
OSCILLATIONS IN GAS GIANTS
ADAM SHOWMAN

1
00:00:10,600 --> 00:00:07,600
[Music]

2
00:00:13,119 --> 00:00:10,610
brown dwarfs and jupiter and saturn have

3
00:00:15,669 --> 00:00:13,129
commonalities or you - and are worth

4
00:00:17,290 --> 00:00:15,679
considering as a class let me first give

5
00:00:18,910 --> 00:00:17,300
you a brief summary of some of the

6
00:00:21,220 --> 00:00:18,920
relevant observations regarding the

7
00:00:23,080 --> 00:00:21,230
atmospheric dynamics regime on these and

8
00:00:25,330 --> 00:00:23,090
then discuss and detail some of the

9
00:00:27,340 --> 00:00:25,340
problems that I'm interested in brown

10
00:00:29,710 --> 00:00:27,350
dwarfs are they're thought to form like

11
00:00:32,170 --> 00:00:29,720
stars they are typically defined to be

12
00:00:34,360 --> 00:00:32,180
hydrogen objects of masses of order 10

13
00:00:36,310 --> 00:00:34,370

to 80 Jupiter masses most of the ones we

14
00:00:38,470 --> 00:00:36,320
know despite the previous talk are

15
00:00:41,229 --> 00:00:38,480
isolated objects there's no nearby star

16
00:00:43,329 --> 00:00:41,239
around them to radiate them and they if

17
00:00:46,000 --> 00:00:43,339
there are dozens of Jupiter masses they

18
00:00:47,439 --> 00:00:46,010
can still be very hot even after many

19
00:00:49,119 --> 00:00:47,449
billions of years despite just

20
00:00:50,680 --> 00:00:49,129
continuously pouring radiation out to

21
00:00:52,270 --> 00:00:50,690
space and so many of them have

22
00:00:53,530 --> 00:00:52,280
temperatures at the top of a thousand

23
00:00:55,570 --> 00:00:53,540
Kelvin or more and they're relatively

24
00:00:57,369 --> 00:00:55,580
easy to observe in comparison to say hot

25
00:00:59,950 --> 00:00:57,379
Jupiters just because they're not being

26
00:01:02,079 --> 00:00:59,960
drawn out by a nearby star and they're

27
00:01:04,060 --> 00:01:02,089
rapidly rotating with periods of

28
00:01:06,789 --> 00:01:04,070
typically two to twelve hours which puts

29
00:01:08,140 --> 00:01:06,799
them in a dynamical regime that similar

30
00:01:10,179 --> 00:01:08,150
that of Jupiter or rotationally

31
00:01:11,950 --> 00:01:10,189
dominated regime different than that of

32
00:01:13,720 --> 00:01:11,960
a more slowly rotating hot Jupiter and

33
00:01:16,420 --> 00:01:13,730
it turns out there's now quite a bit of

34
00:01:17,920 --> 00:01:16,430
evidence for atmospheric dynamics and

35
00:01:19,810 --> 00:01:17,930
circulation on these objects we know

36
00:01:22,330 --> 00:01:19,820
clouds just from spectra and cloud

37
00:01:25,180 --> 00:01:22,340
particles need to be lofted by mixing

38
00:01:27,700 --> 00:01:25,190

mixing there's also signatures of mixing

39
00:01:30,580 --> 00:01:27,710
in disequilibrium chemistry from CO and

40
00:01:32,770 --> 00:01:30,590
ch4 and interestingly there's many

41
00:01:34,990 --> 00:01:32,780
objects most actually for which there's

42
00:01:37,300 --> 00:01:35,000
variability in various infrared bands

43
00:01:39,190 --> 00:01:37,310
shows an example wherein J band this

44
00:01:41,740 --> 00:01:39,200
object with a orbital period with a

45
00:01:44,440 --> 00:01:41,750
rotation period of 2.4 hours has a flux

46
00:01:47,050 --> 00:01:44,450
that varies over time by about say 5% or

47
00:01:48,430 --> 00:01:47,060
so and so that's interesting and the

48
00:01:50,500 --> 00:01:48,440
interpretation is that you're seeing

49
00:01:52,240 --> 00:01:50,510
cloudy and cloud free regions sort of

50
00:01:54,460 --> 00:01:52,250
hatching this view mostly of clouds and

51
00:01:56,020 --> 00:01:54,470
also temperature and those patches are

52
00:01:58,180 --> 00:01:56,030
rotating in and out of view as the brown

53
00:01:59,800 --> 00:01:58,190
dwarf turns and so you're seeing from

54
00:02:01,870 --> 00:01:59,810
Earth different faces with brown dwarf

55
00:02:03,789 --> 00:02:01,880
at different times and the cloudy fruit

56
00:02:04,840 --> 00:02:03,799
in the cloud free regions your sensing

57
00:02:06,789 --> 00:02:04,850
the deeper layers of the atmosphere

58
00:02:09,520 --> 00:02:06,799
what's hotter and the radiation is

59
00:02:11,170 --> 00:02:09,530
greater and the cloudy regions are

60
00:02:13,240 --> 00:02:11,180
cooler and so that there's a patchiness

61
00:02:16,449 --> 00:02:13,250
and the flux actually that causes the

62
00:02:17,800 --> 00:02:16,459
total flux integrated you know signal

63
00:02:19,930 --> 00:02:17,810

that we see it earth fairy and

64
00:02:20,640 --> 00:02:19,940
interestingly over time so if you go

65
00:02:22,080 --> 00:02:20,650
back later

66
00:02:23,910 --> 00:02:22,090
period of course in the same because

67
00:02:25,440 --> 00:02:23,920
that's the rotation period but the shape

68
00:02:29,190 --> 00:02:25,450
of the light curve is different and that

69
00:02:30,449 --> 00:02:29,200
implies that the sort of pattern of the

70
00:02:32,190 --> 00:02:30,459
patchiness on the surface of the

71
00:02:33,600 --> 00:02:32,200
groundwork is changing with times that's

72
00:02:35,220 --> 00:02:33,610
direct evidence for atmospheric

73
00:02:38,460 --> 00:02:35,230
circulation it's not a static structure

74
00:02:40,530 --> 00:02:38,470
and and so it's interesting if there's

75
00:02:42,300 --> 00:02:40,540
no nearby star or so on earth or a hot

76
00:02:44,190 --> 00:02:42,310
Jupiter the dominant mechanism that

77
00:02:46,229 --> 00:02:44,200
drives the circulation is the gradient

78
00:02:48,089 --> 00:02:46,239
and strength of absorbed starlight from

79
00:02:50,039 --> 00:02:48,099
say the equator to the pole or the dance

80
00:02:51,690 --> 00:02:50,049
side to the night side which induces

81
00:02:53,550 --> 00:02:51,700
large-scale horizontal pressure and

82
00:02:54,930 --> 00:02:53,560
temperature variations that's an earth

83
00:02:56,520 --> 00:02:54,940
drive the Hadley cell and the jet

84
00:02:58,920 --> 00:02:56,530
streams and all that and the typical

85
00:03:00,839 --> 00:02:58,930
brown dwarf lacks that mechanism so you

86
00:03:02,849 --> 00:03:00,849
have instead this brown dwarf which is a

87
00:03:05,039 --> 00:03:02,859
very convective convectively active

88
00:03:06,780 --> 00:03:05,049

interior and the convection is pounding

89
00:03:09,899 --> 00:03:06,790
against the bottom of a stratified

90
00:03:11,879 --> 00:03:09,909
atmosphere and the stratified atmosphere

91
00:03:13,710 --> 00:03:11,889
has no external barrel Anisa T as we

92
00:03:15,809 --> 00:03:13,720
like to say there's no external gradient

93
00:03:18,210 --> 00:03:15,819
from a star there is no star but you

94
00:03:19,740 --> 00:03:18,220
have and this convection pounding

95
00:03:21,509 --> 00:03:19,750
against the base of the stratified

96
00:03:23,789 --> 00:03:21,519
atmosphere and that can generate waves

97
00:03:25,619 --> 00:03:23,799
atmospheric waves that propagate up into

98
00:03:26,939 --> 00:03:25,629
the atmosphere they can break we can get

99
00:03:28,650 --> 00:03:26,949
absorbed they can interact with each

100
00:03:30,930 --> 00:03:28,660
other and that in principle can drive a

101
00:03:32,339 --> 00:03:30,940
circulation in fact we have an analogy

102
00:03:34,080 --> 00:03:32,349
for this in the solar system in the

103
00:03:35,430 --> 00:03:34,090
stratosphere of Earth and the giant

104
00:03:36,990 --> 00:03:35,440
plant that's which and in the

105
00:03:39,030 --> 00:03:37,000
circulation in the stratosphere of Earth

106
00:03:41,580 --> 00:03:39,040
is predominantly driven by this same

107
00:03:43,020 --> 00:03:41,590
mechanism there is the course variation

108
00:03:46,319 --> 00:03:43,030
on the strength of the absorb sunlight

109
00:03:47,909 --> 00:03:46,329
mainly just due to ozone absorbing UV

110
00:03:49,619 --> 00:03:47,919
there's a lotta tooth gradient at that

111
00:03:52,140 --> 00:03:49,629
but the dominant driver is this

112
00:03:54,149 --> 00:03:52,150
mechanism and there's also evidence

113
00:03:56,670 --> 00:03:54,159

there's now one brown dwarf where we

114
00:03:58,050 --> 00:03:56,680
have tackiness observed by a nice paper

115
00:03:59,399 --> 00:03:58,060
from Ian Cross field a few years ago

116
00:04:02,250 --> 00:03:59,409
this is from the Doppler imaging

117
00:04:03,689 --> 00:04:02,260
technique so a key question here then is

118
00:04:05,369 --> 00:04:03,699
what is the circulation like in this

119
00:04:07,110 --> 00:04:05,379
regime there have been some models like

120
00:04:09,780 --> 00:04:07,120
this one a nice paper from almost 10

121
00:04:11,580 --> 00:04:09,790
years ago now by Bern Freitag showing

122
00:04:13,979 --> 00:04:11,590
you know how you can produce these waves

123
00:04:16,110 --> 00:04:13,989
but this is a small 2d box calculation

124
00:04:17,640 --> 00:04:16,120
just covering like 1% of the surface of

125
00:04:19,500 --> 00:04:17,650
the brown dwarf and doesn't apply to the

126
00:04:21,420 --> 00:04:19,510
overall interior and doesn't include

127
00:04:23,850 --> 00:04:21,430
rotation so that's kind of the state of

128
00:04:25,560 --> 00:04:23,860
the art and then switching to

129
00:04:27,689 --> 00:04:25,570
observations of the giant planets we

130
00:04:29,399 --> 00:04:27,699
know they're Banda's nice talk on that

131
00:04:31,260 --> 00:04:29,409
we heard about earlier so there's these

132
00:04:33,000 --> 00:04:31,270
nice little jets for Jupiter and Saturn

133
00:04:34,350 --> 00:04:33,010
these are the measured east-west wind

134
00:04:35,670 --> 00:04:34,360
speed or zonal winds

135
00:04:38,580 --> 00:04:35,680
Jupiter and Saturn Uranus and Neptune

136
00:04:39,929 --> 00:04:38,590
and so one could ask questions about

137
00:04:41,879 --> 00:04:39,939
what are the conditions under which you

138
00:04:44,070 --> 00:04:41,889

would expect an amateur to organize into

139
00:04:47,510 --> 00:04:44,080
this banded cloud structure or disbanded

140
00:04:49,740 --> 00:04:47,520
structure at all versus being comprising

141
00:04:51,149 --> 00:04:49,750
isotropic turbulence or you know just

142
00:04:52,790 --> 00:04:51,159
being polka-dotted by a hundred

143
00:04:55,050 --> 00:04:52,800
different great red spots or whatever

144
00:04:56,939 --> 00:04:55,060
and also it turns out there are

145
00:04:58,249 --> 00:04:56,949
stratospheric oscillations on Jupiter

146
00:05:01,230 --> 00:04:58,259
and Saturn they're quite interesting

147
00:05:04,170 --> 00:05:01,240
this basically shows the zonal mean

148
00:05:06,330 --> 00:05:04,180
temperature structure over time over a

149
00:05:09,330 --> 00:05:06,340
20-year period from late 70s to about

150
00:05:11,279 --> 00:05:09,340
2000 and the key point is just that the

151
00:05:13,260 --> 00:05:11,289
Wiggles are Wiggles that move up and

152
00:05:14,730 --> 00:05:13,270
down over time and it turns out this has

153
00:05:16,670 --> 00:05:14,740
about a four year period and so the

154
00:05:18,749 --> 00:05:16,680
variations in the temperature wasn't

155
00:05:21,029 --> 00:05:18,759
amplitude of water five to ten Kelvin

156
00:05:23,159 --> 00:05:21,039
that vary over time in this way on

157
00:05:25,170 --> 00:05:23,169
Jupiter the same thing occurs on Saturn

158
00:05:27,510 --> 00:05:25,180
on Jupiter this is called the quasi

159
00:05:29,969 --> 00:05:27,520
quadrennial oscillation or 2qo

160
00:05:31,529 --> 00:05:29,979
due to its four-year period on Saturn

161
00:05:33,330 --> 00:05:31,539
the same kind of oscillation has a

162
00:05:35,879 --> 00:05:33,340
period of 15 years which interestingly

163
00:05:38,159 --> 00:05:35,889

is half a Saturn year and because of a

164
00:05:40,950 --> 00:05:38,169
dynamical link between temperatures and

165
00:05:42,420 --> 00:05:40,960
winds on a rapidly rotating planet these

166
00:05:44,999 --> 00:05:42,430
variations in temperature imply a

167
00:05:46,499 --> 00:05:45,009
variation that wind and if you use just

168
00:05:47,939 --> 00:05:46,509
this you know do kind of a thermal wind

169
00:05:49,709 --> 00:05:47,949
sort of analysis you can infer

170
00:05:51,659 --> 00:05:49,719
observational II what the wind pattern

171
00:05:53,760 --> 00:05:51,669
is doing and basically the wind pattern

172
00:05:55,980 --> 00:05:53,770
consists of vertically stacked eastward

173
00:05:58,829 --> 00:05:55,990
and westward low latitude Jets that are

174
00:06:01,079 --> 00:05:58,839
shown here and so red is eastward

175
00:06:02,939 --> 00:06:01,089
anomaly blue is westward anomaly at the

176
00:06:05,760 --> 00:06:02,949
equator this is latitude this is for

177
00:06:08,070 --> 00:06:05,770
Saturn latitude on the x axis height on

178
00:06:09,689 --> 00:06:08,080
the y axis and interesting thing is that

179
00:06:11,550 --> 00:06:09,699
the stack pattern of eastward and

180
00:06:13,559 --> 00:06:11,560
westward jets migrates downward over

181
00:06:16,769 --> 00:06:13,569
time so the location of this eastward

182
00:06:20,490 --> 00:06:16,779
jet has moved downward over the sort of

183
00:06:22,769 --> 00:06:20,500
five or six years from 2005 to 2010 this

184
00:06:24,179 --> 00:06:22,779
is from Cassini observations so for

185
00:06:27,869 --> 00:06:24,189
Saturn this is called the semiannual

186
00:06:29,219 --> 00:06:27,879
oscillation or SS or SAO due to its the

187
00:06:30,959 --> 00:06:29,229
fact that it's half of the Saturn here

188
00:06:32,369 --> 00:06:30,969

in length turns out there's an

189
00:06:33,809 --> 00:06:32,379
oscillation just like this on the

190
00:06:35,339 --> 00:06:33,819
Earth's atmosphere which is well known

191
00:06:37,379 --> 00:06:35,349
and have been studied for half century

192
00:06:40,320 --> 00:06:37,389
called the quasi biennial oscillation or

193
00:06:42,570 --> 00:06:40,330
QBO and this shows basically the east

194
00:06:44,760 --> 00:06:42,580
and west word wind speeds at the equator

195
00:06:47,430 --> 00:06:44,770
over time from the 60s through about

196
00:06:50,010 --> 00:06:47,440
1990 and so just imagine first

197
00:06:51,600 --> 00:06:50,020
Stan this being at a single altitude say

198
00:06:53,760 --> 00:06:51,610
30 kilometers and thinking about what

199
00:06:55,710 --> 00:06:53,770
happens over time so 30 kilometers the

200
00:06:57,570 --> 00:06:55,720
winds sign changes from westward to

201
00:06:59,220 --> 00:06:57,580
eastward to westward eastward so if

202
00:07:01,260 --> 00:06:59,230
you're at that one altitude there's an

203
00:07:03,570 --> 00:07:01,270
equatorial jet and the sign of the jet

204
00:07:06,480 --> 00:07:03,580
is switching back and forth every two

205
00:07:07,740 --> 00:07:06,490
years you know just like well it's not

206
00:07:09,810 --> 00:07:07,750
exactly a signal o'clock because it's

207
00:07:11,220 --> 00:07:09,820
not that periodic but anyway so and the

208
00:07:12,630 --> 00:07:11,230
cool thing is that the whole structure

209
00:07:14,700 --> 00:07:12,640
if you look at the height structure it

210
00:07:17,100 --> 00:07:14,710
moves downward over time so the phasing

211
00:07:18,930 --> 00:07:17,110
of these alternating jets is different

212
00:07:21,360 --> 00:07:18,940
at different heights such that you know

213
00:07:22,920 --> 00:07:21,370

say this eastward jet moves downward

214
00:07:25,860 --> 00:07:22,930
over time this westward jet moves

215
00:07:27,630 --> 00:07:25,870
downward so on and the period is

216
00:07:29,760 --> 00:07:27,640
approximately two years since the name

217
00:07:31,650 --> 00:07:29,770
quasi biennial oscillation and I might

218
00:07:33,540 --> 00:07:31,660
add this is not implied that the mass is

219
00:07:35,790 --> 00:07:33,550
moving downward the the zonal wind

220
00:07:37,050 --> 00:07:35,800
contours are not material surfaces but

221
00:07:39,360 --> 00:07:37,060
the materials actually tends to be

222
00:07:40,800 --> 00:07:39,370
moving upward due to sort of a row donal

223
00:07:42,990 --> 00:07:40,810
circulation we have this interesting

224
00:07:44,970 --> 00:07:43,000
oscillation now for giant planets

225
00:07:46,470 --> 00:07:44,980
there's never been a three-dimensional

226
00:07:47,730 --> 00:07:46,480
model that's captured this so I'm

227
00:07:49,320 --> 00:07:47,740
interested in kind of globally

228
00:07:50,730 --> 00:07:49,330
considering these phenomena together the

229
00:07:53,400 --> 00:07:50,740
zonal Jets and these stratospheric

230
00:07:54,540 --> 00:07:53,410
oscillations and so I am doing a three

231
00:07:56,190 --> 00:07:54,550
dimensional going to present three

232
00:07:57,840 --> 00:07:56,200
dimensional atmospheric calculations

233
00:07:59,610 --> 00:07:57,850
using the primitive equations the

234
00:08:02,220 --> 00:07:59,620
standard equation set for a stratified

235
00:08:03,630 --> 00:08:02,230
atmosphere and so we're basically we're

236
00:08:05,280 --> 00:08:03,640
not child represents a deep convection

237
00:08:06,750 --> 00:08:05,290
zone but we kind of go through the

238
00:08:08,880 --> 00:08:06,760

atmosphere down to the top part of the

239
00:08:10,950 --> 00:08:08,890
convection zone and we parameterize can

240
00:08:13,170 --> 00:08:10,960
the effective convection by adding

241
00:08:15,270 --> 00:08:13,180
random perturbations at the base of the

242
00:08:17,310 --> 00:08:15,280
model and the intention of those is just

243
00:08:18,840 --> 00:08:17,320
to push the material surfaces at the

244
00:08:20,880 --> 00:08:18,850
bottom of the model up and down in a

245
00:08:22,500 --> 00:08:20,890
random way that would sort of represent

246
00:08:24,540 --> 00:08:22,510
what convection might do the

247
00:08:26,100 --> 00:08:24,550
characteristic and wave number or wave

248
00:08:27,390 --> 00:08:26,110
length of these is a free parameter that

249
00:08:29,370 --> 00:08:27,400
we very characteristic time scale

250
00:08:30,960 --> 00:08:29,380
likewise although these can be

251
00:08:32,909 --> 00:08:30,970
constrained by what you would expect the

252
00:08:34,560 --> 00:08:32,919
convection to do in the interior so we

253
00:08:36,630 --> 00:08:34,570
have bounds on what we would expect and

254
00:08:38,640 --> 00:08:36,640
we put this in intentionally as a

255
00:08:40,170 --> 00:08:38,650
spatially isotropic pattern meaning in

256
00:08:42,900 --> 00:08:40,180
the forcing there's no preferred

257
00:08:45,590 --> 00:08:42,910
directionality east west north south the

258
00:08:47,430 --> 00:08:45,600
only source of asymmetry or or

259
00:08:49,860 --> 00:08:47,440
anisotropy I should say and this model

260
00:08:51,300 --> 00:08:49,870
is the rotation so banding occurs in

261
00:08:53,130 --> 00:08:51,310
this it's solely due to the planetary

262
00:08:54,540 --> 00:08:53,140
rotation this gives a sense of the

263
00:08:56,460 --> 00:08:54,550

vertical structure and kind of a low

264
00:08:57,990 --> 00:08:56,470
resolution version of the model these

265
00:08:59,850 --> 00:08:58,000
colored bands are just to kind of guide

266
00:09:02,460 --> 00:08:59,860
your eye the actual Lois

267
00:09:04,530 --> 00:09:02,470
here show the model structure for a low

268
00:09:06,600 --> 00:09:04,540
resolution version these are idealized

269
00:09:08,190 --> 00:09:06,610
calculations so we put in the radiation

270
00:09:10,769 --> 00:09:08,200
just by a Newtonian cooling will be

271
00:09:12,780 --> 00:09:10,779
damped to some times that sort of

272
00:09:14,069 --> 00:09:12,790
temperature profile like this critical

273
00:09:16,170 --> 00:09:14,079
is that this is not a function of

274
00:09:18,329 --> 00:09:16,180
longitude or latitude and this is only a

275
00:09:19,970 --> 00:09:18,339
function of height which represents this

276
00:09:22,410 --> 00:09:19,980
fact that I mentioned earlier that most

277
00:09:24,600 --> 00:09:22,420
objects do not have most Brown works do

278
00:09:26,150 --> 00:09:24,610
not have a nearby star and so the

279
00:09:28,710 --> 00:09:26,160
radiative timescale is a free parameter

280
00:09:31,019 --> 00:09:28,720
we have to use high resolution so we

281
00:09:32,790 --> 00:09:31,029
typically use 160 vertical levels which

282
00:09:34,920 --> 00:09:32,800
is necessary to capture the wave

283
00:09:38,190 --> 00:09:34,930
behavior so this shows several

284
00:09:40,079 --> 00:09:38,200
calculations of the flow three different

285
00:09:43,290 --> 00:09:40,089
simulations using different values the

286
00:09:45,300 --> 00:09:43,300
radiative time constant and so and as I

287
00:09:47,009 --> 00:09:45,310
mentioned radiation acts as a damper in

288
00:09:48,660 --> 00:09:47,019

this system radiation is removing

289
00:09:50,730 --> 00:09:48,670
horizontal we're trying to damp out

290
00:09:52,560 --> 00:09:50,740
horizontal temperature variations so

291
00:09:56,250 --> 00:09:52,570
that's opposite of the role of radiation

292
00:09:57,900 --> 00:09:56,260
and say a hot Jupiter and forcing then

293
00:09:59,699 --> 00:09:57,910
just due to this the perturbations by

294
00:10:02,610 --> 00:09:59,709
convection at the base of the model so

295
00:10:04,290 --> 00:10:02,620
all of these develop banded patterns the

296
00:10:06,300 --> 00:10:04,300
left column shows temperature the right

297
00:10:08,759 --> 00:10:06,310
is the zonal wind with red being

298
00:10:10,019 --> 00:10:08,769
eastward and blue being westward and so

299
00:10:12,000 --> 00:10:10,029
you can see that when the radio time

300
00:10:14,699 --> 00:10:12,010
constant is longer that implies that the

301
00:10:16,620 --> 00:10:14,709
flow is has a weaker damping so wind

302
00:10:18,840 --> 00:10:16,630
speeds are stronger reaching 400 meters

303
00:10:20,970 --> 00:10:18,850
a second and the flow forms it's nice

304
00:10:22,740 --> 00:10:20,980
banded pattern not as regular as Jupiter

305
00:10:24,840 --> 00:10:22,750
and then I'll talk about that a second

306
00:10:26,160 --> 00:10:24,850
but still nice banded pattern and then

307
00:10:27,930 --> 00:10:26,170
when the radiative time constant is

308
00:10:29,699 --> 00:10:27,940
stronger there's a tendency to confine

309
00:10:31,410 --> 00:10:29,709
the zonal flow to low latitudes

310
00:10:33,030 --> 00:10:31,420
and the reason that occurs is because

311
00:10:34,769 --> 00:10:33,040
there's a lot of - Tyndall sensitivity

312
00:10:36,480 --> 00:10:34,779
to how to the efficiency of zonal jet

313
00:10:38,699 --> 00:10:36,490

formation zonal Jets form most

314
00:10:40,410 --> 00:10:38,709
efficiently at low latitudes because of

315
00:10:41,730 --> 00:10:40,420
the ability to generate Rossby waves

316
00:10:44,430 --> 00:10:41,740
which are critical for zonal jet

317
00:10:45,930 --> 00:10:44,440
formation at low latitudes some of these

318
00:10:47,310 --> 00:10:45,940
models can produce behavior that is

319
00:10:49,560 --> 00:10:47,320
quite similar to that of Jupiter and

320
00:10:51,180 --> 00:10:49,570
Saturn this top model is an example of

321
00:10:52,829 --> 00:10:51,190
that and the zonal Winfield from that

322
00:10:54,900 --> 00:10:52,839
model is shown here so an alternating

323
00:10:56,670 --> 00:10:54,910
east/west zonal jets with a nice

324
00:10:58,740 --> 00:10:56,680
equatorial super rotation at the equator

325
00:11:02,160 --> 00:10:58,750
and then you get this flow kind of

326
00:11:03,509 --> 00:11:02,170
mixing homogenizing for the dynamics

327
00:11:05,670 --> 00:11:03,519
aficionados out there this is the

328
00:11:08,250 --> 00:11:05,680
potential vorticity basically get this

329
00:11:09,990 --> 00:11:08,260
nice staircase pattern and you can see

330
00:11:11,910 --> 00:11:10,000
this nice pattern those old Jets even

331
00:11:13,269 --> 00:11:11,920
hints of polygons through the hexagons

332
00:11:15,730 --> 00:11:13,279
like structure here

333
00:11:17,199 --> 00:11:15,740
lower row is a model it's analogous but

334
00:11:19,150 --> 00:11:17,209
it's more strongly forced and more

335
00:11:20,619 --> 00:11:19,160
strongly dense so this might be a brown

336
00:11:22,329 --> 00:11:20,629
dwarf that sort of intermediate between

337
00:11:24,309 --> 00:11:22,339
some of the really hot ones and Jupiter

338
00:11:26,019 --> 00:11:24,319

and so what happens is the stronger

339
00:11:28,179 --> 00:11:26,029
forcing and the stronger damping you

340
00:11:29,949 --> 00:11:28,189
still get a banded structure but the

341
00:11:31,869 --> 00:11:29,959
stronger forcing and damping tries to

342
00:11:34,030 --> 00:11:31,879
disrupt that banded pattern and so what

343
00:11:35,799 --> 00:11:34,040
it takes time for the flow to organize

344
00:11:37,150 --> 00:11:35,809
into this banded pattern so if the

345
00:11:39,040 --> 00:11:37,160
forcing and dampering are really strong

346
00:11:40,660 --> 00:11:39,050
it can disrupt that process before it

347
00:11:43,269 --> 00:11:40,670
goes to completion which is why this

348
00:11:44,710 --> 00:11:43,279
lower model is less well banded on to

349
00:11:46,660 --> 00:11:44,720
the oscillations in my last couple

350
00:11:48,489 --> 00:11:46,670
minutes here this shows several

351
00:11:50,110 --> 00:11:48,499
different time snapshots in a single

352
00:11:52,210 --> 00:11:50,120
numerical simulation and you can see the

353
00:11:54,489 --> 00:11:52,220
sign of the equatorial jet switches from

354
00:11:57,040 --> 00:11:54,499
eastward to westward back to eastward

355
00:12:00,460 --> 00:11:57,050
again in this case the period is about

356
00:12:01,809 --> 00:12:00,470
12 years this maybe I'll skip those

357
00:12:03,220 --> 00:12:01,819
through the time constraints but it's

358
00:12:05,199 --> 00:12:03,230
just showing the Miryang structure of

359
00:12:06,639 --> 00:12:05,209
that oscillation this is my version of

360
00:12:09,400 --> 00:12:06,649
that plot that I showed from the

361
00:12:12,549 --> 00:12:09,410
observations for the qbo so here's the

362
00:12:15,009 --> 00:12:12,559
zonal average east west wind at the

363
00:12:17,019 --> 00:12:15,019

equator and showing the eastward wind

364
00:12:19,480 --> 00:12:17,029
and bread and the westward whip blue and

365
00:12:21,460 --> 00:12:19,490
you can see this downward propagation of

366
00:12:23,650 --> 00:12:21,470
the Jets like I described in this case

367
00:12:26,379 --> 00:12:23,660
with a period of sort of 4,000 days or

368
00:12:28,119 --> 00:12:26,389
so and so this is the first time that

369
00:12:29,019 --> 00:12:28,129
this kind of an oscillatory structure

370
00:12:31,179 --> 00:12:29,029
has been simulated in a

371
00:12:33,340 --> 00:12:31,189
three-dimensional model planet the

372
00:12:35,410 --> 00:12:33,350
mechanism it turns out is quite similar

373
00:12:37,569 --> 00:12:35,420
not surprisingly to the well known

374
00:12:39,730 --> 00:12:37,579
mechanism that drives the qpo in the

375
00:12:41,259 --> 00:12:39,740
case of Earth and basically involves the

376
00:12:43,780 --> 00:12:41,269
interaction of these convectively

377
00:12:46,090 --> 00:12:43,790
generated waves with mean flow in the

378
00:12:47,410 --> 00:12:46,100
stratosphere and so I probably don't

379
00:12:48,610 --> 00:12:47,420
have time to walk through all the

380
00:12:50,230 --> 00:12:48,620
subtleties of this but I'll try to

381
00:12:51,579 --> 00:12:50,240
sketch it out in my last minute or so

382
00:12:55,119 --> 00:12:51,589
and feel free to ask follow-up questions

383
00:12:56,799 --> 00:12:55,129
and so basically we did a first off

384
00:12:58,749 --> 00:12:56,809
analyzed what the details of all the

385
00:13:00,749 --> 00:12:58,759
wave types are and how the wave types

386
00:13:03,610 --> 00:13:00,759
vary with latitude with the height and

387
00:13:05,439 --> 00:13:03,620
model and they're crucially both

388
00:13:07,900 --> 00:13:05,449

eastward and westward propagating waves

389
00:13:09,639 --> 00:13:07,910
and so they propagate up and then once

390
00:13:11,710 --> 00:13:09,649
you have the zonal Jets so for example

391
00:13:14,019 --> 00:13:11,720
this is showing speed of either the

392
00:13:16,150 --> 00:13:14,029
zonal jet or the wave phase it's on the

393
00:13:19,179 --> 00:13:16,160
x axis and this was height here so this

394
00:13:21,100 --> 00:13:19,189
dotted line shows the zonal wind turbine

395
00:13:22,629 --> 00:13:21,110
point in time so this point in time

396
00:13:24,970 --> 00:13:22,639
there's an eastward jet at the bottom

397
00:13:26,410 --> 00:13:24,980
westward jet in the middle and then at

398
00:13:27,100 --> 00:13:26,420
the very top and other eastward Jets

399
00:13:29,199 --> 00:13:27,110
vertically

400
00:13:30,970 --> 00:13:29,209
stack pattern of jets and so the east

401
00:13:32,920 --> 00:13:30,980
and then you get waves and the wave

402
00:13:34,480 --> 00:13:32,930
space speed is shown on here this from a

403
00:13:37,210 --> 00:13:34,490
diagnostic analysis of our 3d

404
00:13:38,920 --> 00:13:37,220
simulations and so again both the

405
00:13:40,540 --> 00:13:38,930
westward propagating waves propagate up

406
00:13:42,610 --> 00:13:40,550
the eastward propagating waves propagate

407
00:13:44,680 --> 00:13:42,620
up and what happens is that the westward

408
00:13:46,660 --> 00:13:44,690
propagating waves first hit the face of

409
00:13:48,519 --> 00:13:46,670
this westward jet and they reach what's

410
00:13:49,900 --> 00:13:48,529
termed a critical level so basically as

411
00:13:51,790 --> 00:13:49,910
the waves propagate up they're reaching

412
00:13:53,410 --> 00:13:51,800
a region where the zonal jet speed is

413
00:13:55,300 --> 00:13:53,420

the same as the wave speed that

414
00:13:57,430 --> 00:13:55,310
drastically changes the wave propagation

415
00:13:59,620 --> 00:13:57,440
properties tends to slow down the waves

416
00:14:01,329 --> 00:13:59,630
propagation it squashes together the

417
00:14:03,130 --> 00:14:01,339
wave crests and it makes it much easier

418
00:14:04,840 --> 00:14:03,140
for the wave to be damped and when of

419
00:14:06,550 --> 00:14:04,850
westward propagating wave like this is

420
00:14:08,620 --> 00:14:06,560
damp it deposits westward momentum

421
00:14:11,110 --> 00:14:08,630
however no such region is reached for

422
00:14:12,490 --> 00:14:11,120
the for these eastward went of waves

423
00:14:13,810 --> 00:14:12,500
these were propagating waves are

424
00:14:15,400 --> 00:14:13,820
perfectly happy to just shoot right up

425
00:14:16,930 --> 00:14:15,410
through that region and they get up to

426
00:14:18,100 --> 00:14:16,940
the base of this eastward jet and then

427
00:14:20,650 --> 00:14:18,110
they undergo the same kind of process

428
00:14:22,750 --> 00:14:20,660
where as they approach a region where

429
00:14:25,240 --> 00:14:22,760
the wind speed is similar to their phase

430
00:14:27,490 --> 00:14:25,250
speed a least word in this case the wave

431
00:14:28,900 --> 00:14:27,500
slow down their wave crests mashed

432
00:14:30,579 --> 00:14:28,910
together and they get damped and

433
00:14:33,759 --> 00:14:30,589
crucially if they deposit Eastern

434
00:14:36,639 --> 00:14:33,769
momentum and so the sort of this bottom

435
00:14:38,380 --> 00:14:36,649
plot is showing the acceleration caused

436
00:14:40,810 --> 00:14:38,390
by those waves it's a function of height

437
00:14:43,180 --> 00:14:40,820
D composed into wave speeds and

438
00:14:44,470 --> 00:14:43,190

crucially so the eastward accelerations

439
00:14:46,480 --> 00:14:44,480
are shown in red and westward

440
00:14:48,250 --> 00:14:46,490
accelerations are shown in blue and the

441
00:14:50,139 --> 00:14:48,260
point is that the result of this wave

442
00:14:52,150 --> 00:14:50,149
means flow interactions is to cause an

443
00:14:53,740 --> 00:14:52,160
eastward acceleration at the base of the

444
00:14:55,240 --> 00:14:53,750
eastward Jets and a westward

445
00:14:57,850 --> 00:14:55,250
acceleration at the base of the westward

446
00:14:59,769 --> 00:14:57,860
jet now if that acceleration were Co

447
00:15:01,630 --> 00:14:59,779
aligned exactly with the sort of core

448
00:15:03,160 --> 00:15:01,640
and height of the jet itself it might

449
00:15:05,620 --> 00:15:03,170
just make the just stronger and not

450
00:15:06,880 --> 00:15:05,630
change its its altitude but because of

451
00:15:08,920 --> 00:15:06,890
this mechanism instead you're

452
00:15:10,810 --> 00:15:08,930
preferentially absorbing waves on the

453
00:15:13,180 --> 00:15:10,820
bottom flank of the jet below the jet

454
00:15:15,460 --> 00:15:13,190
peak and as a result that strengthens

455
00:15:17,319 --> 00:15:15,470
the bottom part of the jet below where

456
00:15:19,030 --> 00:15:17,329
the maximum of the wind speed is and it

457
00:15:21,250 --> 00:15:19,040
weakens the top part and so the whole

458
00:15:22,540 --> 00:15:21,260
jet propagates downward over time this

459
00:15:24,009 --> 00:15:22,550
is the mechanism that causes the

460
00:15:25,930 --> 00:15:24,019
downward propagation on this classic

461
00:15:27,850 --> 00:15:25,940
model so this mechanisms been well known

462
00:15:28,960 --> 00:15:27,860
for the QBO for the earth like I said

463
00:15:31,360 --> 00:15:28,970

was the first time this had been done

464
00:15:33,310 --> 00:15:31,370
for a jack flat all right so just to sum

465
00:15:35,590 --> 00:15:33,320
up here so hopefully I've convinced you

466
00:15:37,269 --> 00:15:35,600
the brown dwarfs and Jupiter Saturn have

467
00:15:38,860 --> 00:15:37,279
certain similarities numerical

468
00:15:40,900 --> 00:15:38,870
experiments for this class of bodies

469
00:15:42,760 --> 00:15:40,910
generally showed band and clouds nope

470
00:15:45,190 --> 00:15:42,770
ended pattern in the dynamics so you

471
00:15:47,800 --> 00:15:45,200
would expect even though brown dwarfs

472
00:15:49,990 --> 00:15:47,810
have strongly forced in a sense they're

473
00:15:52,630 --> 00:15:50,000
vigorously convecting we still expect a

474
00:15:54,610 --> 00:15:52,640
banded structure or the more models are

475
00:15:56,560 --> 00:15:54,620
very Jupiter and Saturn like as far as

476
00:15:59,710 --> 00:15:56,570
their zonal jet patterns and we produced

477
00:16:02,170 --> 00:15:59,720
this QQ o and Q and Sao like structure

478
00:16:13,210 --> 00:16:02,180
here for the first time due to upward

479
00:16:22,000 --> 00:16:13,220
propagation of waves thank you thank you

480
00:16:24,760 --> 00:16:22,010
so much I'm Marcin hi Matt Cameron

481
00:16:27,640 --> 00:16:24,770
University the headed so presumably

482
00:16:29,790 --> 00:16:27,650
similar models have also produced

483
00:16:32,200 --> 00:16:29,800
convectively generated waves in the past

484
00:16:33,670 --> 00:16:32,210
why is this model different in that it's

485
00:16:35,440 --> 00:16:33,680
produced this mechanism are you

486
00:16:38,710 --> 00:16:35,450
referring to Jupiter and Saturn yeah

487
00:16:40,300 --> 00:16:38,720
yeah so there's not been that much work

488
00:16:42,760 --> 00:16:40,310

done on Jupiter and Saturn actually for

489
00:16:46,600 --> 00:16:42,770
this type of thing so you see if I have

490
00:16:48,910 --> 00:16:46,610
well I can go back to this shows a

491
00:16:50,170 --> 00:16:48,920
couple examples of just prior work you

492
00:16:51,850 --> 00:16:50,180
know this is an example of a shallow

493
00:16:53,410 --> 00:16:51,860
water calculation which by its very

494
00:16:54,730 --> 00:16:53,420
definition is just a one-layer

495
00:16:57,070 --> 00:16:54,740
calculation that can't represent

496
00:16:59,050 --> 00:16:57,080
vertical wave propagation there's only a

497
00:17:01,240 --> 00:16:59,060
handful you could count them almost on

498
00:17:03,340 --> 00:17:01,250
one hand it's certainly on two hands for

499
00:17:05,170 --> 00:17:03,350
three-dimensional you know sort of

500
00:17:07,660 --> 00:17:05,180
atmospheric calculations for Jupiter and

501
00:17:09,280 --> 00:17:07,670
Saturn and those calculations generally

502
00:17:11,470 --> 00:17:09,290
don't include the stratosphere or if

503
00:17:13,150 --> 00:17:11,480
they do they don't represent this kind

504
00:17:15,190 --> 00:17:13,160
of wave forcing so I mean I parameterize

505
00:17:16,750 --> 00:17:15,200
the the bottom for saying and other this

506
00:17:18,580 --> 00:17:16,760
is an example of the calculation I did

507
00:17:20,920 --> 00:17:18,590
do about 10 years ago or we produce nice

508
00:17:22,270 --> 00:17:20,930
zonal Jets this from the end in showmen

509
00:17:24,760 --> 00:17:22,280
my former graduate student B and then

510
00:17:26,320 --> 00:17:24,770
did this so you get nice little jets you

511
00:17:27,760 --> 00:17:26,330
produce an equatorial super rotation for

512
00:17:29,920 --> 00:17:27,770
Jupiter so that kind of thing has been

513
00:17:31,420 --> 00:17:29,930

done but this model was emphasizing the

514
00:17:33,280 --> 00:17:31,430
troposphere and didn't really go very

515
00:17:35,560 --> 00:17:33,290
high up in the stratosphere it didn't

516
00:17:37,480 --> 00:17:35,570
have enough vertical levels and so on

517
00:17:38,950 --> 00:17:37,490
it's the details like that matter for

518
00:17:40,390 --> 00:17:38,960
the earth case I might add so the

519
00:17:42,190 --> 00:17:40,400
phenomenon was source observed I think

520
00:17:43,720 --> 00:17:42,200
in the 50s and then there were it was

521
00:17:46,030 --> 00:17:43,730
the mechanism was understood through

522
00:17:48,820 --> 00:17:46,040
very idealized GFP experiments and

523
00:17:50,680 --> 00:17:48,830
calculations and full 3d general

524
00:17:53,200 --> 00:17:50,690
circulation models for decades could not

525
00:17:54,140 --> 00:17:53,210
reproduce the phenom mainly because the

526
00:17:55,850 --> 00:17:54,150
vertical resolution

527
00:17:57,800 --> 00:17:55,860
was too low it was only in the mid to

528
00:17:59,510 --> 00:17:57,810
late 90s that finally the vertical

529
00:18:00,950 --> 00:17:59,520
resolutions and GMOs were improved to be

530
00:18:02,930 --> 00:18:00,960
high enough to this bomb and start

531
00:18:06,200 --> 00:18:02,940
appearing in GC atmost even then not

532
00:18:08,840 --> 00:18:06,210
what properties observes so it's hard to

533
00:18:10,610 --> 00:18:08,850
hard to model so we have time for one

534
00:18:12,670 --> 00:18:10,620
more question if you dare standing

535
00:18:20,000 --> 00:18:12,680
between us some coffee

536
00:18:23,810 --> 00:18:20,010
emily's thanks for setting me up like

537
00:18:26,750 --> 00:18:23,820
that vision very nice neat stuff I'm

538
00:18:28,640 --> 00:18:26,760

wondering about the isotropic assumption

539
00:18:30,830 --> 00:18:28,650
of convection because I'm not super

540
00:18:32,030 --> 00:18:30,840
familiar with the literature but I feel

541
00:18:34,940 --> 00:18:32,040
like I've seen models before where

542
00:18:36,530 --> 00:18:34,950
convection comes up differently at

543
00:18:38,510 --> 00:18:36,540
different latitudes because of the

544
00:18:39,800 --> 00:18:38,520
effect of rotation and so I'm wondering

545
00:18:43,280 --> 00:18:39,810
if you could speak a little bit more

546
00:18:46,010 --> 00:18:43,290
about whether there are predictions but

547
00:18:47,450 --> 00:18:46,020
it shouldn't be isotropic and if so how

548
00:18:48,970 --> 00:18:47,460
that might factor into thanks for the

549
00:18:52,100 --> 00:18:48,980
question that's a good question so yeah

550
00:18:55,040 --> 00:18:52,110
mainly it was made as to just define a

551
00:18:56,810 --> 00:18:55,050
clean experiment basically so the prior

552
00:18:58,700 --> 00:18:56,820
work like this is an example this pop

553
00:19:00,110 --> 00:18:58,710
plot is from Scott and Pavan Eze work

554
00:19:02,750 --> 00:19:00,120
and there's work stretching back to the

555
00:19:04,460 --> 00:19:02,760
70s just for pure 2d or shallow water

556
00:19:06,380 --> 00:19:04,470
type calculations which all make this

557
00:19:08,480 --> 00:19:06,390
isentropic assumption so I was kind of

558
00:19:10,250 --> 00:19:08,490
viewing my calculation is a 3d extension

559
00:19:12,500 --> 00:19:10,260
of that whole thirty-year body of work

560
00:19:14,840 --> 00:19:12,510
basically but you're right I mean so you

561
00:19:16,610 --> 00:19:14,850
can imagine two things one could be that

562
00:19:17,780 --> 00:19:16,620
the convection might be non-homogeneous

563
00:19:19,250 --> 00:19:17,790

which means that it can vary spatially

564
00:19:21,260 --> 00:19:19,260
that's kind of what you were alluding to

565
00:19:22,940 --> 00:19:21,270
you could have a for instance through

566
00:19:24,410 --> 00:19:22,950
dimensional calculations of the

567
00:19:25,970 --> 00:19:24,420
convection and interior of the Yohai and

568
00:19:27,560 --> 00:19:25,980
I did actually showed you expect the

569
00:19:29,210 --> 00:19:27,570
heat flux to bury between the equator

570
00:19:30,590 --> 00:19:29,220
and the pole but the heat flux coming

571
00:19:33,410 --> 00:19:30,600
out of the poles being somewhat larger

572
00:19:34,610 --> 00:19:33,420
and so one can put that in the other way

573
00:19:36,260 --> 00:19:34,620
it could matter is that the convection

574
00:19:37,460 --> 00:19:36,270
might not necessarily be actually ice

575
00:19:40,130 --> 00:19:37,470
tropic you know that it could

576
00:19:42,140 --> 00:19:40,140
potentially have a directionality and so

577
00:19:43,430 --> 00:19:42,150
but they if parameter space there is of

578
00:19:45,170 --> 00:19:43,440
course huge so but one can imagine