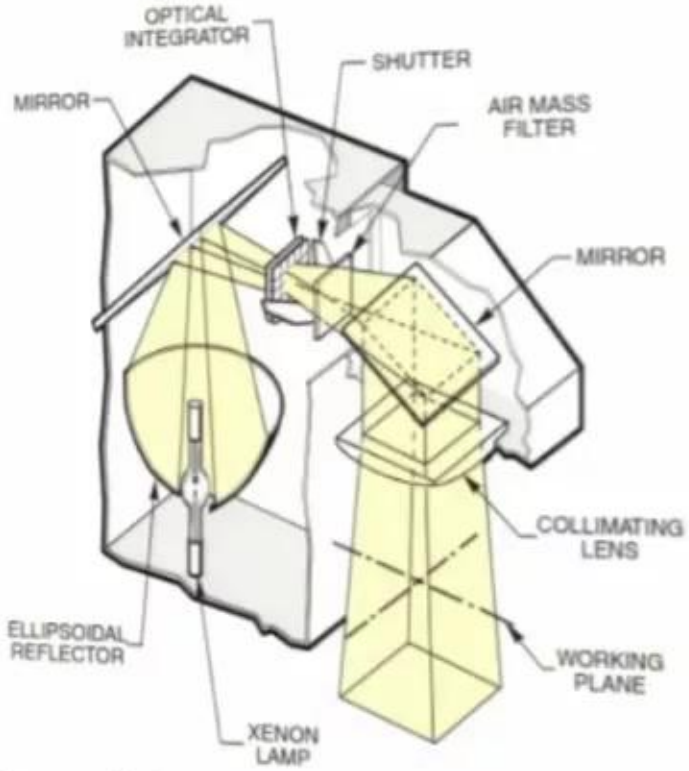
Experimental Design – Solar Simulation

- Powerful light source (usually xenon arc lamp) with special filters match solar spectrum
- Filter for extraterrestrial spectrum, simulating an Earth with no ozone



General diagram of a solar simulator

Figure: Newport Corp.

1
00:00:11,600 --> 00:00:08,450
I'm Parker casselberry this is the

2
00:00:15,020 --> 00:00:11,610
possible photochemical origins of banded

3
00:00:17,930 --> 00:00:15,030
iron formations so just some

4
00:00:20,630 --> 00:00:17,940
introduction and background first our

5
00:00:22,820 --> 00:00:20,640
story starts in space you have an

6
00:00:24,590 --> 00:00:22,830
exoplanet you want to find life on it

7
00:00:27,470 --> 00:00:24,600
okay that's great let's look for

8
00:00:30,770 --> 00:00:27,480
something in the atmosphere say oxygen

9
00:00:33,319 --> 00:00:30,780
easy to detect spectroscopically and

10
00:00:36,950 --> 00:00:33,329
associated with life but the thing is

11
00:00:38,740 --> 00:00:36,960
we're not entirely sure exactly what

12
00:00:43,630 --> 00:00:38,750
controls its build up in the atmosphere

13
00:00:45,920 --> 00:00:43,640

so to do that we look at the earth

14
00:00:48,110 --> 00:00:45,930
specifically like the great oxidation

15
00:00:51,560 --> 00:00:48,120
event so about two and a half billion

16
00:00:55,610 --> 00:00:51,570
years ago earth's oxygen rose

17
00:00:58,190 --> 00:00:55,620
dramatically and the atmos the

18
00:01:03,049 --> 00:00:58,200
environment went from neutral to

19
00:01:07,130 --> 00:01:03,059
oxidizing so and the details of this

20
00:01:10,580 --> 00:01:07,140
though are kind of puzzling and the more

21
00:01:14,090 --> 00:01:10,590
we find the more the mystery deepens for

22
00:01:17,929 --> 00:01:14,100
example evidence of global atmospheric

23
00:01:21,199 --> 00:01:17,939
oxygen is about 2.5 2.4 billion years

24
00:01:24,469 --> 00:01:21,209
old but we have evidence of just

25
00:01:28,849 --> 00:01:24,479
oxygenation on a local scale at 3

26
00:01:34,910 --> 00:01:28,859
billion years ago so Lori investigate

27
00:01:36,529 --> 00:01:34,920
more this like this and all these

28
00:01:40,129 --> 00:01:36,539
investigations though rely on

29
00:01:42,289 --> 00:01:40,139
geochemical proxies some of which are

30
00:01:46,120 --> 00:01:42,299
very subtle effects out of effects of

31
00:01:48,830 --> 00:01:46,130
oxygen well it's often ignored is

32
00:01:50,989 --> 00:01:48,840
photochemistry the potential for

33
00:01:54,800 --> 00:01:50,999
ultraviolet light to cause this

34
00:01:57,499 --> 00:01:54,810
oxidation and there was no ozone layer

35
00:02:01,789 --> 00:01:57,509
back then too so this might completely

36
00:02:04,729 --> 00:02:01,799
be confounding our detective work so one

37
00:02:07,339 --> 00:02:04,739
of these signs of oxygenation and really

38
00:02:09,499 --> 00:02:07,349

big ones are banded iron formations

39
00:02:15,320 --> 00:02:09,509
there are layered sedimentary deposits

40
00:02:18,240 --> 00:02:15,330
of iron oxide the oldest are actually

41
00:02:22,860 --> 00:02:18,250
well before the great oxidation event

42
00:02:24,480 --> 00:02:22,870
but most are leading up to it so they're

43
00:02:28,260 --> 00:02:24,490
classically thought to be formed by

44
00:02:34,230 --> 00:02:28,270
oxygen turning aqueous iron to into iron

45
00:02:36,000 --> 00:02:34,240
3 but there's more to the story so

46
00:02:39,930 --> 00:02:36,010
there's something called photo Farrah

47
00:02:41,820 --> 00:02:39,940
trophy which is a alternate idea so it's

48
00:02:45,660 --> 00:02:41,830
an toxigenic photosynthesis that

49
00:02:46,949 --> 00:02:45,670
directly oxidizes the iron and there's

50
00:02:49,710 --> 00:02:46,959
been experiments that have shown that

51
00:02:52,290 --> 00:02:49,720
this could make ifs but then there's

52
00:02:55,020 --> 00:02:52,300
also photooxidation you have an

53
00:02:57,810 --> 00:02:55,030
ultraviolet photon knocking electron off

54
00:03:01,740 --> 00:02:57,820
of aqueous iron to turning into iron 3

55
00:03:07,440 --> 00:03:01,750
iron species like feo h plus have very

56
00:03:09,870 --> 00:03:07,450
broad UV absorbance so that gives some

57
00:03:11,940 --> 00:03:09,880
interesting results so making a bit with

58
00:03:14,150 --> 00:03:11,950
white you have dissolved iron in

59
00:03:17,240 --> 00:03:14,160
seawater from a hydrothermal vent and

60
00:03:20,280 --> 00:03:17,250
then feo h plus to absorb a photon

61
00:03:25,350 --> 00:03:20,290
electron gets knocked off you form iron

62
00:03:28,080 --> 00:03:25,360
hydroxides that electron creates

63
00:03:33,920 --> 00:03:28,090

hydrogen gas by combining with h plus in

64
00:03:37,110 --> 00:03:33,930
solution and then things precipitate

65
00:03:41,039 --> 00:03:37,120
then over time you get the minerals of

66
00:03:43,979 --> 00:03:41,049
AB if so the implication here is that

67
00:03:46,620 --> 00:03:43,989
you don't need oxygen or even biological

68
00:03:49,080 --> 00:03:46,630
activity so then are these banded iron

69
00:03:53,640 --> 00:03:49,090
formations really signs of oxygen life

70
00:03:57,420 --> 00:03:53,650
or are they completely abiotic so how to

71
00:04:01,110 --> 00:03:57,430
test this experimentally previous work

72
00:04:04,259 --> 00:04:01,120
has been done late 70s it was first

73
00:04:07,110 --> 00:04:04,269
proposed and then in 83 there were

74
00:04:11,210 --> 00:04:07,120
simple experiments that found that it

75
00:04:14,190 --> 00:04:11,220
could more than account for Biff's in 92

76
00:04:18,690 --> 00:04:14,200
more complete simulations concluded the

77
00:04:21,750 --> 00:04:18,700
same in 2007 under completely different

78
00:04:23,100 --> 00:04:21,760
conditions but more complete they

79
00:04:26,700 --> 00:04:23,110
concluded that it would be minor

80
00:04:29,060 --> 00:04:26,710
compared to photo Farrah trophy but all

81
00:04:31,020 --> 00:04:29,070
these experiments are very different

82
00:04:34,560 --> 00:04:31,030
they used different

83
00:04:37,680 --> 00:04:34,570
compositions of their sea water simple

84
00:04:39,300 --> 00:04:37,690
versus complex mixtures iron

85
00:04:42,660 --> 00:04:39,310
concentrations were an order of

86
00:04:45,090 --> 00:04:42,670
magnitude different things different

87
00:04:47,400 --> 00:04:45,100
light sources one of which having a

88
00:04:50,940 --> 00:04:47,410

hundred nanometer bandgap right in the

89
00:04:53,940 --> 00:04:50,950
middle of the UV spectrum and they

90
00:04:56,760 --> 00:04:53,950
concluded different things but then

91
00:04:59,310 --> 00:04:56,770
there is actually a direct conflict the

92
00:05:01,530 --> 00:04:59,320
83 paper they tested different

93
00:05:04,680 --> 00:05:01,540
wavelengths of UV light specifically and

94
00:05:09,030 --> 00:05:04,690
they found that UVA causes precipitation

95
00:05:11,310 --> 00:05:09,040
that's where the fao h+ absorbances but

96
00:05:13,830 --> 00:05:11,320
the later paper they tested UVA

97
00:05:15,600 --> 00:05:13,840
specifically in a simple solution as the

98
00:05:18,420 --> 00:05:15,610
previous experiment and found absolutely

99
00:05:20,960 --> 00:05:18,430
no effect that is the red line on the

100
00:05:26,430 --> 00:05:20,970
graph the black line is their control

101
00:05:29,070 --> 00:05:26,440
yeah major conflict so then this is

102
00:05:31,290 --> 00:05:29,080
where I come in so my experimental

103
00:05:33,360 --> 00:05:31,300
objectives are to test this photo

104
00:05:35,520 --> 00:05:33,370
chemical mechanism get quantitative

105
00:05:39,360 --> 00:05:35,530
rates by measuring iron loss and

106
00:05:42,750 --> 00:05:39,370
solution and compare that to estimated

107
00:05:45,000 --> 00:05:42,760
rates of actual Biff's and hopefully

108
00:05:48,240 --> 00:05:45,010
help resolve the current dispute in the

109
00:05:51,780 --> 00:05:48,250
literature so what i'm doing differently

110
00:05:55,170 --> 00:05:51,790
is having realistic best estimates of

111
00:05:56,700 --> 00:05:55,180
seawater composition haven't quite

112
00:05:58,850 --> 00:05:56,710
figured that out yet want to make sure I

113
00:06:02,730 --> 00:05:58,860

can actually get things working first

114
00:06:05,670 --> 00:06:02,740
but that could affect speciation other

115
00:06:07,800 --> 00:06:05,680
non iron species can absorb and also

116
00:06:10,440 --> 00:06:07,810
there's great potential for dark

117
00:06:15,600 --> 00:06:10,450
reactions between oxidized iron and

118
00:06:17,160 --> 00:06:15,610
other components so the other thing I'm

119
00:06:20,370 --> 00:06:17,170
having more rigorous control of my

120
00:06:21,930 --> 00:06:20,380
atmosphere and temperature previous

121
00:06:24,990 --> 00:06:21,940
experiments some of them did not control

122
00:06:27,530 --> 00:06:25,000
their temperature at all and I'm using

123
00:06:30,300 --> 00:06:27,540
something called a solar simulator so

124
00:06:33,560 --> 00:06:30,310
solar simulator is a powerful light

125
00:06:36,720 --> 00:06:33,570
source i vizi on our clamp that

126
00:06:40,320 --> 00:06:36,730
recreates the solar spectrum with

127
00:06:42,180 --> 00:06:40,330
special filters and I'm using one for

128
00:06:43,540 --> 00:06:42,190
the extra-terrestrial spectrum to

129
00:06:55,390 --> 00:06:43,550
simulate an earth with no

130
00:07:00,190 --> 00:06:55,400
zone as I said before there we go um so

131
00:07:04,300 --> 00:07:00,200
this is my setup there i have my solar

132
00:07:06,010 --> 00:07:04,310
simulator some optics there's a beam

133
00:07:11,620 --> 00:07:06,020
turner which is a really fancy name for

134
00:07:13,600 --> 00:07:11,630
a 45-degree mirror there's my glass

135
00:07:16,150 --> 00:07:13,610
chamber and i have this big machine to

136
00:07:19,450 --> 00:07:16,160
teflon lid that bolts on with 10 bolts

137
00:07:23,950 --> 00:07:19,460
at pain water-cooling jacket control

138
00:07:26,860 --> 00:07:23,960

temperature sensors ph and oxygen

139
00:07:27,970 --> 00:07:26,870
sensors with the USB sensor interface so

140
00:07:30,360 --> 00:07:27,980
i can just walk away and have the

141
00:07:37,240 --> 00:07:30,370
computer continuously log data for me

142
00:07:40,480 --> 00:07:37,250
all this tubing for a gas system so then

143
00:07:43,960 --> 00:07:40,490
my initial experiments i tested simple

144
00:07:47,350 --> 00:07:43,970
solutions of iron salt bicarbonate

145
00:07:50,050 --> 00:07:47,360
buffers basically repeats of the

146
00:07:52,210 --> 00:07:50,060
previous experiments sealed it with a

147
00:07:54,660 --> 00:07:52,220
positive pressure for psi so hopefully

148
00:07:59,250 --> 00:07:54,670
if anything gets in it'll get pushed out

149
00:08:03,360 --> 00:07:59,260
ran for over 18 hours this is what I saw

150
00:08:05,710 --> 00:08:03,370
and it beautiful you can see the iron

151
00:08:12,910 --> 00:08:05,720
precipitation there and all over in the

152
00:08:17,530 --> 00:08:12,920
water I was so excited here's lost so

153
00:08:27,010 --> 00:08:17,540
this is Iron remaining in solution over

154
00:08:28,360 --> 00:08:27,020
time so it looked like yeah um the only

155
00:08:29,710 --> 00:08:28,370
reason why that point is out there is

156
00:08:31,060 --> 00:08:29,720
this was on a weekend I wanted to sleep

157
00:08:36,730 --> 00:08:31,070
in so I didn't come in as a really to

158
00:08:38,410 --> 00:08:36,740
sample it uh but so basically the dark

159
00:08:41,860 --> 00:08:38,420
control showed exactly as much

160
00:08:47,260 --> 00:08:41,870
precipitation as the experiment with the

161
00:08:51,790 --> 00:08:47,270
light on and so essentially what

162
00:08:54,940 --> 00:08:51,800
happened is my oxygen sensor also rose

163
00:08:57,280 --> 00:08:54,950

to about ten percent of atmospheric

164
00:09:02,079 --> 00:08:57,290
oxygen so

165
00:09:06,160 --> 00:09:02,089
I was leaking oxygen significantly which

166
00:09:08,079 --> 00:09:06,170
was quite worrisome but at least I

167
00:09:11,439 --> 00:09:08,089
confirmed that oxygen makes iron

168
00:09:18,819 --> 00:09:11,449
precipitate I confirmed that I convinced

169
00:09:22,470 --> 00:09:18,829
myself of that so my colleagues went to

170
00:09:27,009 --> 00:09:22,480
our house University in Denmark to do

171
00:09:30,819 --> 00:09:27,019
experiments with a group who does they

172
00:09:34,720 --> 00:09:30,829
have this really fancy extremely

173
00:09:38,199 --> 00:09:34,730
sensitive oxygen detector and in doing

174
00:09:39,759 --> 00:09:38,209
that they realize that their setups were

175
00:09:43,210 --> 00:09:39,769
not nearly as oxygen tight as they

176
00:09:48,309 --> 00:09:43,220
thought so they've designed extremely

177
00:09:52,509 --> 00:09:48,319
oxygen tight experiments so I'm learning

178
00:09:56,199 --> 00:09:52,519
from them essentially what they said is

179
00:10:00,249 --> 00:09:56,209
that plastic which I used a lot of

180
00:10:02,879 --> 00:10:00,259
because I wanted to avoid using like

181
00:10:05,800 --> 00:10:02,889
metal because I was working with iron

182
00:10:10,240 --> 00:10:05,810
turns out that plastic is extremely

183
00:10:13,389 --> 00:10:10,250
permeable to oxygen so yeah that was

184
00:10:18,280 --> 00:10:13,399
kind of bad but the good news is is that

185
00:10:20,710 --> 00:10:18,290
glass is actually oxygen does not

186
00:10:24,160 --> 00:10:20,720
permeate well through it so you can

187
00:10:25,329 --> 00:10:24,170
build a nice reactor out of glass so

188
00:10:27,400 --> 00:10:25,339

right now I'm working with the glass

189
00:10:32,740 --> 00:10:27,410
shop to build something like this this

190
00:10:35,050 --> 00:10:32,750
is just a shiny 3d model so the

191
00:10:39,340 --> 00:10:35,060
interesting things eh oxygen sensor

192
00:10:42,550 --> 00:10:39,350
ports there's quartz window to let the

193
00:10:44,800 --> 00:10:42,560
light in stopcock and septum for

194
00:10:46,569 --> 00:10:44,810
headspace sampling remember how I said

195
00:10:48,879 --> 00:10:46,579
earlier that this reaction produces

196
00:10:51,429 --> 00:10:48,889
hydrogen I want to try to sample the

197
00:10:54,100 --> 00:10:51,439
headspace to look for that hydrogen so

198
00:10:58,660 --> 00:10:54,110
that I confirmed that I have photo

199
00:11:00,370 --> 00:10:58,670
chemistry going on um this entire thing

200
00:11:03,329 --> 00:11:00,380
can be placed in a water bath hooked to

201
00:11:05,439 --> 00:11:03,339
a chiller for temperature control

202
00:11:06,319 --> 00:11:05,449
because it will heat up it is getting

203
00:11:09,710 --> 00:11:06,329
hit with the power

204
00:11:11,749 --> 00:11:09,720
the sun so and then this is an

205
00:11:15,859 --> 00:11:11,759
interesting this injection in sample

206
00:11:18,679 --> 00:11:15,869
port so mix things up the seawater

207
00:11:22,280 --> 00:11:18,689
separately deoxygenated it and then

208
00:11:24,169 --> 00:11:22,290
inject it in to the chamber ah through

209
00:11:27,199 --> 00:11:24,179
this long skinny tube and you don't even

210
00:11:29,929 --> 00:11:27,209
have to seal it it's so long and thin

211
00:11:31,519 --> 00:11:29,939
that it will take oxygen longer than the

212
00:11:36,049 --> 00:11:31,529
course of the experiment to diffuse down

213
00:11:37,900 --> 00:11:36,059

it but when you want to sample it you

214
00:11:41,210 --> 00:11:37,910
just stick a needle right down in there

215
00:11:44,539 --> 00:11:41,220
it's absolutely genius thank you guys

216
00:11:46,280 --> 00:11:44,549
endeavor for that so I expect some

217
00:11:48,889 --> 00:11:46,290
amount of iron precipitation due to

218
00:11:51,169 --> 00:11:48,899
photooxidation to occur as has been seen

219
00:11:54,350 --> 00:11:51,179
in the simple experiments once i get all

220
00:11:58,269 --> 00:11:54,360
oxygen out more complex solution depends

221
00:12:01,879 --> 00:11:58,279
on speciation and dark reactions

222
00:12:03,769 --> 00:12:01,889
especially like if i add in some organic

223
00:12:06,949 --> 00:12:03,779
carbon that could interact with the iron

224
00:12:09,229 --> 00:12:06,959
so hopefully i'll answer if this can be

225
00:12:10,699 --> 00:12:09,239
made by UV light which would take the

226
00:12:13,189 --> 00:12:10,709
first step in investigating

227
00:12:17,150 --> 00:12:13,199
photooxidation how it might affect our

228
00:12:24,180 --> 00:12:17,160
geochemical oxygen proxies in general so

229
00:12:33,390 --> 00:12:27,150
okay we have time for a few questions

230
00:12:34,830 --> 00:12:33,400
yes great talk you may already know what

231
00:12:37,350 --> 00:12:34,840
questions i'm going to ask because we

232
00:12:39,570 --> 00:12:37,360
briefly discussed at the banquet i'm

233
00:12:41,430 --> 00:12:39,580
interested in actually kind of two

234
00:12:44,070 --> 00:12:41,440
things first off what kind of ph is

235
00:12:46,110 --> 00:12:44,080
you're going to be trying to keep your

236
00:12:47,580 --> 00:12:46,120
solution ette because it definitely

237
00:12:51,540 --> 00:12:47,590
depends you know with microbes

238
00:12:54,050 --> 00:12:51,550

especially are much faster and oxidizing

239
00:12:56,810 --> 00:12:54,060
iron a very low ph s and even oxygen is

240
00:12:59,520 --> 00:12:56,820
and also how you're going to also

241
00:13:03,390 --> 00:12:59,530
sterilize make sure you're not getting

242
00:13:06,080 --> 00:13:03,400
microbes in there um sort of the UV

243
00:13:08,730 --> 00:13:06,090
light sufficient yeah I was for

244
00:13:12,000 --> 00:13:08,740
sterilization I haven't exactly thought

245
00:13:14,840 --> 00:13:12,010
about that but I do wash this with fifty

246
00:13:17,220 --> 00:13:14,850
percent hydrochloric acid in between so

247
00:13:19,860 --> 00:13:17,230
the glassware is acid washed to remove

248
00:13:26,190 --> 00:13:19,870
the iron in between experiments so

249
00:13:29,790 --> 00:13:26,200
that'll get a lot of things out but and

250
00:13:32,850 --> 00:13:29,800
then as for pH the thinking is that

251
00:13:36,600 --> 00:13:32,860
things were relatively neutral back then

252
00:13:39,360 --> 00:13:36,610
um so that's what I'm shooting for um I

253
00:13:40,500 --> 00:13:39,370
actually broke the pH sensor for those

254
00:13:43,890 --> 00:13:40,510
experiments because it's this really

255
00:13:52,520 --> 00:13:43,900
long skinny glass thing um so I don't

256
00:13:58,140 --> 00:13:52,530
have pH data for that but ok question oh

257
00:14:00,300 --> 00:13:58,150
hi so in the archaean ocean when you

258
00:14:03,300 --> 00:14:00,310
precipitate iron you don't get a pure

259
00:14:05,820 --> 00:14:03,310
iron oxide you get an iron silica co

260
00:14:11,070 --> 00:14:05,830
precipitate or gel because the ocean is

261
00:14:13,050 --> 00:14:11,080
super saturated in silica so I saw that

262
00:14:15,780 --> 00:14:13,060
in the complex solutions of Khan hauser

263
00:14:18,270 --> 00:14:15,790

they have silica in that complex

264
00:14:21,329 --> 00:14:18,280
solution but and then the other ones

265
00:14:24,240 --> 00:14:21,339
don't have the silica so I'm wondering

266
00:14:26,460 --> 00:14:24,250
if you've considered the role of silica

267
00:14:28,860 --> 00:14:26,470
and discrepancy between the two and if

268
00:14:31,290 --> 00:14:28,870
you're going to try to model are keen

269
00:14:32,670 --> 00:14:31,300
seawater more with extent that is one

270
00:14:36,950 --> 00:14:32,680
thing that I most definitely want to do

271
00:14:38,390 --> 00:14:36,960
including silica um so I never

272
00:14:41,180 --> 00:14:38,400
we thought about that effect on the

273
00:14:44,300 --> 00:14:41,190
precipitation that you mentioned but

274
00:14:46,370 --> 00:14:44,310
yeah I mean the other experiments didn't

275
00:14:48,500 --> 00:14:46,380
have it so that very well could be a

276
00:14:51,070 --> 00:14:48,510
cause for discrepancy or the other

277
00:14:54,320 --> 00:14:51,080
numerous things that they have different

278
00:14:55,910 --> 00:14:54,330
okay real quick yeah I just saw this in

279
00:14:57,920 --> 00:14:55,920
the question I might have just missed it

280
00:15:00,770 --> 00:14:57,930
but what was the half reaction that you

281
00:15:04,370 --> 00:15:00,780
were making the hydrogen gas uh it was

282
00:15:13,130 --> 00:15:04,380
an electron combining with um h+ in the