2017 Astrobiology Graduate Conference

Charlottesville, VA

1
00:00:00,790 --> 00:00:08,140
[Music]

2
00:00:13,999 --> 00:00:10,970
Thank You Alec for the lovely

3
00:00:16,340 --> 00:00:14,009
introduction talk what I'd like to talk

4
00:00:18,769 --> 00:00:16,350
to you about today is some of the work

5
00:00:20,840 --> 00:00:18,779
we've been doing funded by a NASA

6
00:00:22,790 --> 00:00:20,850
emerging world proposal to look at the

7
00:00:25,310 --> 00:00:22,800
atmospheric evolution of Venus

8
00:00:27,859 --> 00:00:25,320
especially in its early period when we

9
00:00:31,060 --> 00:00:27,869
expect that it may have lost most of its

10
00:00:35,030 --> 00:00:31,070
ocean and to give you guys some broad

11
00:00:39,139 --> 00:00:35,040
context obviously here's the earth and

12
00:00:41,930 --> 00:00:39,149
here's Venus to scale and like Alex said

13
00:00:46,580 --> 00:00:41,940

we often think of Venus as Earth's twin

14
00:00:49,790 --> 00:00:46,590
if earth had a hotter twin they have

15
00:00:53,029 --> 00:00:49,800
very similar reservoirs for example of

16
00:00:54,680 --> 00:00:53,039
volatile carbon most of it on Venus is

17
00:00:56,270 --> 00:00:54,690
stored in the atmosphere whereas on

18
00:00:58,790 --> 00:00:56,280
earth it's stored in like things like

19
00:01:00,979 --> 00:00:58,800
carbonates in the near surface and a

20
00:01:03,770 --> 00:01:00,989
little bit in the atmosphere similar

21
00:01:06,710 --> 00:01:03,780
amounts of nitrogen we think and it has

22
00:01:08,780 --> 00:01:06,720
a similar mass and radius and one of the

23
00:01:11,800 --> 00:01:08,790
things that sort of drives us to ask

24
00:01:14,899 --> 00:01:11,810
questions about Venus is as a

25
00:01:17,330 --> 00:01:14,909
comparative planetology perspective how

26
00:01:18,920 --> 00:01:17,340
do we go from an object that's beautiful

27
00:01:20,840 --> 00:01:18,930
and blue and has liquid oceans to

28
00:01:23,539 --> 00:01:20,850
something that's a hellish landscape

29
00:01:27,550 --> 00:01:23,549
that you can not let on and then it

30
00:01:32,149 --> 00:01:27,560
rains acid this transition is really

31
00:01:33,710 --> 00:01:32,159
poorly understood and it's often seen in

32
00:01:35,270 --> 00:01:33,720
the perspective of comparative

33
00:01:38,420 --> 00:01:35,280
planetology when we look at something

34
00:01:41,300 --> 00:01:38,430
like the habitable zone and this is a

35
00:01:44,060 --> 00:01:41,310
figure of my own design we can talk

36
00:01:45,679 --> 00:01:44,070
about many variations later on but

37
00:01:48,230 --> 00:01:45,689
essentially what you can see here is we

38
00:01:51,139 --> 00:01:48,240

have this solar system for some sense of

39
00:01:53,270 --> 00:01:51,149
scale and this is the x-axis tells you

40
00:01:55,399 --> 00:01:53,280
about the amount of starlight on plow

41
00:01:58,310 --> 00:01:55,409
planet relative to the sunlight on the

42
00:02:00,980 --> 00:01:58,320
earths of Earth here is that one Venus

43
00:02:03,459 --> 00:02:00,990
receives about twice as much sunlight as

44
00:02:07,940 --> 00:02:03,469
the earth does and Mars receives about

45
00:02:09,889 --> 00:02:07,950
30 48 percent and a number of Kepler

46
00:02:12,410 --> 00:02:09,899
objects and one radial velocity

47
00:02:13,890 --> 00:02:12,420
measurement are on this for to give you

48
00:02:16,660 --> 00:02:13,900
some sense of the

49
00:02:19,870 --> 00:02:16,670
diversity of exoplanets we expect and

50
00:02:22,840 --> 00:02:19,880
have found in around other stars and you

51
00:02:24,640 --> 00:02:22,850
can see that that the the way we've

52
00:02:26,530 --> 00:02:24,650
defined the conservative habitable zone

53
00:02:28,660 --> 00:02:26,540
and the optimistic habitable zone are

54
00:02:30,760 --> 00:02:28,670
these yellow and red lines which are

55
00:02:32,890 --> 00:02:30,770
directly related to what we think is the

56
00:02:35,320 --> 00:02:32,900
underlying process that has driven

57
00:02:37,980 --> 00:02:35,330
Venus's evolution here in the yellow

58
00:02:41,110 --> 00:02:37,990
line is a moist or runaway greenhouse

59
00:02:42,700 --> 00:02:41,120
where the server temperatures heat up to

60
00:02:45,520 --> 00:02:42,710
the point where you evaporate some or

61
00:02:48,130 --> 00:02:45,530
all of your surface ocean it gets broken

62
00:02:52,150 --> 00:02:48,140
apart and you lose it and this recent

63
00:02:54,360 --> 00:02:52,160

Venus limit is a consequence of the most

64
00:02:57,280 --> 00:02:54,370
recent evidence we have for Venus's

65
00:03:00,220 --> 00:02:57,290
resurfacing which will come up again in

66
00:03:01,600 --> 00:03:00,230
the talk but this was a it could be you

67
00:03:04,600 --> 00:03:01,610
know about half a billion or a billion

68
00:03:06,280 --> 00:03:04,610
years ago and this is often based on

69
00:03:08,230 --> 00:03:06,290
some older estimates of when that

70
00:03:10,180 --> 00:03:08,240
resurfacing happens so I'm going to use

71
00:03:14,800 --> 00:03:10,190
a billion years just as a conservative

72
00:03:16,720 --> 00:03:14,810
estimate for that mile milestone and so

73
00:03:18,610 --> 00:03:16,730
the the thing I want to point out is

74
00:03:20,260 --> 00:03:18,620
that the we know that the earth is

75
00:03:21,490 --> 00:03:20,270
habitable conveniently otherwise there

76
00:03:25,330 --> 00:03:21,500
would be no one here to listen to my

77
00:03:27,699 --> 00:03:25,340
talk but somewhere between here and here

78
00:03:29,110 --> 00:03:27,709
there's either one point or several

79
00:03:31,660 --> 00:03:29,120
points or a number of underlying

80
00:03:35,400 --> 00:03:31,670
processes that drives you from beautiful

81
00:03:38,680 --> 00:03:35,410
and blue to bad things have happened and

82
00:03:41,740 --> 00:03:38,690
so one of the things that we asked about

83
00:03:44,590 --> 00:03:41,750
Venus is how did all the water get out

84
00:03:46,990 --> 00:03:44,600
of the atmosphere like Alec mentioned it

85
00:03:48,520 --> 00:03:47,000
has a very high D H ratio which suggests

86
00:03:51,400 --> 00:03:48,530
that it lost a lot of water

87
00:03:53,110 --> 00:03:51,410
it currently has incredibly small

88
00:03:55,960 --> 00:03:53,120

amounts of trace water in its atmosphere

89
00:03:57,820 --> 00:03:55,970
but not anything on its service and the

90
00:03:59,920 --> 00:03:57,830
runaway greenhouse atmosphere takes you

91
00:04:03,580 --> 00:03:59,930
from something that may be temperate

92
00:04:05,199 --> 00:04:03,590
either co2 or n2 dominated and as that

93
00:04:07,330 --> 00:04:05,209
water evaporates the atmosphere becomes

94
00:04:09,550 --> 00:04:07,340
water dominated if you evaporate one

95
00:04:11,590 --> 00:04:09,560
earth ocean you get something like 300

96
00:04:17,260 --> 00:04:11,600
bars of water vapor in your atmosphere

97
00:04:20,440 --> 00:04:17,270
it goes it's an incredibly disastrous

98
00:04:21,640 --> 00:04:20,450
effect in that sense and what you can do

99
00:04:23,110 --> 00:04:21,650
once you put the water into the

100
00:04:25,420 --> 00:04:23,120
atmosphere is you destroy it by

101
00:04:27,330 --> 00:04:25,430
photolysis either in the UV where you

102
00:04:29,580 --> 00:04:27,340
break it in the hydroxyl and atomic

103
00:04:31,290 --> 00:04:29,590
engine or if you're looking at the

104
00:04:32,580 --> 00:04:31,300
extreme ultraviolet instead of just

105
00:04:34,439 --> 00:04:32,590
breaking apart the water you can

106
00:04:36,780 --> 00:04:34,449
actually shatter it into its component

107
00:04:38,670 --> 00:04:36,790
pieces so you might be left with atomic

108
00:04:41,100 --> 00:04:38,680
oxygen and a couple of atomic hydrogen's

109
00:04:44,010 --> 00:04:41,110
if you're pummeling it with an e UV flux

110
00:04:47,520 --> 00:04:44,020
much larger than you see in the modern

111
00:04:50,550 --> 00:04:47,530
and so just to come back to that extreme

112
00:04:52,560 --> 00:04:50,560
ultraviolet the at smaller extreme

113
00:04:55,860 --> 00:04:52,570

ultraviolet fluxes for example less than

114
00:04:58,590 --> 00:04:55,870
10 times the modern solar EUV at the

115
00:05:00,300 --> 00:04:58,600
earth we find that atomic hydrogen is a

116
00:05:03,360 --> 00:05:00,310
minor component in the literature and

117
00:05:10,490 --> 00:05:03,370
that the majority of the hydrogen is

118
00:05:14,190 --> 00:05:10,500
bound up as h2 or h2o now conversely for

119
00:05:15,810 --> 00:05:14,200
higher UV fluxes you would expect that

120
00:05:18,150 --> 00:05:15,820
most of the atmosphere is actually going

121
00:05:20,159 --> 00:05:18,160
to be dominated by atomic hydrogen again

122
00:05:22,110 --> 00:05:20,169
because you're sort of pummeling this

123
00:05:25,439 --> 00:05:22,120
water vapor into its constituent pieces

124
00:05:27,510 --> 00:05:25,449
and that brings us to sort of three

125
00:05:30,450 --> 00:05:27,520
points we can think about in Venus's

126
00:05:32,520 --> 00:05:30,460
timeline where we might expect that the

127
00:05:34,800 --> 00:05:32,530
intersection between the runaway

128
00:05:36,930 --> 00:05:34,810
greenhouse process which is a function

129
00:05:40,320 --> 00:05:36,940
of the total flux that the planet is

130
00:05:42,420 --> 00:05:40,330
receiving versus the escape processes

131
00:05:45,659 --> 00:05:42,430
which are often driven by this EUV

132
00:05:48,690 --> 00:05:45,669
heating can intersect with one another

133
00:05:50,550 --> 00:05:48,700
where there's some overlap and so here

134
00:05:52,800 --> 00:05:50,560
on this lovely diagram i've made for you

135
00:05:54,060 --> 00:05:52,810
this is for example the formation of the

136
00:05:56,909 --> 00:05:54,070
solar system about four-and-a-half

137
00:06:00,420 --> 00:05:56,919
billion years ago this is today and this

138
00:06:04,770 --> 00:06:00,430

is a Venusian timeline we can think

139
00:06:06,779 --> 00:06:04,780
about the amount of EUV the extreme

140
00:06:08,909 --> 00:06:06,789
ultraviolet that Venus is receiving as a

141
00:06:10,740 --> 00:06:08,919
function of time and we can think about

142
00:06:12,150 --> 00:06:10,750
the amount of sunlight that Venus is

143
00:06:14,490 --> 00:06:12,160
receiving with time like I mentioned

144
00:06:17,879 --> 00:06:14,500
earlier Venus is receiving about twice

145
00:06:19,770 --> 00:06:17,889
the flux in both UV and integrated flux

146
00:06:22,890 --> 00:06:19,780
as compared to the earth these are

147
00:06:24,690 --> 00:06:22,900
relative to earth values and one of the

148
00:06:27,529 --> 00:06:24,700
suggestions is that Venus lost its water

149
00:06:30,120 --> 00:06:27,539
very early in its history it accreted

150
00:06:32,219 --> 00:06:30,130
went into a runaway greenhouse as part

151
00:06:34,710 --> 00:06:32,229
of that accretion process and never left

152
00:06:38,250 --> 00:06:34,720
and so that hamana at all result from

153
00:06:40,680 --> 00:06:38,260
2013 would have driven the escape of

154
00:06:41,450 --> 00:06:40,690
Venus's water in the first hundred or so

155
00:06:44,029 --> 00:06:41,460
million year

156
00:06:47,450 --> 00:06:44,039
of its evolution where the installation

157
00:06:50,480 --> 00:06:47,460
was actually relatively lower it's about

158
00:06:53,779 --> 00:06:50,490
135 percent which is still interior to

159
00:06:55,909 --> 00:06:53,789
the runaway greenhouse limit from the

160
00:06:58,670 --> 00:06:55,919
classical habitable zone but the e UV

161
00:07:02,089 --> 00:06:58,680
flux is anywhere between 10 to 20 or

162
00:07:03,650 --> 00:07:02,099
more times larger than the modern a UV

163
00:07:05,330 --> 00:07:03,660

flux and so you're talking about again

164
00:07:08,120 --> 00:07:05,340
this this regime where you're sort of

165
00:07:10,219 --> 00:07:08,130
pummeling the atmosphere which may be

166
00:07:11,689 --> 00:07:10,229
predominantly water vapor shattering

167
00:07:15,050 --> 00:07:11,699
those water vapor molecules so you can

168
00:07:17,029 --> 00:07:15,060
drive that escape and as you move

169
00:07:18,620 --> 00:07:17,039
forward in time you have to go from this

170
00:07:20,990 --> 00:07:18,630
EUV flux that's greater than 20 times

171
00:07:23,240 --> 00:07:21,000
modern to something like 2 times what

172
00:07:25,040 --> 00:07:23,250
the earth receives and this insulation

173
00:07:27,140 --> 00:07:25,050
actually increases in the opposite

174
00:07:29,570 --> 00:07:27,150
direction so the e UV is tailing off but

175
00:07:30,830 --> 00:07:29,580
the insulation is increasing and so the

176
00:07:32,689 --> 00:07:30,840
installation drives the runaway

177
00:07:35,300 --> 00:07:32,699
greenhouse process but the e UV drives

178
00:07:37,820 --> 00:07:35,310
the escape and to other points we can

179
00:07:40,309 --> 00:07:37,830
think about for example a billion years

180
00:07:42,110 --> 00:07:40,319
into Venus's history the e UV has

181
00:07:44,839 --> 00:07:42,120
started to tail off the installation is

182
00:07:47,600 --> 00:07:44,849
increased by about 20 percent this is

183
00:07:50,510 --> 00:07:47,610
really that sort of knee I talked about

184
00:07:53,540 --> 00:07:50,520
when you get below about 10 times modern

185
00:07:55,969 --> 00:07:53,550
solar e UV where the atmosphere goes

186
00:07:58,430 --> 00:07:55,979
from being potentially atomic hydrogen

187
00:08:00,649 --> 00:07:58,440
dominated to something like molecular

188
00:08:01,969 --> 00:08:00,659

hydrogen dominated if you are

189
00:08:04,909 --> 00:08:01,979
dissociating water vapor in the

190
00:08:05,360 --> 00:08:04,919
atmosphere and that atomic hydrogen can

191
00:08:09,110 --> 00:08:05,370
recombine

192
00:08:11,300 --> 00:08:09,120
and as I mentioned before the last

193
00:08:12,649 --> 00:08:11,310
resurfacing was about a billion years

194
00:08:14,899 --> 00:08:12,659
ago or about three-and-a-half billion

195
00:08:18,170 --> 00:08:14,909
years in the Venus's evolution that's

196
00:08:21,860 --> 00:08:18,180
the last possible time that we may have

197
00:08:23,990 --> 00:08:21,870
had water it might likely did not but if

198
00:08:25,550 --> 00:08:24,000
Venus was resurfaced we would have lost

199
00:08:28,100 --> 00:08:25,560
any evidence that it had liquid water

200
00:08:30,980 --> 00:08:28,110
before that time and as you can see the

201
00:08:34,130 --> 00:08:30,990
UV flux is approximately modern and the

202
00:08:36,529 --> 00:08:34,140
insulation is about 175 percent of the

203
00:08:40,040 --> 00:08:36,539
Earth's insulation which is still well

204
00:08:43,219 --> 00:08:40,050
inside the runaway greenhouse limit now

205
00:08:47,000 --> 00:08:43,229
the thing that the atmosphere does is it

206
00:08:51,560 --> 00:08:47,010
absorbs and repurposes solar UV air is

207
00:08:53,420 --> 00:08:51,570
actually the most I'm sorry the most

208
00:08:55,420 --> 00:08:53,430
absorbed wavelengths in the air are the

209
00:08:58,530 --> 00:08:55,430
e UV wavelengths which

210
00:09:01,090 --> 00:08:58,540
run from basically you know ten or so

211
00:09:02,980 --> 00:09:01,100
nanometers up to about a hundred and

212
00:09:04,810 --> 00:09:02,990
twenty-one nanometers which is that

213
00:09:08,170 --> 00:09:04,820

lyman-alpha line a little bit beyond

214
00:09:10,030 --> 00:09:08,180
that 125 nanometers and across that

215
00:09:11,230 --> 00:09:10,040
whole region most of the atmospheric

216
00:09:13,329 --> 00:09:11,240
constituents that we're worried about

217
00:09:14,980 --> 00:09:13,339
for example co2 and n2 which are the

218
00:09:17,320 --> 00:09:14,990
predominant components of Venus's

219
00:09:20,590 --> 00:09:17,330
current atmosphere absorb very strongly

220
00:09:23,019 --> 00:09:20,600
in that region and as you can see the

221
00:09:25,840 --> 00:09:23,029
fluxes vary across a couple orders of

222
00:09:30,370 --> 00:09:25,850
magnitude from a very young Sun to

223
00:09:33,930 --> 00:09:30,380
something more like the modern Sun now

224
00:09:37,360 --> 00:09:33,940
the e UV that's driving this process is

225
00:09:40,600 --> 00:09:37,370
going to essentially move the Venusian

226
00:09:43,420 --> 00:09:40,610
atmosphere from genes escape mode where

227
00:09:45,460 --> 00:09:43,430
individual molecules are reaching escape

228
00:09:49,390 --> 00:09:45,470
velocity and just ballistically exiting

229
00:09:51,370 --> 00:09:49,400
the atmosphere to a regime where there

230
00:09:53,650 --> 00:09:51,380
is flow of the atmosphere the atmosphere

231
00:09:56,590 --> 00:09:53,660
is moving as a fluid and that's why we

232
00:09:59,470 --> 00:09:56,600
call it hydrodynamic escape to a point

233
00:10:01,600 --> 00:09:59,480
where it's no holds barred everyone out

234
00:10:03,160 --> 00:10:01,610
the door escape you're just scooping

235
00:10:05,860 --> 00:10:03,170
large portions of your atmosphere off

236
00:10:08,130 --> 00:10:05,870
thermally and driving it away from the

237
00:10:10,630 --> 00:10:08,140
surface of your planet this is this is

238
00:10:13,090 --> 00:10:10,640

much more cataclysmic than you might

239
00:10:15,820 --> 00:10:13,100
expect for this regime this is like you

240
00:10:18,490 --> 00:10:15,830
are disintegrating your planet bad news

241
00:10:19,600 --> 00:10:18,500
so we I'm going to really focus on this

242
00:10:21,699 --> 00:10:19,610
middle one here where you sort of have

243
00:10:26,710 --> 00:10:21,709
this nice calm regime of things just

244
00:10:28,329 --> 00:10:26,720
flowing away in a mild setting so like I

245
00:10:30,519 --> 00:10:28,339
mentioned before there's there's three

246
00:10:32,370 --> 00:10:30,529
regimes of thermal escape the jeans

247
00:10:34,690 --> 00:10:32,380
escape limit where you have high-energy

248
00:10:36,310 --> 00:10:34,700
molecules on the tale of the Boltzmann

249
00:10:38,199 --> 00:10:36,320
distribution reaching escape velocity

250
00:10:39,820 --> 00:10:38,209
and exiting the atmosphere there's the

251
00:10:41,710 --> 00:10:39,830
energy limit where you assume that all

252
00:10:44,460 --> 00:10:41,720
the energy all a UV that's poured into

253
00:10:47,380 --> 00:10:44,470
the atmosphere is used to drive escape

254
00:10:49,720 --> 00:10:47,390
there's the diffusion limit where you

255
00:10:52,600 --> 00:10:49,730
have some escaping constituent that must

256
00:10:54,340 --> 00:10:52,610
move through a heavy background gas and

257
00:10:56,199 --> 00:10:54,350
that limits the amount of material you

258
00:10:58,329 --> 00:10:56,209
can supply to the upper atmosphere that

259
00:10:59,470 --> 00:10:58,339
can escape and then lastly you have

260
00:11:01,060 --> 00:10:59,480
something called the radiation

261
00:11:03,250 --> 00:11:01,070
recombination limit which I will not

262
00:11:05,590 --> 00:11:03,260
touch on but that's basically you're

263
00:11:08,140 --> 00:11:05,600

limited by essentially the pummeling

264
00:11:09,580 --> 00:11:08,150
that you're giving to the atmosphere and

265
00:11:11,490 --> 00:11:09,590
it's photo ionization

266
00:11:13,360 --> 00:11:11,500
balanced by radiative recombination and

267
00:11:16,990 --> 00:11:13,370
most of the rest of talk is going to

268
00:11:19,750 --> 00:11:17,000
look at these two limits which are at an

269
00:11:22,960 --> 00:11:19,760
interplay in these cases and as a brief

270
00:11:25,060 --> 00:11:22,970
note one Earth Ocean lost in 100 million

271
00:11:27,310 --> 00:11:25,070
years is a flux of about two times ten

272
00:11:28,510 --> 00:11:27,320
to the thirteen molecules per centimeter

273
00:11:30,640 --> 00:11:28,520
squared per second so I'm going to throw

274
00:11:32,410 --> 00:11:30,650
up some numbers and some graphs and

275
00:11:37,360 --> 00:11:32,420
that's really sort of the benchmark here

276
00:11:39,010 --> 00:11:37,370
for the evolution of the atmosphere the

277
00:11:40,480 --> 00:11:39,020
diffusion limit is a strong function of

278
00:11:42,670 --> 00:11:40,490
composition so if you have heavy

279
00:11:44,620 --> 00:11:42,680
constituents as your heavy background

280
00:11:46,510 --> 00:11:44,630
gas and you have a light escaping gas

281
00:11:49,090 --> 00:11:46,520
your flux is much higher than if you had

282
00:11:51,910 --> 00:11:49,100
for example a light background gas and a

283
00:11:55,510 --> 00:11:51,920
lighter escaping constituent I will say

284
00:11:57,790 --> 00:11:55,520
that this point here is sort of a bad

285
00:12:00,070 --> 00:11:57,800
thing to do on a plot like this this

286
00:12:01,750 --> 00:12:00,080
there is no diffusion limit when it's H

287
00:12:04,060 --> 00:12:01,760
and h2 dominated it's you are just

288
00:12:09,190 --> 00:12:04,070

limited by photons at that point there's

289
00:12:11,950 --> 00:12:09,200
no diffusion the research the literature

290
00:12:15,550 --> 00:12:11,960
on this type of project often gets up to

291
00:12:17,500 --> 00:12:15,560
about ten times modern solar in UV for

292
00:12:19,030 --> 00:12:17,510
earth cases because we're worried about

293
00:12:20,800 --> 00:12:19,040
the evolution of the early Earth and a

294
00:12:23,440 --> 00:12:20,810
lot of these circumstances and you can

295
00:12:26,500 --> 00:12:23,450
see that by and large these cases are

296
00:12:29,110 --> 00:12:26,510
all limited by diffusion except when you

297
00:12:30,610 --> 00:12:29,120
roll over here and that's really when

298
00:12:33,190 --> 00:12:30,620
you're reaching that energy limit you

299
00:12:34,900 --> 00:12:33,200
have used as much energy as possible to

300
00:12:37,290 --> 00:12:34,910
drive escape but you cannot get to the

301
00:12:39,850 --> 00:12:37,300
point where you are limited by diffusion

302
00:12:46,750 --> 00:12:39,860
so this is an energetic limit and this

303
00:12:49,330 --> 00:12:46,760
is just a physical chemical limit so the

304
00:12:51,280 --> 00:12:49,340
model is solving these coupled equations

305
00:12:53,500 --> 00:12:51,290
for several components in the atmosphere

306
00:12:55,000 --> 00:12:53,510
at this point there's no chemistry so

307
00:12:56,650 --> 00:12:55,010
the two components are basically what I

308
00:12:58,990 --> 00:12:56,660
tell them to be either atomic hydrogen

309
00:13:02,170 --> 00:12:59,000
molecular hydrogen and then whatever

310
00:13:05,350 --> 00:13:02,180
heavy background gas but the mass

311
00:13:07,240 --> 00:13:05,360
continuity momentum continuity and the

312
00:13:09,340 --> 00:13:07,250
energy equations couple these two

313
00:13:13,690 --> 00:13:09,350

components so that the exchange energy

314
00:13:17,440 --> 00:13:13,700
and velocity over time and so if we use

315
00:13:19,600 --> 00:13:17,450
this model to explore the parameter

316
00:13:21,190 --> 00:13:19,610
space for the earth which is always a

317
00:13:23,440 --> 00:13:21,200
good place to start since there's a lot

318
00:13:26,320 --> 00:13:23,450
of literature on it we see that

319
00:13:28,990 --> 00:13:26,330
the model reproduces fairly well to

320
00:13:31,740 --> 00:13:29,000
within a factor of two or three results

321
00:13:33,820 --> 00:13:31,750
from the literature for the earth and

322
00:13:35,950 --> 00:13:33,830
then we get to the point where we can

323
00:13:37,660 --> 00:13:35,960
start to ask well what about Venus early

324
00:13:39,790 --> 00:13:37,670
in its history here we're talking about

325
00:13:41,470 --> 00:13:39,800
fluxes that are on the order of ten

326
00:13:43,990 --> 00:13:41,480
times modern because remember this is

327
00:13:46,030 --> 00:13:44,000
Earth so if you park a planet twice's a

328
00:13:48,550 --> 00:13:46,040
little bit closer you get twice the flux

329
00:13:50,590 --> 00:13:48,560
which is what the case for Venus if you

330
00:13:53,320 --> 00:13:50,600
do that what you see is that the

331
00:13:55,720 --> 00:13:53,330
Venusian atmosphere early in its history

332
00:13:56,830 --> 00:13:55,730
remember we're at 20 times solar UV so

333
00:13:58,900 --> 00:13:56,840
it's going to be atomic hydrogen

334
00:14:01,150 --> 00:13:58,910
dominated and if you assume the

335
00:14:02,890 --> 00:14:01,160
background atmosphere is a runaway

336
00:14:05,260 --> 00:14:02,900
greenhouse case where it's water vapor

337
00:14:06,880 --> 00:14:05,270
and co2 dominated you find that it's

338
00:14:09,490 --> 00:14:06,890

essentially diffusion limited across a

339
00:14:12,040 --> 00:14:09,500
broad range of potential hydrogen

340
00:14:13,330 --> 00:14:12,050
concentrations which covers a lot of the

341
00:14:15,220 --> 00:14:13,340
parameter space you can start in a

342
00:14:17,560 --> 00:14:15,230
runaway greenhouse way up here where

343
00:14:19,420 --> 00:14:17,570
your hydrogen's being borne by water

344
00:14:20,860 --> 00:14:19,430
vapor and then as you lose that

345
00:14:23,200 --> 00:14:20,870
atmosphere you still follow that

346
00:14:25,720 --> 00:14:23,210
diffusion limit down across this whole

347
00:14:27,730 --> 00:14:25,730
parameter space and this is for Venus

348
00:14:30,130 --> 00:14:27,740
and its early history if for example we

349
00:14:33,190 --> 00:14:30,140
worry about when Venus transition across

350
00:14:34,690 --> 00:14:33,200
that the recombination limit where

351
00:14:36,910 --> 00:14:34,700
you're actually looking at the escape of

352
00:14:39,760 --> 00:14:36,920
molecular hydrogen from a water vapor

353
00:14:41,530 --> 00:14:39,770
co2 atmosphere these limits decrease and

354
00:14:44,530 --> 00:14:41,540
you actually come off the diffusion

355
00:14:46,600 --> 00:14:44,540
limit much sooner so if you drop below a

356
00:14:48,640 --> 00:14:46,610
few tenths of a percent water vapor in

357
00:14:50,320 --> 00:14:48,650
the atmosphere for example it becomes

358
00:14:54,040 --> 00:14:50,330
much harder to get the rest of it out in

359
00:14:56,320 --> 00:14:54,050
this hydrodynamic flow regime and then

360
00:14:57,640 --> 00:14:56,330
lastly if you look at it about a billion

361
00:14:59,350 --> 00:14:57,650
years ago you get the same sort of

362
00:15:00,910 --> 00:14:59,360
behavior where it just touches the

363
00:15:02,440 --> 00:15:00,920

diffusion limit at one point but its

364
00:15:04,150 --> 00:15:02,450
energy limited through much of the

365
00:15:06,340 --> 00:15:04,160
higher hydrogen concentrations and then

366
00:15:11,650 --> 00:15:06,350
it's well below the diffusion limit for

367
00:15:13,000 --> 00:15:11,660
the rest of that and so in conclusion we

368
00:15:14,440 --> 00:15:13,010
think that the radiation environment for

369
00:15:16,450 --> 00:15:14,450
early Venus would have favored rapid

370
00:15:18,130 --> 00:15:16,460
escape of the photons as products and

371
00:15:19,180 --> 00:15:18,140
the parameter space where Venus is

372
00:15:20,680 --> 00:15:19,190
atmosphere would have experienced

373
00:15:22,960 --> 00:15:20,690
diffusion limited escape is diminished

374
00:15:24,940 --> 00:15:22,970
with time composition composition

375
00:15:26,800 --> 00:15:24,950
matters chemistry matters and that's why

376
00:15:37,040 --> 00:15:26,810
that's a second part of this proposal

377
00:15:43,130 --> 00:15:39,180
just a to point out these are all

378
00:15:47,880 --> 00:15:43,140
pictures from as of AB grad Con 2012

379
00:15:55,380 --> 00:15:47,890
2013 2014 2015

380
00:16:00,360 --> 00:15:55,390
is it apps icon folder 20 no I wasn't at

381
00:16:07,110 --> 00:16:00,370
2016 is it apps icon I've been doing

382
00:16:09,360 --> 00:16:07,120
this too long yeah so the blow-off point

383
00:16:11,940 --> 00:16:09,370
yeah what would that look like on a time

384
00:16:14,970 --> 00:16:11,950
scale like how fast does that occur once

385
00:16:17,790 --> 00:16:14,980
it reaches that point it depends on your

386
00:16:19,350 --> 00:16:17,800
your model parameters it tends to you

387
00:16:21,269 --> 00:16:19,360
often see that it's sort of episodic

388
00:16:23,699 --> 00:16:21,279

where you'll heat up the atmosphere and

389
00:16:25,920 --> 00:16:23,709
it'll go through sort of a phase where

390
00:16:27,870 --> 00:16:25,930
it's pushing off atmosphere and then

391
00:16:29,880 --> 00:16:27,880
it'll cool off because of that adiabatic

392
00:16:32,639 --> 00:16:29,890
expansion and collapse a little bit and

393
00:16:34,740 --> 00:16:32,649
then it'll just pulse but tip if you're

394
00:16:36,660 --> 00:16:34,750
driving that if you're putting enough

395
00:16:38,130 --> 00:16:36,670
energy into it to drive that sort of

396
00:16:49,280 --> 00:16:38,140
blow off regime it tends to be fairly

397
00:16:56,340 --> 00:16:54,179
3:40 okay there we go um first off so

398
00:16:57,929 --> 00:16:56,350
all those pictures of our Predacon I

399
00:16:59,759 --> 00:16:57,939
think I may have taken most of those you

400
00:17:01,499 --> 00:16:59,769
took all those and I did not credit you

401
00:17:02,730 --> 00:17:01,509
and I apologize oh no it's just like

402
00:17:07,409 --> 00:17:02,740
wait these look familiar

403
00:17:09,990 --> 00:17:07,419
um secondly um so at one point in my

404
00:17:13,049 --> 00:17:10,000
earlier academic career I spent a bit of

405
00:17:15,299 --> 00:17:13,059
time focusing on potential habitability

406
00:17:17,220 --> 00:17:15,309
of Venus in the upper atmosphere it's

407
00:17:19,529 --> 00:17:17,230
kind of earth like a being oh hey

408
00:17:20,819 --> 00:17:19,539
well if Venus had a lot of water maybe

409
00:17:22,769 --> 00:17:20,829
it had an ocean in there for maybe like

410
00:17:24,689 --> 00:17:22,779
got establish which then migrated to the

411
00:17:27,329 --> 00:17:24,699
upper atmosphere as the greenhouse

412
00:17:28,680 --> 00:17:27,339
effect kicked in from the sounds of it

413
00:17:31,830 --> 00:17:28,690

I'm guessing that's probably less likely

414
00:17:35,580 --> 00:17:31,840
given how early it sounds like things

415
00:17:37,649 --> 00:17:35,590
kind of went downhill yeah so I I

416
00:17:39,779 --> 00:17:37,659
personally like the mono at all result

417
00:17:41,549 --> 00:17:39,789
because it it's really clever and how it

418
00:17:44,970 --> 00:17:41,559
interprets the the evolution of the

419
00:17:46,830 --> 00:17:44,980
solar system and it's from their efforts

420
00:17:48,510 --> 00:17:46,840
it has looked like there's a very sharp

421
00:17:51,029 --> 00:17:48,520
divide between their type 1 and type 2

422
00:17:52,350 --> 00:17:51,039
planets so I think that that Venus and

423
00:17:54,480 --> 00:17:52,360
anything that's close to Venus is going

424
00:17:56,250 --> 00:17:54,490
to go through essentially it's going to

425
00:17:57,600 --> 00:17:56,260
form be in this stuck in this runaway

426
00:18:01,860 --> 00:17:57,610
greenhouse and it's going to lose all of

427
00:18:03,690 --> 00:18:01,870
its water very quickly so they said any

428
00:18:06,149 --> 00:18:03,700
nice talk maybe this is something I

429
00:18:08,039 --> 00:18:06,159
didn't understand but what's like the

430
00:18:09,870 --> 00:18:08,049
limit of how much water you could have

431
00:18:11,880 --> 00:18:09,880
start with such that you would have lost

432
00:18:13,830 --> 00:18:11,890
all of it are you saying that it

433
00:18:16,680 --> 00:18:13,840
happened so fast that you're not really

434
00:18:20,970 --> 00:18:16,690
limited by your initial amount of water

435
00:18:23,399 --> 00:18:20,980
so it really so there's a couple things

436
00:18:26,330 --> 00:18:23,409
in there right so when we talk about the

437
00:18:28,320 --> 00:18:26,340
DTH ratio for example that gives us a

438
00:18:30,210 --> 00:18:28,330

conservative estimate on the amount of

439
00:18:32,039 --> 00:18:30,220
water that Venus could have had but then

440
00:18:33,419 --> 00:18:32,049
if escape rates were higher you could

441
00:18:35,399 --> 00:18:33,429
have just dragged off the Tyrian as well

442
00:18:39,090 --> 00:18:35,409
which would have basically erased your

443
00:18:42,750 --> 00:18:39,100
HD to H ratio the amount of water you

444
00:18:46,680 --> 00:18:42,760
could lose over Venus's lifetime is

445
00:18:49,230 --> 00:18:46,690
essentially if you look here the if

446
00:18:51,690 --> 00:18:49,240
you're if you start with like 10 earth

447
00:18:53,610 --> 00:18:51,700
oceans and you're in this very early

448
00:18:55,169 --> 00:18:53,620
regime where you're close to the

449
00:18:57,539 --> 00:18:55,179
diffusion limit for that whole parameter

450
00:19:00,360 --> 00:18:57,549
space then you can lose 10 earth oceans

451
00:19:02,159 --> 00:19:00,370
in a billion years okay so it's

452
00:19:08,220 --> 00:19:02,169
prodigious the amount of

453
00:19:09,869 --> 00:19:08,230
you could lose Thanks hello yep

454
00:19:11,070 --> 00:19:09,879
thank you for that talk I was wondering

455
00:19:13,859 --> 00:19:11,080
if you might be able to share your

456
00:19:15,960 --> 00:19:13,869
opinion regarding what you may think

457
00:19:18,539 --> 00:19:15,970
about tidally locked planet surround and

458
00:19:19,950 --> 00:19:18,549
inkay dwarf stars man that's a whole

459
00:19:20,970 --> 00:19:19,960
nother session that's not just a

460
00:19:24,210 --> 00:19:20,980
question

461
00:19:26,669 --> 00:19:24,220
so like the lugar and Barnes result for

462
00:19:28,139 --> 00:19:26,679
basically dehydrating em star planets

463
00:19:30,419 --> 00:19:28,149

because of their pre main sequence

464
00:19:32,369 --> 00:19:30,429
lifetime and then tidal locking you can

465
00:19:34,739 --> 00:19:32,379
go into these moist greenhouse States

466
00:19:36,299 --> 00:19:34,749
even when you're in the hab the

467
00:19:39,479 --> 00:19:36,309
conventional a bubble zone because of

468
00:19:41,070 --> 00:19:39,489
the the dayside cloud cover it's I think

469
00:19:42,659 --> 00:19:41,080
M star planets are really hard and I

470
00:19:44,220 --> 00:19:42,669
think they're really cool and we should

471
00:19:45,359 --> 00:19:44,230
look at them definitely but I don't know

472
00:19:46,499 --> 00:19:45,369
that we should go into it thinking that

473
00:19:50,159 --> 00:19:46,509
any of them are going to be even

474
00:19:52,160 --> 00:19:50,169
potentially habitable so yeah with that