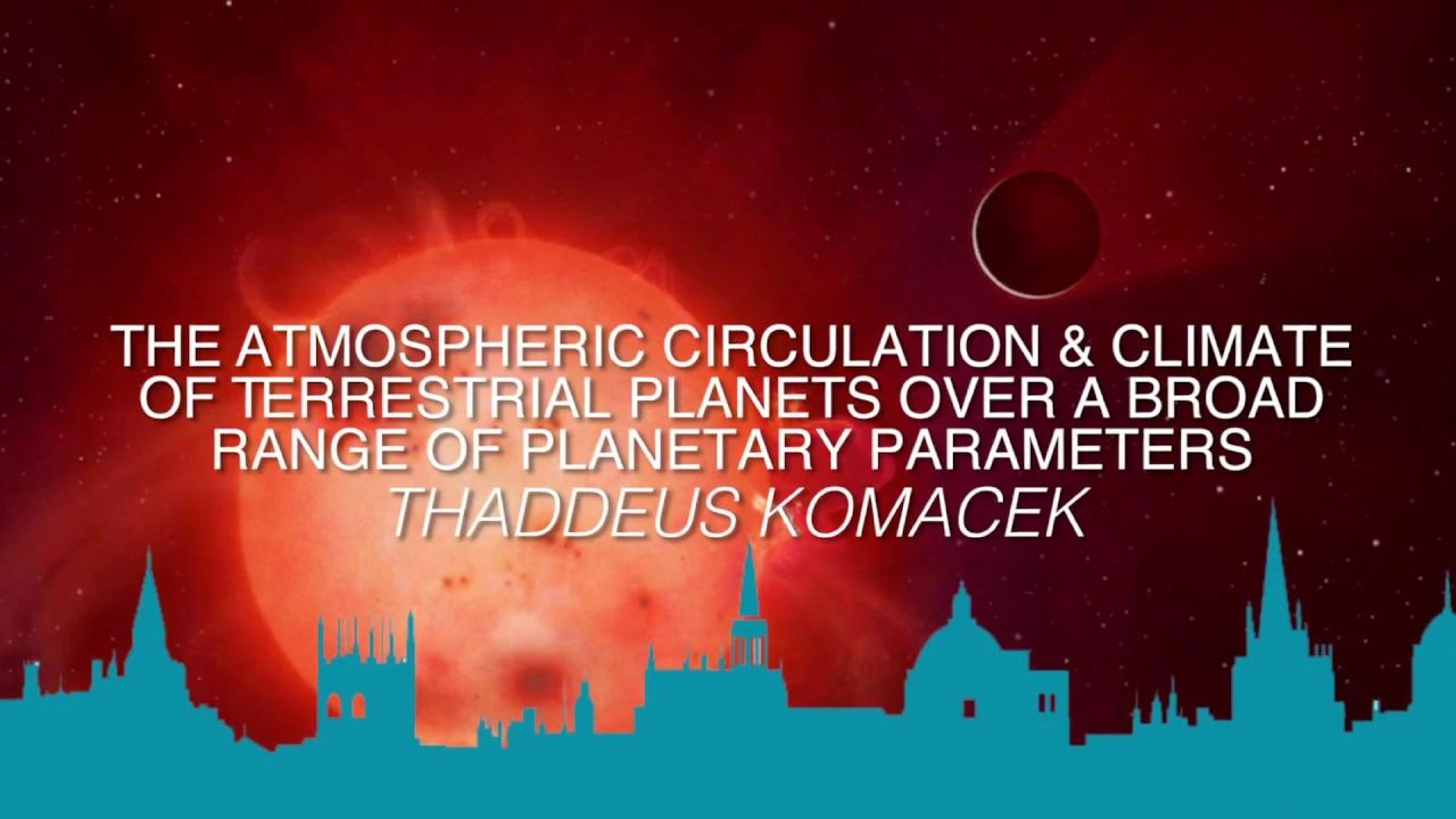

THE ATMOSPHERIC CIRCULATION & CLIMATE OF TERRESTRIAL PLANETS OVER A BROAD RANGE OF PLANETARY PARAMETERS

THADDEUS KOMACEK

1
00:00:09,240 --> 00:00:04,170
[Music]

2
00:00:12,959 --> 00:00:09,250
I guess what's what's on my slide lawyer

3
00:00:16,339 --> 00:00:12,969
okay so thanks for the introduction

4
00:00:18,600 --> 00:00:16,349
and so this talk is kind of a shift from

5
00:00:21,120 --> 00:00:18,610
pre-op pretty bad pretty biotic

6
00:00:25,260 --> 00:00:21,130
chemistry to atmospheric dynamics so

7
00:00:26,460 --> 00:00:25,270
let's all take a deep breath and we're

8
00:00:28,380 --> 00:00:26,470
gonna kind of get back into the

9
00:00:31,019 --> 00:00:28,390
headspace we were in the small thing and

10
00:00:32,100 --> 00:00:31,029
maybe yesterday and Tuesday so I'll be

11
00:00:33,720 --> 00:00:32,110
talking about the atmospheric

12
00:00:35,459 --> 00:00:33,730
circulation and climate of terrestrial

13
00:00:37,259 --> 00:00:35,469

planets orbiting both sun-like stars and

14
00:00:38,790 --> 00:00:37,269
M dwarf stars so this is kind of falling

15
00:00:41,669 --> 00:00:38,800
off of one of our town slides from this

16
00:00:43,349 --> 00:00:41,679
morning and kind of one theme I'll come

17
00:00:45,660 --> 00:00:43,359
back on again again is the effect of

18
00:00:47,579 --> 00:00:45,670
rotation on atmospheric circulation of

19
00:00:49,290 --> 00:00:47,589
terrestrial planets and so here I'm

20
00:00:51,270 --> 00:00:49,300
showing you a plot from Adam Sherman's

21
00:00:53,250 --> 00:00:51,280
review paper from a few years ago on

22
00:00:55,229 --> 00:00:53,260
terrestrial planets and it's showing you

23
00:00:57,720 --> 00:00:55,239
the distinction between tropical regions

24
00:00:59,970 --> 00:00:57,730
which are regions where rotation doesn't

25
00:01:01,229 --> 00:00:59,980
matter in the overall force balance so

26
00:01:03,389 --> 00:01:01,239
the Coriolis force is relatively

27
00:01:04,710 --> 00:01:03,399
unimportant and extra tropical regions

28
00:01:06,600 --> 00:01:04,720
where the Coriolis force does matter

29
00:01:08,280 --> 00:01:06,610
rotation is really important and how

30
00:01:10,560 --> 00:01:08,290
that changes with planetary rotation

31
00:01:12,690 --> 00:01:10,570
period so this goes from an earth-like

32
00:01:14,520 --> 00:01:12,700
rotation period of one day where we have

33
00:01:16,350 --> 00:01:14,530
tropical regions and we have extra

34
00:01:18,320 --> 00:01:16,360
tropical regions and as we go to a

35
00:01:20,610 --> 00:01:18,330
longer rotation periods the tropical

36
00:01:22,560 --> 00:01:20,620
regions the width of them widens and

37
00:01:25,410 --> 00:01:22,570
once you hit a rotation period of about

38
00:01:27,990 --> 00:01:25,420

10 days the entire planet is now in all

39
00:01:29,850 --> 00:01:28,000
tropics world or rotation is relatively

40
00:01:32,310 --> 00:01:29,860
unimportant in overall force balance and

41
00:01:33,900 --> 00:01:32,320
so you can characterize this by the roz

42
00:01:35,190 --> 00:01:33,910
be number of the planet and so if the

43
00:01:37,950 --> 00:01:35,200
roz be number which is the ratio of

44
00:01:40,050 --> 00:01:37,960
effective to Coriolis forces is large

45
00:01:43,080 --> 00:01:40,060
then the Coriolis force this can be

46
00:01:44,550 --> 00:01:43,090
neglected and a global sense and so you

47
00:01:45,570 --> 00:01:44,560
can see this directly in general

48
00:01:47,820 --> 00:01:45,580
circulation models of terrestrial

49
00:01:51,060 --> 00:01:47,830
planets and so here I'm showing you to

50
00:01:52,740 --> 00:01:51,070
GCM results from Ravi Kapoor so the top

51
00:01:54,900 --> 00:01:52,750
panel is showing your simulations of a

52
00:01:57,540 --> 00:01:54,910
earth-like planet around a sun-like star

53
00:01:58,800 --> 00:01:57,550
with a 24-hour rotation period and you

54
00:02:01,590 --> 00:01:58,810
can see that the planet has a hot

55
00:02:03,600 --> 00:02:01,600
equator and a cold pole at a large

56
00:02:06,450 --> 00:02:03,610
equator to pole temperature contrast and

57
00:02:07,800 --> 00:02:06,460
the circulation the atmosphere is trying

58
00:02:08,880 --> 00:02:07,810
to erase this equator to pull

59
00:02:11,130 --> 00:02:08,890
temperature contrast let's switch

60
00:02:13,709 --> 00:02:11,140
driving the large-scale circulation of

61
00:02:15,839 --> 00:02:13,719
the Hadley cells and the Farrell cell

62
00:02:17,300 --> 00:02:15,849
I'll be talking about a bit later but

63
00:02:18,770 --> 00:02:17,310

for the M dwarf

64
00:02:20,150 --> 00:02:18,780
star shown on the bottom here which is

65
00:02:21,680 --> 00:02:20,160
slowly rotating because it's tally

66
00:02:24,440 --> 00:02:21,690
locked with the rotation period of about

67
00:02:25,699 --> 00:02:24,450
58 days you can see that the dayside is

68
00:02:27,229 --> 00:02:25,709
really really hot because that's where

69
00:02:29,210 --> 00:02:27,239
you're seeing the radiation and the

70
00:02:31,070 --> 00:02:29,220
night Sun is cold but the equator to

71
00:02:32,510 --> 00:02:31,080
pole temperature contrast is really tiny

72
00:02:34,339 --> 00:02:32,520
relative to the planner around a

73
00:02:36,080 --> 00:02:34,349
sun-like star and this is because the

74
00:02:39,020 --> 00:02:36,090
entire day side of the planet is acting

75
00:02:42,080 --> 00:02:39,030
like the tropics and one consequence of

76
00:02:43,370 --> 00:02:42,090
this is the cloud coverage in these two

77
00:02:44,449 --> 00:02:43,380
models which is something that Martin

78
00:02:46,490 --> 00:02:44,459
talked about and something that was very

79
00:02:47,740 --> 00:02:46,500
important and potentially an early Venus

80
00:02:51,080 --> 00:02:47,750
of microwave was talking about yesterday

81
00:02:52,610 --> 00:02:51,090
so for the planet around a sun-like star

82
00:02:54,320 --> 00:02:52,620
that has an earth-like rotation rate we

83
00:02:56,509 --> 00:02:54,330
have lots of clouds as you can see here

84
00:02:59,270 --> 00:02:56,519
near the equator which are driven by

85
00:03:01,250 --> 00:02:59,280
deep deep convection in the tropics this

86
00:03:04,039 --> 00:03:01,260
makes all those thunderstorms that are

87
00:03:06,680 --> 00:03:04,049
famous in the tropics and you have less

88
00:03:08,330 --> 00:03:06,690

clouds as you go to higher latitudes in

89
00:03:09,620 --> 00:03:08,340
a general sense but for the planet

90
00:03:11,180 --> 00:03:09,630
orbiting an M dwarf star that's slowly

91
00:03:14,449 --> 00:03:11,190
rotating because there's deep convection

92
00:03:16,009 --> 00:03:14,459
throughout the dayside there's now a

93
00:03:17,839 --> 00:03:16,019
side cloud correction that's relatively

94
00:03:19,520 --> 00:03:17,849
high throughout the day side and this

95
00:03:21,770 --> 00:03:19,530
hide a side cloud fraction as we saw

96
00:03:23,870 --> 00:03:21,780
earlier today in March on stock acts to

97
00:03:25,729 --> 00:03:23,880
affect the hable zone so it makes the

98
00:03:27,410 --> 00:03:25,739
habitable zone potentially wider for

99
00:03:29,000 --> 00:03:27,420
planets orbiting M dwarf stars that are

100
00:03:32,000 --> 00:03:29,010
tightly locked so this is work of

101
00:03:33,920 --> 00:03:32,010
joon-young this is his GCM results for

102
00:03:36,530 --> 00:03:33,930
it slowly rotating planets and the red

103
00:03:38,059 --> 00:03:36,540
line rapidly rotating plants and the in

104
00:03:40,759 --> 00:03:38,069
the black line and then the other two

105
00:03:42,590 --> 00:03:40,769
solid lines show previous 1d models for

106
00:03:43,880 --> 00:03:42,600
the inner edge of the habitable zone as

107
00:03:44,479 --> 00:03:43,890
a function of the temperature of the

108
00:03:46,220 --> 00:03:44,489
host star

109
00:03:48,199 --> 00:03:46,230
so later type stars going down an

110
00:03:49,640 --> 00:03:48,209
incident solar flux so higher stellar

111
00:03:51,650 --> 00:03:49,650
flux is going to the left here on this

112
00:03:53,990 --> 00:03:51,660
diagram and you can see down near the

113
00:03:55,699 --> 00:03:54,000

bottom of the domain here in the M dwarf

114
00:03:57,289 --> 00:03:55,709
region the inner edge of the habitable

115
00:03:59,270 --> 00:03:57,299
zone for the slowly rotating and tightly

116
00:04:01,430 --> 00:03:59,280
locked models is about 50% or more

117
00:04:03,559 --> 00:04:01,440
closer to the host star and instant

118
00:04:06,559 --> 00:04:03,569
solar flux then in the rapidly rotating

119
00:04:08,360 --> 00:04:06,569
models so this is just one example of

120
00:04:10,309 --> 00:04:08,370
how rotation effects

121
00:04:12,559 --> 00:04:10,319
circulation and protection potentially

122
00:04:14,449 --> 00:04:12,569
affects habitability and rotation

123
00:04:16,009 --> 00:04:14,459
affects circulation in other ways but

124
00:04:17,360 --> 00:04:16,019
also there's a broad range right of

125
00:04:19,039 --> 00:04:17,370
planetary parameters that can affect

126
00:04:20,810 --> 00:04:19,049
circulation you can think of things like

127
00:04:23,210 --> 00:04:20,820
the instance of a flux of course the

128
00:04:25,880 --> 00:04:23,220
surface pressure the gravity of the

129
00:04:28,219 --> 00:04:25,890
planet the planetary radius and so I ran

130
00:04:29,930 --> 00:04:28,229
a large grid of simulations of Tresh of

131
00:04:31,080 --> 00:04:29,940
planets orbiting both sun-like stars and

132
00:04:32,820 --> 00:04:31,090
M dwarf stars

133
00:04:34,260 --> 00:04:32,830
that you can see in this paper that was

134
00:04:35,909 --> 00:04:34,270
published earlier this year and so there

135
00:04:36,780 --> 00:04:35,919
they use a kind of idealized model set

136
00:04:39,120 --> 00:04:36,790
up even though they're using a

137
00:04:41,280 --> 00:04:39,130
relatively complex GCM which is EXO cam

138
00:04:42,540 --> 00:04:41,290

which was the same GCM from the

139
00:04:44,580 --> 00:04:42,550
simulations I just showed you earlier

140
00:04:46,590 --> 00:04:44,590
robbery cover-up ooh and so I'm using an

141
00:04:49,530 --> 00:04:46,600
aqua planet set up with a nitrogen water

142
00:04:52,409 --> 00:04:49,540
atmosphere around stars that are either

143
00:04:54,600 --> 00:04:52,419
late type M dwarf stars kind of late K

144
00:04:56,100 --> 00:04:54,610
early M dwarf stars or some like stars

145
00:04:59,159 --> 00:04:56,110
and I'm assuming towel locking if the

146
00:05:01,350 --> 00:04:59,169
plants are orbiting M dwarf stars and so

147
00:05:02,730 --> 00:05:01,360
beaut I'm I'm mostly to be focusing on

148
00:05:04,290 --> 00:05:02,740
rotation period and let's talk a little

149
00:05:05,460 --> 00:05:04,300
bit about surface pressure but if you

150
00:05:07,710 --> 00:05:05,470
want to learn more you can check out the

151
00:05:09,360 --> 00:05:07,720
paper so first I'll talk about the

152
00:05:11,219 --> 00:05:09,370
circulation of planets orbiting sun-like

153
00:05:13,469 --> 00:05:11,229
stars and then move on to planets

154
00:05:15,390 --> 00:05:13,479
orbitting M dwarf stars so here I'm

155
00:05:17,580 --> 00:05:15,400
showing you results from simulations on

156
00:05:20,159 --> 00:05:17,590
the left-hand panel of a planet with a

157
00:05:21,420 --> 00:05:20,169
one-day rotation period same as Earth on

158
00:05:23,400 --> 00:05:21,430
the right-hand panel of planet with an

159
00:05:25,080 --> 00:05:23,410
eight-day rotation period these are

160
00:05:27,030 --> 00:05:25,090
zonal mean temperatures in the colors

161
00:05:28,830 --> 00:05:27,040
and the contours of showing the zonal

162
00:05:30,210 --> 00:05:28,840
mean potential temperature the potential

163
00:05:31,740 --> 00:05:30,220

temperature is a measure of entropy in

164
00:05:33,150 --> 00:05:31,750
the atmosphere and we'll come back to

165
00:05:35,550 --> 00:05:33,160
why this is important in a little bit

166
00:05:36,810 --> 00:05:35,560
and so the y-axis of these panels is the

167
00:05:38,250 --> 00:05:36,820
pressure normalized by the surface

168
00:05:39,990 --> 00:05:38,260
pressure so the bottom of the panels is

169
00:05:42,270 --> 00:05:40,000
the surface and then the x-axis is

170
00:05:43,890 --> 00:05:42,280
latitude and so you can see that in the

171
00:05:46,230 --> 00:05:43,900
1-day case the equator to pole

172
00:05:48,270 --> 00:05:46,240
temperature contrast is larger than in

173
00:05:49,560 --> 00:05:48,280
the eight-day case and additionally in

174
00:05:51,510 --> 00:05:49,570
the 1-day case if you look at the

175
00:05:54,450 --> 00:05:51,520
spacing of the contours they're

176
00:05:55,980 --> 00:05:54,460
relatively more closely spaced and as a

177
00:05:58,620 --> 00:05:55,990
result the potential temperature lapse

178
00:06:00,540 --> 00:05:58,630
rate also increases with increasing

179
00:06:02,040 --> 00:06:00,550
rotation rate and I'll come back to this

180
00:06:04,740 --> 00:06:02,050
later and talk about why it's important

181
00:06:06,990 --> 00:06:04,750
so this is how the climate changes when

182
00:06:08,490 --> 00:06:07,000
you change rotation rate go to floor

183
00:06:11,100 --> 00:06:08,500
rotation rates than Earth but what

184
00:06:13,320 --> 00:06:11,110
happens to the dynamics so this is kind

185
00:06:14,969 --> 00:06:13,330
of alluded to in previous talks so the

186
00:06:17,640 --> 00:06:14,979
dynamics also greatly changes so here

187
00:06:19,500 --> 00:06:17,650
I'm showing you the same parameter space

188
00:06:21,779 --> 00:06:19,510

on the axes but now I'm plotting and the

189
00:06:23,430 --> 00:06:21,789
colors the stream function of the

190
00:06:25,170 --> 00:06:23,440
circulation so the stream function tells

191
00:06:27,570 --> 00:06:25,180
you which direction the circulation goes

192
00:06:29,460 --> 00:06:27,580
so if it's red it's a clockwise

193
00:06:31,350 --> 00:06:29,470
circulation rising at the equator and

194
00:06:32,550 --> 00:06:31,360
descending at higher latitudes and if

195
00:06:34,710 --> 00:06:32,560
it's blue it's showing a

196
00:06:36,300 --> 00:06:34,720
counterclockwise circulation again in

197
00:06:37,830 --> 00:06:36,310
this case because it's a Hadley cell

198
00:06:40,230 --> 00:06:37,840
resident at the equator and descending

199
00:06:42,410 --> 00:06:40,240
at higher latitudes and so you can see

200
00:06:44,030 --> 00:06:42,420
as we vary the rotation period the

201
00:06:46,430 --> 00:06:44,040
with the Hadley cell changes in these

202
00:06:48,290 --> 00:06:46,440
two models as we decrease the rotation

203
00:06:49,700 --> 00:06:48,300
rate increase the rotation period the

204
00:06:51,920 --> 00:06:49,710
Hadley cell becomes wider and

205
00:06:53,690 --> 00:06:51,930
additionally I'm also putting in the

206
00:06:55,250 --> 00:06:53,700
contours here the zonal mean zonal wind

207
00:06:57,050 --> 00:06:55,260
speed in the atmosphere so this is

208
00:06:59,420 --> 00:06:57,060
showing you the east-west Jets in the

209
00:07:01,760 --> 00:06:59,430
atmosphere and so you can see that the

210
00:07:03,650 --> 00:07:01,770
east-west Jets occur at about plus at

211
00:07:05,420 --> 00:07:03,660
minus thirty degree latitude and the

212
00:07:06,860 --> 00:07:05,430
earth light case and these are the same

213
00:07:08,750 --> 00:07:06,870

jets that you know if you flew here from

214
00:07:10,040 --> 00:07:08,760
the USA made your trip a little bit

215
00:07:12,200 --> 00:07:10,050
faster and will make your trip a little

216
00:07:16,130 --> 00:07:12,210
bit slower going back it's gonna be

217
00:07:18,110 --> 00:07:16,140
annoying and you can see that if our

218
00:07:20,090 --> 00:07:18,120
planet was a slower repeater these Jets

219
00:07:22,100 --> 00:07:20,100
would occur at higher latitudes because

220
00:07:23,900 --> 00:07:22,110
these Jets occur at the edge of the

221
00:07:25,390 --> 00:07:23,910
Hadley cell and they're formed by a

222
00:07:28,280 --> 00:07:25,400
mixture of angular momentum conservation

223
00:07:33,730 --> 00:07:28,290
leading to Jets plus any interactions

224
00:07:36,110 --> 00:07:33,740
feeding into the Zola mean flow okay so

225
00:07:37,280 --> 00:07:36,120
that's going to slow rotation periods on

226
00:07:39,170 --> 00:07:37,290
earth but what happens if you make it

227
00:07:41,900 --> 00:07:39,180
rotate faster than Earth so here I'm now

228
00:07:43,040 --> 00:07:41,910
comparing maps of the circulation so on

229
00:07:45,170 --> 00:07:43,050
the left hand panel I'm showing the

230
00:07:46,490 --> 00:07:45,180
zonal wind so this is the east-west wind

231
00:07:47,810 --> 00:07:46,500
and the right-hand panel is I'm showing

232
00:07:50,300 --> 00:07:47,820
the eddies on the wind so this is the

233
00:07:52,820 --> 00:07:50,310
deviation of the east-west wind from the

234
00:07:54,590 --> 00:07:52,830
zonal mean east-west wind so the

235
00:07:57,230 --> 00:07:54,600
deviation from the east-west average of

236
00:07:59,330 --> 00:07:57,240
the east-west wind that's a mouthful

237
00:08:01,100 --> 00:07:59,340
so you can see again our subtropical

238
00:08:03,800 --> 00:08:01,110

jets at plus or minus 30 degree latitude

239
00:08:05,750 --> 00:08:03,810
and you can see large-scale Eddie's that

240
00:08:07,340 --> 00:08:05,760
are driven by instabilities

241
00:08:08,480 --> 00:08:07,350
near the jet and you can also see

242
00:08:10,280 --> 00:08:08,490
large-scale Eddie's in the tropical

243
00:08:11,810 --> 00:08:10,290
regions as well and for the fast

244
00:08:14,240 --> 00:08:11,820
rotating case you can see that we no

245
00:08:15,620 --> 00:08:14,250
longer just have to eastward Jets one in

246
00:08:17,750 --> 00:08:15,630
each hemisphere we now have many many

247
00:08:19,190 --> 00:08:17,760
eastward Jets and additionally you can

248
00:08:21,620 --> 00:08:19,200
see that the life skill of Eddie's

249
00:08:23,750 --> 00:08:21,630
decrease with increasing rotation rate

250
00:08:25,040 --> 00:08:23,760
this was alluded to earlier today and so

251
00:08:27,380 --> 00:08:25,050
for faster rotating plants we have

252
00:08:28,940 --> 00:08:27,390
smaller Eddy length scales we can fit in

253
00:08:30,440 --> 00:08:28,950
more zonal Jets and also I'm not showing

254
00:08:32,990 --> 00:08:30,450
it here but the equator to pole

255
00:08:36,320 --> 00:08:33,000
temperature contrast also increases with

256
00:08:39,920 --> 00:08:36,330
increasing rotation rate so the question

257
00:08:41,719 --> 00:08:39,930
is is can we explain this how the

258
00:08:44,960 --> 00:08:41,729
large-scale circulation changes in a

259
00:08:46,580 --> 00:08:44,970
simple analytic way and so I just want

260
00:08:48,890 --> 00:08:46,590
to introduce a concept here that I'll be

261
00:08:50,420 --> 00:08:48,900
referring back to so what I'm plotting

262
00:08:52,430 --> 00:08:50,430
on this diagram these different lines

263
00:08:53,990 --> 00:08:52,440

they're ice and Tropes so they're

264
00:08:55,890 --> 00:08:54,000
contours of constant potential

265
00:08:58,260 --> 00:08:55,900
temperature in the atmosphere or

266
00:08:59,850 --> 00:08:58,270
contours of constant entropy and the y

267
00:09:02,460 --> 00:08:59,860
axis here is height going from the

268
00:09:04,320 --> 00:09:02,470
surface to the tropopause and the x-axis

269
00:09:06,900 --> 00:09:04,330
is latitude going from the equator to

270
00:09:09,300 --> 00:09:06,910
the pole and so I'm plotting here one

271
00:09:11,430 --> 00:09:09,310
line the red line which has a slope that

272
00:09:13,680 --> 00:09:11,440
I'm defining as a slope of one so it's a

273
00:09:15,630 --> 00:09:13,690
isin't rope that rises from the surface

274
00:09:18,360 --> 00:09:15,640
at the equator through the tropopause at

275
00:09:22,290 --> 00:09:18,370
the pole and this is where earth lies on

276
00:09:24,630 --> 00:09:22,300
this diagram it has a slope such that a

277
00:09:25,710 --> 00:09:24,640
nice intrepid rise from the surface of

278
00:09:28,410 --> 00:09:25,720
the equator to the tropopause of the

279
00:09:30,440 --> 00:09:28,420
pole and so the reason why earth is that

280
00:09:32,820 --> 00:09:30,450
this kind of this kind of state has been

281
00:09:35,820 --> 00:09:32,830
kind of debated over the past 50 years

282
00:09:38,550 --> 00:09:35,830
since the 70s so people think that earth

283
00:09:40,140 --> 00:09:38,560
once Earth's atmosphere if in a

284
00:09:43,320 --> 00:09:40,150
radiative convective sense without

285
00:09:45,380 --> 00:09:43,330
dynamics would be in an unstable state

286
00:09:48,300 --> 00:09:45,390
where the slope is greater than 1 and

287
00:09:49,950 --> 00:09:48,310
the planet would be unstable to so

288
00:09:52,019 --> 00:09:49,960

called bear clinic instabilities which

289
00:09:54,060 --> 00:09:52,029
are the large-scale fluid instabilities

290
00:09:56,820 --> 00:09:54,070
that lead to weather and storms and Arce

291
00:09:58,740 --> 00:09:56,830
mid latitudes where we are not and so

292
00:10:00,390 --> 00:09:58,750
basically these instabilities will lead

293
00:10:02,460 --> 00:10:00,400
to an adjustment social that the planet

294
00:10:04,980 --> 00:10:02,470
would go from this unstable state back

295
00:10:06,990 --> 00:10:04,990
to the stable state and so there's a

296
00:10:09,180 --> 00:10:07,000
wide range of literature on this but

297
00:10:11,340 --> 00:10:09,190
relatively recently multi Anson

298
00:10:13,890 --> 00:10:11,350
developed a simple theory to explain

299
00:10:15,690 --> 00:10:13,900
that in principle if the forcing regimes

300
00:10:18,120 --> 00:10:15,700
are very different than Earth the

301
00:10:20,100 --> 00:10:18,130
atmosphere can stay in an unstable state

302
00:10:23,579 --> 00:10:20,110
it doesn't necessarily have to adjust

303
00:10:26,160 --> 00:10:23,589
back so in that in that case it just

304
00:10:27,990 --> 00:10:26,170
kind of happens to be in this slope

305
00:10:29,400 --> 00:10:28,000
equals one state and note that if the

306
00:10:31,019 --> 00:10:29,410
slope is less than one then the

307
00:10:32,940 --> 00:10:31,029
atmosphere is on a large scale sense

308
00:10:36,449 --> 00:10:32,950
stable to bear a clinic instabilities

309
00:10:38,310 --> 00:10:36,459
and so know that if you understand if

310
00:10:40,110 --> 00:10:38,320
you have some sort of theory for this

311
00:10:42,210 --> 00:10:40,120
slope and principle you should

312
00:10:44,790 --> 00:10:42,220
understand how the equator to pole

313
00:10:45,990 --> 00:10:44,800

temperature contrasts and the surface of

314
00:10:48,510 --> 00:10:46,000
tropopause potential temperature

315
00:10:50,760 --> 00:10:48,520
contrast depend on planetary parameters

316
00:10:53,280 --> 00:10:50,770
because this criticality parameter is

317
00:10:54,329 --> 00:10:53,290
directly related to the ratio of the

318
00:10:55,980 --> 00:10:54,339
horizontal potential temperature

319
00:10:57,390 --> 00:10:55,990
contrast in the vertical potential

320
00:10:59,310 --> 00:10:57,400
temperature contrast in the atmosphere

321
00:11:02,220 --> 00:10:59,320
and so I just kind of want to show you

322
00:11:03,449 --> 00:11:02,230
in a basic sense what these two

323
00:11:04,829 --> 00:11:03,459
parameters the horizontal in the

324
00:11:07,500 --> 00:11:04,839
vertical potential temperature contrast

325
00:11:09,950 --> 00:11:07,510
mean and in in terms of the climate of

326
00:11:12,920 --> 00:11:09,960
an exoplanet so here I'm showing you

327
00:11:14,510 --> 00:11:12,930
of zonal mean potential temperature so

328
00:11:16,610 --> 00:11:14,520
these were the contours of my earlier

329
00:11:19,010 --> 00:11:16,620
plot showing the climate and I'm

330
00:11:21,050 --> 00:11:19,020
highlighting the horizontal potential

331
00:11:22,460 --> 00:11:21,060
temperature contrast in the red so this

332
00:11:23,990 --> 00:11:22,470
is basically just the equator to pole

333
00:11:25,850 --> 00:11:24,000
temperature contrast at the surface

334
00:11:27,830 --> 00:11:25,860
because at the surface potential

335
00:11:30,290 --> 00:11:27,840
temperature and normal temperature are

336
00:11:31,520 --> 00:11:30,300
the same and the vertical potential

337
00:11:32,600 --> 00:11:31,530
temperature contrast is just the

338
00:11:34,760 --> 00:11:32,610

difference of the potential temperature

339
00:11:38,630 --> 00:11:34,770
from the surface to the tropopause

340
00:11:40,880 --> 00:11:38,640
in the mid latitudes and so we can try

341
00:11:42,050 --> 00:11:40,890
to figure out what the slope of a nice

342
00:11:43,880 --> 00:11:42,060
and trope would be in this kind of

343
00:11:46,940 --> 00:11:43,890
atmosphere so if we basically just

344
00:11:48,890 --> 00:11:46,950
connect the lines from where a nice and

345
00:11:51,080 --> 00:11:48,900
trope or a contour of constant potential

346
00:11:53,330 --> 00:11:51,090
temperature is at the surface at the

347
00:11:55,310 --> 00:11:53,340
equator to the pole you can see that it

348
00:11:57,020 --> 00:11:55,320
rises up to about here so not quite the

349
00:11:59,270 --> 00:11:57,030
tropopause in this case so this

350
00:12:01,010 --> 00:11:59,280
atmosphere is stable and a large-scale

351
00:12:03,560 --> 00:12:01,020
bulk sense to bear clinic instabilities

352
00:12:08,660 --> 00:12:03,570
because the slope of a sites and tropes

353
00:12:12,740 --> 00:12:08,670
across a hemisphere is less than one and

354
00:12:14,180 --> 00:12:12,750
so multi Anton developed a simple theory

355
00:12:15,380 --> 00:12:14,190
to try to explain how the criticality

356
00:12:17,600 --> 00:12:15,390
parameter should depend on planar

357
00:12:18,980 --> 00:12:17,610
Triplanetary parameters it should

358
00:12:20,900 --> 00:12:18,990
increase with increasing rotation rate

359
00:12:21,830 --> 00:12:20,910
because bare clinic instabilities should

360
00:12:23,000 --> 00:12:21,840
increase with the increase in the

361
00:12:25,100 --> 00:12:23,010
strength of a cushioned rotation rate

362
00:12:26,750 --> 00:12:25,110
because deformation scales decrease with

363
00:12:28,370 --> 00:12:26,760

increasing rotation rate and it should

364
00:12:30,590 --> 00:12:28,380
also depend on the surface pressure of

365
00:12:32,030 --> 00:12:30,600
the planet the tropopause height or the

366
00:12:35,210 --> 00:12:32,040
scale height and many other parameters

367
00:12:36,800 --> 00:12:35,220
and so here's just that scaling so this

368
00:12:39,320 --> 00:12:36,810
is how the slope of ice and Tropes

369
00:12:41,540 --> 00:12:39,330
depend on rotation rate pressure and

370
00:12:43,040 --> 00:12:41,550
then H which is the minimum in this case

371
00:12:44,930 --> 00:12:43,050
of the scale height and the tropopause

372
00:12:46,340 --> 00:12:44,940
height note that Earth is in a state

373
00:12:47,990 --> 00:12:46,350
where the scale height is actually kind

374
00:12:49,370 --> 00:12:48,000
of similar to the tropopause height it's

375
00:12:50,930 --> 00:12:49,380
just a little bit smaller but in

376
00:12:53,590 --> 00:12:50,940
principle it can be larger for a

377
00:12:56,240 --> 00:12:53,600
different kind of atmosphere and so

378
00:12:57,620 --> 00:12:56,250
these are comparisons with my GCM

379
00:12:59,120 --> 00:12:57,630
results so the solid lines in these

380
00:13:01,340 --> 00:12:59,130
plots are showing you the GCM results

381
00:13:03,380 --> 00:13:01,350
and the dashed line is the scaling for

382
00:13:04,670 --> 00:13:03,390
the criticality parameter the slope as a

383
00:13:06,530 --> 00:13:04,680
function of rotation rate on the

384
00:13:08,510 --> 00:13:06,540
left-hand panel and surface pressure on

385
00:13:10,430 --> 00:13:08,520
the right panel and so you can see as a

386
00:13:12,140 --> 00:13:10,440
function of surface pressure but scaling

387
00:13:13,400 --> 00:13:12,150
does a really good job throughout the

388
00:13:15,530 --> 00:13:13,410

full range of surface pressures we

389
00:13:17,690 --> 00:13:15,540
considered as a function of rotation

390
00:13:20,480 --> 00:13:17,700
rate the scaling does a good job for the

391
00:13:21,860 --> 00:13:20,490
fast rotating cases around here but it's

392
00:13:23,950 --> 00:13:21,870
also do such a good job for the slowly

393
00:13:26,440 --> 00:13:23,960
rotating cases with appreciation period

394
00:13:28,570 --> 00:13:26,450
greater than about four days and the

395
00:13:31,030 --> 00:13:28,580
reason why is because these cases down

396
00:13:33,010 --> 00:13:31,040
here rotates slow enough that the Ralphy

397
00:13:34,870 --> 00:13:33,020
deformation radius is larger than the

398
00:13:36,130 --> 00:13:34,880
planetary radius and so Barry clinic

399
00:13:36,970 --> 00:13:36,140
instability shouldn't be very important

400
00:13:38,770 --> 00:13:36,980
these atmospheres and

401
00:13:40,180 --> 00:13:38,780
this theory wouldn't apply to these

402
00:13:41,860 --> 00:13:40,190
slowly rotating planets only applies to

403
00:13:43,270 --> 00:13:41,870
planets with the rotation rates it's

404
00:13:46,090 --> 00:13:43,280
kind of they're kind of like earth or

405
00:13:47,890 --> 00:13:46,100
faster and so I said before if we

406
00:13:49,630 --> 00:13:47,900
understand this slope of ice and ropes

407
00:13:50,950 --> 00:13:49,640
we should also understand the equator

408
00:13:52,900 --> 00:13:50,960
droople temperature contrast in the

409
00:13:54,850 --> 00:13:52,910
vertical potential temperature contrast

410
00:13:56,350 --> 00:13:54,860
and in principle the vertical potential

411
00:13:58,120 --> 00:13:56,360
temperature contrast can be related to

412
00:14:00,070 --> 00:13:58,130
the lapse rate of the atmosphere which

413
00:14:02,050 --> 00:14:00,080

is something that we could in principle

414
00:14:04,030 --> 00:14:02,060
with a really awesome giant light bucket

415
00:14:05,620 --> 00:14:04,040
actually constrained with with

416
00:14:07,840 --> 00:14:05,630
retrievals onto our selection planet

417
00:14:12,310 --> 00:14:07,850
atmospheres you know when I'm maybe 50

418
00:14:15,100 --> 00:14:12,320
or something so or older we'll see so

419
00:14:16,930 --> 00:14:15,110
here I'm plotting the scaling between

420
00:14:18,820 --> 00:14:16,940
the GCM in theory for the equator pole

421
00:14:20,350 --> 00:14:18,830
temperature contrast on the left-hand

422
00:14:21,760 --> 00:14:20,360
panel and the bulk lapse rate or the

423
00:14:23,290 --> 00:14:21,770
vertical potential temperature contrast

424
00:14:25,330 --> 00:14:23,300
on the right-hand panel and you can see

425
00:14:26,950 --> 00:14:25,340
the theory predicts that both of these

426
00:14:28,930 --> 00:14:26,960
should increase with increasing rotation

427
00:14:29,110 --> 00:14:28,940
rate and our GCM results do bear that

428
00:14:31,090 --> 00:14:29,120
out

429
00:14:32,200 --> 00:14:31,100
note that this is kind of more of a

430
00:14:34,240 --> 00:14:32,210
broad agreement than the criticality

431
00:14:35,380 --> 00:14:34,250
parameter but in general the scaling

432
00:14:37,210 --> 00:14:35,390
predicts that this should this should

433
00:14:39,340 --> 00:14:37,220
hold over a wide range of parameters and

434
00:14:43,780 --> 00:14:39,350
so we've also tested surface pressure

435
00:14:46,180 --> 00:14:43,790
gravity and plenty radius did you or

436
00:14:53,310 --> 00:14:46,190
you're holding up a sign I have 20

437
00:14:55,480 --> 00:14:53,320
seconds great all right so to the end I

438
00:14:57,340 --> 00:14:55,490

talked a lot slower than I know that I

439
00:14:59,290 --> 00:14:57,350
normally do but so I've also looked at

440
00:15:00,760 --> 00:14:59,300
planets orbiting M dwarf stars and so

441
00:15:02,620 --> 00:15:00,770
the one thing I kind of want to get

442
00:15:04,600 --> 00:15:02,630
across is that for planets orbiting M

443
00:15:05,920 --> 00:15:04,610
dwarf stars we know that they're cloud

444
00:15:08,440 --> 00:15:05,930
coverage should depend on the rotation

445
00:15:10,030 --> 00:15:08,450
period so slowly rotating planets have

446
00:15:12,340 --> 00:15:10,040
more dayside cloud covers than fast

447
00:15:13,750 --> 00:15:12,350
rotating planets and in principle with

448
00:15:15,400 --> 00:15:13,760
future observations phase curve

449
00:15:17,770 --> 00:15:15,410
observations of these planets we could

450
00:15:19,450 --> 00:15:17,780
actually distinguish between these so

451
00:15:21,640 --> 00:15:19,460
for rapid rotating planets which don't

452
00:15:23,470 --> 00:15:21,650
have a sight sitting civics significant

453
00:15:24,970 --> 00:15:23,480
day sight cloud coverage you can easily

454
00:15:26,650 --> 00:15:24,980
see the outgoing cluck-cluck from the

455
00:15:28,540 --> 00:15:26,660
day side peaking near the substellar

456
00:15:29,980 --> 00:15:28,550
point but for slowly rotating planets

457
00:15:31,660 --> 00:15:29,990
which have significant dayside cloud

458
00:15:33,520 --> 00:15:31,670
coverage you wouldn't be able to seek

459
00:15:35,050 --> 00:15:33,530
this outgoing flux peak near the some

460
00:15:36,900 --> 00:15:35,060
stellar point because clouds would

461
00:15:38,160 --> 00:15:36,910
inhibit the olr and

462
00:15:39,780 --> 00:15:38,170
so you would actually see an inverted

463
00:15:41,430 --> 00:15:39,790

face curve and so in principle we can

464
00:15:43,560 --> 00:15:41,440
test all of our theories for cloud

465
00:15:45,600 --> 00:15:43,570
coverage on Endor fresco planets by

466
00:15:47,250 --> 00:15:45,610
through infrared phase curves all right

467
00:15:59,510 --> 00:15:47,260
thank you

468
00:16:04,830 --> 00:16:02,640
hi Neil is from the University of Oxford

469
00:16:07,530 --> 00:16:04,840
I was just wondering in the scaling as

470
00:16:09,900 --> 00:16:07,540
you showed it why you had the presence

471
00:16:11,940 --> 00:16:09,910
of the rotation rate but not the radius

472
00:16:14,190 --> 00:16:11,950
because in a number of ways they come

473
00:16:17,010 --> 00:16:14,200
into the momentum equations in the same

474
00:16:18,600 --> 00:16:17,020
place and you know both say if you're

475
00:16:21,150 --> 00:16:18,610
thinking about the light equatorial

476
00:16:23,640 --> 00:16:21,160
deformation radius has like a feature in

477
00:16:26,340 --> 00:16:23,650
it which has a inside and although the

478
00:16:29,250 --> 00:16:26,350
Rose be number is like you over L which

479
00:16:30,540 --> 00:16:29,260
hasn't hey yeah so this scaling I didn't

480
00:16:32,010 --> 00:16:30,550
I purposely didn't talk about how it's

481
00:16:34,290 --> 00:16:32,020
derived it doesn't come from the

482
00:16:34,800 --> 00:16:34,300
momentum equation it's very very simple

483
00:16:37,020 --> 00:16:34,810
actually

484
00:16:38,730 --> 00:16:37,030
so it just comes from the slope of right

485
00:16:40,290 --> 00:16:38,740
the slope of a nice and trope is related

486
00:16:42,030 --> 00:16:40,300
to the scale height divided by the

487
00:16:44,010 --> 00:16:42,040
length of a nation trip and so what we

488
00:16:45,840 --> 00:16:44,020

do is we scale the length of isin't rope

489
00:16:48,210 --> 00:16:45,850
saying that the maximum like ninth

490
00:16:49,830 --> 00:16:48,220
length of a nice intro is basically

491
00:16:51,930 --> 00:16:49,840
related to an any diffusion parameter

492
00:16:53,130 --> 00:16:51,940
times the rate of timescale and so if

493
00:16:54,840 --> 00:16:53,140
you can relate that a t diffusion

494
00:16:56,610 --> 00:16:54,850
parameter to large-scale properties of

495
00:16:58,680 --> 00:16:56,620
the circulation so if you scale it with

496
00:17:01,350 --> 00:16:58,690
in this case the the Ryans the rhine

497
00:17:03,570 --> 00:17:01,360
scale then you can basically then relate

498
00:17:05,250 --> 00:17:03,580
that back out to planetary parameters

499
00:17:06,660 --> 00:17:05,260
doesn't make sense so it's very very

500
00:17:08,940 --> 00:17:06,670
simple it basically it's just a scaling

501
00:17:10,290 --> 00:17:08,950
for these slopes it's not necessarily

502
00:17:11,910 --> 00:17:10,300
like a full scaling of momentum

503
00:17:24,810 --> 00:17:11,920
equations like maybe Mark Hammonds done

504
00:17:28,170 --> 00:17:24,820
yeah Mark Hyman to University of Oxford

505
00:17:29,940 --> 00:17:28,180
are there any observational tests beyond

506
00:17:31,830 --> 00:17:29,950
face curbs or other ones that you

507
00:17:34,560 --> 00:17:31,840
thought of for these scaling relations

508
00:17:36,420 --> 00:17:34,570
Oh so for the scaling relations I don't

509
00:17:38,970 --> 00:17:36,430
know if face curves would necessarily be

510
00:17:40,230 --> 00:17:38,980
a great test so for terrestrial planets

511
00:17:41,640 --> 00:17:40,240
I'm thinking about treasure planets that

512
00:17:43,440 --> 00:17:41,650
are orbiting sun-like stars something

513
00:17:45,870 --> 00:17:43,450

about reflected light with like Louvois

514
00:17:48,990 --> 00:17:45,880
or high backs in the far future and so

515
00:17:50,710 --> 00:17:49,000
in principle if the planet is inclined

516
00:17:51,850 --> 00:17:50,720
you can back out

517
00:17:52,990 --> 00:17:51,860
and equator to pole brightness

518
00:17:54,700 --> 00:17:53,000
difference if you can make brightness

519
00:17:55,810 --> 00:17:54,710
match to the planet and so that would be

520
00:17:57,340 --> 00:17:55,820
really really challenging that would

521
00:17:59,560 --> 00:17:57,350
require face cream observations over a

522
00:18:00,519 --> 00:17:59,570
long time baseline but in principle you

523
00:18:02,529 --> 00:18:00,529
can constrain the equator to pole

524
00:18:04,629 --> 00:18:02,539
temperature contrast in that case but

525
00:18:06,399 --> 00:18:04,639
more directly one could constrain the

526
00:18:08,019 --> 00:18:06,409
bulk lapse rate through retrieval so if

527
00:18:09,009 --> 00:18:08,029
you have a spectra you understand right

528
00:18:10,299 --> 00:18:09,019
the brightness as a function of

529
00:18:11,889 --> 00:18:10,309
wavelength that tells you a bit about

530
00:18:14,080 --> 00:18:11,899
the bride this is function of pressure

531
00:18:18,210 --> 00:18:14,090
which lets you back out a lot rate and

532
00:18:20,470 --> 00:18:18,220
so cat things worked a lot on that yeah

533
00:18:21,909 --> 00:18:20,480
quick question Ted I mean if you're

534
00:18:23,259 --> 00:18:21,919
looking for reflected light with like

535
00:18:25,389 --> 00:18:23,269
the warned havoc studies aren't gonna be

536
00:18:27,220 --> 00:18:25,399
tidally locked anymore right then we

537
00:18:29,220 --> 00:18:27,230
won't have to actually observe them that

538
00:18:31,869 --> 00:18:29,230

long as you're looking for a rotation

539
00:18:33,909 --> 00:18:31,879
shoot so I didn't get this across so in

540
00:18:35,320 --> 00:18:33,919
the first half of the first part the the

541
00:18:36,820 --> 00:18:35,330
scaling theory is for planets around

542
00:18:40,659 --> 00:18:36,830
sun-like stars that aren't highly locked

543
00:18:41,169 --> 00:18:40,669
yeah so it would it's not doable in the

544
00:18:45,419 --> 00:18:41,179
near future

545
00:18:49,419 --> 00:18:45,429
okay yeah sorry hi Pam

546
00:18:51,009 --> 00:18:49,429
what no stay on in the back he gave me

547
00:18:54,970 --> 00:18:51,019
the microphone but that was it okay

548
00:19:00,970 --> 00:18:54,980
that's fine who are you again IVF emoji

549
00:19:02,980 --> 00:19:00,980
Oxford uh does that apply and can you

550
00:19:04,480 --> 00:19:02,990
give me a scaling for hot Jupiters for

551
00:19:07,149 --> 00:19:04,490
the equator support operator grad young

552
00:19:08,740 --> 00:19:07,159
because that's something emily is gonna

553
00:19:10,690 --> 00:19:08,750
tell you we can observe we sugandha

554
00:19:13,629 --> 00:19:10,700
replicate mapping pretty soon which i'm

555
00:19:16,720 --> 00:19:13,639
sorry i'm gonna be mysterious so that's

556
00:19:19,690 --> 00:19:16,730
a really really good question so i think

557
00:19:21,249 --> 00:19:19,700
most of us are a little unsure how

558
00:19:22,960 --> 00:19:21,259
relevant bear clinic instabilities are

559
00:19:25,180 --> 00:19:22,970
for the atmospheric circulation of hot

560
00:19:26,590 --> 00:19:25,190
Jupiters i think in a bulk sense most of

561
00:19:28,629 --> 00:19:26,600
the instabilities we've seen our GCMs

562
00:19:31,119 --> 00:19:28,639
are barotropic right like the shedding

563
00:19:33,909 --> 00:19:31,129

of the shedding of Eddie's from the from

564
00:19:35,379 --> 00:19:33,919
the equatorial jet right and so I'm not

565
00:19:36,909 --> 00:19:35,389
really sure if there's bear clinic

566
00:19:38,980 --> 00:19:36,919
instabilities on our simulations it's

567
00:19:40,869 --> 00:19:38,990
kind of in like a stick where maybe they

568
00:19:43,149 --> 00:19:40,879
would occur if we had the right like

569
00:19:45,340 --> 00:19:43,159
forcing setup or something but in

570
00:19:47,860 --> 00:19:45,350
principle I would expect that warm

571
00:19:49,060 --> 00:19:47,870
Jupiter's might might have might be more

572
00:19:50,680 --> 00:19:49,070
likely to have better clinic

573
00:19:52,240 --> 00:19:50,690
instabilities because they can be faster

574
00:19:53,740 --> 00:19:52,250
rotating and actually that's what I'm

575
00:19:55,180 --> 00:19:53,750
doing next right now there's a we have a

576
00:19:56,740 --> 00:19:55,190
summer student who's running warm

577
00:19:58,600 --> 00:19:56,750
Jupiter simulations and we're gonna see

578
00:19:59,889 --> 00:19:58,610
if the same idea applies to them so we

579
00:20:01,690 --> 00:19:59,899
can test this sooner which James Webb

580
00:20:03,970 --> 00:20:01,700
rather than having to wait till the

581
00:20:07,190 --> 00:20:03,980
2040s yeah