
AbSciCon
2017
MESA, ARIZONA

1
00:00:12,250 --> 00:00:06,150
you

2
00:00:16,420 --> 00:00:14,370
[Music]

3
00:00:17,830 --> 00:00:16,430
well everyone I hope you're having a

4
00:00:19,510 --> 00:00:17,840
great conference I'm glad to be here

5
00:00:21,790 --> 00:00:19,520
into session so I'm going to talk about

6
00:00:24,550 --> 00:00:21,800
some work on the habitable zone which I

7
00:00:25,900 --> 00:00:24,560
hope by now you've heard about and this

8
00:00:28,990 --> 00:00:25,910
is work I've done with Ravi Natasha

9
00:00:31,090 --> 00:00:29,000
sunny and Jim casting so to start with

10
00:00:33,400 --> 00:00:31,100
what do we mean by habitable zone we

11
00:00:34,600 --> 00:00:33,410
mean really a liquid water habitable

12
00:00:35,920 --> 00:00:34,610
zone this is important because it has

13
00:00:37,840 --> 00:00:35,930

two biologists we like to be imaginative

14
00:00:39,250 --> 00:00:37,850
and we don't want to say that the

15
00:00:41,110 --> 00:00:39,260
habitable zone is the only place that

16
00:00:43,750 --> 00:00:41,120
could possibly ever be habitable but

17
00:00:46,180 --> 00:00:43,760
this is an observational tool that helps

18
00:00:47,830 --> 00:00:46,190
us constrain exoplanet observations it's

19
00:00:49,630 --> 00:00:47,840
based on the orbital distance of a star

20
00:00:51,430 --> 00:00:49,640
the orbital distance of a planet from a

21
00:00:53,440 --> 00:00:51,440
star it's the region where you could

22
00:00:54,970 --> 00:00:53,450
sustain liquid water on the surface well

23
00:00:56,770 --> 00:00:54,980
what do you really need for that you

24
00:00:58,360 --> 00:00:56,780
need a rocky planet this doesn't really

25
00:01:02,170 --> 00:00:58,370
apply to gas giants you need an

26
00:01:03,639 --> 00:01:02,180
atmosphere with you know n2 water vapor

27
00:01:05,260 --> 00:01:03,649
and co2 this is least the assumptions

28
00:01:06,460 --> 00:01:05,270
that go into our model you can do this

29
00:01:07,690 --> 00:01:06,470
with some other greenhouse gases and

30
00:01:10,090 --> 00:01:07,700
there's plenty of papers that do that

31
00:01:11,980 --> 00:01:10,100
but but for calculating just the

32
00:01:13,300 --> 00:01:11,990
essential outer and inner edge of the

33
00:01:15,190 --> 00:01:13,310
habitable zone we're really interested

34
00:01:17,080 --> 00:01:15,200
in water vapor co2 is greenhouse gases

35
00:01:18,039 --> 00:01:17,090
and nitrogen to buffer the atmosphere

36
00:01:20,500 --> 00:01:18,049
add some pressure

37
00:01:22,510 --> 00:01:20,510
you also need some method for recycling

38
00:01:24,100 --> 00:01:22,520

volatile plate tectonics is a really

39
00:01:26,170 --> 00:01:24,110
good way of doing this we don't really

40
00:01:29,109 --> 00:01:26,180
have any other great examples of other

41
00:01:30,969 --> 00:01:29,119
ways of recycling volatiles on earth but

42
00:01:33,160 --> 00:01:30,979
there's there's some see reticle ideas

43
00:01:34,359 --> 00:01:33,170
out there you know stagnant lid or

44
00:01:36,910 --> 00:01:34,369
something like that but you need to be

45
00:01:39,280 --> 00:01:36,920
able to recycle the volatile so this

46
00:01:40,630 --> 00:01:39,290
plot I hope many of you have seen I will

47
00:01:43,240 --> 00:01:40,640
go through it very briefly though this

48
00:01:45,969 --> 00:01:43,250
is the the habitable zone as drawn by

49
00:01:47,260 --> 00:01:45,979
sunny we have the effective temperature

50
00:01:50,469 --> 00:01:47,270
of the star here or you can just think

51
00:01:52,359 --> 00:01:50,479
of this as stellar type to F g/km dwarfs

52
00:01:54,069 --> 00:01:52,369
down here and this is the effective

53
00:01:55,960 --> 00:01:54,079
stellar flux you could also think of

54
00:01:58,030 --> 00:01:55,970
this in terms of distance if you want so

55
00:02:00,190 --> 00:01:58,040
this is closer to the star this is

56
00:02:01,929 --> 00:02:00,200
further away from the star earth is

57
00:02:03,520 --> 00:02:01,939
right here we're situated in this nice

58
00:02:05,130 --> 00:02:03,530
habitable region where we can have

59
00:02:07,569 --> 00:02:05,140
liquid water on the surface thankfully

60
00:02:10,270 --> 00:02:07,579
but if earth were to be pushed a little

61
00:02:12,280 --> 00:02:10,280
further in toward the Sun you would

62
00:02:13,449 --> 00:02:12,290
start to increase the rate of

63
00:02:15,130 --> 00:02:13,459

evaporation of oceans and you would

64
00:02:17,350 --> 00:02:15,140
actually start to lose your water vapor

65
00:02:19,030 --> 00:02:17,360
would probably first happen is a moist

66
00:02:20,229 --> 00:02:19,040
greenhouse where the water actually gets

67
00:02:22,300 --> 00:02:20,239
photolyze out at the top of the

68
00:02:23,619 --> 00:02:22,310
stratosphere but if you push further in

69
00:02:25,330 --> 00:02:23,629
or if conditions are slightly different

70
00:02:25,930 --> 00:02:25,340
you may even enter a runaway greenhouse

71
00:02:31,300 --> 00:02:25,940
where

72
00:02:33,370 --> 00:02:31,310
very rapidly so the inner edge I'm not

73
00:02:34,390 --> 00:02:33,380
going to focus much on today you might

74
00:02:36,310 --> 00:02:34,400
hear about that later in the session

75
00:02:38,740 --> 00:02:36,320
though the outer edge of the habitable

76
00:02:41,830 --> 00:02:38,750
zone is where we're concerned for this

77
00:02:43,990 --> 00:02:41,840
problem the outer edge is defined by the

78
00:02:46,750 --> 00:02:44,000
maximum amount of warming you can get

79
00:02:48,610 --> 00:02:46,760
out of co2 so if you pull the planet

80
00:02:50,500 --> 00:02:48,620
away from the Sun and I'm going to show

81
00:02:52,510 --> 00:02:50,510
you in the next slide why this is but we

82
00:02:54,340 --> 00:02:52,520
expect that a planet like Earth that

83
00:02:56,410 --> 00:02:54,350
tectonically active would build up

84
00:02:58,090 --> 00:02:56,420
carbon dioxide in its atmosphere as you

85
00:03:01,030 --> 00:02:58,100
move away from the Sun as it gets colder

86
00:03:03,310 --> 00:03:01,040
the the threshold then where you have

87
00:03:05,680 --> 00:03:03,320
which says maximum greenhouse that's the

88
00:03:08,460 --> 00:03:05,690

point at which the warming you get from

89
00:03:11,020 --> 00:03:08,470
the greenhouse effect of co2 is actually

90
00:03:12,670 --> 00:03:11,030
outweighed by the cooling that you get

91
00:03:14,710 --> 00:03:12,680
from Raleigh scattering because you have

92
00:03:16,330 --> 00:03:14,720
a very dense co2 atmosphere so this

93
00:03:18,220 --> 00:03:16,340
defines the outer edge of the habitable

94
00:03:21,700 --> 00:03:18,230
zone but beyond that your planet is

95
00:03:22,780 --> 00:03:21,710
basically an ice ball so what's going on

96
00:03:24,370 --> 00:03:22,790
with this outer edge of the habitable

97
00:03:27,310 --> 00:03:24,380
zone why do I say that you're going to

98
00:03:30,340 --> 00:03:27,320
build up co2 what's going on is it's the

99
00:03:33,460 --> 00:03:30,350
long term carbon cycle the carbonate

100
00:03:35,680 --> 00:03:33,470
silicate cycle refer to it as starts

101
00:03:37,900 --> 00:03:35,690
with volcanoes volcanoes put co2 in the

102
00:03:39,240 --> 00:03:37,910
atmosphere the co2 stays in the

103
00:03:41,620 --> 00:03:39,250
atmosphere where it's a greenhouse gas

104
00:03:43,690 --> 00:03:41,630
but you've got water on the planet

105
00:03:45,760 --> 00:03:43,700
you've a hydrological cycle so some of

106
00:03:48,280 --> 00:03:45,770
the co2 is going to get dissolved in

107
00:03:51,970 --> 00:03:48,290
rainwater where it rains out onto land

108
00:03:55,449 --> 00:03:51,980
here when when carbonic acid dissolved

109
00:03:57,670 --> 00:03:55,459
in rainwater hits calcium silicate rocks

110
00:04:00,160 --> 00:03:57,680
you get weathering which breaks down

111
00:04:02,290 --> 00:04:00,170
into ions that will then run off the

112
00:04:04,509 --> 00:04:02,300
rivers into the ocean where they then

113
00:04:06,520 --> 00:04:04,519

saturate the ocean with these ions if

114
00:04:08,110 --> 00:04:06,530
you have life on your planet you know

115
00:04:09,460 --> 00:04:08,120
life might make shells and things out of

116
00:04:10,840 --> 00:04:09,470
these if you don't have life that that's

117
00:04:13,270 --> 00:04:10,850
okay this process still works you just

118
00:04:15,130 --> 00:04:13,280
saturate your ocean until precipitation

119
00:04:17,199 --> 00:04:15,140
occurs anyway and so then you've got

120
00:04:19,680 --> 00:04:17,209
these calcium carbonates on the ocean

121
00:04:24,490 --> 00:04:19,690
floor which then subduct and

122
00:04:27,280 --> 00:04:24,500
metamorphism changes this into casi o3

123
00:04:29,800 --> 00:04:27,290
and releases the co2 which then goes

124
00:04:30,940 --> 00:04:29,810
back into volcanoes so this is a carbon

125
00:04:32,350 --> 00:04:30,950
cycle it's not going to help us with

126
00:04:33,969 --> 00:04:32,360
with contemporary climate change it

127
00:04:36,670 --> 00:04:33,979
operates on a half a million year

128
00:04:39,100 --> 00:04:36,680
timescale or so but this is this

129
00:04:39,709 --> 00:04:39,110
weathering stuff is temperature

130
00:04:42,079 --> 00:04:39,719
dependent

131
00:04:44,539 --> 00:04:42,089
and so as the planet cools as you move

132
00:04:46,429 --> 00:04:44,549
earth away from the sign in a you know

133
00:04:48,139 --> 00:04:46,439
thought experiment

134
00:04:49,789 --> 00:04:48,149
you're slowing down the rate of

135
00:04:52,069 --> 00:04:49,799
weathering which means you're going to

136
00:04:53,719 --> 00:04:52,079
increase the amount of co2 in the

137
00:04:56,389 --> 00:04:53,729
atmosphere and this is what gives us the

138
00:04:58,159 --> 00:04:56,399

a dreaded habitable zone well what was

139
00:04:59,659 --> 00:04:58,169
pointed out and we didn't actually

140
00:05:02,479 --> 00:04:59,669
realize that this was pointed out by a

141
00:05:04,669 --> 00:05:02,489
by a Tajik and also Kristin Manoa

142
00:05:06,679 --> 00:05:04,679
pointed 2020 15 the weathering process

143
00:05:08,839 --> 00:05:06,689
is not just temperature dependent it's

144
00:05:11,329 --> 00:05:08,849
also dependent on how much co2 you have

145
00:05:12,829 --> 00:05:11,339
and maybe this actually seems kind of

146
00:05:15,649 --> 00:05:12,839
obvious in retrospect if you have more

147
00:05:17,449 --> 00:05:15,659
co2 you're going to whether you have

148
00:05:20,149 --> 00:05:17,459
more weathering and you're going to end

149
00:05:21,290 --> 00:05:20,159
up with an overall you know different

150
00:05:24,499 --> 00:05:21,300
concentration of co2 in the atmosphere

151
00:05:26,689 --> 00:05:24,509
than you would otherwise have so this is

152
00:05:29,269 --> 00:05:26,699
important because this actually gives us

153
00:05:31,309 --> 00:05:29,279
some very different behaviors that are

154
00:05:33,319 --> 00:05:31,319
transient some some time dependent

155
00:05:34,819 --> 00:05:33,329
climate states that we didn't get

156
00:05:36,319 --> 00:05:34,829
otherwise when we only considered the

157
00:05:38,779 --> 00:05:36,329
temperature dependence not the co2

158
00:05:41,329 --> 00:05:38,789
dependence so this is what we call it my

159
00:05:43,579 --> 00:05:41,339
title has this phrase a limit cycle and

160
00:05:45,049 --> 00:05:43,589
so this is a climate limit cycle which

161
00:05:48,259 --> 00:05:45,059
means you see you're alternating between

162
00:05:51,319 --> 00:05:48,269
a glacial state and a warm state driven

163
00:05:53,179 --> 00:05:51,329

by these oscillations in co2 so what I'm

164
00:05:55,129 --> 00:05:53,189
doing these are calculations with a one

165
00:05:58,189 --> 00:05:55,139
dimensional energy balance climate model

166
00:06:00,350 --> 00:05:58,199
I start planet this is a planet around a

167
00:06:02,359 --> 00:06:00,360
G star I'm looking at like an early

168
00:06:04,759 --> 00:06:02,369
Earth case where the solar constants

169
00:06:06,799 --> 00:06:04,769
about 70% and in the tenth of the

170
00:06:08,869 --> 00:06:06,809
volcanic outgassing rate as today and

171
00:06:11,959 --> 00:06:08,879
I'll explain why it shows that in a

172
00:06:15,589 --> 00:06:11,969
minute so imagine that you start with a

173
00:06:18,559 --> 00:06:15,599
cold planet that's an ice ball and it

174
00:06:20,749 --> 00:06:18,569
completely frozen but and with a an

175
00:06:23,029 --> 00:06:20,759
active carbon silicon carbonate silicate

176
00:06:24,799 --> 00:06:23,039
cycle so what happens is your frozen

177
00:06:27,259 --> 00:06:24,809
planet so you've got volcanoes

178
00:06:29,899 --> 00:06:27,269
outgassing into the atmosphere adding

179
00:06:32,359 --> 00:06:29,909
greenhouse warming so this Green Line

180
00:06:33,859 --> 00:06:32,369
shows co2 here's the access for co2

181
00:06:35,659 --> 00:06:33,869
partial pressure black line is

182
00:06:38,389 --> 00:06:35,669
temperature so as we march forward in

183
00:06:40,429 --> 00:06:38,399
time you're building up co2 slowly from

184
00:06:42,019 --> 00:06:40,439
volcanoes now the fruit the surface is

185
00:06:43,579 --> 00:06:42,029
frozen so you're not weathering any of

186
00:06:45,919 --> 00:06:43,589
it down you're just building co2 to the

187
00:06:47,809 --> 00:06:45,929
atmosphere so we continue building co2

188
00:06:49,549 --> 00:06:47,819

in the atmosphere until you reach this

189
00:06:50,390 --> 00:06:49,559
critical point where you've got enough

190
00:06:52,850 --> 00:06:50,400
warming

191
00:06:56,570 --> 00:06:52,860
that your ice-melt you Daglish d

192
00:06:58,879 --> 00:06:56,580
glaciated lanit and you very rapidly

193
00:07:01,370 --> 00:06:58,889
warm so now you're warm you're above for

194
00:07:02,689 --> 00:07:01,380
you thing you're a habitable planet in

195
00:07:04,820 --> 00:07:02,699
the sense of being able to have liquid

196
00:07:07,310 --> 00:07:04,830
water on its surface but what happens

197
00:07:08,990 --> 00:07:07,320
now weathering turns on you you start

198
00:07:12,110 --> 00:07:09,000
drawing down all the co2 from the

199
00:07:14,030 --> 00:07:12,120
atmosphere and we we go we get this

200
00:07:15,950 --> 00:07:14,040
sawtooth co2 goes down because

201
00:07:18,200 --> 00:07:15,960
weathering turns on well now you've lost

202
00:07:20,300 --> 00:07:18,210
your greenhouse effect so temperature

203
00:07:22,610 --> 00:07:20,310
goes down as well you plummet back into

204
00:07:25,189 --> 00:07:22,620
a glacial state and so this is what we

205
00:07:27,170 --> 00:07:25,199
call a limit cycle is long periods of

206
00:07:32,350 --> 00:07:27,180
glaciation followed by punctuated

207
00:07:35,689 --> 00:07:32,360
periods of warmth repeated over time

208
00:07:38,210 --> 00:07:35,699
this limit cycle phenomenon doesn't

209
00:07:40,580 --> 00:07:38,220
behave the same around all stellar

210
00:07:42,830 --> 00:07:40,590
spectral types it's actually a function

211
00:07:44,029 --> 00:07:42,840
of stellar type so here's what the plot

212
00:07:46,129 --> 00:07:44,039
I just showed you exactly the same

213
00:07:48,409 --> 00:07:46,139

that's a rounded G star so here I've

214
00:07:49,760 --> 00:07:48,419
kept the parameters the same still 70%

215
00:07:51,529 --> 00:07:49,770
of solar constant same volcanic

216
00:07:53,719 --> 00:07:51,539
outgassing rate we're just around an F

217
00:07:55,279 --> 00:07:53,729
star now so a hotter star but it's not

218
00:07:56,839 --> 00:07:55,289
just hotter it actually puts out more

219
00:07:58,790 --> 00:07:56,849
energy in the blue end of the spectrum

220
00:08:01,159 --> 00:07:58,800
and less energy in the red end of the

221
00:08:03,200 --> 00:08:01,169
spectrum so what that does if you get in

222
00:08:05,420 --> 00:08:03,210
hot enhanced ice albedo feedback this

223
00:08:08,719 --> 00:08:05,430
has been discussed by I think Bob

224
00:08:10,700 --> 00:08:08,729
Heverly omoi shields and others that you

225
00:08:13,190 --> 00:08:10,710
would expect this so you get enhanced

226
00:08:15,110 --> 00:08:13,200
ice albedo feedback around an F F dwarf

227
00:08:17,960 --> 00:08:15,120
stars and so that actually just

228
00:08:20,420 --> 00:08:17,970
increases the frequency that the timing

229
00:08:22,460 --> 00:08:20,430
of these events so you build up co2 here

230
00:08:25,250 --> 00:08:22,470
you warm but notice how sharp this peak

231
00:08:27,770 --> 00:08:25,260
is you have a very very narrow range of

232
00:08:29,270 --> 00:08:27,780
time when your planet is warm most of

233
00:08:30,680 --> 00:08:29,280
the time you're in this cold phase where

234
00:08:33,980 --> 00:08:30,690
you're just building up co2 in the

235
00:08:37,070 --> 00:08:33,990
atmosphere but not D glaciated so this

236
00:08:39,829 --> 00:08:37,080
this suggests that if a planet is in is

237
00:08:42,100 --> 00:08:39,839
called in this limit cycle perhaps the

238
00:08:45,140 --> 00:08:42,110

g-type stars have a slightly more

239
00:08:48,019 --> 00:08:45,150
likelihood for for sustaining longer

240
00:08:49,610 --> 00:08:48,029
periods of warmth than the F dwarfs now

241
00:08:50,900 --> 00:08:49,620
I've mentioned volcanic outgassing read

242
00:08:52,610 --> 00:08:50,910
a couple of times the volcanic

243
00:08:54,470 --> 00:08:52,620
outgassing rate as you may imagine is a

244
00:08:56,930 --> 00:08:54,480
very critical parameter for this because

245
00:08:59,870 --> 00:08:56,940
that determines how quickly do you build

246
00:09:02,449 --> 00:08:59,880
up co2 in your atmosphere and so I've

247
00:09:03,890 --> 00:09:02,459
shown that here right here this is the

248
00:09:06,110 --> 00:09:03,900
volcanic outgassing rate

249
00:09:08,750 --> 00:09:06,120
we're 10 to the 0 this is just based on

250
00:09:11,000 --> 00:09:08,760
its scaled to present-day earth the

251
00:09:13,880 --> 00:09:11,010
other important factor to think about

252
00:09:17,180 --> 00:09:13,890
though is how much co2 should be

253
00:09:19,130 --> 00:09:17,190
dissolved or sequestered in soil now

254
00:09:20,330 --> 00:09:19,140
it's a tricky question and I'd love to

255
00:09:21,620 --> 00:09:20,340
talk to you more about this later I

256
00:09:23,570 --> 00:09:21,630
don't want to get bogged down the

257
00:09:26,840 --> 00:09:23,580
details but on earth today

258
00:09:29,300 --> 00:09:26,850
co2 sequestration is very much driven by

259
00:09:30,680 --> 00:09:29,310
life and if we had a planet that was in

260
00:09:32,660 --> 00:09:30,690
limit cycles you may think that your

261
00:09:34,490 --> 00:09:32,670
soils not going to be fully inhabited by

262
00:09:36,560 --> 00:09:34,500
microbes you might you may reach a very

263
00:09:38,210 --> 00:09:36,570

different equilibrium soil co2

264
00:09:40,580 --> 00:09:38,220
concentration and so what we've shown

265
00:09:43,220 --> 00:09:40,590
here is this is the range of parameter

266
00:09:45,020 --> 00:09:43,230
space where co2 partial pressure vs.

267
00:09:47,660 --> 00:09:45,030
outgassing rate in this shaded region

268
00:09:49,160 --> 00:09:47,670
you would expect limit cycles whereas in

269
00:09:51,140 --> 00:09:49,170
this gray region you would not expect

270
00:09:53,150 --> 00:09:51,150
limit cycles there's just illustrator

271
00:09:55,580 --> 00:09:53,160
for a G star around for an early Earth

272
00:09:59,240 --> 00:09:55,590
case really the point of this plot is

273
00:10:00,860 --> 00:09:59,250
these two things are not really well

274
00:10:03,410 --> 00:10:00,870
constrained for exoplanets we got a good

275
00:10:05,780 --> 00:10:03,420
idea of these values for Earth today but

276
00:10:07,130 --> 00:10:05,790
you know they're not easily constrained

277
00:10:08,990 --> 00:10:07,140
with observations but I think we need to

278
00:10:12,020 --> 00:10:09,000
think more about what would we expect

279
00:10:14,780 --> 00:10:12,030
out guessing and soil co2 to be on

280
00:10:16,460 --> 00:10:14,790
exoplanet so when we do this here's the

281
00:10:18,650 --> 00:10:16,470
new version of the habitable zone that

282
00:10:20,210 --> 00:10:18,660
you get it's a function of the volcanic

283
00:10:22,010 --> 00:10:20,220
outgassing rate as I just mentioned so

284
00:10:24,080 --> 00:10:22,020
we've drawn a couple lines here this

285
00:10:26,570 --> 00:10:24,090
line is if the volcanic outgassing rate

286
00:10:28,820 --> 00:10:26,580
on the planet is 1/10 of Earth today and

287
00:10:31,070 --> 00:10:28,830
this is if it's half today if it's equal

288
00:10:32,630 --> 00:10:31,080

to earth today then this line is out

289
00:10:34,460 --> 00:10:32,640
here and the planet doesn't have limit

290
00:10:37,220 --> 00:10:34,470
cycles at all so again it's definitely a

291
00:10:39,530 --> 00:10:37,230
function of volcanic outgassing rate so

292
00:10:41,570 --> 00:10:39,540
you notice here around F dwarfs this

293
00:10:43,700 --> 00:10:41,580
this habitable region this blue region

294
00:10:45,620 --> 00:10:43,710
there's no limit cycles then in this

295
00:10:48,980 --> 00:10:45,630
region here there are limit cycles so

296
00:10:52,430 --> 00:10:48,990
the F Dwarfs this this range of stable

297
00:10:55,970 --> 00:10:52,440
climate is very small compared to G Dorf

298
00:10:57,530 --> 00:10:55,980
whereas K and M dwarfs actually remain

299
00:10:59,480 --> 00:10:57,540
stable without limit cycles at all

300
00:11:03,020 --> 00:10:59,490
because they have reduced ice albedo

301
00:11:04,820 --> 00:11:03,030
feedback so the last thing I want to

302
00:11:06,500 --> 00:11:04,830
mention is that we also looked at

303
00:11:08,060 --> 00:11:06,510
applying this not just to the outer edge

304
00:11:09,950 --> 00:11:08,070
of the habitable zone in general but

305
00:11:12,590 --> 00:11:09,960
specifically did the problem of early

306
00:11:15,200 --> 00:11:12,600
Mars could the floovio features on early

307
00:11:17,150 --> 00:11:15,210
Mars be telling us that Mars was caught

308
00:11:20,329 --> 00:11:17,160
in this limit cycle early on in

309
00:11:21,499 --> 00:11:20,339
history and this just is a slightly

310
00:11:23,329 --> 00:11:21,509
different way of plotting an average

311
00:11:26,079 --> 00:11:23,339
surface temperature here co2 partial

312
00:11:29,720 --> 00:11:26,089
pressure and what we're showing here is

313
00:11:31,999 --> 00:11:29,730

this red line gets above this weathering

314
00:11:33,319 --> 00:11:32,009
curve which means you're going to cycle

315
00:11:36,980 --> 00:11:33,329
sorry this plot is a little confusing

316
00:11:38,749 --> 00:11:36,990
but the basic message is if you have in

317
00:11:41,780 --> 00:11:38,759
these calculations if you have an 80%

318
00:11:43,910 --> 00:11:41,790
co2 atmosphere with 20% hydrogen you get

319
00:11:46,040 --> 00:11:43,920
cycling whereas if we have you know only

320
00:11:48,439 --> 00:11:46,050
5% hydrogen we don't get cycling

321
00:11:50,150 --> 00:11:48,449
however Robin Wordsworth recently did

322
00:11:53,420 --> 00:11:50,160
some calculations where he showed that

323
00:11:55,220 --> 00:11:53,430
in a mixture of co2 and h2 you actually

324
00:11:57,470 --> 00:11:55,230
get collision induced warming from the

325
00:11:58,579 --> 00:11:57,480
hydrogen that actually is much more

326
00:12:00,139 --> 00:11:58,589
efficient than this so we're actually

327
00:12:02,030 --> 00:12:00,149
redoing some of these calculations now

328
00:12:03,230 --> 00:12:02,040
and we're pretty sure that you're going

329
00:12:05,689 --> 00:12:03,240
to be able to show that you can get

330
00:12:08,780 --> 00:12:05,699
cycling on Mars with with much less

331
00:12:10,249 --> 00:12:08,790
hydrogen than we've required and so I'm

332
00:12:19,100 --> 00:12:10,259
at the end of my time I'll just stop

333
00:12:20,629 --> 00:12:19,110
here and take some questions if you're

334
00:12:23,780 --> 00:12:20,639
able to please go up to the microphone

335
00:12:25,429 --> 00:12:23,790
to ask your questions hi Jacob calling

336
00:12:28,249 --> 00:12:25,439
Goldblatt University of Victoria I'd

337
00:12:31,100 --> 00:12:28,259
like to add to your introduction a

338
00:12:33,309 --> 00:12:31,110

little bit which is the co2 dependence

339
00:12:37,429 --> 00:12:33,319
of westburg was proposed by a paper by

340
00:12:39,350 --> 00:12:37,439
burner in the early 80s but and then

341
00:12:43,240 --> 00:12:39,360
there were limit cycles in the earth

342
00:12:46,100 --> 00:12:43,250
science literature especially from

343
00:12:49,280 --> 00:12:46,110
Tajikistan the 8th late 90s and early

344
00:12:52,040 --> 00:12:49,290
2000s and I know that Jim didn't realize

345
00:12:53,990 --> 00:12:52,050
that so I'll blame your post your PhD is

346
00:12:55,910 --> 00:12:54,000
like this one we do cite those in our

347
00:12:57,410 --> 00:12:55,920
paper ok but ya know that's that's a

348
00:12:59,030 --> 00:12:57,420
very good point actually before people

349
00:13:00,799 --> 00:12:59,040
thought about limit cycles for

350
00:13:02,990 --> 00:13:00,809
exoplanets it was thinking about does it

351
00:13:04,460 --> 00:13:03,000
explain some features of early Earth and

352
00:13:06,230 --> 00:13:04,470
I think you even are on a paper where

353
00:13:07,549 --> 00:13:06,240
you look at the snowball earth episodes

354
00:13:09,710 --> 00:13:07,559
it's yes correct and they leave sort of

355
00:13:11,090 --> 00:13:09,720
types of see yes so this may have

356
00:13:13,160 --> 00:13:11,100
occurred on earth as well for other

357
00:13:16,369 --> 00:13:13,170
reasons yes the most substantive

358
00:13:19,639 --> 00:13:16,379
question is why does it matter if you're

359
00:13:23,269 --> 00:13:19,649
have if you have sub warm periods let's

360
00:13:26,569 --> 00:13:23,279
just slice then and set down spores

361
00:13:28,759 --> 00:13:26,579
which can last for millions of years

362
00:13:30,450 --> 00:13:28,769
between those limit cycles and we're

363
00:13:31,350 --> 00:13:30,460

just a sonically habitable

364
00:13:34,380 --> 00:13:31,360
yeah I'm glad you asked that question

365
00:13:37,050 --> 00:13:34,390
and oh my slide disappeared that's okay

366
00:13:38,970 --> 00:13:37,060
I had a statement that said earth-like

367
00:13:40,470 --> 00:13:38,980
planets with complex life may be less

368
00:13:42,150 --> 00:13:40,480
prevalent than those with simple or no

369
00:13:43,170 --> 00:13:42,160
life I put a question mark there and I

370
00:13:44,640 --> 00:13:43,180
was actually thinking about you when I

371
00:13:47,430 --> 00:13:44,650
put that question mark there because

372
00:13:50,070 --> 00:13:47,440
you're right does what does this mean if

373
00:13:52,500 --> 00:13:50,080
you have 80 million years of glaciation

374
00:13:54,480 --> 00:13:52,510
followed by ten million years of warmth

375
00:13:57,810 --> 00:13:54,490
we wouldn't like that our type of

376
00:13:59,340 --> 00:13:57,820
complex life would not survive I would

377
00:14:01,260 --> 00:13:59,350
not make the strong statement that all

378
00:14:03,420 --> 00:14:01,270
potential life in the universe cannot

379
00:14:08,180 --> 00:14:03,430
survive this so this is a new question

380
00:14:10,650 --> 00:14:08,190
to be had I think I have an easier time

381
00:14:12,480 --> 00:14:10,660
imagining microbial life surviving that

382
00:14:15,660 --> 00:14:12,490
type of transition than something

383
00:14:17,070 --> 00:14:15,670
resembling complex animal life but we

384
00:14:18,990 --> 00:14:17,080
should have this conversation thanks

385
00:14:21,570 --> 00:14:19,000
Jacob we have time for one quick

386
00:14:23,730 --> 00:14:21,580
question in the carbonate silicates

387
00:14:26,550 --> 00:14:23,740
cycle do you have any idea how efficient

388
00:14:30,090 --> 00:14:26,560

the I guess the pulling up of that co2

389
00:14:31,920 --> 00:14:30,100
during volcanism is do is it 90% goes

390
00:14:33,600 --> 00:14:31,930
back up in the atmosphere and 10% keeps

391
00:14:35,640 --> 00:14:33,610
on going down or you have any idea about

392
00:14:37,290 --> 00:14:35,650
the relative percentages there I don't

393
00:14:48,100 --> 00:14:37,300
know that number did Robbie or Colin do

394
00:14:51,710 --> 00:14:50,210
but for the cycle that you're invoking

395
00:14:53,720 --> 00:14:51,720
here you're assuming a hundred percent

396
00:14:55,250 --> 00:14:53,730
that's right we just prescribe a

397
00:14:56,780 --> 00:14:55,260
volcanic outgassing rate that's how much

398
00:14:59,300 --> 00:14:56,790
and we also get solar constant equal to

399
00:15:01,640 --> 00:14:59,310
0.7 you're assuming that you have 30%

400
00:15:04,220 --> 00:15:01,650
land on the ocean on the earth rather

401
00:15:05,510 --> 00:15:04,230
than the almost 0% land covering that

402
00:15:10,450 --> 00:15:05,520
most earth scientists who study

403
00:15:12,410 --> 00:15:10,460
continental growth will tell you we had

404
00:15:13,790 --> 00:15:12,420
what I can't remember what land

405
00:15:15,740 --> 00:15:13,800
distribution we did with it I think we

406
00:15:16,970 --> 00:15:15,750
did aqua planets actually we'll have to

407
00:15:18,950 --> 00:15:16,980
we'll have to cut it out there okay

408
00:15:21,340 --> 00:15:18,960
we'll get out Martha all right let's uh