:09,990 --> 00:18:07,470
Pictoris is an example of a

321
00:18:12,780 --> 00:18:10,000
protoplanetary disk that we that's

322
00:18:17,400 --> 00:18:12,790
nearby that we can image easily in study

323
00:18:21,080 --> 00:18:17,410
in detail rocky Roe marriage a prize

324
00:18:23,670 --> 00:18:21,090
postdoc at Goddard who's working with me

325
00:18:27,320 --> 00:18:23,680
if it has just completed this inventory

326
00:18:30,450 --> 00:18:27,330
of the chemistry of the gas in this dish

327
00:18:36,460 --> 00:18:30,460
that's the green axis

328
00:18:42,039 --> 00:18:39,460
and she's learned that the carbon oxygen

329
00:18:46,380 --> 00:18:42,049
ratio in the gas in this disc is a

330
00:18:49,539 --> 00:18:46,390
spectacular 921 which is 18 times that

331
00:18:57,220 --> 00:18:49,549
house is christian spectra based on mass

332
00:18:59,289 --> 00:18:57,230
spectra that's crazy huh all right so

333
00:19:03,279 --> 00:18:59,299
what's going on here well of course as

334
00:19:05,230 --> 00:19:03,289
soon as she what was that did with the

335
00:19:08,680 --> 00:19:05,240
desk of the answer other than Singh the

336
00:19:11,529 --> 00:19:08,690
gas is is is is pretty low actually

337
00:19:15,549 --> 00:19:11,539
convincing this is the residual yeah

338
00:19:19,690 --> 00:19:15,559

okay so at first I went Wow 921 carbon

339
00:19:23,080 --> 00:19:19,700
planets right but of course there's

340
00:19:26,200 --> 00:19:23,090
always more to the story the this

341
00:19:29,649 --> 00:19:26,210
particular disk is a debris disk the gas

342
00:19:32,799 --> 00:19:29,659
is very sparse right and it's quite

343
00:19:34,630 --> 00:19:32,809
possible it probably this gas actually

344
00:19:37,630 --> 00:19:34,640
represents gas released in the

345
00:19:41,380 --> 00:19:37,640
destruction of planetesimals so photo

346
00:19:42,970 --> 00:19:41,390
comments that are our vaporizing gases

347
00:19:46,360 --> 00:19:42,980
released in the collisions of

348
00:19:49,419 --> 00:19:46,370
planetesimals something in this disc is

349
00:19:51,220 --> 00:19:49,429
carbon rich I don't know if it's

350
00:19:53,289 --> 00:19:51,230
planet-sized bodies that are carbon rich

351
00:19:55,600 --> 00:19:53,299
but this may point to carbon rich

352
00:19:56,919 --> 00:19:55,610
planetesimals and it may be that the

353
00:20:02,710 --> 00:19:56,929
solar system went through a phase like

354
00:20:04,649 --> 00:20:02,720
this right it may be that the young that

355
00:20:08,380 --> 00:20:04,659
the proto asteroids in the solar system

356
00:20:10,690 --> 00:20:08,390
were carbon rich and that they lost

357
00:20:11,919 --> 00:20:10,700
their volatile due to the process

358
00:20:17,970 --> 00:20:11,929
similar to what we're seeing in beta

359
00:20:25,500 --> 00:20:23,130
hey destruction of maybe we're seeing

360
00:20:28,140 --> 00:20:25,510
the death of carbon him dat evict Horace

361
00:20:29,940 --> 00:20:28,150
right maybe when the planets are not

362
00:20:35,610 --> 00:20:29,950
going to incorporate this carbon that's

363
00:20:38,250 --> 00:20:35,620

been yes but also makes you think that

364
00:20:40,950 --> 00:20:38,260
there's something interesting going on

365
00:20:44,100 --> 00:20:40,960
there and there is possibility of carbon

366
00:20:48,419 --> 00:20:44,110
rich mode of planet formation I was your

367
00:20:53,490 --> 00:20:48,429
ratio of halle this meeting off here

368
00:20:56,310 --> 00:20:53,500
looks pretty much close to one yeah are

369
00:21:00,120 --> 00:20:56,320
you getting on it so slow kind of sulfur

370
00:21:02,370 --> 00:21:00,130
book club to that indicate what is

371
00:21:05,909 --> 00:21:02,380
happening possible burns I don't know

372
00:21:10,180 --> 00:21:05,919
they're there may be other interesting

373
00:21:12,300 --> 00:21:10,190
publix yeah in this spot

374
00:21:17,130 --> 00:21:12,310
there

375
00:21:19,800 --> 00:21:17,140
debris disks where we can measure gas

376
00:21:21,930 --> 00:21:19,810
and gas chemistry and this can be fun

377
00:21:27,480 --> 00:21:21,940
trying to put together when all this

378
00:21:34,960 --> 00:21:33,130
all right in my last talk i showed you

379
00:21:36,940 --> 00:21:34,970
some of my cartoons about different

380
00:21:39,010 --> 00:21:36,950
planet detection techniques one i want

381
00:21:46,730 --> 00:21:39,020
to focus on right now is transit

382
00:21:51,360 --> 00:21:49,500
okay so trans and observations are when

383
00:21:55,740 --> 00:21:51,370
you stare plenty telescope and to start

384
00:21:59,549 --> 00:21:55,750
and you look for a situation where the

385
00:22:01,919 --> 00:21:59,559
star becomes temporarily dimmer and you

386
00:22:06,210 --> 00:22:01,929
infer from that the presence of a planet

387
00:22:08,009 --> 00:22:06,220
that's orbiting around the star so the

388
00:22:11,120 --> 00:22:08,019

kuro mission and the Kepler missions

389
00:22:14,399 --> 00:22:11,130
that I mentioned on the first view graph

390
00:22:16,680 --> 00:22:14,409
are expected to bring home lots of

391
00:22:18,750 --> 00:22:16,690
different candidates of transiting

392
00:22:22,560 --> 00:22:18,760
planets and when we follow these up

393
00:22:25,580 --> 00:22:22,570
using medium velocity observations will

394
00:22:28,289 --> 00:22:25,590
probably have many examples of

395
00:22:32,220 --> 00:22:28,299
extrasolar earthlike planets that we can

396
00:22:35,909 --> 00:22:32,230
study and once you've found a transiting

397
00:22:38,490 --> 00:22:35,919
planet you can we observe the transiting

398
00:22:39,720 --> 00:22:38,500
planet with a fancier more expensive

399
00:22:41,970 --> 00:22:39,730
telescope like the James Webb Space

400
00:22:44,730 --> 00:22:41,980
Telescope and use the transit to take a

401
00:22:48,690 --> 00:22:44,740
spectrum of the planet and this is

402
00:22:50,970 --> 00:22:48,700
starting to be a very exciting field of

403
00:22:55,700 --> 00:22:50,980
research and the Spitzer Space Telescope

404
00:23:02,310 --> 00:22:58,409
measurements of colors and spectra of

405
00:23:08,190 --> 00:23:02,320
planets that have been detected first

406
00:23:10,860 --> 00:23:08,200
using the transit technique so Sarah and

407
00:23:12,659 --> 00:23:10,870
I went about trying to figure out what

408
00:23:16,350 --> 00:23:12,669
is the spectrum of the paint carbon

409
00:23:17,850 --> 00:23:16,360
planet going to look like so what do you

410
00:23:21,560 --> 00:23:17,860
see when you look at the spectrum of a

411
00:23:24,950 --> 00:23:21,570
transiting planet you see its atmosphere

412
00:23:28,810 --> 00:23:24,960
so here is a calculation of the

413
00:23:36,110 --> 00:23:28,820

composition of a

414
00:23:38,980 --> 00:23:36,120
of a planetary atmosphere it's a

415
00:23:41,779 --> 00:23:38,990
chemical equilibrium calculation so

416
00:23:43,990 --> 00:23:41,789
serenata calculated at every different

417
00:23:47,390 --> 00:23:44,000
combination of pressure and temperature

418
00:23:50,419 --> 00:23:47,400
what is the equilibrium chemistry for

419
00:23:54,590 --> 00:23:50,429
gas that has atomic composition to

420
00:23:57,740 --> 00:23:54,600
sugandha sun and also on this diagram

421
00:24:01,539 --> 00:23:57,750
who plotted a typical temperature

422
00:24:04,549 --> 00:24:01,549
pressure profile for Neptune mass planet

423
00:24:06,770 --> 00:24:04,559
for a hot Neptune has planned like the

424
00:24:11,690 --> 00:24:06,780
kind of planet that you would see in the

425
00:24:14,779 --> 00:24:11,700
transit survey so here in the land of

426
00:24:17,320 --> 00:24:14,789
solar composition events the comfortable

427
00:24:22,279 --> 00:24:17,330
boring land of solar composition planets

428
00:24:24,380 --> 00:24:22,289
you can see that the entire atmosphere

429
00:24:27,860 --> 00:24:24,390
of the planet lies in this blue region

430
00:24:31,250 --> 00:24:27,870
of the diagram where the gases are rich

431
00:24:33,919 --> 00:24:31,260
in water and none of the atmosphere

432
00:24:37,070 --> 00:24:33,929
lives of the red diagram which is the

433
00:24:43,310 --> 00:24:37,080
water poor carbon monoxide which part of

434
00:24:47,659 --> 00:24:43,320
the diagram now if we turn up the carbon

435
00:24:51,110 --> 00:24:47,669
to oxygen ratio in the calculation the

436
00:24:55,220 --> 00:24:51,120
scene changes and most of this

437
00:24:58,930 --> 00:24:55,230
temperature pressure regime used now the

438
00:25:02,270 --> 00:24:58,940

carbon dioxide rich regime for this

439
00:25:07,370 --> 00:25:02,280
example temperature pressure profile for

440
00:25:10,430 --> 00:25:07,380
this example hot Neptune we see that

441
00:25:12,980 --> 00:25:10,440
most of the atmosphere is in a very

442
00:25:19,730 --> 00:25:12,990
water for carbon monoxide which regime

443
00:25:22,549 --> 00:25:19,740
and the synthetic spectrum as we go from

444
00:25:26,330 --> 00:25:22,559
solar composition carbon diox-- term

445
00:25:29,680 --> 00:25:26,340
ratio of a half to carbon rich regime

446
00:25:38,810 --> 00:25:33,860
so here is the ordinary solar

447
00:25:42,590 --> 00:25:38,820
composition hot next election it's full

448
00:25:45,980 --> 00:25:42,600
of these water absorption features

449
00:25:47,840 --> 00:25:45,990
here's this plastic you've probably

450
00:25:53,090 --> 00:25:47,850
heard of this for micron the mission

451
00:25:56,180 --> 00:25:53,100
peak from extra hot Jupiters right there

452
00:25:59,720 --> 00:25:56,190
it is when you turn up the carbon oxygen

453
00:26:01,760 --> 00:25:59,730
ratio the spectrum automatically maybe

454
00:26:04,540 --> 00:26:01,770
we will start finding the transiting

455
00:26:12,649 --> 00:26:04,550
planets that have these carbon monoxide

456
00:26:19,849 --> 00:26:15,649
what else can we do with transit

457
00:26:21,619 --> 00:26:19,859
observations well if we stay a very hard

458
00:26:23,810 --> 00:26:21,629
we can get a spectrum but you don't have

459
00:26:25,719 --> 00:26:23,820
to very stare very hard at all just to

460
00:26:28,999 --> 00:26:25,729
get the mass and radius of the planet

461
00:26:31,719 --> 00:26:29,009
here is a collection of mass and radius

462
00:26:34,389 --> 00:26:31,729
measurements for real transiting planets

463
00:26:40,849 --> 00:26:34,399

from our do paper by name Charbonneau

464
00:26:43,070 --> 00:26:40,859
others okay so here are all these

465
00:26:48,259 --> 00:26:43,080
different mass radius measurements for

466
00:26:50,479 --> 00:26:48,269
transiting planets and for comparison

467
00:26:52,369 --> 00:26:50,489
these folks have plotted some very

468
00:26:59,029 --> 00:26:52,379
simple models with the mass previous

469
00:27:02,450 --> 00:26:59,039
relationships of large hot planets their

470
00:27:04,820 --> 00:27:02,460
model consists of let's their their

471
00:27:10,639 --> 00:27:04,830
model is a constant density model okay

472
00:27:14,299 --> 00:27:10,649
so this is the radius that a ball with

473
00:27:19,129 --> 00:27:14,309
density one gram per cubic centimeter

474
00:27:23,749 --> 00:27:19,139
will have this line here is the radius

475
00:27:27,919 --> 00:27:23,759
goes as cube root of mass line you can

476
00:27:30,019 --> 00:27:27,929
see by comparing the mass radius

477
00:27:34,099 --> 00:27:30,029
measurements from transit observations

478
00:27:37,369 --> 00:27:34,109
to these lines that there are some

479
00:27:40,119 --> 00:27:37,379
surprises here for one a large enough

480
00:27:43,940 --> 00:27:40,129
fraction of these transiting planets are

481
00:27:46,940 --> 00:27:43,950
less dense average than water so they

482
00:27:54,240 --> 00:27:50,940
we don't really understand yet why the

483
00:28:02,850 --> 00:27:54,250
density of someone else's solo it defies

484
00:28:04,350 --> 00:28:02,860
our attempt to explain well I wasn't

485
00:28:10,260 --> 00:28:04,360
planning to tell you all the wonderful

486
00:28:13,050 --> 00:28:10,270
details about models of the radii of

487
00:28:18,480 --> 00:28:13,060
these transiting massive planets I want

488
00:28:20,750 --> 00:28:18,490

to show you only that trans observations

489
00:28:25,500 --> 00:28:20,760
are good at measuring masses and radii

490
00:28:27,390 --> 00:28:25,510
well I mean is this part of the curve

491
00:28:32,120 --> 00:28:27,400
down here where we're going to reach

492
00:28:36,990 --> 00:28:32,130
with Kepler and corel below mass small

493
00:28:39,180 --> 00:28:37,000
exoplanets so here is a more detailed

494
00:28:41,850 --> 00:28:39,190
calculation of the mass radius

495
00:28:43,950 --> 00:28:41,860
relationships for extrasolar planets by

496
00:28:47,370 --> 00:28:43,960
as a policy and saltpeter of nineteen

497
00:28:51,360 --> 00:28:47,380
sixty-nine they need these models for

498
00:28:56,310 --> 00:28:51,370
the mass radius relationships which take

499
00:28:57,840 --> 00:28:56,320
into account the way that the planet

500
00:29:01,980 --> 00:28:57,850
becomes crushed when it gets more

501
00:29:04,710 --> 00:29:01,990
massive when the planet is small down

502
00:29:07,190 --> 00:29:04,720
here the density of plans the same

503
00:29:14,130 --> 00:29:11,370
hey uniform density sphere is a good

504
00:29:17,330 --> 00:29:14,140
model and the radius varies is the cube

505
00:29:19,950 --> 00:29:17,340
root of the mass but then at some point

506
00:29:24,470 --> 00:29:19,960
the center of the planet compresses and

507
00:29:27,900 --> 00:29:24,480
that law stops upon now if here the

508
00:29:30,240 --> 00:29:27,910
curves reach a maximum and then the

509
00:29:32,580 --> 00:29:30,250
planet starts shrinking if you added

510
00:29:34,710 --> 00:29:32,590
more mass on the Jupiter to increase its

511
00:29:37,670 --> 00:29:34,720
mass by a factor of 10 or so he would

512
00:29:40,080 --> 00:29:37,680
start compressing and what do you drink

513
00:29:47,490 --> 00:29:40,090

that's what it's Paul Sneed salpeter per

514
00:29:49,380 --> 00:29:47,500
day so again Sarah and I Sara Seager and

515
00:29:53,640 --> 00:29:49,390
I we're working on this together or

516
00:29:55,650 --> 00:29:53,650
focusing on the earth to super earth

517
00:29:58,620 --> 00:29:55,660
region of this diagram here in this

518
00:30:01,890 --> 00:29:58,630
corner we try to improve on the work of

519
00:30:04,560 --> 00:30:01,900
suppose need salt here so where does the

520
00:30:06,990 --> 00:30:04,570
phosphine saltpeter go wrong where they

521
00:30:08,610 --> 00:30:07,000
went wrong is that they used a

522
00:30:10,950 --> 00:30:08,620
particular equation of state called

523
00:30:14,820 --> 00:30:10,960
Thomas Fermi Dirac equation state which

524
00:30:21,870 --> 00:30:14,830
really only worse at high pressures is

525
00:30:23,430 --> 00:30:21,880
Mike Brennan around ok so the Thomas

526
00:30:26,910 --> 00:30:23,440
Fermi Dirac equation of state for

527
00:30:29,910 --> 00:30:26,920
example doesn't incorporate molecules so

528
00:30:33,090 --> 00:30:29,920
clearly at low temperatures and low

529
00:30:35,100 --> 00:30:33,100
pressures most substances exist in the

530
00:30:38,190 --> 00:30:35,110
form of molecules we wanted to update

531
00:30:41,099 --> 00:30:38,200
this work taking into account improved

532
00:30:49,619 --> 00:30:46,570
so this diagram shows where planets in

533
00:30:56,409 --> 00:30:49,629
the solar system lie on the mass radius

534
00:30:58,299 --> 00:30:56,419
plot and it shows you that plants are

535
00:31:00,609 --> 00:30:58,309
expected to have different radii based

536
00:31:04,210 --> 00:31:00,619
on their bulk compositions so you can

537
00:31:06,639 --> 00:31:04,220
look at Jupiter and at these models and

538
00:31:10,080 --> 00:31:06,649

infer just from knowing its size and

539
00:31:13,810 --> 00:31:10,090
mass that it's mostly made of hydrogen

540
00:31:15,460 --> 00:31:13,820
and you can also look at Neptune of the

541
00:31:17,889 --> 00:31:15,470
earth and see that they are mostly not

542
00:31:20,259 --> 00:31:17,899
made out of hydrogen they'd lie below

543
00:31:22,450 --> 00:31:20,269
the hydrogen the pure hydrogen planet

544
00:31:23,680 --> 00:31:22,460
curves on this diagram they must have

545
00:31:27,969 --> 00:31:23,690
some of these heavier elements

546
00:31:32,219 --> 00:31:27,979
incorporated can we use the same method

547
00:31:40,029 --> 00:31:35,700
extrasolar transiting low-mass planets

548
00:31:42,009 --> 00:31:40,039
and what we find examples of planets

549
00:31:43,810 --> 00:31:42,019
that fill in some of these gaps on this

550
00:31:48,460 --> 00:31:43,820
diagram alright maybe their plans out

551
00:31:49,889 --> 00:31:48,470
there that will are purely made of

552
00:31:52,180 --> 00:31:49,899
carbon like the ones I showed before

553
00:31:53,769 --> 00:31:52,190
maybe they will find planets that are

554
00:31:57,999 --> 00:31:53,779
mostly made out of iron that are super

555
00:32:03,009 --> 00:31:58,009
dense down here meaning we'll find other

556
00:32:07,289 --> 00:32:03,019
exotic creatures so for example water

557
00:32:09,669 --> 00:32:07,299
planets should be extremely low density

558
00:32:14,999 --> 00:32:09,679
we have some water planets in our own

559
00:32:18,190 --> 00:32:15,009
solar system right the moons of Jupiter

560
00:32:23,799 --> 00:32:18,200
probably Stanley made out of water water

561
00:32:28,889 --> 00:32:23,809
ice liquid water imagine that you have a

562
00:32:32,049 --> 00:32:28,899
a a free planet with the composition of

563
00:32:34,930 --> 00:32:32,059

Ganymede right I call that an ocean

564
00:32:37,880 --> 00:32:34,940
planet or water plan

565
00:32:40,730 --> 00:32:37,890
so there was Paul ski in south peters

566
00:32:43,010 --> 00:32:40,740
models on one end of the spectrum they

567
00:32:45,470 --> 00:32:43,020
took one simple equation state that

568
00:32:47,600 --> 00:32:45,480
didn't include molecules and then there

569
00:32:51,200 --> 00:32:47,610
is another extreme of modelers which are

570
00:32:53,360 --> 00:32:51,210
people like diana valencia and dimitar

571
00:32:56,420 --> 00:32:53,370
SAS log who have been working on very

572
00:33:01,760 --> 00:32:56,430
detailed and this shows some of their

573
00:33:08,200 --> 00:33:01,770
work model of the structures of water

574
00:33:15,170 --> 00:33:08,210
planets and a a giant silica planet so

575
00:33:16,640 --> 00:33:15,180
bless ya all have modeled all kinds of

576
00:33:18,800 --> 00:33:16,650
genomes they've thrown as many details

577
00:33:23,750 --> 00:33:18,810
as they possibly could in these models

578
00:33:27,700 --> 00:33:23,760
and they've included phase transitions

579
00:33:31,370 --> 00:33:27,710
they've concluded attempts to understand

580
00:33:36,740 --> 00:33:31,380
all the different subtleties of mantle

581
00:33:38,890 --> 00:33:36,750
chemistry and they've poured a lot of

582
00:33:41,240 --> 00:33:38,900
work into these models but this isn't

583
00:33:43,190 --> 00:33:41,250
necessarily where you want to go if

584
00:33:47,840 --> 00:33:43,200
you're presented with an astronomical

585
00:33:50,180 --> 00:33:47,850
observation Sarah and I said well what

586
00:33:53,090 --> 00:33:50,190
if someone tells us this is the mass is

587
00:33:54,830 --> 00:33:53,100
the radius of a particular plans is what

588
00:33:58,100 --> 00:33:54,840

we know about it what can we infer from

589
00:34:00,800 --> 00:33:58,110
it so instead of doing a detailed model

590
00:34:04,490 --> 00:34:00,810
of a single particular case we want to

591
00:34:07,160 --> 00:34:04,500
understand the broad range of masses and

592
00:34:09,020 --> 00:34:07,170
radii but that work like Valencia Dell

593
00:34:12,980 --> 00:34:09,030
was just starting with different

594
00:34:16,040 --> 00:34:12,990
compositions yes soulard that's all it

595
00:34:18,620 --> 00:34:16,050
buried yeah so Valencia and all assumed

596
00:34:21,410 --> 00:34:18,630
they started with the earth for example

597
00:34:26,120 --> 00:34:21,420
has scaled it up so this is a very

598
00:34:31,220 --> 00:34:26,130
detailed model of a changing missiles of

599
00:34:32,450 --> 00:34:31,230
a higher mass earth analog and we say we

600
00:34:37,800 --> 00:34:32,460
don't know Whitson if it's an earth

601
00:34:47,470 --> 00:34:40,870
so we actually throw out a lot of these

602
00:34:49,540 --> 00:34:47,480
details people like Mike Brown spend a

603
00:34:53,590 --> 00:34:49,550
lot of time trying to understand the

604
00:34:57,100 --> 00:34:53,600
equations of state for example of the

605
00:35:03,660 --> 00:34:57,110
materials that was the earth if you make

606
00:35:09,970 --> 00:35:07,120
profs kite you've just built yourself a

607
00:35:11,770 --> 00:35:09,980
nice tall matthew right so that's not a

608
00:35:14,440 --> 00:35:11,780
small error when you're understanding

609
00:35:17,350 --> 00:35:14,450
the structure of our own planet because

610
00:35:18,910 --> 00:35:17,360
we can measure it very precisely but if

611
00:35:21,310 --> 00:35:18,920
your son understanding an extra slow

612
00:35:25,270 --> 00:35:21,320
planet and there's a ten percent error

613
00:35:29,370 --> 00:35:25,280

bar on the radius then it makes sense to

614
00:35:35,140 --> 00:35:29,380
approximate that level of detail away

615
00:35:37,600 --> 00:35:35,150
plus you so here are the equations of

616
00:35:39,490 --> 00:35:37,610
eternal internal structure that tell you

617
00:35:43,960 --> 00:35:39,500
the mass radius relationship for a

618
00:35:47,020 --> 00:35:43,970
planet I'm gonna argue with but this is

619
00:35:49,600 --> 00:35:47,030
what we saw americlean in order to solve

620
00:35:52,810 --> 00:35:49,610
those equations you need to understand

621
00:35:55,630 --> 00:35:52,820
the behavior of the rocks that you put

622
00:35:57,880 --> 00:35:55,640
in the planet as you compress them so

623
00:36:00,640 --> 00:35:57,890
here are some of our improved equations

624
00:36:02,650 --> 00:36:00,650
of state taking a step beyond thomas

625
00:36:04,780 --> 00:36:02,660
fermi dirac equation state gone through

626
00:36:07,960 --> 00:36:04,790
the literature and use equations of

627
00:36:09,970 --> 00:36:07,970
state by vinay aperture Murnaghan tests

628
00:36:13,600 --> 00:36:09,980
and did our best to paste them together

629
00:36:18,160 --> 00:36:13,610
into a improved representation of how

630
00:36:22,900 --> 00:36:18,170
these various minerals from iron to

631
00:36:26,890 --> 00:36:22,910
silicon carbide water etc compress as

632
00:36:30,010 --> 00:36:26,900
you put them under pressure right here

633
00:36:34,620 --> 00:36:30,020
is the pressure of the material there's

634
00:36:36,990 --> 00:36:34,630
the density down here at low pressures

635
00:36:40,589 --> 00:36:37,000
most planet-forming materials don't

636
00:36:42,180 --> 00:36:40,599
compress know if you make the turn up

637
00:36:45,509 --> 00:36:42,190
the pressure enough they started

638
00:36:50,880 --> 00:36:45,519

compressing right that's what's going on

639
00:36:53,730 --> 00:36:50,890
this diagram and here are some of our

640
00:36:58,519 --> 00:36:53,740
predictions unfortunately we discovered

641
00:37:01,970 --> 00:36:58,529
that carbon planets are probably not

642
00:37:07,049 --> 00:37:01,980
distinguishable from silicate planets

643
00:37:12,809 --> 00:37:07,059
using transit techniques so this diagram

644
00:37:14,849 --> 00:37:12,819
shows the radius Maps relationships that

645
00:37:17,640 --> 00:37:14,859
we predicted using our models for

646
00:37:20,099 --> 00:37:17,650
variety of different compositions the

647
00:37:22,140 --> 00:37:20,109
lowest radius planets the smallest

648
00:37:23,309 --> 00:37:22,150
planets at a good mass of all the

649
00:37:25,829 --> 00:37:23,319
different equations of state that we

650
00:37:29,069 --> 00:37:25,839
study are the iron tonight so for

651
00:37:34,019 --> 00:37:29,079
example you could imagine a planet that

652
00:37:36,569 --> 00:37:34,029
is all core mercury is a step in that

653
00:37:38,940 --> 00:37:36,579
direction it's the densest planet in the

654
00:37:40,799 --> 00:37:38,950
solar system it's probably the closest

655
00:37:45,269 --> 00:37:40,809
of any of the plans we know to be in

656
00:37:50,089 --> 00:37:45,279
just a pure metal core so mercury would

657
00:37:52,559 --> 00:37:50,099
sit down aarons line actually it's

658
00:37:57,509 --> 00:37:52,569
little nastier to sit down here in this

659
00:37:59,039 --> 00:37:57,519
diagram so the least dense planets of

660
00:38:01,650 --> 00:37:59,049
all the different plans we considered

661
00:38:03,779 --> 00:38:01,660
other pure water plants we think we

662
00:38:07,270 --> 00:38:03,789
probably can distinguish you a water

663
00:38:10,060 --> 00:38:07,280

planet easily from a silica plan

664
00:38:13,570 --> 00:38:10,070
in transit observations so we'll be able

665
00:38:16,180 --> 00:38:13,580
to use these observations to test ideas

666
00:38:18,790 --> 00:38:16,190
about the origin of the Earth's water

667
00:38:24,780 --> 00:38:18,800
for example and transport of volatiles

668
00:38:27,850 --> 00:38:24,790
around planetary system these are some

669
00:38:30,550 --> 00:38:27,860
seven percent error bars and error bars

670
00:38:35,920 --> 00:38:30,560
that we think are plausible expectations

671
00:38:41,320 --> 00:38:35,930
for the performance of Kepler and this

672
00:38:48,690 --> 00:38:41,330
purple dot here represents the measured

673
00:38:51,940 --> 00:38:48,700
mass of Lisa 876 D this is a real live

674
00:38:57,100 --> 00:38:51,950
little mass planet detected by after we

675
00:39:02,680 --> 00:38:59,710
you may notice that these curves all

676
00:39:04,630 --> 00:39:02,690
have similar shapes so i'll just show

677
00:39:11,770 --> 00:39:04,640
you for a second like that what that

678
00:39:14,620 --> 00:39:11,780
represents these equations of state as

679
00:39:16,990 --> 00:39:14,630
i've shown you are flat here and then at

680
00:39:22,600 --> 00:39:17,000
some point they turn out the point where

681
00:39:24,580 --> 00:39:22,610
the equations of state art rising is the

682
00:39:27,310 --> 00:39:24,590
bulk modulus of the material it's good

683
00:39:30,790 --> 00:39:27,320
the pressure which the material starts

684
00:39:34,090 --> 00:39:30,800
to crush and this pressure gives you a

685
00:39:39,190 --> 00:39:34,100
scale a scale that you can use to solve

686
00:39:41,560 --> 00:39:39,200
differential equations so so we put

687
00:39:43,390 --> 00:39:41,570
together an analytic solution to the

688
00:39:49,540 --> 00:39:43,400

equations of internal structure using

689
00:39:53,440 --> 00:39:49,550
this scale to help us find an

690
00:39:56,650 --> 00:39:53,450
approximate solution so we scale all the

691
00:40:00,550 --> 00:39:56,660
variables a lot and when we do that we

692
00:40:02,200 --> 00:40:00,560
discover that if you choose the

693
00:40:04,180 --> 00:40:02,210
appropriate variables to solve the

694
00:40:07,300 --> 00:40:04,190
differential equations you can ignore

695
00:40:10,060 --> 00:40:07,310
this if you're not a geek like me that

696
00:40:12,490 --> 00:40:10,070
all of the mass radius relationships

697
00:40:13,900 --> 00:40:12,500
collapse onto each other and you see

698
00:40:25,510 --> 00:40:13,910
that they all have the same functional

699
00:40:29,200 --> 00:40:25,520
form Oh trivia okay but now back to

700
00:40:31,360 --> 00:40:29,210
other weird kinds of plans you may know

701
00:40:35,860 --> 00:40:31,370
that the first extrasolar plan is

702
00:40:38,530 --> 00:40:35,870
discovered we're not planets around

703
00:40:42,420 --> 00:40:38,540
sun-like stars they were planets around

704
00:40:47,430 --> 00:40:42,430
a pulsar here are the discovery plots

705
00:40:51,740 --> 00:40:47,440
showing you the

706
00:40:56,880 --> 00:40:51,750
the signals that Alex Walsh amused

707
00:40:59,430 --> 00:40:56,890
ultra-trail used to distinguish to

708
00:41:02,730 --> 00:40:59,440
recognize that this pulse art had

709
00:41:06,000 --> 00:41:02,740
planets and what am i showing you this

710
00:41:09,510 --> 00:41:06,010
plot it's because the planets around the

711
00:41:12,829 --> 00:41:09,520
Pulsar probably formed the

712
00:41:16,710 --> 00:41:12,839
protoplanetary disk is quite different

713
00:41:18,809 --> 00:41:16,720

solar nebula you might imagine that the

714
00:41:20,670 --> 00:41:18,819
chemistry of a disk around the Pulsar

715
00:41:22,950 --> 00:41:20,680
will be very different from the

716
00:41:27,900 --> 00:41:22,960
chemistry that solar nebula does

717
00:41:35,550 --> 00:41:27,910
everybody know what a pulse are you I've

718
00:41:38,099 --> 00:41:35,560
SI hay pulsar is a remnant of stellar

719
00:41:42,510 --> 00:41:38,109
evolution you take a very massive star

720
00:41:48,630 --> 00:41:42,520
and you wait until the end of its life a

721
00:41:53,099 --> 00:41:48,640
star will explode catastrophic Lena in a

722
00:41:56,940 --> 00:41:53,109
supernova and then all its left of the

723
00:42:00,500 --> 00:41:56,950
star after the supernova is a object

724
00:42:04,980 --> 00:42:00,510
called the neutron star which is a

725
00:42:10,710 --> 00:42:04,990
earthside sorry a mountain-sized ball

726
00:42:14,819 --> 00:42:10,720
with extremely high density for example

727
00:42:16,680 --> 00:42:14,829
look nearby at a nebula called the Crab

728
00:42:20,970 --> 00:42:16,690
Nebula this nebula is thought to

729
00:42:22,890 --> 00:42:20,980
represent a the remnants of a of a

730
00:42:25,250 --> 00:42:22,900
supernova explosion in the center of

731
00:42:30,390 --> 00:42:25,260
that nebula we see a neutron star

732
00:42:33,349 --> 00:42:30,400
neutron stars the service of neutron

733
00:42:38,040 --> 00:42:33,359
star can be very exciting they have

734
00:42:40,880 --> 00:42:38,050
launched these Jets and the neutron

735
00:42:44,300 --> 00:42:40,890
stars can also spin rapidly

736
00:42:46,880 --> 00:42:44,310
and every now and then when the star

737
00:42:49,790 --> 00:42:46,890
rotates interview 1 then this star is

738
00:42:52,460 --> 00:42:49,800

rotated to the right position the jet

739
00:42:55,100 --> 00:42:52,470
can intersect our website and we'll see

740
00:42:57,380 --> 00:42:55,110
the neutron star become brighter and

741
00:43:00,740 --> 00:42:57,390
fainter as a jet rotates in and out of

742
00:43:08,660 --> 00:43:00,750
you so that's what a pulsar is insane

743
00:43:14,140 --> 00:43:08,670
it's a spinning neutron star okay so the

744
00:43:20,210 --> 00:43:14,150
timing of the pulses as a signal to

745
00:43:22,700 --> 00:43:20,220
indicate how far away the Pulsar is

746
00:43:28,850 --> 00:43:22,710
along our line of sight right if a

747
00:43:31,280 --> 00:43:28,860
pulsar emits a pulse and then jumps

748
00:43:33,350 --> 00:43:31,290
backwards say under the gravitational

749
00:43:34,940 --> 00:43:33,360
influence but planet the next pulse it

750
00:43:37,190 --> 00:43:34,950
emits it's going to take a little bit

751
00:43:40,190 --> 00:43:37,200
longer to get to you because now it's

752
00:43:42,710 --> 00:43:40,200
farther away from you would then to the

753
00:43:46,760 --> 00:43:42,720
first policy so you can measure the time

754
00:43:48,530 --> 00:43:46,770
when the pulses arrive and that's an

755
00:43:53,930 --> 00:43:48,540
indication of motion of the pulse are

756
00:43:59,590 --> 00:43:53,940
along the line of sight and Alex used

757
00:44:02,020 --> 00:43:59,600
this technique to infer the

758
00:44:04,060 --> 00:44:02,030
the motion that the Pulsar in response

759
00:44:06,550 --> 00:44:04,070
to locate planetary systems now at

760
00:44:07,870 --> 00:44:06,560
latest count has four planets it anyway

761
00:44:12,940 --> 00:44:07,880
this is the first discovery of

762
00:44:18,130 --> 00:44:12,950
extrasolar planet oh and these planets

763
00:44:19,060 --> 00:44:18,140

are quite possibly carbon planets the

764
00:44:21,400 --> 00:44:19,070
other place where you might have

765
00:44:24,550 --> 00:44:21,410
interesting planet formation chemistry

766
00:44:27,990 --> 00:44:24,560
would be in a disk on a white door we

767
00:44:30,370 --> 00:44:28,000
often see systems of white dwarfs

768
00:44:33,910 --> 00:44:30,380
systems of pairs of white dorm so a

769
00:44:37,840 --> 00:44:33,920
white door is another kind of evolved

770
00:44:40,420 --> 00:44:37,850
star if a lower mass star if you wait to

771
00:44:42,370 --> 00:44:40,430
the end of the life of a lower mass star

772
00:44:45,250 --> 00:44:42,380
like something the mass of our Sun

773
00:44:49,920 --> 00:44:45,260
eventually becomes a white dwarf and

774
00:44:58,180 --> 00:44:56,500
if the Kerravala such a way that the the

775
00:45:01,720 --> 00:44:58,190
two white dwarfs are very close to each

776
00:45:03,370 --> 00:45:01,730
other the white dwarfs converge this

777
00:45:06,040 --> 00:45:03,380
produces a variety of interesting

778
00:45:08,620 --> 00:45:06,050
phenomena from another kind of supernova

779
00:45:12,670 --> 00:45:08,630
amazing for another kind of supernova to

780
00:45:15,840 --> 00:45:12,680
have a lot to other kinds of phenomena

781
00:45:21,900 --> 00:45:17,940
white dwarfs with disks and things like

782
00:45:26,280 --> 00:45:21,910
that and a white door free disk can form

783
00:45:27,660 --> 00:45:26,290
planets right why not I always suspect

784
00:45:30,570 --> 00:45:27,670
that whenever i see you natural physical

785
00:45:35,730 --> 00:45:30,580
disk there may be some kind of plans for

786
00:45:37,710 --> 00:45:35,740
me to disc a disc made out of a shredded

787
00:45:41,100 --> 00:45:37,720
white dwarf like something that you

788
00:45:43,530 --> 00:45:41,110

might see in this binary white dwarf

789
00:45:46,500 --> 00:45:43,540
configuration would be made mostly of

790
00:45:48,840 --> 00:45:46,510
carbon monoxide so perhaps there are

791
00:45:52,830 --> 00:45:48,850
white dwarf systems out there the carbon

792
00:45:55,830 --> 00:45:52,840
relates like clouds again sounds like

793
00:45:58,320 --> 00:45:55,840
I'm telling you a fairy tale but we've

794
00:46:00,690 --> 00:45:58,330
done a survey of white dwarfs with the

795
00:46:03,780 --> 00:46:00,700
Spitzer Space Telescope a huge list of

796
00:46:11,370 --> 00:46:03,790
some of my collaborators looking for

797
00:46:14,490 --> 00:46:11,380
these disks and we've discovered a least

798
00:46:17,280 --> 00:46:14,500
one example of a very massive white

799
00:46:21,770 --> 00:46:17,290
dwarf with the disk around this plot

800
00:46:24,870 --> 00:46:21,780
shows you a spectrum that we took of

801
00:46:28,580 --> 00:46:24,880
this white Dorf GD 362 which is one of

802
00:46:34,650 --> 00:46:28,590
the most massive white doors and the

803
00:46:37,530 --> 00:46:34,660
spectrum shows you the light emitted by

804
00:46:41,610 --> 00:46:37,540
the white door over here that's what

805
00:46:43,500 --> 00:46:41,620
this line represents and it also shows

806
00:46:46,560 --> 00:46:43,510
you are photometry that we took the

807
00:46:50,310 --> 00:46:46,570
dispenser space so it shows you that

808
00:46:52,830 --> 00:46:50,320
this model consisting of a single plain

809
00:46:54,690 --> 00:46:52,840
white Dolph is wrong and that finally

810
00:46:56,460 --> 00:46:54,700
the white dwarf is hosting some

811
00:46:59,990 --> 00:46:56,470
circumstellar material that's colder

812
00:47:05,670 --> 00:47:00,000
than the surface of the white dwarf

813
00:47:08,400 --> 00:47:05,680

probably a disk the GD 362 is special

814
00:47:10,710 --> 00:47:08,410
because one of the most massive white

815
00:47:13,080 --> 00:47:10,720
dwarfs suggesting that perhaps the

816
00:47:17,690 --> 00:47:13,090
system was formed in a white door merger

817
00:47:21,410 --> 00:47:20,940
protoplanetary disk substantial amount

818
00:47:36,980 --> 00:47:21,420
of

819
00:47:41,780 --> 00:47:36,990
want to think about representing the

820
00:47:44,839 --> 00:47:41,790
range of carbon oxygen ratios it's

821
00:47:47,059 --> 00:47:44,849
pretty vague at the moment but perhaps

822
00:47:51,799 --> 00:47:47,069
the details will be filled in as time

823
00:47:54,440 --> 00:47:51,809
goes by at low carbon oxygen ratios we

824
00:47:57,789 --> 00:47:54,450
have the solar system where the low-mass

825
00:48:01,220 --> 00:47:57,799
planets here are made of silicate

826
00:48:03,859 --> 00:48:01,230
sometimes they have water on them the

827
00:48:08,630 --> 00:48:03,869
high mass planets are planets like

828
00:48:11,930 --> 00:48:08,640
Jupiter substantially a hydrogen the

829
00:48:15,069 --> 00:48:11,940
thinking is that have a massive enough

830
00:48:18,950 --> 00:48:15,079
core inside a proprietary disk that the

831
00:48:22,910 --> 00:48:18,960
folding track the hydrogen the disk

832
00:48:25,730 --> 00:48:22,920
adaptation and all planets that are

833
00:48:29,070 --> 00:48:25,740
using the massive we mostly hide that's

834
00:48:32,970 --> 00:48:29,080
the story for

835
00:48:34,470 --> 00:48:32,980
this company understood then we have on

836
00:48:37,640 --> 00:48:34,480
the other side of the carbon-oxygen

837
00:48:40,860 --> 00:48:37,650
equals 1 ratio we have carbon rich

838
00:48:43,770 --> 00:48:40,870

plantation which may be occurring in

839
00:48:48,540 --> 00:48:43,780
disks around pulsars and disks around

840
00:48:51,300 --> 00:48:48,550
white dwarfs and there you might infer

841
00:48:54,840 --> 00:48:51,310
from the calculations of enstatite con

842
00:48:58,080 --> 00:48:54,850
droid formation perhaps you would expect

843
00:49:00,870 --> 00:48:58,090
to see carbon-rich planets perhaps made

844
00:49:13,710 --> 00:49:00,880
of silicon carbide perhaps formative

845
00:49:23,080 --> 00:49:18,270
it means I had a ten minutes left right

846
00:49:25,210 --> 00:49:23,090
then I've also suggested that perhaps

847
00:49:30,760 --> 00:49:25,220
there are some protoplanetary disks that

848
00:49:34,960 --> 00:49:30,770
without carbon monoxide and mario livio

849
00:49:38,800 --> 00:49:34,970
has written a paper allowed possibility

850
00:49:41,170 --> 00:49:38,810
of carbon monoxide planet formation so

851
00:49:45,460 --> 00:49:41,180
these would be planets that form out of

852
00:49:48,880 --> 00:49:45,470
gas right not out of solids gas-rich

853
00:49:52,120 --> 00:49:48,890
planets that form a disk of carbon

854
00:49:55,510 --> 00:49:52,130
monoxide there may be planets around

855
00:50:00,719 --> 00:49:55,520
white dwarfs for example that carbon

856
00:50:06,789 --> 00:50:03,009
of course the bottom of this diagram

857
00:50:10,989 --> 00:50:06,799
couldn't help speculating about the

858
00:50:16,839 --> 00:50:10,999
possibility of life on a carbon-rich

859
00:50:19,959 --> 00:50:16,849
planet the life on our planet has a

860
00:50:24,269 --> 00:50:19,969
whole range of metabolisms of course but

861
00:50:27,849 --> 00:50:24,279
you and I get our energy by oxidizing

862
00:50:31,989 --> 00:50:27,859
carbon rich material perhaps there will

863
00:50:34,359 --> 00:50:31,999

be life on carbon planets that works in

864
00:50:38,939 --> 00:50:34,369
a different way perhaps there can be

865
00:50:41,919 --> 00:50:38,949
life on a carbon planet that instead of

866
00:50:46,529 --> 00:50:41,929
generating energy through oxidation

867
00:50:54,339 --> 00:50:46,539
perhaps generates interview by reduction

868
00:50:57,219 --> 00:50:54,349
so for example if you had we we generate

869
00:51:00,390 --> 00:50:57,229
energy by combining oxygen with our

870
00:51:06,069 --> 00:51:00,400
carbon rich food imagine an animal that

871
00:51:07,959 --> 00:51:06,079
had very oxygen-rich food and extracted

872
00:51:11,529 --> 00:51:07,969
carbon abundant carbon from its

873
00:51:14,650 --> 00:51:11,539
surroundings to reduce it with and use

874
00:51:21,230 --> 00:51:14,660
that source of energy and that's about

875
00:51:28,520 --> 00:51:26,630
I think I'll start off the your

876
00:51:32,660 --> 00:51:28,530
dynamicists also you didn't talk about

877
00:51:34,190 --> 00:51:32,670
stability like the time what you got a

878
00:51:37,180 --> 00:51:34,200
planet and so forth which of course is

879
00:51:39,230 --> 00:51:37,190
important for life also so right are you

880
00:51:42,290 --> 00:51:39,240
seriously suggesting that you might have

881
00:51:45,550 --> 00:51:42,300
enough time in a planet that for me on

882
00:51:49,730 --> 00:51:45,560
the right dwarf it's good life going ah

883
00:51:52,100 --> 00:51:49,740
question okay what's your opinion on how

884
00:51:55,190 --> 00:51:52,110
long it takes to get life going Oh few

885
00:51:58,220 --> 00:51:55,200
hundred million years if you by the way

886
00:52:03,950 --> 00:51:58,230
if you got the right conditions right um

887
00:52:05,570 --> 00:52:03,960
well the we have several examples of

888
00:52:08,600 --> 00:52:05,580

disks around white dwarfs that we know

889
00:52:12,080 --> 00:52:08,610
and we don't always know the ages of

890
00:52:13,850 --> 00:52:12,090
each particular disc because in order to

891
00:52:16,310 --> 00:52:13,860
measure the age of the white dorm you

892
00:52:18,890 --> 00:52:16,320
generally need to know the distance to

893
00:52:22,040 --> 00:52:18,900
the white dwarf or you need a very

894
00:52:24,950 --> 00:52:22,050
detailed model of its temperature in

895
00:52:29,510 --> 00:52:24,960
flux me we don't always have that luxury

896
00:52:31,160 --> 00:52:29,520
but we do know we that on average the

897
00:52:36,340 --> 00:52:31,170
kind of white dwarf that we looked at

898
00:52:38,870 --> 00:52:36,350
the typical age is a gig a year so

899
00:52:41,300 --> 00:52:38,880
perhaps we're looking at examples of

900
00:52:44,000 --> 00:52:41,310
white dwarf disks that have had a

901
00:52:46,640 --> 00:52:44,010
million years to evolve whatever

902
00:52:49,520 --> 00:52:46,650
concrete is really like

903
00:52:53,330 --> 00:52:49,530
certainly opened up the spectrum of

904
00:52:56,030 --> 00:52:53,340
places to be okay so today but like

905
00:52:57,680 --> 00:52:56,040
another person TPF you talked at noon

906
00:53:00,650 --> 00:52:57,690
about the tremendous problems with the

907
00:53:02,480 --> 00:53:00,660
dynamic range you need to see the light

908
00:53:04,370 --> 00:53:02,490
from the planet versus the star right

909
00:53:07,490 --> 00:53:04,380
the white dwarf is a much lower

910
00:53:11,500 --> 00:53:07,500
luminosity object is helpful exactly

911
00:53:15,620 --> 00:53:11,510
that's that should be very helpful so

912
00:53:19,370 --> 00:53:15,630
for example in our survey of white

913
00:53:25,250 --> 00:53:19,380

dwarfs we calculated that we would have

914
00:53:27,830 --> 00:53:25,260
enough dynamic range to see a 3d

915
00:53:29,870 --> 00:53:27,840
jupiter-mass planet around most of our

916
00:53:33,710 --> 00:53:29,880
targets you know how much dynamic range

917
00:53:36,020 --> 00:53:33,720
it took not 10 to the minus 10 not 10 to

918
00:53:39,710 --> 00:53:36,030
the 10 contrast and to the one contrast

919
00:53:44,000 --> 00:53:39,720
and that return was that it what are you

920
00:53:47,120 --> 00:53:44,010
or all we didn't expect to resolve any

921
00:53:51,770 --> 00:53:47,130
of the planetary system so anywhere in

922
00:54:02,560 --> 00:53:51,780
within our Johnny 30 seconds other

923
00:54:09,590 --> 00:54:05,390
will be answered tapped high profile as

924
00:54:12,580 --> 00:54:09,600
you move further toward perfectly pretty

925
00:54:18,230 --> 00:54:12,590
never have work I sure think it could

926
00:54:20,780 --> 00:54:18,240
mean why do we have bought earlier chat

927
00:54:26,660 --> 00:54:20,790
about this book

928
00:54:31,150 --> 00:54:26,670
graduate students yesterday but you can

929
00:54:33,260 --> 00:54:31,160
you should expect the planet to receive

930
00:54:34,910 --> 00:54:33,270
volvo's from house wearing planetary

931
00:54:41,210 --> 00:54:34,920
system like the planet that's what's on

932
00:54:49,029 --> 00:54:41,220
fly around you can easily imagine comets

933
00:54:49,039 --> 00:54:59,900
waiting on too hard

934
00:55:03,210 --> 00:55:01,890
so you're saying the situation is not

935
00:55:05,040 --> 00:55:03,220
too different from silica plants you

936
00:55:06,390 --> 00:55:05,050
you're making it in a place where you

937
00:55:08,700 --> 00:55:06,400
don't have the water initially it's got

938
00:55:11,640 --> 00:55:08,710

to get delivered to some other kind of

939
00:55:15,090 --> 00:55:11,650
process right in the soldiers but the

940
00:55:17,400 --> 00:55:15,100
difference is of course the hats on the

941
00:55:23,160 --> 00:55:17,410
carbon plan you have this vast reservoir

942
00:55:25,830 --> 00:55:23,170
of organics you never have to you're

943
00:55:32,640 --> 00:55:25,840
never short of gasoline tank on the

944
00:55:35,700 --> 00:55:32,650
earth we fight wars over petroleum

945
00:55:40,859 --> 00:55:35,710
products carbon planet like little fight

946
00:55:43,320 --> 00:55:40,869
wars over oxidizers not reducers right

947
00:55:44,730 --> 00:55:43,330
they all fight wars over water okay in

948
00:55:48,090 --> 00:55:44,740
India they fight about water all time

949
00:55:49,830 --> 00:55:48,100
but right so maybe that's not too

950
00:55:51,840 --> 00:55:49,840
digging for work but anyway they will

951
00:55:54,810 --> 00:55:51,850
never fight over gassing you okay come

952
00:55:58,260 --> 00:55:54,820
on a car that's only gonna fight over

953
00:55:59,970 --> 00:55:58,270
silicon carbide revolutio politics

954
00:56:07,200 --> 00:55:59,980
introduction electoral politics we

955
00:56:09,900 --> 00:56:07,210
better not go there in four yes sir your

956
00:56:14,640 --> 00:56:09,910
plot of the oh I think it was the mass

957
00:56:15,960 --> 00:56:14,650
versus the radius versus mask I've got a

958
00:56:18,900 --> 00:56:15,970
spread of lines for different

959
00:56:21,000 --> 00:56:18,910
compositions except for carbon seem to

960
00:56:25,620 --> 00:56:21,010
get much more constrained

961
00:56:30,630 --> 00:56:25,630
I page back here for that was the main

962
00:56:31,650 --> 00:56:30,640
mass versus radius yeah lot but this one

963
00:56:35,310 --> 00:56:31,660

oh I didn't tell you all the details

964
00:56:38,270 --> 00:56:35,320
right I I focused on the the pure

965
00:56:42,060 --> 00:56:38,280
planets right so solid lines are pure

966
00:56:46,500 --> 00:56:42,070
planets that hatch lines are planets

967
00:56:50,880 --> 00:56:46,510
that have mixtures of for example water

968
00:56:56,700 --> 00:56:50,890
and iron imagine having an iron core to

969
00:57:02,400 --> 00:56:56,710
whatever you like don't question from

970
00:57:04,440 --> 00:57:02,410
Ames oh hi Ames hi Dave Dima right here

971
00:57:06,930 --> 00:57:04,450
I had a question about the thermal

972
00:57:08,670 --> 00:57:06,940
evolution of planets you know for

973
00:57:11,940 --> 00:57:08,680
example if you had a carbon-rich planet

974
00:57:14,250 --> 00:57:11,950
with a silicon carbide mantle well one

975
00:57:15,450 --> 00:57:14,260
one question is the radioactive elements

976
00:57:17,310 --> 00:57:15,460
which are so important for determining

977
00:57:18,870 --> 00:57:17,320
the thermal structure of silicate

978
00:57:20,790 --> 00:57:18,880
planets what do you think would be the

979
00:57:22,620 --> 00:57:20,800
situation in a carbon-rich planet and

980
00:57:24,510 --> 00:57:22,630
then a related question of course is

981
00:57:26,370 --> 00:57:24,520
that liquid and solid phases in the

982
00:57:28,170 --> 00:57:26,380
planet have a lot to do with plate

983
00:57:30,030 --> 00:57:28,180
tectonics which of course would affect

984
00:57:31,530 --> 00:57:30,040
the heat flow to the surface so even in

985
00:57:33,540 --> 00:57:31,540
the early phase of a planet's history

986
00:57:35,820 --> 00:57:33,550
when you're accreting you gotta chrétien

987
00:57:37,350 --> 00:57:35,830
airy heat how does that get out of one

988
00:57:39,000 --> 00:57:37,360

of your carbon rich planets if you guys

989
00:57:47,070 --> 00:57:39,010
thought at all about the thermal

990
00:57:49,230 --> 00:57:47,080
consequences of the models thanks to

991
00:57:52,950 --> 00:57:49,240
first order we have purposefully ignored

992
00:57:55,500 --> 00:57:52,960
that right so we have purposefully

993
00:57:57,330 --> 00:57:55,510
simplified as much as we could in order

994
00:58:00,870 --> 00:57:57,340
to explore the range of possibilities

995
00:58:02,940 --> 00:58:00,880
and find analytic solutions to the

996
00:58:06,930 --> 00:58:02,950
equations that will tell us the range of

997
00:58:09,840 --> 00:58:06,940
answers right so our philosophy to start

998
00:58:14,040 --> 00:58:09,850
out with but simplify to the point where

999
00:58:16,200 --> 00:58:14,050
we understand okay then

1000
00:58:17,460 --> 00:58:16,210
yes of course we thought about all these

1001
00:58:21,480 --> 00:58:17,470
other kinds of fun things I was just

1002
00:58:25,520 --> 00:58:21,490
having a nice conversation with Roger

1003
00:58:34,010 --> 00:58:30,600
possibilities for for example radiogenic

1004
00:58:38,120 --> 00:58:34,020
sorry radioactive heating of the planets

1005
00:58:46,380 --> 00:58:42,690
radioactive heat sources though I tend

1006
00:58:48,870 --> 00:58:46,390
to I tend to you have to stop and say

1007
00:58:51,300 --> 00:58:48,880
well is that really related to the

1008
00:58:53,700 --> 00:58:51,310
carbon planet NIST of the body right I

1009
00:58:55,500 --> 00:58:53,710
mean we're not living on the uranium

1010
00:58:58,590 --> 00:58:55,510
planet it's a small amount of uranium

1011
00:59:00,500 --> 00:58:58,600
that's doing the job so that's really

1012
00:59:03,270 --> 00:59:00,510
sort of a higher order question

1013
00:59:06,240 --> 00:59:03,280

compositionally it's a very important

1014
00:59:11,070 --> 00:59:06,250
question thoroughly but it's really not

1015
00:59:12,780 --> 00:59:11,080
a competition for the composition so you

1016
00:59:16,500 --> 00:59:12,790
can imagine a lot a wide range of

1017
00:59:18,960 --> 00:59:16,510
possibilities that are secondary to the

1018
00:59:20,580 --> 00:59:18,970
to the observational indicators that

1019
00:59:22,260 --> 00:59:20,590
we're trying to model like the mass

1020
00:59:24,420 --> 00:59:22,270
radiance relationship and the spectra

1021
00:59:28,110 --> 00:59:24,430
right what if the planet was right next

1022
00:59:31,800 --> 00:59:28,120
to a a giant star the one supernova and

1023
00:59:33,750 --> 00:59:31,810
dumped iron 60 all over it okay that

1024
00:59:35,610 --> 00:59:33,760
could happen to a carbon planet as well

1025
00:59:37,170 --> 00:59:35,620
as it could happen a carbon planet

1026
00:59:42,120 --> 00:59:37,180
system as well can have as it could

1027
00:59:43,620 --> 00:59:42,130
happen to to that was only one of your

1028
00:59:46,590 --> 00:59:43,630
questions the SEC the first one was

1029
00:59:52,170 --> 00:59:46,600
laser tonics Oh plate tectonics yeah

1030
00:59:55,620 --> 00:59:52,180
yeah oh just this is exactly what Roger

1031
00:59:59,910 --> 00:59:55,630
longer Talia but earlier have plate

1032
01:00:04,290 --> 00:59:59,920
tectonics pond a carbon planet I don't

1033
01:00:08,060 --> 01:00:04,300
know carbon as you know the place

1034
01:00:11,400 --> 01:00:08,070
etonics require some lubrication right

1035
01:00:13,230 --> 01:00:11,410
there could be water available to

1036
01:00:16,860 --> 01:00:13,240
provide the lubricant maybe you can

1037
01:00:21,590 --> 01:00:16,870
lubricate the plate tectonics with no

1038
01:00:25,560 --> 01:00:21,600

butter Crisco some other carbon

1039
01:00:28,290 --> 01:00:25,570
carbon compound I would expect that the

1040
01:00:33,330 --> 01:00:28,300
surface of a of a carbon planet would be

1041
01:00:40,140 --> 01:00:33,340
a little bit would be full of all kinds

1042
01:00:43,710 --> 01:00:40,150
of organics right you might expect the

1043
01:00:49,740 --> 01:00:43,720
smog the atmosphere a surface covered

1044
01:00:54,270 --> 01:00:49,750
with car sort of like Los Angeles police

1045
01:00:57,930 --> 01:00:54,280
come Brea Tar Pits Richard how you need

1046
01:00:59,610 --> 01:00:57,940
is your 7.3 Mike on feature for so and

1047
01:01:01,590 --> 01:00:59,620
is it related of the few center

1048
01:01:06,120 --> 01:01:01,600
celebrates what's the evidence for the

1049
01:01:10,260 --> 01:01:06,130
viticulture ah that's good there are a

1050
01:01:14,790 --> 01:01:10,270
variety of pH features that have been

1051
01:01:19,039 --> 01:01:14,800
detected next fiscal sources besides the

1052
01:01:24,029 --> 01:01:21,359
each is it there are lots of other

1053
01:01:28,609 --> 01:01:24,039
different features so people are have

1054
01:01:34,559 --> 01:01:28,619
seen you know spectacular PAH spectra

1055
01:01:37,020 --> 01:01:34,569
from the thermal than 3,000 far but you

1056
01:01:38,220 --> 01:01:37,030
only have one future spits irregular yes

1057
01:01:41,240 --> 01:01:38,230
those are getting really operate in the

1058
01:01:45,960 --> 01:01:41,250
firebreak but oh but Spencer has seen

1059
01:01:51,299 --> 01:01:45,970
other weaker features in t-tauri stars

1060
01:01:54,680 --> 01:01:51,309
perfect movie stars from 5 micron top 20

1061
01:01:56,849 --> 01:01:54,690
casino is we're not hanging on one

1062
01:01:59,670 --> 01:01:56,859
special on that's what you know that's

1063
01:02:03,289 --> 01:01:59,680

what kind of look like in this mass

1064
01:02:06,510 --> 01:02:03,299
radius diagram raised country

1065
01:02:08,640 --> 01:02:06,520
implemented oh good I didn't explain

1066
01:02:10,559 --> 01:02:08,650
that very well if you see a transiting

1067
01:02:13,020 --> 01:02:10,569
planet you know a couple of things you

1068
01:02:18,059 --> 01:02:13,030
know how deep transit is right tell you

1069
01:02:22,440 --> 01:02:18,069
will the cross-section stuff and you

1070
01:02:25,380 --> 01:02:22,450
also know true asian you know how the

1071
01:02:27,210 --> 01:02:25,390
duration compares to the duration of the

1072
01:02:29,130 --> 01:02:27,220
orbit right so you have the frequency

1073
01:02:32,549 --> 01:02:29,140
and you know that the trend that the

1074
01:02:35,730 --> 01:02:32,559
transit lasted for one percent of the

1075
01:02:39,329 --> 01:02:35,740
orbit that'd be a pretty long but you

1076
01:02:43,589 --> 01:02:39,339
see that's that's the other observable

1077
01:02:50,009 --> 01:02:48,180
I still have necessary what should you

1078
01:02:52,529 --> 01:02:50,019
need you mean you need the mass of the

1079
01:02:54,660 --> 01:02:52,539
star which is currently the major source

1080
01:03:00,779 --> 01:02:54,670
of uncertainty in these mats

1081
01:03:02,670 --> 01:03:00,789
observations it's common that it's there

1082
01:03:08,309 --> 01:03:02,680
are surprisingly few stars that we have

1083
01:03:11,279 --> 01:03:08,319
very inaccurate masses right so but if

1084
01:03:16,039 --> 01:03:11,289
you know possibly the masculine star and

1085
01:03:20,249 --> 01:03:16,049
you know Kepler's third law you know the

1086
01:03:22,469 --> 01:03:20,259
timing of the of the duration of the

1087
01:03:24,450 --> 01:03:22,479
transit a period of the orbit that we

1088
01:03:26,309 --> 01:03:24,460

could infer the message this is the mass

1089
01:03:33,589 --> 01:03:26,319
of the planner the preg that equation at

1090
01:03:40,740 --> 01:03:38,460
but more but more importantly the reflex

1091
01:03:42,870 --> 01:03:40,750
motion of the star that you know from

1092
01:03:44,579 --> 01:03:42,880
great velocity measurements tells you

1093
01:03:52,500 --> 01:03:44,589
the mass ratio so you know some of the