THE ATMOSPHERE/INTERIOR CONNECTION FOR TRANSITING GIANT PLANETS

JONATHAN FORTNEY

1
00:00:09,190 --> 00:00:06,900
[Music]

2
00:00:10,869 --> 00:00:09,200
so my talk today is talking about

3
00:00:12,869 --> 00:00:10,879
planetary atmospheres and planetary

4
00:00:16,209 --> 00:00:12,879
interiors in the connection between them

5
00:00:18,670 --> 00:00:16,219
so this is really what you might call a

6
00:00:20,080 --> 00:00:18,680
statistical view of planetary physics a

7
00:00:21,820 --> 00:00:20,090
lot of times in planets we talk about

8
00:00:23,259 --> 00:00:21,830
the physics of particular objects or

9
00:00:24,849 --> 00:00:23,269
trying to make connections between two

10
00:00:26,080 --> 00:00:24,859
or three objects is really about trying

11
00:00:28,240 --> 00:00:26,090
to make connections between a large

12
00:00:29,200 --> 00:00:28,250
number of objects we've already heard

13
00:00:31,330 --> 00:00:29,210

about that a little bit this morning

14
00:00:32,439 --> 00:00:31,340
things about the radius Valley how can

15
00:00:35,079 --> 00:00:32,449
we explain that by looking at a

16
00:00:37,900 --> 00:00:35,089
collection of planets so this is a

17
00:00:39,220 --> 00:00:37,910
statistical view it's typically I would

18
00:00:41,139 --> 00:00:39,230
say a bit easier we were thinking about

19
00:00:43,209 --> 00:00:41,149
planetary structure rather than talking

20
00:00:44,680 --> 00:00:43,219
about planetary atmospheres because for

21
00:00:46,060 --> 00:00:44,690
planetary structure it's typically a

22
00:00:47,500 --> 00:00:46,070
little bit less demanding you might only

23
00:00:49,029 --> 00:00:47,510
need to measure a planet's mass and

24
00:00:51,010 --> 00:00:49,039
radius learn something about its density

25
00:00:52,600 --> 00:00:51,020
you might have dozens or hundreds of

26
00:00:54,819 --> 00:00:52,610
objects where you know the densities

27
00:00:55,900 --> 00:00:54,829
whereas for planetary atmospheres you

28
00:00:57,130 --> 00:00:55,910
might want to get spectra of those

29
00:00:59,500 --> 00:00:57,140
objects it's a lot more time-consuming

30
00:01:01,569 --> 00:00:59,510
and harder to get spectra of dozens or

31
00:01:05,499 --> 00:01:01,579
hundreds of objects will certainly get

32
00:01:07,210 --> 00:01:05,509
there so today's top really about some

33
00:01:09,219 --> 00:01:07,220
findings we have for planetary structure

34
00:01:10,779 --> 00:01:09,229
I want to talk about two topics and how

35
00:01:12,839 --> 00:01:10,789
we can extend those to learn something

36
00:01:15,130 --> 00:01:12,849
about planetary atmospheres

37
00:01:17,529 --> 00:01:15,140
so the first half of the talk is

38
00:01:19,389 --> 00:01:17,539

thinking about these cold colder

39
00:01:21,279 --> 00:01:19,399
transiting giant planets this is like

40
00:01:23,410 --> 00:01:21,289
again work led by Daniel this is planet

41
00:01:25,870 --> 00:01:23,420
radius in Jupiter radii this is like the

42
00:01:27,699 --> 00:01:25,880
solar constant and for planets cooler

43
00:01:29,469 --> 00:01:27,709
than about a thousand degrees we can see

44
00:01:31,809 --> 00:01:29,479
these objects are not anomalously

45
00:01:33,910 --> 00:01:31,819
inflated this dashed red curve would be

46
00:01:35,680 --> 00:01:33,920
a naive expectation for the radius of

47
00:01:37,270 --> 00:01:35,690
these planets the hottest of the hot

48
00:01:39,160 --> 00:01:37,280
Jupiters tend to be the most inflated

49
00:01:41,050 --> 00:01:39,170
you look at these cooler objects out

50
00:01:44,680 --> 00:01:41,060
here there's about 50 objects actually

51
00:01:46,630 --> 00:01:44,690
now it's up to about 75 I think we could

52
00:01:48,010 --> 00:01:46,640
measure their mass their radius we can

53
00:01:50,229 --> 00:01:48,020
infer their density and we can run a

54
00:01:52,089 --> 00:01:50,239
structure model to infer something about

55
00:01:54,580 --> 00:01:52,099
the metal enrichment of the planets

56
00:01:56,859 --> 00:01:54,590
these objects are all smaller and denser

57
00:01:58,540 --> 00:01:56,869
pure hydrogen helium objects you can

58
00:02:00,309 --> 00:01:58,550
infer something about their metallicity

59
00:02:03,070 --> 00:02:00,319
the amount of heavy elements from metals

60
00:02:04,839 --> 00:02:03,080
inside of them and so Daniel Dunn that's

61
00:02:07,210 --> 00:02:04,849
in a fully Bayesian way by running many

62
00:02:08,350 --> 00:02:07,220
thousands of models per planet just for

63
00:02:10,869 --> 00:02:08,360

instance you can look at them in like

64
00:02:12,640 --> 00:02:10,879
walk eights we can infer inside that

65
00:02:14,800 --> 00:02:12,650
planet there's something like 80 earth

66
00:02:17,520 --> 00:02:14,810
masses have the elements with the

67
00:02:19,080 --> 00:02:17,530
distribution around that the details

68
00:02:20,610 --> 00:02:19,090
colors aren't particularly important we

69
00:02:22,530 --> 00:02:20,620
don't really know if the heavy elements

70
00:02:25,140 --> 00:02:22,540
are mostly in a core or mostly in the

71
00:02:26,940 --> 00:02:25,150
envelope or some sort of distribution

72
00:02:28,830 --> 00:02:26,950
between the two of them we can do this

73
00:02:32,010 --> 00:02:28,840
for about 50 planets here it's just for

74
00:02:33,300 --> 00:02:32,020
four for example and we can derive this

75
00:02:35,400 --> 00:02:33,310
sort of relation this was published

76
00:02:38,010 --> 00:02:35,410
about three years ago now through the

77
00:02:39,750 --> 00:02:38,020
inferred heavy element mass inside of a

78
00:02:42,090 --> 00:02:39,760
planet in Earth masses that gets us from

79
00:02:44,550 --> 00:02:42,100
a structure model of the planet versus

80
00:02:46,320 --> 00:02:44,560
planet mass you can find something that

81
00:02:48,420 --> 00:02:46,330
it's pretty interesting I think in that

82
00:02:49,920 --> 00:02:48,430
there's a good evidence that I'm planets

83
00:02:51,780 --> 00:02:49,930
has to have on the order of something

84
00:02:54,000 --> 00:02:51,790
like ten earth masses that have yellen's

85
00:02:55,770 --> 00:02:54,010
inside them which agrees quite well with

86
00:02:57,750 --> 00:02:55,780
expectations from the core accretion

87
00:02:59,550 --> 00:02:57,760
model of planet formation there as you

88
00:03:01,199 --> 00:02:59,560

get to larger and larger planet masses

89
00:03:03,509 --> 00:03:01,209
your accreting not just hydrogen and

90
00:03:05,790 --> 00:03:03,519
helium you're also treating significant

91
00:03:07,770 --> 00:03:05,800
additional metals as well so these

92
00:03:10,380 --> 00:03:07,780
objects are not just hydrogen helium

93
00:03:11,790 --> 00:03:10,390
spheres with small core these objects

94
00:03:14,309 --> 00:03:11,800
are typically accreting tens or even

95
00:03:15,990 --> 00:03:14,319
hundreds of earth mass heavy elements at

96
00:03:18,300 --> 00:03:16,000
the same time they're creating hydrogen

97
00:03:20,640 --> 00:03:18,310
helium these objects are quite metal

98
00:03:21,930 --> 00:03:20,650
enriched and then Jupiter and Saturn

99
00:03:23,490 --> 00:03:21,940
there are sitting there amongst their

100
00:03:25,860 --> 00:03:23,500
cousin planets looking very nicely

101
00:03:27,930 --> 00:03:25,870
within the distribution we can make a

102
00:03:30,030 --> 00:03:27,940
diagram like this it's as if I'm at the

103
00:03:32,550 --> 00:03:30,040
metals mass fraction of the planet again

104
00:03:34,410 --> 00:03:32,560
from the structure model compared to Z

105
00:03:36,090 --> 00:03:34,420
star that's from measuring the iron

106
00:03:38,759 --> 00:03:36,100
abundance of the parent star as the star

107
00:03:40,590 --> 00:03:38,769
we can look at the metal enrichment of

108
00:03:42,000 --> 00:03:40,600
the planet as a function of planet mass

109
00:03:43,800 --> 00:03:42,010
this is just another way of showing the

110
00:03:45,479 --> 00:03:43,810
same data set you can see there's the

111
00:03:47,610 --> 00:03:45,489
characteristic slope and a

112
00:03:49,830 --> 00:03:47,620
characteristic spread to me that spread

113
00:03:51,720 --> 00:03:49,840

is as important as the slope and that

114
00:03:53,520 --> 00:03:51,730
there's no one way of making a giant

115
00:03:55,560 --> 00:03:53,530
planet if you look at Saturn mass

116
00:03:57,420 --> 00:03:55,570
planets there's less metal-rich set

117
00:03:59,130 --> 00:03:57,430
Saturn's there's very metal enriched

118
00:04:02,310 --> 00:03:59,140
Saturn there's a big diversity at a

119
00:04:04,199 --> 00:04:02,320
given planet math this is entirely

120
00:04:06,810 --> 00:04:04,209
complementary to what people are doing

121
00:04:08,910 --> 00:04:06,820
for atmospheres so on the left of the

122
00:04:11,520 --> 00:04:08,920
exact same plot I just showed the planet

123
00:04:13,110 --> 00:04:11,530
over T star on the right is a diagram

124
00:04:14,759 --> 00:04:13,120
people have been working very hard to

125
00:04:17,250 --> 00:04:14,769
add additional planets to it since again

126
00:04:20,159 --> 00:04:17,260
planet mass in Jupiter masses this is

127
00:04:22,290 --> 00:04:20,169
the implied atmospheric metallicity in

128
00:04:24,480 --> 00:04:22,300
solar abundances we have the solar

129
00:04:26,279 --> 00:04:24,490
systems for gas giants where this is

130
00:04:28,649 --> 00:04:26,289
measuring the methane abundance so to

131
00:04:30,300 --> 00:04:28,659
infer carbon comparing to the water

132
00:04:31,159 --> 00:04:30,310
abundance in a variety of transiting

133
00:04:32,959 --> 00:04:31,169
planets

134
00:04:34,730 --> 00:04:32,969
and so the point I want to make of the

135
00:04:36,739 --> 00:04:34,740
first half of the talk is already on the

136
00:04:39,050 --> 00:04:36,749
left-hand side you can see there's a

137
00:04:41,330 --> 00:04:39,060
large spread although there is a slope

138
00:04:43,040 --> 00:04:41,340

you can see on the right-hand side we

139
00:04:44,119 --> 00:04:43,050
don't really have enough objects yet to

140
00:04:46,040 --> 00:04:44,129
say that because we're looking at a

141
00:04:48,439 --> 00:04:46,050
sample size of something like 8 not

142
00:04:51,350 --> 00:04:48,449
let's amplify that 50 but I would expect

143
00:04:53,749 --> 00:04:51,360
the spread over here to be larger and

144
00:04:54,769 --> 00:04:53,759
that's for two reasons one is that

145
00:04:56,540 --> 00:04:54,779
there's going to be certainly a

146
00:04:58,309 --> 00:04:56,550
diversity in sharing these metals

147
00:05:00,409 --> 00:04:58,319
between the core and the envelope and

148
00:05:02,390 --> 00:05:00,419
that's that's going to increase the

149
00:05:03,800 --> 00:05:02,400
spread if on the right hand side we

150
00:05:06,019 --> 00:05:03,810
don't know the fraction of metals over

151
00:05:07,100 --> 00:05:06,029
there in the envelope versus the core

152
00:05:09,050 --> 00:05:07,110
and there's probably going to be a

153
00:05:11,360 --> 00:05:09,060
diversity in that because we think for

154
00:05:12,619 --> 00:05:11,370
instance Jupiter perhaps most of its

155
00:05:14,209 --> 00:05:12,629
metals are in the envelope where it's

156
00:05:16,309 --> 00:05:14,219
Saturn we think most of its metals are

157
00:05:18,200 --> 00:05:16,319
in the core that's gonna lead to some

158
00:05:20,330 --> 00:05:18,210
bigger spread so we should expect a

159
00:05:22,249 --> 00:05:20,340
bigger spread on the right I think also

160
00:05:25,040 --> 00:05:22,259
we have some apples to oranges effects

161
00:05:27,409 --> 00:05:25,050
here right so in the solar system we're

162
00:05:29,179 --> 00:05:27,419
measuring the carbon abundance and on

163
00:05:31,279 --> 00:05:29,189

the right over here we're measuring some

164
00:05:33,260 --> 00:05:31,289
fraction of the oxygen abundance we're

165
00:05:35,059 --> 00:05:33,270
seeing what's what's in water and that's

166
00:05:37,429 --> 00:05:35,069
what you might call apples to oranges I

167
00:05:39,769 --> 00:05:37,439
was reading a book about the mother top

168
00:05:41,269 --> 00:05:39,779
icannot talked about when you think

169
00:05:42,559 --> 00:05:41,279
you're comparing apples to oranges make

170
00:05:47,029 --> 00:05:42,569
sure you're not really comparing apples

171
00:05:49,670 --> 00:05:47,039
to Buicks and boy that really stopped me

172
00:05:51,260 --> 00:05:49,680
in my tracks for a long time I think

173
00:05:52,969 --> 00:05:51,270
when we're thinking about carbon and

174
00:05:55,969 --> 00:05:52,979
oxygen it really is apples orange it's

175
00:05:58,070 --> 00:05:55,979
not apples to Buicks but we should be

176
00:05:59,719 --> 00:05:58,080
mindful that this diagram and the writes

177
00:06:00,920 --> 00:05:59,729
really get a good I think it's going to

178
00:06:02,510 --> 00:06:00,930
be messier than the one on the left

179
00:06:06,529 --> 00:06:02,520
because there's a lot more physical

180
00:06:08,179 --> 00:06:06,539
effects going on so for the second half

181
00:06:10,070 --> 00:06:08,189
of my talk I want to think about the

182
00:06:12,350 --> 00:06:10,080
objects on the far right hand side these

183
00:06:13,369 --> 00:06:12,360
are the anomalously inflated hot

184
00:06:18,800 --> 00:06:13,379
Jupiters it's been a long-standing

185
00:06:21,290 --> 00:06:18,810
problem going back 20 years now where we

186
00:06:23,209 --> 00:06:21,300
have a sample of over 200 planets here

187
00:06:25,459 --> 00:06:23,219
and the typical object is larger and

188
00:06:28,879 --> 00:06:25,469

less dense than the expectation of a

189
00:06:30,980 --> 00:06:28,889
naive model in red so we can think about

190
00:06:34,100 --> 00:06:30,990
what this implies for the structure of

191
00:06:35,689 --> 00:06:34,110
planetary atmospheres this is a lot of

192
00:06:37,850 --> 00:06:35,699
text but on the right hand side I just

193
00:06:39,649 --> 00:06:37,860
want to show that for a long time people

194
00:06:41,480 --> 00:06:39,659
have been modeling the structure of

195
00:06:43,879 --> 00:06:41,490
exoplanet atmospheres pretty strongly

196
00:06:45,050 --> 00:06:43,889
radiated planets this is pressure versus

197
00:06:48,470 --> 00:06:45,060
temperature from stars

198
00:06:50,210 --> 00:06:48,480
all 2003 this is a four model that all

199
00:06:52,340 --> 00:06:50,220
have the same parent star but these are

200
00:06:55,010 --> 00:06:52,350
interiors that are cooling off over time

201
00:06:57,020 --> 00:06:55,020
if you have a young planet with a hot

202
00:06:59,240 --> 00:06:57,030
intrinsic temperature you get a

203
00:07:01,730 --> 00:06:59,250
shallower radiative convective boundary

204
00:07:05,000 --> 00:07:01,740
and as the interior cools off to smaller

205
00:07:07,129 --> 00:07:05,010
and smaller fluxes you have a stronger

206
00:07:08,450 --> 00:07:07,139
mismatch between the infinite flux and

207
00:07:09,740 --> 00:07:08,460
the intrinsic flux and your radiative

208
00:07:12,290 --> 00:07:09,750
convective boundary would get keyed

209
00:07:14,150 --> 00:07:12,300
deeper and deeper than deep and so if

210
00:07:16,070 --> 00:07:14,160
you look at Jupiter itself Jupiter's

211
00:07:18,740 --> 00:07:16,080
intrinsic temperature is on the order of

212
00:07:21,110 --> 00:07:18,750
a hundred Kelvin if you put that around

213
00:07:22,820 --> 00:07:21,120

in a five day orbit around a parent star

214
00:07:24,770 --> 00:07:22,830
you naturally get a radiant convective

215
00:07:27,320 --> 00:07:24,780
boundary at like one killable that's

216
00:07:29,629 --> 00:07:27,330
down here at ten to the three bar also

217
00:07:31,520 --> 00:07:29,639
if you run a simple cooling model of a

218
00:07:33,830 --> 00:07:31,530
transiting planet you find the interior

219
00:07:35,750 --> 00:07:33,840
of your hot Jupiter should cool off to

220
00:07:37,850 --> 00:07:35,760
around about a hundred Kelvin and then

221
00:07:39,680 --> 00:07:37,860
you should get at Giggy year ages a

222
00:07:41,840 --> 00:07:39,690
radiant convective boundary at around

223
00:07:45,110 --> 00:07:41,850
one kilobots been a number that's been

224
00:07:46,820 --> 00:07:45,120
thrown around for a long time in

225
00:07:49,520 --> 00:07:46,830
principle though we know this is

226
00:07:51,800 --> 00:07:49,530
probably not really correct in that if

227
00:07:55,340 --> 00:07:51,810
you have a very large radius planet

228
00:07:57,560 --> 00:07:55,350
that's like 1.5 jupiter radii that

229
00:07:59,180 --> 00:07:57,570
implies the interiors hot and low

230
00:08:01,760 --> 00:07:59,190
density that implies there's a lot of

231
00:08:03,860 --> 00:08:01,770
flux coming out of the interior and so

232
00:08:06,290 --> 00:08:03,870
that implies that these models with

233
00:08:07,880 --> 00:08:06,300
hotter interiors are probably closer to

234
00:08:09,860 --> 00:08:07,890
reality in these models within cooler

235
00:08:11,840 --> 00:08:09,870
interiors so people have who have

236
00:08:13,700 --> 00:08:11,850
modeled 1d and 3-dimensional models have

237
00:08:15,740 --> 00:08:13,710
sometimes thought of it as a free

238
00:08:17,629 --> 00:08:15,750

parameter running hot interiors running

239
00:08:21,260 --> 00:08:17,639
cold interiors but there hasn't really

240
00:08:22,610 --> 00:08:21,270
been any sort of kind of rule of thumb

241
00:08:24,469 --> 00:08:22,620
people have used for what's actually

242
00:08:26,300 --> 00:08:24,479
realistic so the radio convective

243
00:08:28,400 --> 00:08:26,310
boundary is often ignored or is left at

244
00:08:30,290 --> 00:08:28,410
the free parameter but as I said these

245
00:08:33,350 --> 00:08:30,300
structure models actually can suggest

246
00:08:34,610 --> 00:08:33,360
what is a realistic intrinsic flux

247
00:08:38,240 --> 00:08:34,620
coming out of the interior in a

248
00:08:40,760 --> 00:08:38,250
realistic rate of convective boundary so

249
00:08:43,190 --> 00:08:40,770
the goal then is to use the radius

250
00:08:46,100 --> 00:08:43,200
distribution of all of these planets

251
00:08:50,610 --> 00:08:46,110
it's over 300 objects to infer something

252
00:08:55,079 --> 00:08:52,920
so what that is is to assess the needed

253
00:08:56,820 --> 00:08:55,089
inflation power to explain the radius of

254
00:08:58,769 --> 00:08:56,830
these planets this is a paper genuine I

255
00:09:01,470 --> 00:08:58,779
did last year where we're trying to

256
00:09:03,390 --> 00:09:01,480
figure out what if you imagine what's

257
00:09:05,040 --> 00:09:03,400
causing hot Jupiter inflation is some

258
00:09:07,290 --> 00:09:05,050
anomalous heating from the parent star

259
00:09:09,780 --> 00:09:07,300
getting its way into the planets deep

260
00:09:10,980 --> 00:09:09,790
interior what fraction of that energy do

261
00:09:12,690 --> 00:09:10,990
you need it to do

262
00:09:14,790 --> 00:09:12,700
and so it's something on the order of a

263
00:09:16,950 --> 00:09:14,800

few percent it starts out small but the

264
00:09:18,750 --> 00:09:16,960
colder hot Jupiters are not inflated

265
00:09:21,600 --> 00:09:18,760
then you get up to objects at around

266
00:09:23,220 --> 00:09:21,610
1500 K that are really inflated then it

267
00:09:25,200 --> 00:09:23,230
actually has to go down again so it

268
00:09:27,150 --> 00:09:25,210
looks like the kind of quasi Gaussian

269
00:09:29,490 --> 00:09:27,160
shape and that's where the heating

270
00:09:31,829 --> 00:09:29,500
efficiency what we're doing now is

271
00:09:33,840 --> 00:09:31,839
recasting that in terms of what the

272
00:09:35,640 --> 00:09:33,850
intrinsic flux coming out of the

273
00:09:37,740 --> 00:09:35,650
interior is the transferometer eyes by

274
00:09:39,990 --> 00:09:37,750
some temperature it also looks something

275
00:09:43,320 --> 00:09:40,000
like it caused the Gaussian in that it

276
00:09:46,620 --> 00:09:43,330
Peaks it around something like 700

277
00:09:47,700 --> 00:09:46,630
Kelvin so 700 to the fourth compared to

278
00:09:50,670 --> 00:09:47,710
a hundred to the fourth it's a

279
00:09:52,530 --> 00:09:50,680
difference of about 2,400 so a factor

280
00:09:55,170 --> 00:09:52,540
and the flux coming out of the interior

281
00:09:57,240 --> 00:09:55,180
over two thousand times higher but if

282
00:09:59,910 --> 00:09:57,250
you just use Jupiter's intrinsic flux

283
00:10:01,260 --> 00:09:59,920
which is around a hundred degrees so

284
00:10:03,269 --> 00:10:01,270
what that does is it dramatically

285
00:10:06,390 --> 00:10:03,279
changes the structure of your atmosphere

286
00:10:08,250 --> 00:10:06,400
and so uh what we've done with Peter Gao

287
00:10:09,840 --> 00:10:08,260
in the past few months is compute a

288
00:10:11,820 --> 00:10:09,850

series of models we're looking at

289
00:10:14,519 --> 00:10:11,830
different distances from from the sun

290
00:10:17,430 --> 00:10:14,529
point one a you put o 1au up to point

291
00:10:19,560 --> 00:10:17,440
one at you using this list this derived

292
00:10:21,690 --> 00:10:19,570
law for the flux coming out of the

293
00:10:23,430 --> 00:10:21,700
interior and so we typically find ray D

294
00:10:25,530 --> 00:10:23,440
to convective boundaries that are not at

295
00:10:27,260 --> 00:10:25,540
a Killah bar but Reed and convective

296
00:10:30,840 --> 00:10:27,270
boundaries that are typically at

297
00:10:33,000 --> 00:10:30,850
something like a bar or so these are all

298
00:10:35,190 --> 00:10:33,010
I think Saturn site type gravities with

299
00:10:36,900 --> 00:10:35,200
a slightly metal enriched atmosphere so

300
00:10:39,150 --> 00:10:36,910
the typical hot Jupiters then have radio

301
00:10:40,680 --> 00:10:39,160
convective boundaries at a few bars it's

302
00:10:42,750 --> 00:10:40,690
only once you get to the cooler and

303
00:10:44,550 --> 00:10:42,760
cooler objects for this much less flux

304
00:10:46,290 --> 00:10:44,560
coming out of the interior that you get

305
00:10:48,390 --> 00:10:46,300
these deep rated convective boundaries

306
00:10:50,160 --> 00:10:48,400
at around several hundred bars I should

307
00:10:53,250 --> 00:10:50,170
mention that thick curves are convective

308
00:10:54,600 --> 00:10:53,260
the thin curves are radiative this has a

309
00:10:56,190 --> 00:10:54,610
number of important implications which

310
00:10:58,019 --> 00:10:56,200
I'll show on the next slide but one here

311
00:10:59,850 --> 00:10:58,029
visually is you can see if you have a

312
00:11:02,160 --> 00:10:59,860
condensation curve where a cloud might

313
00:11:03,960 --> 00:11:02,170

be forming like four stripes if you have

314
00:11:06,449 --> 00:11:03,970
a shallow ray to come back

315
00:11:07,769 --> 00:11:06,459
down the cloud might form at a bar or if

316
00:11:09,480 --> 00:11:07,779
you have a deep rate of convective zone

317
00:11:12,420 --> 00:11:09,490
you follow this dotted curve and your

318
00:11:14,759 --> 00:11:12,430
cloud might actually be at 500 bars so

319
00:11:18,509 --> 00:11:14,769
clouds and the height at which they form

320
00:11:19,860 --> 00:11:18,519
is one particularly important aspect so

321
00:11:21,689 --> 00:11:19,870
we can compute then what the rate of

322
00:11:24,179 --> 00:11:21,699
convective boundary would be in pressure

323
00:11:25,170 --> 00:11:24,189
as a function of the infinite flux for

324
00:11:27,269 --> 00:11:25,180
different gravities different

325
00:11:29,639 --> 00:11:27,279
metallicity x' and you can see typically

326
00:11:31,319 --> 00:11:29,649
then for the typical runner hot Jupiters

327
00:11:33,660 --> 00:11:31,329
you're at something like a few bars

328
00:11:35,429 --> 00:11:33,670
where as it gets deeper as you get to

329
00:11:38,879 --> 00:11:35,439
cooler planets where there's much less

330
00:11:40,379 --> 00:11:38,889
flux coming out of the interior so the

331
00:11:42,749 --> 00:11:40,389
implications then I think are pretty

332
00:11:43,860 --> 00:11:42,759
interesting so just the the first bullet

333
00:11:45,990 --> 00:11:43,870
point of what have repeated several

334
00:11:48,269 --> 00:11:46,000
times now this is potentially important

335
00:11:50,519 --> 00:11:48,279
for a number of things one would be the

336
00:11:52,350 --> 00:11:50,529
day/night circulation what is the bound

337
00:11:54,749 --> 00:11:52,360
of butter what is the bottom boundary in

338
00:11:56,790 --> 00:11:54,759

your 3-dimensional model is it just a

339
00:11:58,920 --> 00:11:56,800
radiative atmosphere all the way down to

340
00:12:00,960 --> 00:11:58,930
it's essentially infinity or if you have

341
00:12:03,389 --> 00:12:00,970
a convection actually happening just

342
00:12:05,009 --> 00:12:03,399
below the visible atmosphere another is

343
00:12:07,019 --> 00:12:05,019
for interpreting observed phase curves

344
00:12:08,879 --> 00:12:07,029
if your night side your planet actually

345
00:12:11,730 --> 00:12:08,889
has a fair amount of convective flux

346
00:12:13,619 --> 00:12:11,740
coming out that you weren't accounting

347
00:12:15,420 --> 00:12:13,629
for before that might make one way of

348
00:12:17,429 --> 00:12:15,430
making night sides a bit hotter than you

349
00:12:19,110 --> 00:12:17,439
typically might think another is

350
00:12:20,819 --> 00:12:19,120
vertical mixing we've tend to thought

351
00:12:22,829 --> 00:12:20,829
about hot Jupiter atmospheres as being

352
00:12:24,869 --> 00:12:22,839
radiative down to an extremely deep

353
00:12:26,970 --> 00:12:24,879
depth but if they're actually convective

354
00:12:28,799 --> 00:12:26,980
down below a few bars that's one way of

355
00:12:30,079 --> 00:12:28,809
keeping particulates quite a bit higher

356
00:12:33,240 --> 00:12:30,089
up in the atmosphere

357
00:12:35,400 --> 00:12:33,250
another is related these deep cold traps

358
00:12:37,199 --> 00:12:35,410
people have thought about how cold traps

359
00:12:40,290 --> 00:12:37,209
deep in the atmosphere might wrap

360
00:12:41,730 --> 00:12:40,300
materials and condensates down in the

361
00:12:42,929 --> 00:12:41,740
atmosphere but the atmosphere is

362
00:12:44,639 --> 00:12:42,939
actually hot and convective

363
00:12:48,689 --> 00:12:44,649

these things might get wash it up more

364
00:12:50,670 --> 00:12:48,699
easily so my second to last side is is

365
00:12:53,460 --> 00:12:50,680
there any direct observational test for

366
00:12:56,999 --> 00:12:53,470
this so we can compute models with

367
00:13:00,869 --> 00:12:57,009
different temperature interiors 700k 400

368
00:13:02,939 --> 00:13:00,879
K 200 100 we can calculate the pressure

369
00:13:04,829 --> 00:13:02,949
that we see down to as a function of

370
00:13:06,809 --> 00:13:04,839
wavelength it's typically around maybe a

371
00:13:09,240 --> 00:13:06,819
tenth of a bar but it varies very

372
00:13:11,040 --> 00:13:09,250
strongly with wavelength in the jhk

373
00:13:12,720 --> 00:13:11,050
window that's where we see the deepest

374
00:13:14,879 --> 00:13:12,730
where the opacity is the bad the minimum

375
00:13:17,980 --> 00:13:14,889
and we might be able to actually see

376
00:13:19,450 --> 00:13:17,990
enhanced fluxes in the near infrared

377
00:13:22,540 --> 00:13:19,460
this blue curve compared to the red

378
00:13:24,220 --> 00:13:22,550
curve for a hot interior of like 700k

379
00:13:28,390 --> 00:13:24,230
that's the project I'm working on right

380
00:13:30,010 --> 00:13:28,400
now so summarize then we should expect I

381
00:13:31,660 --> 00:13:30,020
think a mass metallicity relation for

382
00:13:33,100 --> 00:13:31,670
giant planets I think it's going to be

383
00:13:35,230 --> 00:13:33,110
Messier in terms of atmospheric

384
00:13:37,900 --> 00:13:35,240
abundances and it will be for the actual

385
00:13:39,640 --> 00:13:37,910
structure of the planet and we have some

386
00:13:41,500 --> 00:13:39,650
new results on the radiative convective

387
00:13:43,150 --> 00:13:41,510
boundary depth which we think is a lot

388
00:13:45,220 --> 00:13:43,160

shallower than most people have

389
00:13:54,670 --> 00:13:45,230
suggested in the past thanks a lot I'll

390
00:13:57,520 --> 00:13:54,680
take any questions Thank You Jonathan um

391
00:14:02,410 --> 00:13:57,530
I see a couple of questions we don't

392
00:14:09,880 --> 00:14:02,420
have much time please state your name

393
00:14:12,310 --> 00:14:09,890
and affiliation hi Hanna wait for Space

394
00:14:14,620 --> 00:14:12,320
Telescope and a lot of the implications

395
00:14:16,680 --> 00:14:14,630
that you listed seem to produce more

396
00:14:18,610 --> 00:14:16,690
clouds is there a testable prediction on

397
00:14:21,370 --> 00:14:18,620
ratios of planets that we find the

398
00:14:26,860 --> 00:14:21,380
clouds there ah

399
00:14:28,450 --> 00:14:26,870
so should we see like the fraction of

400
00:14:31,990 --> 00:14:28,460
planets that would be cloudy and is not

401
00:14:33,580 --> 00:14:32,000
cloudy yes a Peter GAO has a paper that

402
00:14:35,410 --> 00:14:33,590
he's leading was just submitted to

403
00:14:37,990 --> 00:14:35,420
Nature astronomy that tries to look at

404
00:14:40,300 --> 00:14:38,000
the transmission spectra in in in in

405
00:14:42,310 --> 00:14:40,310
Hubble a Wide Field Camera 3 the

406
00:14:44,320 --> 00:14:42,320
cloudiness is a function of planetary

407
00:14:46,330 --> 00:14:44,330
temperature and so one of the things

408
00:14:47,980 --> 00:14:46,340
Peter finds is that we can only fit this

409
00:14:50,710 --> 00:14:47,990
trend of cloudiness versus wavelength

410
00:14:52,870 --> 00:14:50,720
with these higher rate of convective

411
00:14:55,360 --> 00:14:52,880
boundaries that the compounder YZ are

412
00:14:56,740 --> 00:14:55,370
much deeper he finds cloudiness versus

413
00:14:58,150 --> 00:14:56,750

wavelength that doesn't actually fit

414
00:15:05,490 --> 00:14:58,160
observations that's another nice

415
00:15:11,700 --> 00:15:05,500
observational test may be a really short

416
00:15:17,500 --> 00:15:15,610
interesting UCLA a very interesting talk

417
00:15:19,240 --> 00:15:17,510
I'm curious does that that's the

418
00:15:21,520 --> 00:15:19,250
shallower right of collective boundaries

419
00:15:23,350 --> 00:15:21,530
help you in terms of explaining the

420
00:15:27,310 --> 00:15:23,360
inflated hot Jupiters because it would

421
00:15:31,870 --> 00:15:27,320
make it easier to yeah he's back inside

422
00:15:34,120 --> 00:15:31,880
yeah so any inflated objects

423
00:15:35,800 --> 00:15:34,130
no matter what the mechanism is has to

424
00:15:38,410 --> 00:15:35,810
have a shallower rated conductive

425
00:15:41,230 --> 00:15:38,420
boundary and so it might make some

426
00:15:43,420 --> 00:15:41,240
mechanisms like ohmic dissipation a bit

427
00:15:45,999 --> 00:15:43,430
easier to do and that you don't need to

428
00:15:46,689 --> 00:15:46,009
get the energy down really deep so

429
00:15:49,710 --> 00:15:46,699
that's something that we're thinking

430
00:15:57,680 --> 00:15:49,720
about as well in the next year

431
00:15:57,690 --> 00:16:03,100
[Music]

432
00:16:07,689 --> 00:16:05,290
Ted come Chuck has an entire paper on

433
00:16:10,629 --> 00:16:07,699
this so in our models we're assuming

434
00:16:13,780 --> 00:16:10,639
that the energy is deposited within the

435
00:16:15,280 --> 00:16:13,790
convective interior but it does matter a

436
00:16:16,930 --> 00:16:15,290
lot if you're putting it into the deep

437
00:16:27,480 --> 00:16:16,940
radiative atmosphere you need a lot more

438
00:16:29,800 --> 00:16:27,490

energy yeah good point be a pair exactly

439
00:16:31,120 --> 00:16:29,810
so what sort of implications do you

440
00:16:33,129 --> 00:16:31,130
think this has for the long term

441
00:16:35,050 --> 00:16:33,139
evolution of the planet because you're

442
00:16:38,079 --> 00:16:35,060
looking at an interior flux that kind of

443
00:16:44,710 --> 00:16:38,089
comfort they call collapse into cooling

444
00:16:46,569 --> 00:16:44,720
toward that where the energy yeah so I

445
00:16:48,370 --> 00:16:46,579
think the I think the planets are

446
00:16:49,960 --> 00:16:48,380
essentially in a steady state their

447
00:16:54,040 --> 00:16:49,970
interiors are not cooling the planets

448
00:16:55,780 --> 00:16:54,050
are not contracting there's you know

449
00:16:58,269 --> 00:16:55,790
there's as you well know there's a

450
00:16:59,650 --> 00:16:58,279
variety of perhaps a dozen dynamical

451
00:17:01,449 --> 00:16:59,660
mechanisms where people are trying to

452
00:17:03,009 --> 00:17:01,459
get energy from the parents are some

453
00:17:07,179 --> 00:17:03,019
small fraction of that into the

454
00:17:08,679 --> 00:17:07,189
convective interior I'm trying to be

455
00:17:11,020 --> 00:17:08,689
agnostic about what I think the

456
00:17:12,760 --> 00:17:11,030
mechanism is but I think it does make it

457
00:17:14,380 --> 00:17:12,770
easier for a lot of these dynamical

458
00:17:16,090 --> 00:17:14,390
mechanisms if people have to only get

459
00:17:19,059 --> 00:17:16,100
the energy down to a few bars rather

460
00:17:20,880 --> 00:17:19,069
than kill a bar okay we have to postpone

461
00:17:24,940 --> 00:17:20,890
everything else into coffee breaks and