



Paul Falkowski

*Keynote: The Origin & Emergence of Global
Coupled Biogeochemical Cycles on a
Planetary Scale*

1
00:00:12,950 --> 00:00:10,430

[Music]

2
00:00:16,310 --> 00:00:12,960

I'll see what I can do to help wrap this

3
00:00:18,050 --> 00:00:16,320

up in a way that is stimulating and yet

4
00:00:20,810 --> 00:00:18,060

a little bit puzzling so I just want to

5
00:00:24,410 --> 00:00:20,820

explain to you that when I was about 10

6
00:00:26,150 --> 00:00:24,420

years old we went on a class trip I was

7
00:00:28,040 --> 00:00:26,160

growing up in New York City we went on a

8
00:00:29,900 --> 00:00:28,050

class trip to the planetarium the Hayden

9
00:00:34,940 --> 00:00:29,910

Planetarium in Museum of Natural History

10
00:00:36,380 --> 00:00:34,950

and I was the first time I was ever in

11
00:00:38,530 --> 00:00:36,390

the planetarium the planetarium was an

12
00:00:42,260 --> 00:00:38,540

incredibly interesting place for me and

13
00:00:45,170 --> 00:00:42,270

the speaker I don't know who it was

14

00:00:47,420 --> 00:00:45,180

wasn't Neil deGrasse Tyson but it was a

15

00:00:50,000 --> 00:00:47,430

very interesting person and he explained

16

00:00:52,250 --> 00:00:50,010

that we have oxygen on earth and to our

17

00:00:54,400 --> 00:00:52,260

knowledge this was the only body in the

18

00:00:57,950 --> 00:00:54,410

solar system that had molecular oxygen

19

00:00:59,390 --> 00:00:57,960

in the atmosphere and I came home and I

20

00:01:01,250 --> 00:00:59,400

thought about this and I explained to my

21

00:01:03,470 --> 00:01:01,260

mother that this is the case and I could

22

00:01:07,190 --> 00:01:03,480

light a match and light a candle here

23

00:01:11,330 --> 00:01:07,200

and I can't do that on Mars and then I

24

00:01:16,160 --> 00:01:11,340

thought naively that some adult is

25

00:01:17,989 --> 00:01:16,170

hiding from me how we make oxygen so I

26

00:01:20,209 --> 00:01:17,999

didn't know how we make oxygen I knew

27

00:01:23,359 --> 00:01:20,219

plants made oxygen so I thought somebody

28

00:01:25,520 --> 00:01:23,369

knows how oxygen is made in a plant it

29

00:01:27,919 --> 00:01:25,530

just that just was a secret that they

30

00:01:31,190 --> 00:01:27,929

were going to keep from me and I thought

31

00:01:34,099 --> 00:01:31,200

maybe when I was 15 this this the secret

32

00:01:37,999 --> 00:01:34,109

would be revealed and then I was 20 and

33

00:01:41,270 --> 00:01:38,009

I thought the secret revealed and then I

34

00:01:45,949 --> 00:01:41,280

realize we don't know the answer to this

35

00:01:47,230 --> 00:01:45,959

day now if you think about that that's

36

00:01:50,599 --> 00:01:47,240

pretty profound

37

00:01:51,859 --> 00:01:50,609

so Shen is working at Okayama University

38

00:01:53,569 --> 00:01:51,869

there are others that are working around

39

00:01:56,929 --> 00:01:53,579

the world trying to understand the

40

00:02:03,050 --> 00:01:56,939

natural process by which organisms have

41

00:02:06,739 --> 00:02:03,060

evolved to split water we don't know how

42

00:02:08,240 --> 00:02:06,749

nitrogen is fixed we don't know so I'm

43

00:02:11,390 --> 00:02:08,250

just saying this to the younger people

44

00:02:14,300 --> 00:02:11,400

in the audience that the fundamental

45

00:02:16,640 --> 00:02:14,310

processes of the catalysis of reactions

46

00:02:21,440 --> 00:02:16,650

that are so critical with a function of

47

00:02:23,450 --> 00:02:21,450

the earth are largely unknown let alone

48

00:02:24,360 --> 00:02:23,460

their evolutionary history so just how

49

00:02:27,059 --> 00:02:24,370

they work

50

00:02:28,850 --> 00:02:27,069

today isn't very one so I want to talk

51
00:02:31,949 --> 00:02:28,860
today a little bit about the origin and

52
00:02:35,190 --> 00:02:31,959
the emergence of coupled biogeochemical

53
00:02:37,440 --> 00:02:35,200
cycles and this is the bridge part that

54
00:02:39,119 --> 00:02:37,450
I look at the origin is on the other

55
00:02:42,750 --> 00:02:39,129
side of the bridge in that that little

56
00:02:45,360 --> 00:02:42,760
island Manhattan obviously and we are

57
00:02:47,430 --> 00:02:45,370
moving out into the rest of the world so

58
00:02:49,440 --> 00:02:47,440
this bridge goes to the rest of the

59
00:02:52,140 --> 00:02:49,450
world this this connects the origin to

60
00:02:53,880 --> 00:02:52,150
the rest of the world and really what I

61
00:02:56,280 --> 00:02:53,890
focus on here let me just go back for

62
00:02:59,789 --> 00:02:56,290
one second before I get there is the

63
00:03:01,470 --> 00:02:59,799

scaffolding right so we can build the

64

00:03:05,150 --> 00:03:01,480

lanes and someone we can ferry things

65

00:03:08,250 --> 00:03:05,160

across but really it's the strings

66

00:03:10,650 --> 00:03:08,260

across the bridge that keep it going and

67

00:03:13,979 --> 00:03:10,660

allow it to say stay suspended and

68

00:03:16,559 --> 00:03:13,989

stable and that's an analogy that I

69

00:03:18,839 --> 00:03:16,569

think is a pretty interesting one let's

70

00:03:20,369 --> 00:03:18,849

start at the beginning so I really like

71

00:03:22,410 --> 00:03:20,379

this plot this is of course the

72

00:03:26,759 --> 00:03:22,420

classical Goldschmidt plot the victor

73

00:03:28,039 --> 00:03:26,769

Goldschmidt was a genius actually uh was

74

00:03:32,009 --> 00:03:28,049

born in Zurich

75

00:03:34,140 --> 00:03:32,019

his parents were Jewish his father was a

76

00:03:41,240 --> 00:03:34,150

chemistry professor and was given a

77

00:03:45,089 --> 00:03:41,250

position in Oslo at around 1895 in 1898

78

00:03:47,520 --> 00:03:45,099

and Viktor who was born in 1888 moved to

79

00:03:50,129 --> 00:03:47,530

Oslo and he actually never really wanted

80

00:03:51,750 --> 00:03:50,139

to ever leave Norway again he was

81

00:03:54,599 --> 00:03:51,760

arrested by the Gestapo during the

82

00:03:59,069 --> 00:03:54,609

Second World War and actually freed by

83

00:04:02,430 --> 00:03:59,079

mi5 and another group of Brits he was

84

00:04:05,250 --> 00:04:02,440

arrested twice and he was taken to

85

00:04:08,940 --> 00:04:05,260

England for safety during the war and

86

00:04:10,800 --> 00:04:08,950

after the war in 1947 I guess he

87

00:04:14,009 --> 00:04:10,810

returned back to us well he didn't wanna

88

00:04:14,909 --> 00:04:14,019

stay meaning but he spent his life as a

89

00:04:18,210 --> 00:04:14,919

mineralogist

90

00:04:20,339 --> 00:04:18,220

and and and tried to understand probably

91

00:04:21,599 --> 00:04:20,349

one of the most profound things which he

92

00:04:23,760 --> 00:04:21,609

didn't understand of course in the

93

00:04:25,770 --> 00:04:23,770

beginning what the distribution of

94

00:04:28,950 --> 00:04:25,780

elements are in in our neck of the

95

00:04:32,610 --> 00:04:28,960

universe and of course we didn't know

96

00:04:33,810 --> 00:04:32,620

about cosmochemistry and we still don't

97

00:04:36,080 --> 00:04:33,820

know a lot of the issues about

98

00:04:40,370 --> 00:04:36,090

cosmochemistry but

99

00:04:42,720 --> 00:04:40,380

this graph were distribution of elements

100

00:04:47,880 --> 00:04:42,730

is an interesting one for several

101
00:04:51,930 --> 00:04:47,890
reasons first of all sorry first of all

102
00:04:56,070 --> 00:04:51,940
there is the primordial BIGBANG element

103
00:04:59,190 --> 00:04:56,080
or elements hydrogen helium and these

104
00:05:01,320 --> 00:04:59,200
two last elements out here uranium and

105
00:05:03,990 --> 00:05:01,330
thorium which with potassium-40

106
00:05:06,420 --> 00:05:04,000
formed the radiogenic core of our planet

107
00:05:09,480 --> 00:05:06,430
and all the rocky planets that we know

108
00:05:11,970 --> 00:05:09,490
of in our solar system but the issue is

109
00:05:14,550 --> 00:05:11,980
here if you think about the energy

110
00:05:19,940 --> 00:05:14,560
sources for life or the energy sources

111
00:05:21,680 --> 00:05:19,950
in aw in the universe we know of two

112
00:05:24,780 --> 00:05:21,690
sorry

113
00:05:26,430 --> 00:05:24,790

one is the fusion reactions that are

114

00:05:31,020 --> 00:05:26,440

coming from these very light isotopes

115

00:05:35,370 --> 00:05:31,030

where hydrogen primarily giving us solar

116

00:05:39,210 --> 00:05:35,380

energy and the other is radioactive

117

00:05:43,080 --> 00:05:39,220

decay within the rocky planet which is

118

00:05:44,790 --> 00:05:43,090

giving us heat so it's interesting that

119

00:05:47,730 --> 00:05:44,800

the extremes of this elemental

120

00:05:50,090 --> 00:05:47,740

distribution are the sources of energy

121

00:05:52,350 --> 00:05:50,100

everything else in the middle is

122

00:05:57,050 --> 00:05:52,360

something that is used as a building

123

00:06:01,409 --> 00:05:57,060

block either for rocks or for lucky

124

00:06:06,330 --> 00:06:01,419

now the second interesting issue here is

125

00:06:07,409 --> 00:06:06,340

obviously the the RS distribution of

126

00:06:09,060 --> 00:06:07,419

elements I'm not going to go through

127

00:06:11,969 --> 00:06:09,070

this in a cosmochemistry world but we

128

00:06:18,030 --> 00:06:11,979

wind up with a very very stable metal

129

00:06:20,370 --> 00:06:18,040

and that's on so iron becomes the most

130

00:06:26,010 --> 00:06:20,380

abundant transition element that we find

131

00:06:29,880 --> 00:06:26,020

cosmically and that's that accident if

132

00:06:32,670 --> 00:06:29,890

you will of nature has led to a lot of

133

00:06:35,460 --> 00:06:32,680

chemistry that is based on in life on

134

00:06:37,770 --> 00:06:35,470

this element now the elements that of

135

00:06:40,430 --> 00:06:37,780

course make up life in the polymer world

136

00:06:45,300 --> 00:06:40,440

is hydrogen carbon nitrogen oxygen

137

00:06:48,270 --> 00:06:45,310

sulfur and phosphorus and so those big

138

00:06:51,680 --> 00:06:48,280

six the schnapps as they're called

139

00:07:00,240 --> 00:06:57,029

those big six elements form all the

140

00:07:02,999 --> 00:07:00,250

polymers of life that we know the lipids

141

00:07:08,400 --> 00:07:03,009

the proteins and nucleic acids the

142

00:07:12,450 --> 00:07:08,410

carbohydrates now within the big six one

143

00:07:13,469 --> 00:07:12,460

is unique and that's phosphorus so

144

00:07:15,870 --> 00:07:13,479

phosphorus

145

00:07:18,089 --> 00:07:15,880

although the fugacity is very very very

146

00:07:22,620 --> 00:07:18,099

low for which you can do reduce the

147

00:07:24,570 --> 00:07:22,630

phosphorus and it can be done for the

148

00:07:29,180 --> 00:07:24,580

most part phosphorus is an oxidized

149

00:07:34,800 --> 00:07:29,190

species as phosphate in nature in rocks

150

00:07:36,689 --> 00:07:34,810

and it doesn't undergo oxidation

151
00:07:41,990 --> 00:07:36,699
reduction reactions for any to any great

152
00:07:45,990 --> 00:07:42,000
extent the other five are in a dance a

153
00:07:47,300 --> 00:07:46,000
great dance of transferring electrons to

154
00:07:50,850 --> 00:07:47,310
and from each other

155
00:07:55,770 --> 00:07:50,860
driven by either thermal energy or solar

156
00:08:02,640 --> 00:07:55,780
energy and that dance has created a

157
00:08:04,589 --> 00:08:02,650
global metabolic pathway which is very

158
00:08:08,670 --> 00:08:04,599
similar to what you will see in a cake

159
00:08:11,100 --> 00:08:08,680
plot for a cell so the entire planet is

160
00:08:11,939 --> 00:08:11,110
basically a big cell and I'll describe

161
00:08:16,020 --> 00:08:11,949
that in a bit

162
00:08:19,620 --> 00:08:16,030
so let's first of all take away one life

163
00:08:21,270 --> 00:08:19,630

is electric this is not a metaphor this

164

00:08:23,640 --> 00:08:21,280

is not a metaphor it's not I'm not

165

00:08:24,600 --> 00:08:23,650

saying electric as a metaphor it is

166

00:08:29,129 --> 00:08:24,610

electric

167

00:08:31,260 --> 00:08:29,139

we're moving electrons around okay so

168

00:08:32,490 --> 00:08:31,270

all organisms are deriving energy for

169

00:08:34,199 --> 00:08:32,500

growth and maintenance by moving

170

00:08:36,120 --> 00:08:34,209

electrons from a substrate to a product

171

00:08:39,209 --> 00:08:36,130

we've witnessed this throughout the

172

00:08:41,310 --> 00:08:39,219

entire last two days and today so it

173

00:08:45,269 --> 00:08:41,320

obviously follows that substrates and

174

00:08:47,819 --> 00:08:45,279

products must be cycled which means

175

00:08:50,310 --> 00:08:47,829

biological processes are paired they're

176

00:08:52,730 --> 00:08:50,320

half cells you're a half cell I'm a half

177

00:09:00,360 --> 00:08:57,720

okay so and we can talk about the

178

00:09:03,060 --> 00:09:00,370

triviality of it and we've seen this in

179

00:09:06,270 --> 00:09:03,070

in several slides of the photos

180

00:09:07,980 --> 00:09:06,280

this is respiration process and we can

181

00:09:09,750 --> 00:09:07,990

talk about photosynthesis in a number of

182

00:09:13,740 --> 00:09:09,760

ways so photosynthesis can drive

183

00:09:16,410 --> 00:09:13,750

electrons off of some molecule in the

184

00:09:17,790 --> 00:09:16,420

case of the most of us sitting here

185

00:09:19,530 --> 00:09:17,800

today we're most familiar with the

186

00:09:23,970 --> 00:09:19,540

photosynthesis driving electrons over

187

00:09:25,800 --> 00:09:23,980

water to produce molecular oxygen and

188

00:09:27,660 --> 00:09:25,810

they drive electrons off and produce

189

00:09:30,720 --> 00:09:27,670

protons they don't drive that electrons

190

00:09:31,340 --> 00:09:30,730

often produce hydrogen you can discuss

191

00:09:35,460 --> 00:09:31,350

that later

192

00:09:37,950 --> 00:09:35,470

but in the early earth and we can see

193

00:09:40,500 --> 00:09:37,960

this in extant metabolism of purple

194

00:09:43,110 --> 00:09:40,510

bacteria for example we can drive

195

00:09:47,520 --> 00:09:43,120

electrons with very simple amounts of

196

00:09:52,820 --> 00:09:47,530

energy off of hydrogen gas or ion - or

197

00:09:55,640 --> 00:09:52,830

h₂s or even carbohydrate so those were

198

00:09:58,740 --> 00:09:55,650

electron sources in the Archaean and

199

00:10:03,930 --> 00:09:58,750

today of course the electron source is

200

00:10:05,210 --> 00:10:03,940

liquid water and liquid water has a

201
00:10:09,330 --> 00:10:05,220
great advantage over the other

202
00:10:12,390 --> 00:10:09,340
substrates as liquid water is readily

203
00:10:16,920 --> 00:10:12,400
vastly available so you don't have to

204
00:10:19,050 --> 00:10:16,930
carry your volcano with you you don't

205
00:10:21,810 --> 00:10:19,060
have to worry about substrate limitation

206
00:10:23,520 --> 00:10:21,820
ever because it's always going to be

207
00:10:25,890 --> 00:10:23,530
available on the surface of the planet

208
00:10:28,860 --> 00:10:25,900
as long as it's just right

209
00:10:30,900 --> 00:10:28,870
we don't boil the water off like we do

210
00:10:34,590 --> 00:10:30,910
in a neighboring planet and we don't

211
00:10:36,690 --> 00:10:34,600
freeze it down so as long as there's

212
00:10:40,140 --> 00:10:36,700
liquid water we have a source of

213
00:10:42,990 --> 00:10:40,150

electrons and then we come to this which

214

00:10:45,390 --> 00:10:43,000

will hair or I believe referred to

215

00:10:46,290 --> 00:10:45,400

earlier and that is this disequilibrium

216

00:10:49,380 --> 00:10:46,300

between

217

00:10:51,060 --> 00:10:49,390

the photosynthetic rate of oxygen ik

218

00:10:53,340 --> 00:10:51,070

photosynthesis which is producing

219

00:10:56,730 --> 00:10:53,350

molecular oxygen and carbohydrate sugar

220

00:10:58,320 --> 00:10:56,740

candy this is candy and the aerobic

221

00:11:00,930 --> 00:10:58,330

respiration that takes the candy and

222

00:11:04,230 --> 00:11:00,940

consumes it back to water in carbon

223

00:11:06,840 --> 00:11:04,240

dioxide which is what we do in the room

224

00:11:09,600 --> 00:11:06,850

so when we're breathing right now two

225

00:11:13,890 --> 00:11:09,610

gases are coming out of our bodies least

226

00:11:16,230 --> 00:11:13,900

from our nose and they are water and

227

00:11:22,470 --> 00:11:16,240

carbon dioxide so the water

228

00:11:26,730 --> 00:11:22,480

is just a water water cycle right that's

229

00:11:31,139 --> 00:11:26,740

that's the planetary upper extreme now

230

00:11:33,240 --> 00:11:31,149

of of the redox couple so obviously

231

00:11:34,769 --> 00:11:33,250

these these can't be balanced on a

232

00:11:37,290 --> 00:11:34,779

planetary scale over geologic time

233

00:11:38,910 --> 00:11:37,300

otherwise we would not have had oxygen

234

00:11:40,680 --> 00:11:38,920

in the atmosphere as we're here said so

235

00:11:42,829 --> 00:11:40,690

let's explain this a little bit more

236

00:11:47,030 --> 00:11:42,839

this is the the water is viewed by

237

00:11:51,360 --> 00:11:47,040

Apollo this is an actual photograph I

238

00:11:53,400 --> 00:11:51,370

love it and here's another interesting

239

00:11:56,449 --> 00:11:53,410

problem so if I took all that water

240

00:12:00,440 --> 00:11:56,459

which is at 73% of Earth's surface

241

00:12:02,100 --> 00:12:00,450

roughly and I roll it up into a ball

242

00:12:05,370 --> 00:12:02,110

that's all it is

243

00:12:10,440 --> 00:12:05,380

it's nothing it's nothing it said being

244

00:12:15,690 --> 00:12:10,450

thin thin thin veneer thin and yet it's

245

00:12:17,269 --> 00:12:15,700

been on the planet for at least 4.4

246

00:12:21,990 --> 00:12:17,279

billion years

247

00:12:24,590 --> 00:12:22,000

it's amazing it's amazing now here's

248

00:12:28,980 --> 00:12:24,600

another thing we don't really understand

249

00:12:32,880 --> 00:12:28,990

where the water came from we don't know

250

00:12:36,389 --> 00:12:32,890

exactly where the water came from it's

251
00:12:38,040 --> 00:12:36,399
probably not cometary water ro-bear in

252
00:12:40,019 --> 00:12:38,050
Paris would tell you that it's probably

253
00:12:43,440 --> 00:12:40,029
meteoritic at least baked based on the D

254
00:12:44,970 --> 00:12:43,450
H Hydra ratios and then Drake would say

255
00:12:47,510 --> 00:12:44,980
of course is the thin wet veneer that

256
00:12:51,449 --> 00:12:47,520
this is just water that has come out as

257
00:12:52,980 --> 00:12:51,459
as The Rock started to cool it begs the

258
00:12:55,560 --> 00:12:52,990
question well how did the rocks get the

259
00:12:57,860 --> 00:12:55,570
water so it's just kind of a panspermia

260
00:13:02,819 --> 00:12:57,870
problem where did the water come from

261
00:13:06,660 --> 00:13:02,829
all right now it takes a lot of energy

262
00:13:17,400 --> 00:13:06,670
to split water at shg it's about 1.2

263
00:13:19,440 --> 00:13:17,410

electron volts at pH 7 it's 0.8 - all

264

00:13:28,180 --> 00:13:19,450

right

265

00:13:32,260 --> 00:13:28,190

now vernadsky Vladimir vernadsky was

266

00:13:39,250 --> 00:13:32,270

another character he was Ukrainian born

267

00:13:41,740 --> 00:13:39,260

in Kiev who was let Goldschmidt he was

268

00:13:43,420 --> 00:13:41,750

an extraordinarily intelligent person

269

00:13:51,639 --> 00:13:43,430

very I mean Goldschmidt I think got his

270

00:13:56,100 --> 00:13:51,649

PhD at 22 or 21 PhD vernadsky went to

271

00:13:59,850 --> 00:13:56,110

Moscow with his family early in his life

272

00:14:03,449 --> 00:13:59,860

lived most of his life in Moscow and

273

00:14:08,470 --> 00:14:03,459

created a field which we call

274

00:14:11,800 --> 00:14:08,480

biogeochemistry he created it he wrote a

275

00:14:17,110 --> 00:14:11,810

book in 1928 which was never translated

276

00:14:21,220 --> 00:14:17,120

into English until 1998 his son George

277

00:14:24,639 --> 00:14:21,230

was a professor of history and Russian

278

00:14:27,310 --> 00:14:24,649

studies at Yale University he made an

279

00:14:29,800 --> 00:14:27,320

asylum leap in France and came to the

280

00:14:31,900 --> 00:14:29,810

United States his father remained

281

00:14:34,300 --> 00:14:31,910

forever in the Soviet Union and was the

282

00:14:40,030 --> 00:14:34,310

father of the atomic bomb in the Soviet

283

00:14:43,300 --> 00:14:40,040

times vernadsky had a perception of of

284

00:14:45,370 --> 00:14:43,310

things that was an intuition of things

285

00:14:47,650 --> 00:14:45,380

which for which he had no proof but was

286

00:14:51,250 --> 00:14:47,660

one of the most profound insights that

287

00:14:54,010 --> 00:14:51,260

he had was that all organisms that are

288

00:14:59,680 --> 00:14:54,020

alive exchanged gases with their

289

00:15:02,110 --> 00:14:59,690

environment that's profound so that

290

00:15:04,269 --> 00:15:02,120

means that if an organism constraint

291

00:15:06,880 --> 00:15:04,279

exchange has to exchange F it's a lot

292

00:15:08,880 --> 00:15:06,890

gases with the environment it can change

293

00:15:14,100 --> 00:15:08,890

the gas composition of a planet and

294

00:15:16,360 --> 00:15:14,110

vernadsky realized this and we use that

295

00:15:20,889 --> 00:15:16,370

subconsciously we don't state it but we

296

00:15:28,660 --> 00:15:20,899

use it subconsciously in our search for

297

00:15:33,250 --> 00:15:28,670

life on exoplanets so the gas exchange

298

00:15:37,870 --> 00:15:33,260

via redox reactions so you're

299

00:15:45,250 --> 00:15:37,880

transforming a solute or a liquid to a

300

00:15:48,070 --> 00:15:45,260

gas phase it's a state transition it's

301
00:15:48,990 --> 00:15:48,080
not just simply gases going in and gases

302
00:15:51,370 --> 00:15:49,000
coming out

303
00:15:53,130 --> 00:15:51,380
there's state transitions we're taking

304
00:16:00,520 --> 00:15:53,140
liquid water and converting it to

305
00:16:02,920 --> 00:16:00,530
protons electrons and owed to gas we're

306
00:16:05,800 --> 00:16:02,930
taking sugar and converting it to carbon

307
00:16:07,990 --> 00:16:05,810
dioxide or in the case of a

308
00:16:10,360 --> 00:16:08,000
photosynthetic organism taking a gas and

309
00:16:17,500 --> 00:16:10,370
converting it to a solute in this case

310
00:16:19,690 --> 00:16:17,510
for example sugar so the core reactions

311
00:16:26,650 --> 00:16:19,700
many of them in the metabolic processes

312
00:16:30,310 --> 00:16:26,660
are related to gas exchanges now if we

313
00:16:31,810 --> 00:16:30,320

start to look at who created metabolism

314

00:16:36,220 --> 00:16:31,820

and where it is today and I'm not going

315

00:16:38,500 --> 00:16:36,230

back to Luca I want to take a look at

316

00:16:40,150 --> 00:16:38,510

extant metabolism and its origins in

317

00:16:42,550 --> 00:16:40,160

some ways but let's let's not worry

318

00:16:45,010 --> 00:16:42,560

about Luca for the moment what we see is

319

00:16:46,960 --> 00:16:45,020

these two main clade sorry I'm going to

320

00:16:50,590 --> 00:16:46,970

go back here to main clades of

321

00:16:53,050 --> 00:16:50,600

prokaryotic organisms the bacteria and

322

00:16:55,870 --> 00:16:53,060

the Archaea which have the ability to

323

00:17:01,450 --> 00:16:55,880

exchange genes as we've heard by viruses

324

00:17:05,200 --> 00:17:01,460

or even by free DNA across in a

325

00:17:10,050 --> 00:17:05,210

horizontal transfer mechanism and so

326

00:17:12,520 --> 00:17:10,060

many metabolisms are scrambled okay and

327

00:17:19,420 --> 00:17:12,530

then we come up to this curious group of

328

00:17:23,050 --> 00:17:19,430

organisms up here eukaryotes and in as

329

00:17:26,830 --> 00:17:23,060

one eukaryote talking to others in the

330

00:17:29,280 --> 00:17:26,840

room frankly eukaryotes are terribly

331

00:17:31,830 --> 00:17:29,290

boring from a metabolic point of view

332

00:17:35,800 --> 00:17:31,840

they didn't create anything

333

00:17:39,810 --> 00:17:35,810

metabolically they're just we are just

334

00:17:43,340 --> 00:17:39,820

big versions of e.coli with less

335

00:17:50,430 --> 00:17:43,350

metabolic flexibility

336

00:17:52,350 --> 00:17:50,440

all right now I just want to take a few

337

00:17:57,200 --> 00:17:52,360

seconds of historical diversion for a

338

00:18:10,110 --> 00:18:08,000

in 1665 charles ii by edict in england

339

00:18:12,390 --> 00:18:10,120

established the Royal Society and why

340

00:18:16,020 --> 00:18:12,400

did he establish the Royal Society well

341

00:18:21,230 --> 00:18:16,030

he went to France and Louie the King

342

00:18:24,060 --> 00:18:21,240

showed him the French Academy and

343

00:18:26,940 --> 00:18:24,070

Charles went back to London and he was

344

00:18:30,080 --> 00:18:26,950

not going to be outdone by the French so

345

00:18:33,720 --> 00:18:30,090

he established the Royal Society and

346

00:18:35,250 --> 00:18:33,730

within the Royal Society there were many

347

00:18:37,110 --> 00:18:35,260

people in the Royal Society at that time

348

00:18:39,960 --> 00:18:37,120

there are not many but I mean members

349

00:18:42,899 --> 00:18:39,970

were not all or the original fellows

350

00:18:45,750 --> 00:18:42,909

were not just scientists so peeps was a

351

00:18:47,279 --> 00:18:45,760

member I believe and so on but one of

352

00:18:50,880 --> 00:18:47,289

them was an interesting character was

353

00:18:52,980 --> 00:18:50,890

Robert Hooke and Robert Hooke was a

354

00:18:55,320 --> 00:18:52,990

porush guy he didn't he didn't come from

355

00:18:59,789 --> 00:18:55,330

great wealth he didn't have a university

356

00:19:03,090 --> 00:18:59,799

position like Newton or so on but he he

357

00:19:06,510 --> 00:19:03,100

wanted to have a microscope and and and

358

00:19:10,380 --> 00:19:06,520

a guy named crock I think it was crock

359

00:19:12,539 --> 00:19:10,390

in London was commissioned to create a

360

00:19:15,149 --> 00:19:12,549

microscope for him and it was a compound

361

00:19:17,520 --> 00:19:15,159

microscope of two lenses and the

362

00:19:19,380 --> 00:19:17,530

spherical aberrations were pretty bad so

363

00:19:21,720 --> 00:19:19,390

you couldn't really get magnification

364

00:19:24,930 --> 00:19:21,730

beyond around twenty to thirty X without

365

00:19:30,990 --> 00:19:24,940

having a lot of fuzz so it didn't work

366

00:19:34,830 --> 00:19:31,000

very well but what he could see were

367

00:19:38,010 --> 00:19:34,840

eyes of fleas or wings of fleas I know a

368

00:19:41,340 --> 00:19:38,020

lot of fleas that he study fleas were

369

00:19:44,279 --> 00:19:41,350

apparently pretty abundant on and other

370

00:19:46,169 --> 00:19:44,289

organisms and he also cut a little

371

00:19:48,810 --> 00:19:46,179

little little little thin section of a

372

00:19:50,610 --> 00:19:48,820

piece of cork and he identified these

373

00:19:52,980 --> 00:19:50,620

little squares within this thin section

374

00:19:55,169 --> 00:19:52,990

which he called cells and that was the

375

00:19:55,890 --> 00:19:55,179

very first identification of what he

376

00:20:00,210 --> 00:19:55,900

called

377

00:20:02,010 --> 00:20:00,220

come down to now to be a cell and the

378

00:20:03,630 --> 00:20:02,020

reason we call that a cell is because

379

00:20:05,880 --> 00:20:03,640

Hooke called it a cell and why did he

380

00:20:09,180 --> 00:20:05,890

call it a cell because it reminded him

381

00:20:12,390 --> 00:20:09,190

of a place in which the monks lived in a

382

00:20:15,630 --> 00:20:12,400

room a cell it looked to him like a son

383

00:20:19,680 --> 00:20:15,640

Noorie now in Holland totally

384

00:20:22,820 --> 00:20:19,690

independently in Delft there was a

385

00:20:27,690 --> 00:20:22,830

fabric merchant named Lewin oak and

386

00:20:29,430 --> 00:20:27,700

Lewin Hooke was also fascinated by what

387

00:20:31,190 --> 00:20:29,440

what he couldn't see now you have to

388

00:20:34,730 --> 00:20:31,200

think about this for a minute

389

00:20:38,660 --> 00:20:34,740

Galileo had already had a telescope so

390

00:20:42,419 --> 00:20:38,670

you can see stars you know they're there

391

00:20:45,299 --> 00:20:42,429

and you just wanted to get them to be

392

00:20:48,930 --> 00:20:45,309

closer to you so you could build optics

393

00:20:51,410 --> 00:20:48,940

that could make things big from

394

00:20:54,120 --> 00:20:51,420

something you already knew existed

395

00:20:55,620 --> 00:20:54,130

now it turned out that Galileo if you

396

00:20:58,919 --> 00:20:55,630

inverted the telescope you had a

397

00:21:01,770 --> 00:20:58,929

microscope and one of his microscope

398

00:21:03,570 --> 00:21:01,780

makers actually made him my telescope

399

00:21:10,530 --> 00:21:03,580

makers made him a microscope which sat

400

00:21:14,610 --> 00:21:10,540

on his desk he was convicted and sent to

401

00:21:18,360 --> 00:21:14,620

house arrest in the Inquisition close to

402

00:21:20,549 --> 00:21:18,370

his daughter Galileo and he never wrote

403

00:21:23,340 --> 00:21:20,559

anything that I know of about any

404

00:21:27,049 --> 00:21:23,350

microscopic observations but we knew how

405

00:21:34,770 --> 00:21:31,230

Lewin Hooke was quite wealthy successful

406

00:21:37,500 --> 00:21:34,780

businessmen and he bought the finest

407

00:21:41,280 --> 00:21:37,510

Venetian glass that he could find and he

408

00:21:43,340 --> 00:21:41,290

pulled it into a little strings and then

409

00:21:47,540 --> 00:21:43,350

he would melt the string into a sphere

410

00:21:51,690 --> 00:21:47,550

and he polished these little spheres

411

00:21:54,000 --> 00:21:51,700

little spheres being two millimeters 2.5

412

00:21:56,280 --> 00:21:54,010

millimeters he couldn't control them

413

00:21:58,740 --> 00:21:56,290

very well but he would polish them and

414

00:22:01,380 --> 00:21:58,750

he never ever gave away the secret even

415

00:22:05,760 --> 00:22:01,390

up until his death of how he polished

416

00:22:08,520 --> 00:22:05,770

these spheres so nobody knew exactly how

417

00:22:09,510 --> 00:22:08,530

he made these lenses and he would put

418

00:22:14,430 --> 00:22:09,520

these lenses

419

00:22:16,500 --> 00:22:14,440

in a very very simple - slab piece of

420

00:22:20,610 --> 00:22:16,510

metal usually made out of copper or

421

00:22:22,919 --> 00:22:20,620

silver and there's the lens and he put a

422

00:22:26,970 --> 00:22:22,929

sample behind it and he would peer

423

00:22:28,799 --> 00:22:26,980

through it usually to a to a candle but

424

00:22:33,990 --> 00:22:28,809

you could also put it up to a diffuse

425

00:22:39,110 --> 00:22:34,000

lie in the in the Sun and he could get

426

00:22:43,530 --> 00:22:39,120

magnification up to 400 X amazing

427

00:22:49,650 --> 00:22:43,540

amazing so he started to write papers

428

00:22:53,549 --> 00:22:49,660

and he sent them to hook in London book

429

00:22:58,020 --> 00:22:53,559

and he never could read any English nor

430

00:22:59,700 --> 00:22:58,030

nope don't know English so Hooke had

431

00:23:05,010 --> 00:22:59,710

these papers translated and then hook

432

00:23:07,980 --> 00:23:05,020

became so fascinated with Iuan hook that

433

00:23:11,549 --> 00:23:07,990

he's taught himself Dutch so he could

434

00:23:13,049 --> 00:23:11,559

translate Iuan hooks papers and Iuan

435

00:23:15,240 --> 00:23:13,059

hooks papers were published in the

436

00:23:19,350 --> 00:23:15,250

philosophical transactions of the Royal

437

00:23:22,049 --> 00:23:19,360

Society and Iuayn hook himself was made

438

00:23:26,880 --> 00:23:22,059

a foreign fellow of the Royal Society he

439

00:23:31,049 --> 00:23:26,890

never went to England he never went when

440

00:23:33,480 --> 00:23:31,059

Lewin hoop died he had already made 500

441

00:23:36,590 --> 00:23:33,490

microscopes of which about 300 were in

442

00:23:39,540 --> 00:23:36,600

his collection his sole surviving

443

00:23:43,380 --> 00:23:39,550

offspring Maria his daughter the others

444

00:23:47,940 --> 00:23:43,390

had all died Maria sold the microscopes

445

00:23:49,830 --> 00:23:47,950

at auction for the price of the metal 4

446

00:23:53,190 --> 00:23:49,840

of the microscopes were given to the

447

00:23:55,380 --> 00:23:53,200

Royal Society as gifts when I was

448

00:23:56,669 --> 00:23:55,390

writing my book life's engines I went to

449

00:24:00,350 --> 00:23:56,679

the Royal Society and I know the

450

00:24:02,790 --> 00:24:00,360

librarian and I asked him if I could see

451
00:24:05,160 --> 00:24:02,800
blue and Hook's microscopes and he comes

452
00:24:07,400 --> 00:24:05,170
back with a box with white gloves and

453
00:24:10,320 --> 00:24:07,410
very gently puts it down on the desk

454
00:24:12,540 --> 00:24:10,330
presents me a pair of white gloves opens

455
00:24:14,580 --> 00:24:12,550
the box takes out the microscope and

456
00:24:17,130 --> 00:24:14,590
gives it to me and I'm looking at it as

457
00:24:19,820 --> 00:24:17,140
fascinating it's fascinating he says

458
00:24:23,389 --> 00:24:19,830
it's a reproduction

459
00:24:26,149 --> 00:24:23,399
what he says well we were given four

460
00:24:29,139 --> 00:24:26,159
and fellows through the years borrowed

461
00:24:31,969 --> 00:24:29,149
them and somehow they've never returned

462
00:24:34,369 --> 00:24:31,979
so there are four microscopes sitting in

463
00:24:38,089 --> 00:24:34,379

London in England somewhere hopefully

464

00:24:40,899 --> 00:24:38,099

still that are the original Lewin hooked

465

00:24:44,089 --> 00:24:40,909

microscopes nobody knows where they are

466

00:24:47,409 --> 00:24:44,099

now what did Lewin look really learn

467

00:24:51,589 --> 00:24:47,419

Lewin hook started to describe cells and

468

00:24:55,849 --> 00:24:51,599

he called them anima cools and I really

469

00:24:58,959 --> 00:24:55,859

like this one down here so the anima

470

00:25:02,149 --> 00:24:58,969

cules were thought to be little animals

471

00:25:05,539 --> 00:25:02,159

they had little brains little stomachs

472

00:25:08,119 --> 00:25:05,549

little livers little sex organs there

473

00:25:11,930 --> 00:25:08,129

were just little miniature versions of

474

00:25:17,119 --> 00:25:11,940

animals but then he realized something

475

00:25:21,320 --> 00:25:17,129

which was really interesting he got a

476

00:25:24,769 --> 00:25:21,330

cold Lewin hook did and he started to

477

00:25:27,529 --> 00:25:24,779

take preparations for this cold so he

478

00:25:29,239 --> 00:25:27,539

would put peppers peppercorns in water

479

00:25:30,919 --> 00:25:29,249

and soak it for a couple of days and

480

00:25:33,950 --> 00:25:30,929

then drink it thinking maybe this would

481

00:25:36,979 --> 00:25:33,960

help him taste the terrible and a few

482

00:25:38,269 --> 00:25:36,989

weeks after he was better he realized

483

00:25:40,579 --> 00:25:38,279

that there was a bottle of this

484

00:25:44,029 --> 00:25:40,589

peppercorn sitting on the shelf and it

485

00:25:45,919 --> 00:25:44,039

was cloudy so he took this cloudy water

486

00:25:48,049 --> 00:25:45,929

and he put it in his microscope and with

487

00:25:50,599 --> 00:25:48,059

the highest magnification lenses he

488

00:25:53,690 --> 00:25:50,609

could see very small things that were

489

00:25:57,139 --> 00:25:53,700

running around like this thousands and

490

00:26:00,320 --> 00:25:57,149

thousands and thousands of them and he

491

00:26:01,759 --> 00:26:00,330

wrote a paper to the Royal Society for

492

00:26:04,789 --> 00:26:01,769

the Philosophical Transactions

493

00:26:08,289 --> 00:26:04,799

describing these ultra small animals the

494

00:26:11,659 --> 00:26:08,299

first description of bacteria

495

00:26:13,279 --> 00:26:11,669

well Hooke hadn't had enough I mean he'd

496

00:26:15,529 --> 00:26:13,289

published several of these papers and

497

00:26:21,529 --> 00:26:15,539

now he's getting this total science

498

00:26:23,810 --> 00:26:21,539

fiction so he sends ten people to Delft

499

00:26:25,879 --> 00:26:23,820

including a vicar you know everybody was

500

00:26:29,810 --> 00:26:25,889

a vicar at the time but he sent a vicar

501
00:26:31,430 --> 00:26:29,820
to actually verify that Lewin Hooke

502
00:26:35,329 --> 00:26:31,440
hadn't been drinking too much or wasn't

503
00:26:36,560 --> 00:26:35,339
making up the story so these guys come

504
00:26:38,450 --> 00:26:36,570
to Delft

505
00:26:42,139 --> 00:26:38,460
they look through the microscope and

506
00:26:45,019 --> 00:26:42,149
they believe what Lewin he'll grow so

507
00:26:47,539 --> 00:26:45,029
new and hooked now as prima facie

508
00:26:49,580 --> 00:26:47,549
evidence and witnesses that there are

509
00:26:52,970 --> 00:26:49,590
these microbial organisms that you could

510
00:26:54,769 --> 00:26:52,980
not see even with a lens where you could

511
00:26:57,200 --> 00:26:54,779
see these kinds of guys they're smaller

512
00:26:58,970 --> 00:26:57,210
much smaller than this and then he does

513
00:27:01,999 --> 00:26:58,980

something even more clever in a way and

514

00:27:05,090 --> 00:27:02,009

I'd like this one he takes an old man

515

00:27:07,549 --> 00:27:05,100

whose teeth are rotting and he swabs the

516

00:27:10,570 --> 00:27:07,559

mouth and he observes there's a

517

00:27:15,950 --> 00:27:10,580

microbial Zoo and in this guy's mouth

518

00:27:18,590 --> 00:27:15,960

with rotten teeth he does the same thing

519

00:27:20,570 --> 00:27:18,600

to himself and he realizes that he also

520

00:27:23,629 --> 00:27:20,580

has a microbial Zoo but not nearly as

521

00:27:26,779 --> 00:27:23,639

bad as the guy with the rotten teeth but

522

00:27:29,810 --> 00:27:26,789

then he drinks a hot cup of coffee and

523

00:27:31,940 --> 00:27:29,820

he does the same thing and he realizes

524

00:27:36,379 --> 00:27:31,950

the microbial Zoo is virtually dead from

525

00:27:38,810 --> 00:27:36,389

the hot coffee so is the first time that

526

00:27:41,840 --> 00:27:38,820

we start to realize that microbes could

527

00:27:43,310 --> 00:27:41,850

be killed by heat and we could go on and

528

00:27:45,019 --> 00:27:43,320

on with spontaneous generation I just

529

00:27:50,350 --> 00:27:45,029

want to talk to you for one second and

530

00:27:56,180 --> 00:27:54,860

created by hook we still can't make one

531

00:28:06,230 --> 00:27:56,190

we still don't know how were they're

532

00:28:08,570 --> 00:28:06,240

made it's really amazing to me so I'm

533

00:28:11,090 --> 00:28:08,580

just pointing this out because we can

534

00:28:13,190 --> 00:28:11,100

talk about Luca we can talk about a lot

535

00:28:16,490 --> 00:28:13,200

of things but there are a lot of very

536

00:28:19,340 --> 00:28:16,500

very simple quote simple problems that

537

00:28:21,080 --> 00:28:19,350

are challenging so I want to up for a

538

00:28:22,070 --> 00:28:21,090

little bit now about what's inside the

539

00:28:26,210 --> 00:28:22,080

cells I'm going to look under the hood

540

00:28:30,259 --> 00:28:26,220

for a second with you and I spent most

541

00:28:32,149 --> 00:28:30,269

of my career trying to do this and I

542

00:28:33,830 --> 00:28:32,159

focused on this machine because I've

543

00:28:36,409 --> 00:28:33,840

spent most of my career working on that

544

00:28:40,519 --> 00:28:36,419

machine so I first started working on

545

00:28:42,320 --> 00:28:40,529

this part of the machine oops sorry this

546

00:28:43,879 --> 00:28:42,330

part of the machine photosystem one and

547

00:28:45,139 --> 00:28:43,889

I've spent the last 20 or so years

548

00:28:47,299 --> 00:28:45,149

working on this part of the machine

549

00:28:50,360 --> 00:28:47,309

photosystem 2 and this is the water

550

00:28:51,410 --> 00:28:50,370

splitting business end of the machine

551
00:28:57,940 --> 00:28:51,420
I don't want to go through the whole

552
00:29:04,250 --> 00:28:57,950
story here so basically Eric this is

553
00:29:07,640 --> 00:29:04,260
this is a bifurcating system we split

554
00:29:11,240 --> 00:29:07,650
the water the protons go here the

555
00:29:13,280 --> 00:29:11,250
electrons go there we pump some more

556
00:29:14,840 --> 00:29:13,290
protons the electrons go to pump some

557
00:29:16,930 --> 00:29:14,850
more protons the protons finally go up

558
00:29:19,750 --> 00:29:16,940
there the electron winds up here and

559
00:29:23,860 --> 00:29:19,760
then the protons and electrons meet in

560
00:29:27,169 --> 00:29:23,870
NADPH so we always have this couple

561
00:29:28,790 --> 00:29:27,179
proton electron proton electron proton

562
00:29:32,419 --> 00:29:28,800
electron proton electron that's why

563
00:29:35,110 --> 00:29:32,429

every single electron transfer chain is

564

00:29:39,919 --> 00:29:35,120

working in all of life

565

00:29:42,260 --> 00:29:39,929

what do you why do we do that we do that

566

00:29:43,760 --> 00:29:42,270

because if a bug is making hydrogen it's

567

00:29:45,470 --> 00:29:43,770

screwed if it makes hydrogen the

568

00:29:47,090 --> 00:29:45,480

hydrogen just pops right out of the cell

569

00:29:49,520 --> 00:29:47,100

you can't do a damn thing with it you

570

00:29:51,500 --> 00:29:49,530

keep the hydrogen as protons and

571

00:29:56,600 --> 00:29:51,510

electrons and you can manipulate the

572

00:29:58,010 --> 00:29:56,610

protons and electrons all right I'm not

573

00:29:59,900 --> 00:29:58,020

going to go through the whirligig here

574

00:30:03,140 --> 00:29:59,910

but I want to point out one thing this

575

00:30:04,610 --> 00:30:03,150

is the reaction center as a few years

576

00:30:06,260 --> 00:30:04,620

ago I left this structure here because

577

00:30:10,640 --> 00:30:06,270

it's simple to see this is a ribbon

578

00:30:13,220 --> 00:30:10,650

structure about three years ago Shannon

579

00:30:14,690 --> 00:30:13,230

Okayama University published another we

580

00:30:15,710 --> 00:30:14,700

every year we get a little bit better a

581

00:30:17,870 --> 00:30:15,720

little bit better a little bit better

582

00:30:19,850 --> 00:30:17,880

Shannon is but probably the best in the

583

00:30:21,200 --> 00:30:19,860

world at this now is one of he's been

584

00:30:23,840 --> 00:30:21,210

obsessed with this since he came to

585

00:30:31,490 --> 00:30:23,850

Japan to Renkin I didn't know 2530 years

586

00:30:34,130 --> 00:30:31,500

ago the structures at now about 1.9

587

00:30:37,549 --> 00:30:34,140

angstroms resolution a very very very

588

00:30:39,980 --> 00:30:37,559

high resolution and we know there's a

589

00:30:41,210 --> 00:30:39,990

business end of this structure we know

590

00:30:45,049 --> 00:30:41,220

there are several parts of this

591

00:30:47,210 --> 00:30:45,059

structure that we can trace so this part

592

00:30:49,070 --> 00:30:47,220

of the structure is coming from purple

593

00:30:51,110 --> 00:30:49,080

bacteria and we know there are four

594

00:30:52,910 --> 00:30:51,120

manganese atoms that are sitting at the

595

00:30:54,110 --> 00:30:52,920

bottom end of the structure that are the

596

00:31:00,320 --> 00:30:54,120

business-end that are splitting the

597

00:31:05,300 --> 00:31:00,330

water now

598

00:31:12,840 --> 00:31:08,490

those four manganese atoms are not found

599

00:31:20,430 --> 00:31:12,850

in any known mineral nature made a

600

00:31:23,070 --> 00:31:20,440

mineral there are 31 manganese

601
00:31:25,590 --> 00:31:23,080
containing minerals that I know of that

602
00:31:30,540 --> 00:31:25,600
Bob downs tells me have a cubane

603
00:31:32,610 --> 00:31:30,550
structure of manganese but not with a

604
00:31:34,350 --> 00:31:32,620
calcium and not in that configuration

605
00:31:39,690 --> 00:31:34,360
and they can't split water than I know

606
00:31:42,390 --> 00:31:39,700
of now they're found in bacteria so they

607
00:31:44,010 --> 00:31:42,400
evolved in cyanobacteria once and then

608
00:31:45,930 --> 00:31:44,020
they were spread across many clades so

609
00:31:47,640 --> 00:31:45,940
this is a diatom this is a Kaka Luthor

610
00:31:50,460 --> 00:31:47,650
for and of course they became higher

611
00:31:53,040 --> 00:31:50,470
plants so this is all higher land plants

612
00:31:55,500 --> 00:31:53,050
right there and you could see that

613
00:31:57,780 --> 00:31:55,510

they're distributed on many many many

614

00:32:00,150 --> 00:31:57,790

eukaryotic lineages but only one

615

00:32:03,840 --> 00:32:00,160

prokaryotic lineages is capable of

616

00:32:06,330 --> 00:32:03,850

putting water extant so this is

617

00:32:08,520 --> 00:32:06,340

horizontal gene transfer in a massive

618

00:32:10,170 --> 00:32:08,530

way we call it endosymbiosis it's

619

00:32:11,790 --> 00:32:10,180

basically another fancy term for

620

00:32:13,530 --> 00:32:11,800

horizontal gene transfer

621

00:32:21,990 --> 00:32:13,540

instead of taking three genes or five

622

00:32:25,890 --> 00:32:22,000

genes you're taking 140 genes and of

623

00:32:28,380 --> 00:32:25,900

course on a global scale we have great

624

00:32:33,330 --> 00:32:28,390

satellite images and I've spent a large

625

00:32:38,970 --> 00:32:33,340

portion of my career working on this so

626

00:32:41,130 --> 00:32:38,980

this is what these things do today so

627

00:32:43,710 --> 00:32:41,140

these are actually obviously satellite

628

00:32:46,200 --> 00:32:43,720

images in false color but but you could

629

00:32:48,390 --> 00:32:46,210

see on land and in the ocean these guys

630

00:32:56,370 --> 00:32:48,400

become the major engine of life on the

631

00:32:58,290 --> 00:32:56,380

planet and as roll hare said a little

632

00:32:59,550 --> 00:32:58,300

bit of that sinks but now I want to get

633

00:33:00,800 --> 00:32:59,560

into something a little bit more

634

00:33:03,780 --> 00:33:00,810

profound

635

00:33:05,190 --> 00:33:03,790

it doesn't just sink everywhere I mean

636

00:33:07,170 --> 00:33:05,200

it does sink everywhere but it doesn't

637

00:33:09,930 --> 00:33:07,180

matter if it sinks in the middle of the

638

00:33:12,000 --> 00:33:09,940

deep ocean it's not going to get into

639

00:33:13,210 --> 00:33:12,010

the sediments of the deep ocean it gets

640

00:33:17,350 --> 00:33:13,220

oxidized before it get

641

00:33:19,060 --> 00:33:17,360

there it's shallow seas and continental

642

00:33:27,669 --> 00:33:19,070

margins where this organic matter

643

00:33:32,730 --> 00:33:27,679

originally gets to positive and because

644

00:33:35,230 --> 00:33:32,740

of the Wilson cycle which Everett

645

00:33:38,080 --> 00:33:35,240

alluded to but didn't really describe in

646

00:33:39,880 --> 00:33:38,090

in this sense that was that Wilson

647

00:33:43,060 --> 00:33:39,890

really thought this through quite

648

00:33:48,370 --> 00:33:43,070

interestingly so this stable crate on

649

00:33:53,529 --> 00:33:48,380

which is the accumulated bit of light

650

00:33:56,169 --> 00:33:53,539

rock floats and it's very thick so it's

651
00:33:58,120 --> 00:33:56,179
heat conduction is very weak whereas the

652
00:33:59,980 --> 00:33:58,130
thin little bit of basalt out here gets

653
00:34:01,810 --> 00:33:59,990
heat can go through it pretty early so

654
00:34:04,149 --> 00:34:01,820
if I put a candle under here the

655
00:34:06,640 --> 00:34:04,159
Archimedes principle in the candle I can

656
00:34:09,760 --> 00:34:06,650
break this in principle this is the idea

657
00:34:12,629 --> 00:34:09,770
and then we start to fill in the gap by

658
00:34:18,060 --> 00:34:12,639
making more basalt and pushing these two

659
00:34:22,270 --> 00:34:18,070
bits of kraton away now here's the gig

660
00:34:25,119 --> 00:34:22,280
at some point when that basalt becomes

661
00:34:28,540 --> 00:34:25,129
cooler and heavier it's going to subduct

662
00:34:30,369 --> 00:34:28,550
so this is the Atlantic Ocean today now

663
00:34:33,609 --> 00:34:30,379

it turns out that California is not

664

00:34:35,829 --> 00:34:33,619

going to bump into Japan it's going to

665

00:34:38,980 --> 00:34:35,839

go back and bump into France or at least

666

00:34:40,780 --> 00:34:38,990

you New Yorker bump into France so we'll

667

00:34:45,250 --> 00:34:40,790

have American fries will become french

668

00:34:46,960 --> 00:34:45,260

fries again that little bit of organic

669

00:34:50,500 --> 00:34:46,970

matter that is on continental shelves

670

00:34:57,480 --> 00:34:50,510

will be shaved off and uplifted onto the

671

00:35:00,190 --> 00:34:57,490

crate on if it just stayed in the ocean

672

00:35:02,430 --> 00:35:00,200

we would not have appreciable amounts of

673

00:35:05,920 --> 00:35:02,440

oxygen it would be subducted and burned

674

00:35:09,010 --> 00:35:05,930

you have to get it out of the cycle you

675

00:35:11,770 --> 00:35:09,020

lift it up onto the crate on so where

676

00:35:15,460 --> 00:35:11,780

does the candy get hidden the lockbox of

677

00:35:17,770 --> 00:35:15,470

the candy is in rocks so here's an

678

00:35:20,530 --> 00:35:17,780

example a very dramatic example from

679

00:35:22,420 --> 00:35:20,540

Spain this is my former postdoc vashvan

680

00:35:24,520 --> 00:35:22,430

shortened brook and we were working on

681

00:35:27,040 --> 00:35:24,530

this sequence here this is a very nice

682

00:35:28,230 --> 00:35:27,050

sequence but these are black shales mud

683

00:35:32,710 --> 00:35:28,240

stones black shells they've become

684

00:35:37,690 --> 00:35:32,720

repositories on land of the reducing

685

00:35:39,460 --> 00:35:37,700

equivalents allowing the oxygen now for

686

00:35:42,060 --> 00:35:39,470

those of you who are students I'm going

687

00:35:45,100 --> 00:35:42,070

to give you a little puzzler

688

00:35:47,980 --> 00:35:45,110

there's 21% oxygen by mass in the

689

00:35:50,260 --> 00:35:47,990

atmosphere if I converted it back to

690

00:35:51,790 --> 00:35:50,270

water got rid of all the oxygen the

691

00:35:56,400 --> 00:35:51,800

atmosphere converted it back to water

692

00:36:01,840 --> 00:35:56,410

how high were the sea level rise okay

693

00:36:04,900 --> 00:36:01,850

just you can do that now we went through

694

00:36:07,030 --> 00:36:04,910

this so we go from this first half of

695

00:36:09,040 --> 00:36:07,040

Earth's history we're reduced then we

696

00:36:11,080 --> 00:36:09,050

have some oxidation event so the

697

00:36:13,480 --> 00:36:11,090

oxidation event is not just simply

698

00:36:15,190 --> 00:36:13,490

because of the evolution of that for

699

00:36:18,190 --> 00:36:15,200

manganese cluster at the bottom of

700

00:36:21,400 --> 00:36:18,200

photosystem 2 it's also the ability to

701
00:36:27,520 --> 00:36:21,410
bury and store that organic matter and

702
00:36:31,390 --> 00:36:27,530
take it out of this cycle so the first

703
00:36:35,380 --> 00:36:31,400
half of Earth's history we have a

704
00:36:39,610 --> 00:36:35,390
relatively stable condition and somehow

705
00:36:43,000 --> 00:36:39,620
and I don't know exactly how the ball

706
00:36:46,770 --> 00:36:43,010
flipped into a second Bowl and it's

707
00:36:51,820 --> 00:36:46,780
stable again and we're not going back

708
00:36:57,490 --> 00:36:51,830
we're not going back it's directional so

709
00:36:59,170 --> 00:36:57,500
it's a two-state problem now several

710
00:37:00,700 --> 00:36:59,180
years ago and this is the meat of the

711
00:37:02,680 --> 00:37:00,710
paper or the meat of the talk

712
00:37:06,520 --> 00:37:02,690
it's an old paper but it's still a meat

713
00:37:08,500 --> 00:37:06,530

of the talk Tom pencil and Ed's along

714

00:37:10,810 --> 00:37:08,510

and I sat down with Tom for a long time

715

00:37:14,320 --> 00:37:10,820

and in in my office and I said you know

716

00:37:18,160 --> 00:37:14,330

I really want to draw the wiring diagram

717

00:37:20,020 --> 00:37:18,170

of the planet and this is the wiring

718

00:37:21,700 --> 00:37:20,030

we've left out a few things I didn't put

719

00:37:24,370 --> 00:37:21,710

arson a terse eliminated and stuff in

720

00:37:26,620 --> 00:37:24,380

here this is kind of secondary we put in

721

00:37:28,630 --> 00:37:26,630

the major wiring diagrams of the planet

722

00:37:31,630 --> 00:37:28,640

so this is the electron this is The Keg

723

00:37:33,850 --> 00:37:31,640

diagram if you will with just the wires

724

00:37:36,160 --> 00:37:33,860

okay so this is the metabolic map of

725

00:37:37,840 --> 00:37:36,170

planet Earth and it may look a little

726

00:37:40,329 --> 00:37:37,850

bit like this actually this is a little

727

00:37:45,219 --> 00:37:40,339

simpler to follow than the one I drew

728

00:37:48,069 --> 00:37:45,229

showed you but I asked my graduate

729

00:37:52,479 --> 00:37:48,079

student Ben Yellen a few years ago to

730

00:37:55,329 --> 00:37:52,489

annotate that map and if you take away

731

00:37:58,870 --> 00:37:55,339

all the orthologues and paralogs what

732

00:38:03,509 --> 00:37:58,880

you get is 392 genes that move all the

733

00:38:09,420 --> 00:38:03,519

electrons all around all of Earth only

734

00:38:13,870 --> 00:38:09,430

392 genes that's not a lot

735

00:38:16,620 --> 00:38:13,880

now those 392 genes are responsible for

736

00:38:21,609 --> 00:38:16,630

all of this type of metabolism all of it

737

00:38:24,549 --> 00:38:21,619

and you might not be surprised but those

738

00:38:26,650 --> 00:38:24,559

oxido reductase is 45% of the oxido

739

00:38:30,459 --> 00:38:26,660

reductase is contain transition metals

740

00:38:32,769 --> 00:38:30,469

and while zinc is a transition metal

741

00:38:34,719 --> 00:38:32,779

it's not found in the oxido reductase is

742

00:38:37,150 --> 00:38:34,729

so the transition metals of zinc zinc

743

00:38:37,680 --> 00:38:37,160

actually can be oxidized obviously zinc

744

00:38:40,180 --> 00:38:37,690

too

745

00:38:42,249 --> 00:38:40,190

but those electrons are not coming from

746

00:38:44,140 --> 00:38:42,259

the normal shells of the transition

747

00:38:50,829 --> 00:38:44,150

metals this is acting more like calcium

748

00:38:52,839 --> 00:38:50,839

or magnesium so I'm going to go into

749

00:38:54,969 --> 00:38:52,849

this I'm going to focus on the sequences

750

00:38:56,890 --> 00:38:54,979

and folds for a second the evolution of

751

00:39:00,130 --> 00:38:56,900

these structures is what we've been

752

00:39:01,450 --> 00:39:00,140

working on with Vic for years and the

753

00:39:03,430 --> 00:39:01,460

paradox of structure and sequence

754

00:39:05,620 --> 00:39:03,440

diversion is one that I want to not

755

00:39:08,079 --> 00:39:05,630

dwell on we can talk about it later

756

00:39:10,180 --> 00:39:08,089

but I really think that this from this

757

00:39:12,219 --> 00:39:10,190

is a throwaway line from from from

758

00:39:14,650 --> 00:39:12,229

Margaret Dayhoff spay / that was been

759

00:39:16,709 --> 00:39:14,660

cited a couple of times now from 1966

760

00:39:19,809 --> 00:39:16,719

the processes of natural selection

761

00:39:22,059 --> 00:39:19,819

severely inhibit any change in a well

762

00:39:24,819 --> 00:39:22,069

adapted system on which several other

763

00:39:27,279 --> 00:39:24,829

essential components depend and that's

764

00:39:29,589 --> 00:39:27,289

why you don't see massive changes in

765

00:39:31,959 --> 00:39:29,599

Rubisco evolution massive changes in

766

00:39:39,950 --> 00:39:31,969

nitrogenous evolution massive changes in

767

00:39:42,349 --> 00:39:39,960

d1 evolution now I think about

768

00:39:44,390 --> 00:39:42,359

from a point of view one you know I went

769

00:39:46,700 --> 00:39:44,400

to a Technical High School I was trained

770

00:39:48,440 --> 00:39:46,710

in engineering and so electrical

771

00:39:50,420 --> 00:39:48,450

engineering you know we all think about

772

00:39:52,310 --> 00:39:50,430

circuit diagrams so I think about just

773

00:39:54,260 --> 00:39:52,320

think about the analogy of the planet of

774

00:39:56,990 --> 00:39:54,270

the surface of the planet as a circuit

775

00:39:59,810 --> 00:39:57,000

board so you have a power supply one

776

00:40:04,849 --> 00:39:59,820

major power supply the Sun you have two

777

00:40:07,190 --> 00:40:04,859

wires the ocean and the atmosphere those

778

00:40:08,839 --> 00:40:07,200

are the two wires and then everything

779

00:40:11,450 --> 00:40:08,849

else on the planet that is moving

780

00:40:13,609 --> 00:40:11,460

electrons is basically is alive there's

781

00:40:15,710 --> 00:40:13,619

some exceptions but mostly they're alive

782

00:40:19,070 --> 00:40:15,720

so these are organisms that are acting

783

00:40:23,030 --> 00:40:19,080

primarily as transistors moving

784

00:40:25,370 --> 00:40:23,040

electrons well alright let's follow that

785

00:40:28,160 --> 00:40:25,380

analogy for a bit what's in what's

786

00:40:31,280 --> 00:40:28,170

doping those transistors well not

787

00:40:32,930 --> 00:40:31,290

surprisingly of the 45% of the oxido

788

00:40:36,109 --> 00:40:32,940

reductase --is that contain transition

789

00:40:45,109 --> 00:40:36,119

metals the other 55% contained nadh or

790

00:40:47,720 --> 00:40:45,119

fadh₂ the electrons the vast majority of

791

00:40:52,160 --> 00:40:47,730

them contain iron as either iron or iron

792

00:40:54,260 --> 00:40:52,170

sulphur or he there's copper manganese

793

00:40:56,120 --> 00:40:54,270

nickel a little bit of molybdenum and

794

00:41:00,440 --> 00:40:56,130

then you have a little bit of cobalt and

795

00:41:03,050 --> 00:41:00,450

blah blah so the biggies are iron copper

796

00:41:05,900 --> 00:41:03,060

manganese a little bit of nickel a

797

00:41:08,060 --> 00:41:05,910

little bit of molybdenum and of course

798

00:41:11,780 --> 00:41:08,070

then we've looked at these folds so so

799

00:41:13,609 --> 00:41:11,790

this is the classic ferredoxin fold the

800

00:41:15,290 --> 00:41:13,619

sistine coordinated for cysteine is

801

00:41:17,660 --> 00:41:15,300

coordinated with the cysteine x axis

802

00:41:19,040 --> 00:41:17,670

teen XX cysteine xx and then you go on

803

00:41:23,329 --> 00:41:19,050

to the fourth cysteine wrapping it

804

00:41:26,510 --> 00:41:23,339

around and that fold you can see is is

805

00:41:28,070 --> 00:41:26,520

is everywhere when you have iron sulfur

806

00:41:30,200 --> 00:41:28,080

clusters and I just want to point out

807

00:41:32,240 --> 00:41:30,210

for those of you that are not molecular

808

00:41:34,940 --> 00:41:32,250

structural biologists you can see all

809

00:41:39,770 --> 00:41:34,950

three secondary structures here so this

810

00:41:45,410 --> 00:41:39,780

is a sheet a loop of the loop here and a

811

00:41:48,109 --> 00:41:45,420

helix now this is nitrogenase and I

812

00:41:53,570 --> 00:41:48,119

would argue the first order this is a

813

00:41:56,240 --> 00:41:53,580

super paradox type of fold

814

00:41:58,160 --> 00:41:56,250

and then we have other kinds of folds

815

00:42:00,800 --> 00:41:58,170

imidazole nitrogen z' that are

816

00:42:03,320 --> 00:42:00,810

coordinated to copper plus the sign and

817

00:42:05,390 --> 00:42:03,330

type of fold and the manganese fold for

818

00:42:08,570 --> 00:42:05,400

example into oxide super oxide dismutase

819

00:42:12,260 --> 00:42:08,580

and as Vic was explaining yesterday we

820

00:42:15,110 --> 00:42:12,270

have tried to do a molecular autopsy if

821

00:42:17,000 --> 00:42:15,120

you will a structural autopsy huh guys

822

00:42:19,810 --> 00:42:17,010

have been doing this with Vic and and

823

00:42:22,160 --> 00:42:19,820

Doug Pike and I think a yeoman's job and

824

00:42:24,770 --> 00:42:22,170

coming out with this network of the

825

00:42:27,500 --> 00:42:24,780

major folds of the metal containing

826

00:42:29,000 --> 00:42:27,510

proteins that are moving electrons all

827

00:42:31,610 --> 00:42:29,010

across the Tree of Life and there are

828

00:42:33,800 --> 00:42:31,620

these four so similar in we have the

829

00:42:36,170 --> 00:42:33,810

ferredoxin fold the cytochrome c fold

830

00:42:37,760 --> 00:42:36,180

this is the heme and then a ferry dock I

831

00:42:41,510 --> 00:42:37,770

mean a clasp design and for containing

832

00:42:44,360 --> 00:42:41,520

the copper no I don't know the real

833

00:42:46,460 --> 00:42:44,370

number but there appear to be I think

834

00:42:49,430 --> 00:42:46,470

there will be about twelve or so maybe

835

00:42:51,140 --> 00:42:49,440

fifteen core structural motifs and all

836

00:42:58,420 --> 00:42:51,150

the electron proton transfer reactions

837

00:43:02,630 --> 00:43:00,980

now deciphering one of the things we're

838

00:43:04,220 --> 00:43:02,640

trying to do I call it a grand challenge

839

00:43:08,960 --> 00:43:04,230

this is a grand challenge because we're

840

00:43:11,840 --> 00:43:08,970

trying to figure out how these are

841

00:43:14,030 --> 00:43:11,850

little little tiny bits of the proteins

842

00:43:16,930 --> 00:43:14,040

the extant proteins probably moved

843

00:43:21,710 --> 00:43:16,940

electrons around early on to create

844

00:43:25,340 --> 00:43:21,720

metabolism not of a cell per se but in a

845

00:43:28,390 --> 00:43:25,350

global sense and here's something that's

846

00:43:32,390 --> 00:43:28,400

old but new and I think about it a lot

847

00:43:36,050 --> 00:43:32,400

so and John Kim who was a PhD student

848

00:43:40,430 --> 00:43:36,060

with us at the time he arranged all at

849

00:43:43,580 --> 00:43:40,440

that time the major metal containing

850

00:43:45,890 --> 00:43:43,590

proteins into this isosceles triangle of

851
00:43:49,310 --> 00:43:45,900
a hundred percent sheet 100 percent loop

852
00:43:50,900 --> 00:43:49,320
or a hundred percent helix and one you

853
00:43:53,240 --> 00:43:50,910
could do that you can make a Euclidean

854
00:43:56,120 --> 00:43:53,250
vector from point to point to point and

855
00:43:59,000 --> 00:43:56,130
develop a tree and before we do that by

856
00:44:01,790 --> 00:43:59,010
the by this is if you're obviously a

857
00:44:03,980 --> 00:44:01,800
loop you're sitting here you have very

858
00:44:06,440 --> 00:44:03,990
very few hydrogen bonds you're very

859
00:44:07,310 --> 00:44:06,450
floppy and flexible when you get down to

860
00:44:14,060 --> 00:44:07,320
of

861
00:44:16,580 --> 00:44:14,070
a sheet very very very sheet if you will

862
00:44:18,920 --> 00:44:16,590
or very very very helix e if you will

863
00:44:21,530 --> 00:44:18,930

you're pretty stiff a lot of hydrogen

864

00:44:24,680 --> 00:44:21,540

bonds so if you're thinking about

865

00:44:27,260 --> 00:44:24,690

promiscuity of electrons moving through

866

00:44:34,190 --> 00:44:27,270

something you're more promiscuous here

867

00:44:38,210 --> 00:44:34,200

you're less promiscuous here all right

868

00:44:43,420 --> 00:44:38,220

and this is a secondary structural tree

869

00:44:48,530 --> 00:44:43,430

of these proteins so here you can see

870

00:44:52,100 --> 00:44:48,540

that some of the earliest protein folds

871

00:44:57,260 --> 00:44:52,110

are in an iron hydrogenous they're very

872

00:45:01,640 --> 00:44:57,270

close to the ferredoxin fold and we walk

873

00:45:05,510 --> 00:45:01,650

down and walk down and walk down and one

874

00:45:09,200 --> 00:45:05,520

of the last structures to evolve or at

875

00:45:12,820 --> 00:45:09,210

least in terms of complexity in the

876

00:45:15,230 --> 00:45:12,830

helix clade is the cytochrome C oxidase

877

00:45:18,290 --> 00:45:15,240

that's the enzyme that is allowing you

878

00:45:26,350 --> 00:45:18,300

to put the electrons onto oxygen to make

879

00:45:28,910 --> 00:45:26,360

water and it contains copper now today

880

00:45:30,590 --> 00:45:28,920

you know almost all these electron

881

00:45:34,220 --> 00:45:30,600

transfer reactions are driven by light

882

00:45:38,980 --> 00:45:34,230

not by heat and I just want to point

883

00:45:42,710 --> 00:45:38,990

this out because here's where we have a

884

00:45:45,710 --> 00:45:42,720

stone that is really missing in my head

885

00:45:48,350 --> 00:45:45,720

and we're working on this and I don't

886

00:45:50,270 --> 00:45:48,360

know if I'm going to see a solution to

887

00:45:55,700 --> 00:45:50,280

this in my lifetime but let's just think

888

00:45:57,200 --> 00:45:55,710

about this for a minute this is a solar

889

00:46:02,810 --> 00:45:57,210

energy at the top of the atmosphere and

890

00:46:08,380 --> 00:46:02,820

these lines by the way is that noise is

891

00:46:11,150 --> 00:46:08,390

that noise it's not noise what is that

892

00:46:13,370 --> 00:46:11,160

why are those lines there huh their

893

00:46:16,220 --> 00:46:13,380

absorption but what do we call it what's

894

00:46:18,290 --> 00:46:16,230

the Fraunhofer lines right so you're

895

00:46:19,760 --> 00:46:18,300

looking you're looking now at elements

896

00:46:21,019 --> 00:46:19,770

on the corona of the Sun that are

897

00:46:23,120 --> 00:46:21,029

absorbing in

898

00:46:24,439 --> 00:46:23,130

lines right they're not bands because

899

00:46:26,779 --> 00:46:24,449

they're not molecules they're elements

900

00:46:31,009 --> 00:46:26,789

that are absorbing in lines this is how

901
00:46:34,009 --> 00:46:31,019
we develop quantum mechanics they're

902
00:46:38,809 --> 00:46:34,019
quantized now at the top of the

903
00:46:42,079 --> 00:46:38,819
atmosphere today whoops there's a lot of

904
00:46:44,329 --> 00:46:42,089
UV light that is attenuated by ozone but

905
00:46:46,640 --> 00:46:44,339
in the Archaean we didn't have ozone we

906
00:46:47,949 --> 00:46:46,650
think so this light would have reached

907
00:46:51,380 --> 00:46:47,959
the surface of the planet

908
00:46:52,429 --> 00:46:51,390
now ozone when it attenuates the light

909
00:46:56,149 --> 00:46:52,439
cut that out

910
00:46:58,069 --> 00:46:56,159
but up until the great oxidation event

911
00:47:00,469 --> 00:46:58,079
which is how we actually define it from

912
00:47:02,469 --> 00:47:00,479
the mass independent to mass dependent

913
00:47:05,509 --> 00:47:02,479

sulphur isotope fractionation which is

914

00:47:11,539 --> 00:47:05,519

apparently due to the evolution of ozone

915

00:47:12,979 --> 00:47:11,549

itself this UV light would have hit the

916

00:47:16,880 --> 00:47:12,989

surface of the earth now I just want to

917

00:47:18,919 --> 00:47:16,890

point out it one more thing it is

918

00:47:21,739 --> 00:47:18,929

commonly thought that UV light is highly

919

00:47:25,789 --> 00:47:21,749

attenuated by the ocean by seawater it's

920

00:47:27,709 --> 00:47:25,799

not true UV light is pretty penetrable

921

00:47:32,929 --> 00:47:27,719

as long as they're not lots of organics

922

00:47:34,579 --> 00:47:32,939

who absorb it now this is an experiment

923

00:47:36,049 --> 00:47:34,589

that was done by the same John Kim who

924

00:47:39,229 --> 00:47:36,059

did the isosceles triangle of the

925

00:47:42,349 --> 00:47:39,239

structural tree but he was he's a pretty

926

00:47:45,140 --> 00:47:42,359

interesting character we make city right

927

00:47:46,849 --> 00:47:45,150

which is iron carbonate and iron

928

00:47:48,589 --> 00:47:46,859

carbonate has an anti-bonding orbital

929

00:47:50,959 --> 00:47:48,599

about 4.8 electron volts and that's

930

00:47:55,489 --> 00:47:50,969

calculable I mean it's you you don't

931

00:47:58,339 --> 00:47:55,499

need you just do spectrum so if you can

932

00:48:01,489 --> 00:47:58,349

populate the anti-bonding orbital with

933

00:48:04,279 --> 00:48:01,499

photons you can oxidize the iron 2 to

934

00:48:07,069 --> 00:48:04,289

iron 3 under anaerobic conditions you

935

00:48:09,099 --> 00:48:07,079

don't need oxygen just need photons a

936

00:48:12,469 --> 00:48:09,109

photon will pop an electron off of iron

937

00:48:15,799 --> 00:48:12,479

easily so what does that correspond to

938

00:48:20,419 --> 00:48:15,809

that corresponds to a wavelength of

939

00:48:22,130 --> 00:48:20,429

approximately 280 nanometers and here

940

00:48:24,169 --> 00:48:22,140

you can see I don't know if you can see

941

00:48:27,199 --> 00:48:24,179

it but here you can see we we just

942

00:48:29,089 --> 00:48:27,209

irradiated it with a on our clamp for a

943

00:48:31,789 --> 00:48:29,099

while so you could see that we could

944

00:48:33,289 --> 00:48:31,799

blow off the electrons right there so

945

00:48:34,820 --> 00:48:33,299

follow the electrons what did we do with

946

00:48:36,710 --> 00:48:34,830

the electrons by the way here's

947

00:48:38,570 --> 00:48:36,720

here's what happens to the iron this is

948

00:48:40,910 --> 00:48:38,580

Sidda right this is the product the

949

00:48:43,220 --> 00:48:40,920

product is magnetite ultimately in the

950

00:48:46,490 --> 00:48:43,230

presence of oxygen but you can see that

951
00:48:49,100 --> 00:48:46,500
we get we get magnetic fields that are

952
00:48:53,420 --> 00:48:49,110
induced from this from this photo

953
00:48:57,530 --> 00:48:53,430
oxidation and here's the absorption

954
00:49:11,780 --> 00:48:57,540
maximum it's 270 or so and it's a two

955
00:49:13,550 --> 00:49:11,790
photon reaction the product is h2 we can

956
00:49:15,890 --> 00:49:13,560
do the same thing and this is a

957
00:49:19,220 --> 00:49:15,900
preliminary experiment but with magnet

958
00:49:23,840 --> 00:49:19,230
manganese carbonate we can oxidize

959
00:49:27,440 --> 00:49:23,850
manganese 2 to manganese 4 and here you

960
00:49:32,270 --> 00:49:27,450
see an HPLC diagram and make form a

961
00:49:41,510 --> 00:49:32,280
formic acid we can also make

962
00:49:48,350 --> 00:49:41,520
formaldehyde just water manganese

963
00:49:54,830 --> 00:49:48,360

carbonate UV light and it goes now I'm

964

00:49:57,620 --> 00:49:54,840

going to end this this talk for a while

965

00:50:01,360 --> 00:49:57,630

I was the only biologist actually I was

966

00:50:03,110 --> 00:50:01,370

the only biologist that was on the

967

00:50:05,300 --> 00:50:03,120

scientific working group for the

968

00:50:07,610 --> 00:50:05,310

terrestrial planet finder and I I joined

969

00:50:09,020 --> 00:50:07,620

the the interferometer group so the

970

00:50:10,310 --> 00:50:09,030

interferometer group was one of the more

971

00:50:12,980 --> 00:50:10,320

interesting groups that I had worked on

972

00:50:17,740 --> 00:50:12,990

so they wanted to put an interferometer

973

00:50:20,660 --> 00:50:17,750

at L to the Lagrangian point too and

974

00:50:24,830 --> 00:50:20,670

NASA got scared they couldn't they

975

00:50:29,870 --> 00:50:24,840

didn't want to invest in a program

976

00:50:31,910 --> 00:50:29,880

apparently where three or four

977

00:50:34,520 --> 00:50:31,920

satellites had to fly in formation at I2

978

00:50:37,370 --> 00:50:34,530

with very very very little chatter

979

00:50:39,800 --> 00:50:37,380

between them I mean a small amount of

980

00:50:42,770 --> 00:50:39,810

wiggle and you lose the you lose the

981

00:50:44,540 --> 00:50:42,780

image but the interferometer was able to

982

00:50:46,880 --> 00:50:44,550

null out this is the cool part of the

983

00:50:48,470 --> 00:50:46,890

interferometer why you want to look at

984

00:50:53,450 --> 00:50:48,480

the dark side of a planet as

985

00:50:55,370 --> 00:50:53,460

comes in front of its Sun right and you

986

00:50:57,109 --> 00:50:55,380

want to know lout the background star so

987

00:51:00,109 --> 00:50:57,119

the interferometer was capable of

988

00:51:04,790 --> 00:51:00,119

knowing the background star 210 to this

989

00:51:06,680 --> 00:51:04,800

sixth so you had incredibly small small

990

00:51:10,070 --> 00:51:06,690

small amounts of photons coming from the

991

00:51:13,880 --> 00:51:10,080

store and by looking in the IR you could

992

00:51:17,420 --> 00:51:13,890

crop price possibly capture the infrared

993

00:51:21,290 --> 00:51:17,430

absorption of the gases if there are any

994

00:51:25,849 --> 00:51:21,300

on that planetary body and they were

995

00:51:28,520 --> 00:51:25,859

going out to about 5.5 parsecs roughly

996

00:51:31,070 --> 00:51:28,530

the stare time would be about one month

997

00:51:34,700 --> 00:51:31,080

for a planetary body I'm sure we could

998

00:51:36,620 --> 00:51:34,710

probably do better now but the idea was

999

00:51:40,370 --> 00:51:36,630

killed ultimately in the last decade

1000

00:51:42,260 --> 00:51:40,380

Olivia and the Darwin an analog of this

1001
00:51:45,320 --> 00:51:42,270
in the European Space Agency ultimately

1002
00:51:47,359 --> 00:51:45,330
was killed and so we have nothing so now

1003
00:51:51,170 --> 00:51:47,369
what do we look at we look at limb then

1004
00:51:55,640 --> 00:51:51,180
measurements horrible horrible the

1005
00:51:59,120 --> 00:51:55,650
number of photons you get it's just it's

1006
00:52:01,490 --> 00:51:59,130
not a good way to you can do better this

1007
00:52:03,440 --> 00:52:01,500
is what you do when you trying to do it

1008
00:52:06,410 --> 00:52:03,450
and astronomers are very good at

1009
00:52:08,900 --> 00:52:06,420
addition and subtraction but you know

1010
00:52:09,980 --> 00:52:08,910
here you have a lot of noise so we're

1011
00:52:13,310 --> 00:52:09,990
trying to get the glow some other

1012
00:52:16,070 --> 00:52:13,320
planets and of course what are the gases

1013
00:52:20,690 --> 00:52:16,080

that we want to look for and what are

1014

00:52:23,660 --> 00:52:20,700

those Suites of gases that's of course

1015

00:52:25,370 --> 00:52:23,670

one of the big debates right now I'm not

1016

00:52:28,040 --> 00:52:25,380

going to enter that debate here in this

1017

00:52:30,800 --> 00:52:28,050

this lecture so I want to conclude by

1018

00:52:32,330 --> 00:52:30,810

first of all thinking about this but

1019

00:52:34,280 --> 00:52:32,340

first two-and-a-half years of Earth's

1020

00:52:38,510 --> 00:52:34,290

history were a research and development

1021

00:52:43,099 --> 00:52:38,520

phase this is when Apple was really

1022

00:52:44,960 --> 00:52:43,109

cooking okay or this was this was the

1023

00:52:49,609 --> 00:52:44,970

phase when a core set of metabolic

1024

00:52:52,760 --> 00:52:49,619

machines evolved and after that the

1025

00:52:58,820 --> 00:52:52,770

factory shut down all they did was

1026
00:53:00,800 --> 00:52:58,830
invent bodies to put the machines in all

1027
00:53:02,630 --> 00:53:00,810
of the key metabolic processes were

1028
00:53:04,880 --> 00:53:02,640
evolved in

1029
00:53:08,780 --> 00:53:04,890
and they're only approximately 400

1030
00:53:10,849 --> 00:53:08,790
metabolic genes so the machinery really

1031
00:53:12,849 --> 00:53:10,859
wasn't that complicated I don't know why

1032
00:53:15,620 --> 00:53:12,859
we try to you know I don't know how many

1033
00:53:17,089 --> 00:53:15,630
genes we've identified but really we're

1034
00:53:19,640 --> 00:53:17,099
spending a lot of time looking at

1035
00:53:22,280 --> 00:53:19,650
whether the color of the bug is brown or

1036
00:53:24,050 --> 00:53:22,290
green or red or it has chrome on the

1037
00:53:27,050 --> 00:53:24,060
trim or doesn't have chrome on the trim

1038
00:53:30,440 --> 00:53:27,060

or whether it has electric windows or

1039

00:53:32,990 --> 00:53:30,450

this is totally irrelevant for the most

1040

00:53:38,480 --> 00:53:33,000

part you want to get down and figure out

1041

00:53:44,690 --> 00:53:38,490

how the Pistons work right or whether

1042

00:53:47,390 --> 00:53:44,700

it's got a jet engine the metabolic

1043

00:53:49,760 --> 00:53:47,400

sequences are coupled on local scales

1044

00:53:53,079 --> 00:53:49,770

obviously but studying this in a test

1045

00:53:56,000 --> 00:53:53,089

tube is not the only way to do this and

1046

00:53:57,620 --> 00:53:56,010

so isotopes are a way to do this but I

1047

00:54:01,190 --> 00:53:57,630

think there are other ways to do this

1048

00:54:03,680 --> 00:54:01,200

and you can facilitate electron markets

1049

00:54:06,650 --> 00:54:03,690

and that's what it is in a way and so

1050

00:54:10,760 --> 00:54:06,660

here's really a challenge in a sense to

1051
00:54:16,809 --> 00:54:10,770
Nigel and others much more smart than I

1052
00:54:19,250 --> 00:54:16,819
am can you invent a planet that is got a

1053
00:54:21,109 --> 00:54:19,260
homeostatic environment for millions of

1054
00:54:25,370 --> 00:54:21,119
years with gas compositions that don't

1055
00:54:28,220 --> 00:54:25,380
change appreciably with metabolic fluxes

1056
00:54:30,170 --> 00:54:28,230
that are incredibly high and yet the

1057
00:54:39,079 --> 00:54:30,180
oxygen concentration is going up and

1058
00:54:43,099 --> 00:54:39,089
down like this it's really hard bang it

1059
00:54:51,460 --> 00:54:43,109
you know bang it with a meteorite 65

1060
00:54:56,180 --> 00:54:53,810
now and the contemporary electron

1061
00:54:59,990 --> 00:54:56,190
potential is driven by light so with

1062
00:55:02,210 --> 00:55:00,000
that I just want to thank many people

1063
00:55:03,470 --> 00:55:02,220

more than are on this picture most of

1064

00:55:06,530 --> 00:55:03,480

this work was funded by the Moore

1065

00:55:09,130 --> 00:55:06,540

Foundation some of the last most recent

1066

00:55:11,900 --> 00:55:09,140

work has been funded by NASA on the

1067

00:55:15,440 --> 00:55:11,910

photo geochemistry but especially want

1068

00:55:18,770 --> 00:55:15,450

to thank Vic and and and Ben Yellin and

1069

00:55:22,010 --> 00:55:18,780

and John Kim and Jana Bromberg and and

1070

00:55:23,870 --> 00:55:22,020

Dave case who have helped helped us

1071

00:55:27,200 --> 00:55:23,880

understand a little bit about you know

1072

00:55:29,360 --> 00:55:27,210

we're still learning obviously about how

1073

00:55:31,250 --> 00:55:29,370

these protein nanomachines evolved and

1074

00:55:36,220 --> 00:55:31,260

how they created a metabolic network on

1075

00:55:38,450 --> 00:55:36,230

the planet and in so doing potentially

1076

00:55:40,550 --> 00:55:38,460

how we went from the sacrificial

1077

00:55:42,230 --> 00:55:40,560

chemistry of the photo oxidation of

1078

00:55:45,310 --> 00:55:42,240

Sidda right or manganese carbonate to

1079

00:55:48,290 --> 00:55:45,320

the catalytic chemistry of

1080

00:55:51,170 --> 00:55:48,300

photosynthesis that to me is probably

1081

00:55:56,150 --> 00:55:51,180

one of the biggest challenges that I can

1082

00:55:57,740 --> 00:55:56,160

I can handle and that's what I think

1083

00:56:00,800 --> 00:55:57,750

about so I thank you all very very much

1084

00:56:08,750 --> 00:56:00,810

for the opportunity to to at least have

1085

00:56:13,190 --> 00:56:08,760

this conversation with him thank you the

1086

00:56:32,240 --> 00:56:13,200

Nam time for question anybody who had a

1087

00:56:35,600 --> 00:56:32,250

comment questions yeah that was very

1088

00:56:39,200 --> 00:56:35,610

interesting I'm a planetary scientist so

1089

00:56:43,310 --> 00:56:39,210

I wanted to comment on something you

1090

00:56:47,030 --> 00:56:43,320

said earlier about water delivery it's a

1091

00:56:49,430 --> 00:56:47,040

very big problem that still I think has

1092

00:56:52,850 --> 00:56:49,440

not been solved although much progress

1093

00:56:57,320 --> 00:56:52,860

has been made seeded as you correctly

1094

00:56:59,960 --> 00:56:57,330

pointed out we know that the water was

1095

00:57:01,730 --> 00:56:59,970

not mostly cometary in origin that is

1096

00:57:03,770 --> 00:57:01,740

from hydrogen isotopes that is from

1097

00:57:06,080 --> 00:57:03,780

xenon isotopes that is from lots of

1098

00:57:07,880 --> 00:57:06,090

other things so it had to be meteoritic

1099

00:57:09,680 --> 00:57:07,890

but even there we're running into

1100

00:57:13,370 --> 00:57:09,690

certain problems because of what kind of

1101

00:57:16,070 --> 00:57:13,380

meteorite you do and so forth recent

1102

00:57:19,870 --> 00:57:16,080

progress however seems to point towards

1103

00:57:22,760 --> 00:57:19,880

the water being delivered very early

1104

00:57:25,130 --> 00:57:22,770

previous theories for example by Francie

1105

00:57:26,900 --> 00:57:25,140

Alvarez and some others they said that

1106

00:57:29,420 --> 00:57:26,910

the water must have been delivered late

1107

00:57:31,190 --> 00:57:29,430

so after the moon formation in terms of

1108

00:57:32,720 --> 00:57:31,200

the late veneer late accretion and so

1109

00:57:35,270 --> 00:57:32,730

forth because that's how you can keep it

1110

00:57:38,030 --> 00:57:35,280

at the service turns out that that

1111

00:57:40,070 --> 00:57:38,040

picture is probably no longer true and

1112

00:57:42,290 --> 00:57:40,080

that instead the water was delivered

1113

00:57:45,530 --> 00:57:42,300

early in the first couple of million

1114

00:57:48,590 --> 00:57:45,540

years five to may at most ten million

1115

00:57:52,820 --> 00:57:48,600

years and the remaining accretion was

1116

00:57:56,060 --> 00:57:52,830

then rather dry and reduced and that is

1117

00:57:58,730 --> 00:57:56,070

a new result which I think some people

1118

00:58:00,740 --> 00:57:58,740

in the origins of life community and the

1119

00:58:03,470 --> 00:58:00,750

Haiti and earth and Archaean earth may

1120

00:58:05,630 --> 00:58:03,480

want to think about because it might be

1121

00:58:07,880 --> 00:58:05,640

able to provide you with the reduced

1122

00:58:09,970 --> 00:58:07,890

environment rather than an oxidizing

1123

00:58:14,060 --> 00:58:09,980

environment early on on the earth

1124

00:58:16,430 --> 00:58:14,070

okay so who's published this where I

1125

00:58:18,380 --> 00:58:16,440

have started to publish this there's one

1126

00:58:20,900 --> 00:58:18,390

or two other collaborators this is

1127

00:58:22,640 --> 00:58:20,910

slowly coming out okay but it's

1128

00:58:24,380 --> 00:58:22,650

relatively new I just wanted to point

1129

00:58:26,060 --> 00:58:24,390

that out and so some people do we have

1130

00:58:29,750 --> 00:58:26,070

zircons or something that can help us

1131

00:58:36,830 --> 00:58:29,760

inform this or its models it's both okay

1132

00:58:41,990 --> 00:58:36,840

it's a combination of both okay Justin

1133

00:58:44,240 --> 00:58:42,000

uh-oh no no to him over here okay on a

1134

00:58:45,770 --> 00:58:44,250

big perspective note so you you I

1135

00:58:47,420 --> 00:58:45,780

completely agree that you carrots are

1136

00:58:49,280 --> 00:58:47,430

absolutely boring in terms of metabolism

1137

00:58:51,440 --> 00:58:49,290

and biochemistry but they are not in

1138

00:58:53,420 --> 00:58:51,450

terms of complexity of course okay and

1139

00:58:55,880 --> 00:58:53,430

and so I wanted to know your perspective

1140

00:58:59,300 --> 00:58:55,890

just in general the it being a keynote

1141

00:59:01,850 --> 00:58:59,310

speaker and everything on how you would

1142

00:59:03,620 --> 00:59:01,860

see complexity arising because it only

1143

00:59:06,980 --> 00:59:03,630

did one so there's only one type of

1144

00:59:08,810 --> 00:59:06,990

complex thing on earth which then led on

1145

00:59:11,300 --> 00:59:08,820

to plant and animals and fungi and so on

1146

00:59:12,920 --> 00:59:11,310

do you see that happening more than once

1147

00:59:14,510 --> 00:59:12,930

on earth and maybe elsewhere in the

1148

00:59:15,810 --> 00:59:14,520

universe if there's life assume let's

1149

00:59:17,310 --> 00:59:15,820

assume there is life wouldn't

1150

00:59:20,010 --> 00:59:17,320

would there be complex life somewhere

1151
00:59:21,840 --> 00:59:20,020
else end so let's ask the quest the

1152
00:59:24,870 --> 00:59:21,850
question which is seldom asked actually

1153
00:59:26,970 --> 00:59:24,880
why are there animals why multicellular

1154
00:59:28,320 --> 00:59:26,980
what's so great about multicellularity

1155
00:59:30,210 --> 00:59:28,330
everything I think about in

1156
00:59:32,160 --> 00:59:30,220
multicellularity you have a lower

1157
00:59:35,820 --> 00:59:32,170
reproductive rate you have a higher

1158
00:59:37,800 --> 00:59:35,830
energy intensity it's it's there's no

1159
00:59:39,720 --> 00:59:37,810
great advantage until you start to think

1160
00:59:41,610 --> 00:59:39,730
about it in terms of a physics problem

1161
00:59:46,290 --> 00:59:41,620
so here's the way I think about it in a

1162
00:59:48,990 --> 00:59:46,300
physics problem if I take a

1163
00:59:52,440 --> 00:59:49,000

single-celled organism that is trying to

1164

00:59:57,960 --> 00:59:52,450

for example use a flagella to get some

1165

01:00:00,810 --> 00:59:57,970

bacteria into its orifice its mouth it's

1166

01:00:03,410 --> 01:00:00,820

working at a very very very low Reynolds

1167

01:00:07,770 --> 01:00:03,420

number so the viscosity that this guy is

1168

01:00:09,990 --> 01:00:07,780

experiencing is very very hot so these

1169

01:00:11,910 --> 01:00:10,000

are be for example a single-cell Kawana

1170

01:00:13,920 --> 01:00:11,920

flageolet this is the one of the

1171

01:00:16,860 --> 01:00:13,930

earliest organisms that we can think of

1172

01:00:20,790 --> 01:00:16,870

that forms or we know that today forms

1173

01:00:25,560 --> 01:00:20,800

colonies and why am I thinking about

1174

01:00:28,950 --> 01:00:25,570

this for many years we know that the

1175

01:00:31,050 --> 01:00:28,960

first fossils of organisms were like

1176
01:00:33,570 --> 01:00:31,060
sponges in the Cambrian now there were

1177
01:00:35,220 --> 01:00:33,580
sponges in the Ediacaran and there are

1178
01:00:36,840 --> 01:00:35,230
other organisms in the Ediacaran which

1179
01:00:39,240 --> 01:00:36,850
nobody knows what the hell they really

1180
01:00:39,750 --> 01:00:39,250
did but let's think about sponges for a

1181
01:00:42,720 --> 01:00:39,760
minute

1182
01:00:45,900 --> 01:00:42,730
so sponges were dissected in the by the

1183
01:00:49,200 --> 01:00:45,910
by many people but a French guy in the

1184
01:00:52,170 --> 01:00:49,210
1880s or so noticed that the linings of

1185
01:00:54,240 --> 01:00:52,180
the inside of a sponge had flagella that

1186
01:00:59,640 --> 01:00:54,250
looked like Oh Anna flageolets and he

1187
01:01:00,810 --> 01:00:59,650
called those cells : Oh sites now why am

1188
01:01:02,520 --> 01:01:00,820

I saying that because you can take a

1189

01:01:05,880 --> 01:01:02,530

sponge and put it through a sieve and

1190

01:01:08,100 --> 01:01:05,890

the cells will self assemble which is

1191

01:01:10,140 --> 01:01:08,110

amazing and they will form these co ana

1192

01:01:12,390 --> 01:01:10,150

sites will form a colony again right up

1193

01:01:14,580 --> 01:01:12,400

through a tube now let's think about

1194

01:01:17,910 --> 01:01:14,590

this for a minute the kiwanis sites are

1195

01:01:20,730 --> 01:01:17,920

all beating their flagella in the same

1196

01:01:23,040 --> 01:01:20,740

direction so instead of having a single

1197

01:01:26,580 --> 01:01:23,050

cell now forage a few millimeters at a

1198

01:01:29,760 --> 01:01:26,590

time for bacteria now you can filter

1199

01:01:32,130 --> 01:01:29,770

from a stationary organism hundreds of

1200

01:01:36,750 --> 01:01:32,140

of seawater in a day so the foraging

1201
01:01:39,180 --> 01:01:36,760
area is huge without having to move so

1202
01:01:42,060 --> 01:01:39,190
it's a fluid dynamics problem to me that

1203
01:01:43,970 --> 01:01:42,070
originated complexity it's an

1204
01:01:47,160 --> 01:01:43,980
interesting one I'm not sure I'm right

1205
01:01:49,680 --> 01:01:47,170
but it's at least something to think

1206
01:01:52,680 --> 01:01:49,690
about when you start to get to organisms

1207
01:01:55,380 --> 01:01:52,690
that became marine organisms that are

1208
01:01:58,950 --> 01:01:55,390
living in this world of a high viscous

1209
01:02:01,650 --> 01:01:58,960
property at very small size becoming

1210
01:02:03,870 --> 01:02:01,660
much less inhibited by the reynolds

1211
01:02:06,180 --> 01:02:03,880
number issue when they become larger and

1212
01:02:10,740 --> 01:02:06,190
larger and then the selection pressure

1213
01:02:13,320 --> 01:02:10,750

to go from a spherical blob to a by

1214

01:02:17,490 --> 01:02:13,330

latarian which is able to cut through

1215

01:02:20,790 --> 01:02:17,500

water much more efficiently leads to

1216

01:02:23,460 --> 01:02:20,800

body forms so I've had this conversation

1217

01:02:26,940 --> 01:02:23,470

with several paleontologists Dugger when

1218

01:02:31,050 --> 01:02:26,950

others but this issue of why animals is

1219

01:02:34,290 --> 01:02:31,060

really kind of sidestepped it's not just

1220

01:02:37,080 --> 01:02:34,300

complexity but what is the advantage of

1221

01:02:39,770 --> 01:02:37,090

multicellularity okay what are the

1222

01:02:43,440 --> 01:02:39,780

advantages of multicellularity so I

1223

01:02:46,560 --> 01:02:43,450

completely complexity is a subjective

1224

01:02:49,860 --> 01:02:46,570

term multicellularity is an objective

1225

01:02:52,830 --> 01:02:49,870

term and I would rather I think an

1226

01:02:55,800 --> 01:02:52,840

e.coli is complex okay

1227

01:02:57,390 --> 01:02:55,810

so I just think that we should be a

1228

01:02:59,820 --> 01:02:57,400

little careful about what the selection

1229

01:03:04,730 --> 01:02:59,830

pressures were to allow this now if you

1230

01:03:07,260 --> 01:03:04,740

think about this this foraging issue

1231

01:03:10,320 --> 01:03:07,270

becomes really interesting if you can

1232

01:03:12,960 --> 01:03:10,330

out-compete other organisms right then

1233

01:03:16,650 --> 01:03:12,970

you can become more efficient even in

1234

01:03:20,310 --> 01:03:16,660

multicellularity if you grow slowly but

1235

01:03:22,590 --> 01:03:20,320

you still capture more food so it is to

1236

01:03:24,180 --> 01:03:22,600

me it's some place to explore I I don't

1237

01:03:30,030 --> 01:03:24,190

have the answers but I just think about

1238

01:03:32,670 --> 01:03:30,040

a lot all right thanks for yeah the

1239

01:03:34,830 --> 01:03:32,680

incredible incredible talk I see my

1240

01:03:37,470 --> 01:03:34,840

question is is sort of quite closely

1241

01:03:41,240 --> 01:03:37,480

related to the previous one so you've

1242

01:03:43,000 --> 01:03:41,250

alluded to the fact that the bulk of the

1243

01:03:46,180 --> 01:03:43,010

electron transport

1244

01:03:49,690 --> 01:03:46,190

the bulk of metabolic biochemical

1245

01:03:51,640 --> 01:03:49,700

activity on earth can be can be narrowed

1246

01:03:55,390 --> 01:03:51,650

down to this very small number of genes

1247

01:03:59,770 --> 01:03:55,400

very small number of nano scale machines

1248

01:04:01,900 --> 01:03:59,780

so if that's true why is it that that

1249

01:04:04,660 --> 01:04:01,910

implies that life is carrying around a

1250

01:04:06,580 --> 01:04:04,670

lot of redundant excess baggage and the

1251

01:04:08,380 --> 01:04:06,590

question is why does it not dump my

1252

01:04:14,140 --> 01:04:08,390

question is why does it not ditch all

1253

01:04:15,820 --> 01:04:14,150

that excess baggage I I was talking here

1254

01:04:17,950 --> 01:04:15,830

about the electron transfer part of it

1255

01:04:20,410 --> 01:04:17,960

so you have other genes that are

1256

01:04:22,870 --> 01:04:20,420

responsible for replication other genes

1257

01:04:24,610 --> 01:04:22,880

are responsible for making the membranes

1258

01:04:27,250 --> 01:04:24,620

and so on so I mean when you get down to

1259

01:04:28,780 --> 01:04:27,260

it as we know we need about thousand

1260

01:04:31,540 --> 01:04:28,790

genes or something to make a book right

1261

01:04:33,190 --> 01:04:31,550

I don't know what the minimal number is

1262

01:04:36,010 --> 01:04:33,200

I mean craig Venter probably can make a

1263

01:04:41,200 --> 01:04:36,020

bug with 400 genes or 500 genes for one

1264

01:04:42,940 --> 01:04:41,210

bug but if you start to make say 40

1265

01:04:45,070 --> 01:04:42,950

different bugs that carry out all the

1266

01:04:50,470 --> 01:04:45,080

basic metabolic processes on the planet

1267

01:04:55,840 --> 01:04:50,480

a few tens of thousands of genes yeah so

1268

01:04:58,650 --> 01:04:55,850

I guess well sort of an alternative for

1269

01:05:01,840 --> 01:04:58,660

my question is why

1270

01:05:03,340 --> 01:05:01,850

if metabolism is so simple is relatively

1271

01:05:05,530 --> 01:05:03,350

simple on the bulk level why did the

1272

01:05:09,730 --> 01:05:05,540

earth not just choose to to just do

1273

01:05:12,700 --> 01:05:09,740

these that do that bioenergetics in bulk

1274

01:05:14,710 --> 01:05:12,710

instead and why did it choose to it

1275

01:05:16,210 --> 01:05:14,720

probably was much simpler a long time

1276

01:05:18,040 --> 01:05:16,220

ago you know eukaryotes screwed this

1277

01:05:20,590 --> 01:05:18,050

thing up we have a lot of so you only

1278

01:05:25,710 --> 01:05:20,600

have 20,000 22,000 genes protein coding

1279

01:05:28,390 --> 01:05:25,720

genes right I take a dinoflagellate

1280

01:05:30,790 --> 01:05:28,400

let's take the dinoflagellates have as

1281

01:05:32,830 --> 01:05:30,800

far as I know the largest genomes of a

1282

01:05:35,250 --> 01:05:32,840

single-celled organism on the planet the

1283

01:05:37,450 --> 01:05:35,260

smallest dinoflagellate genome is in

1284

01:05:39,510 --> 01:05:37,460

symbiotically at accom which is the

1285

01:05:45,430 --> 01:05:39,520

zooxanthellae that lives inside a coral

1286

01:05:49,750 --> 01:05:45,440

that genome is about 1.9 giga bases it

1287

01:05:51,610 --> 01:05:49,760

also has 20,000 protein coding genes if

1288

01:05:53,860 --> 01:05:51,620

I take another dinoflagellate that's

1289

01:05:56,720 --> 01:05:53,870

free living I can get up to 12 Giga

1290

01:05:59,520 --> 01:05:56,730

bases it has 20,000

1291

01:06:03,170 --> 01:05:59,530

genes that are protein-coding so most of

1292

01:06:09,660 --> 01:06:03,180

these genes are simply dispersed in

1293

01:06:12,150 --> 01:06:09,670

within introns and transposons and it's

1294

01:06:14,520 --> 01:06:12,160

it's that to me is the selfish genome

1295

01:06:18,930 --> 01:06:14,530

problem right so this is this goes back

1296

01:06:21,990 --> 01:06:18,940

to Carmon Sapienza and and and for

1297

01:06:25,460 --> 01:06:22,000

Doolittle I mean it it is a problem of

1298

01:06:27,900 --> 01:06:25,470

why these pieces of DNA are not shocked

1299

01:06:30,210 --> 01:06:27,910

and you don't see this in you carry I

1300

01:06:31,920 --> 01:06:30,220

prokaryotes so much but it certainly is

1301

01:06:33,540 --> 01:06:31,930

a very interesting problem of you know

1302

01:06:36,440 --> 01:06:33,550

the minimalist why aren't we all

1303

01:06:40,349 --> 01:06:36,450

minimalist right I don't know the answer

1304

01:06:42,780 --> 01:06:40,359

that's two questions first Paul I've got

1305

01:06:45,420 --> 01:06:42,790

a kind of two related questions the

1306

01:06:48,120 --> 01:06:45,430

first question is is in your sitter ID

1307

01:06:51,750 --> 01:06:48,130

experiments is the sitter ID acting as a

1308

01:06:55,849 --> 01:06:51,760

catalyst and the split water and and in

1309

01:06:58,410 --> 01:06:55,859

doing so is being oxidized by the the

1310

01:06:59,790 --> 01:06:58,420

oxygen radical that's being produced so

1311

01:07:02,520 --> 01:06:59,800

that's the first question but then the

1312

01:07:05,849 --> 01:07:02,530

second follow-up regardless of that it's

1313

01:07:07,590 --> 01:07:05,859

it's a really interesting process that

1314

01:07:09,390 --> 01:07:07,600

you observe because and I think it's

1315

01:07:11,160 --> 01:07:09,400

incredibly relevant to the origin of

1316

01:07:13,200 --> 01:07:11,170

life or at least early life because of

1317

01:07:16,500 --> 01:07:13,210

some of the recent results people are

1318

01:07:18,630 --> 01:07:16,510

showing for methanogens heterotrophic genes and

1319

01:07:22,050 --> 01:07:18,640

sulfur reducers whatever in that they

1320

01:07:23,940 --> 01:07:22,060

can reduce iron with hydrogen many of

1321

01:07:25,530 --> 01:07:23,950

them can they can set you know so but

1322

01:07:27,420 --> 01:07:25,540

with antigens don't necessarily need to

1323

01:07:29,670 --> 01:07:27,430

reduce CO₂ for their energy metabolism

1324

01:07:32,130 --> 01:07:29,680

as it appears you're absolutely right

1325

01:07:33,510 --> 01:07:32,140

Eric so in in the real world that would

1326
01:07:36,180 --> 01:07:33,520
have been a cycle so you would have

1327
01:07:39,000 --> 01:07:36,190
oxidized the iron the city right you

1328
01:07:42,720 --> 01:07:39,010
would have reduced it by either a bug or

1329
01:07:44,760 --> 01:07:42,730
or just an environmental reducing agent

1330
01:07:46,080 --> 01:07:44,770
and you could have get this going and

1331
01:07:49,470 --> 01:07:46,090
going and going and going again

1332
01:07:51,120 --> 01:07:49,480
continuously and it has occurred to us

1333
01:07:55,109 --> 01:07:51,130
that this is probably what happened

1334
01:07:56,580 --> 01:07:55,119
early on now just a brain fart just to

1335
01:07:58,940 --> 01:07:56,590
think about that when I we published

1336
01:08:01,230 --> 01:07:58,950
this paper I send it to Korat singer I

1337
01:08:03,140 --> 01:08:01,240
said that's why there's no carbonates

1338
01:08:05,880 --> 01:08:03,150

left on Mars from the surface of Mars

1339

01:08:09,960 --> 01:08:05,890

because you probably had a thin wet

1340

01:08:11,700 --> 01:08:09,970

vener at some point you had UV Sun like

1341

01:08:14,400 --> 01:08:11,710

bombarding the surface that regolith

1342

01:08:21,749 --> 01:08:14,410

became oxidized and what happens to the

1343

01:08:23,820 --> 01:08:21,759

carbon becomes co2 and so it's a very

1344

01:08:26,370 --> 01:08:23,830

interesting very interesting problem

1345

01:08:31,740 --> 01:08:26,380

planet airily I don't know if that's the

1346

01:08:32,910 --> 01:08:31,750

real case on Mars but it's certainly one

1347

01:08:34,620 --> 01:08:32,920

of these things that could have happened

1348

01:08:36,240 --> 01:08:34,630

it never happened on the moon by the way

1349

01:08:41,370 --> 01:08:36,250

it didn't happen on the moon you need

1350

01:08:43,229 --> 01:08:41,380

liquid water so at least we seem to need

1351

01:08:45,720 --> 01:08:43,239

with liquid water but we don't spit we

1352

01:08:47,010 --> 01:08:45,730

don't split water I wish if we were

1353

01:08:49,890 --> 01:08:47,020

splitting water I wouldn't be here

1354

01:08:51,900 --> 01:08:49,900

talking to you I'd be cutting it writing

1355

01:08:54,209 --> 01:08:51,910

the ends of a cheque for a few million

1356

01:08:59,400 --> 01:08:54,219

dollars of a patent and and I would be

1357

01:09:03,030 --> 01:08:59,410

living in Hawaii or something I wish you

1358

01:09:04,709 --> 01:09:03,040

know Nate Lewis and chuck dis music via

1359

01:09:06,209 --> 01:09:04,719

lot of people on this planet are trying

1360

01:09:09,269 --> 01:09:06,219

to split water with earth-abundant

1361

01:09:13,890 --> 01:09:09,279

transition metals as catalysts so Dan de

1362

01:09:16,289 --> 01:09:13,900

cera has been using cobalt in at Rutgers

1363

01:09:17,370 --> 01:09:16,299

chuck de smokes uses iron there are

1364

01:09:21,900 --> 01:09:17,380

others people that are trying to use

1365

01:09:25,289 --> 01:09:21,910

manganese we're just we're just taking

1366

01:09:27,479 --> 01:09:25,299

protons and sticking electrons onto the

1367

01:09:31,170 --> 01:09:27,489

protons to make hydrogen in that case

1368

01:09:33,090 --> 01:09:31,180

what was the second question so in the

1369

01:09:36,120 --> 01:09:33,100

process that you're oxidizing the iron

1370

01:09:36,959 --> 01:09:36,130

in the city right okay right well it's

1371

01:09:39,510 --> 01:09:36,969

more of a comment

1372

01:09:41,519 --> 01:09:39,520

it's just has incredible relevance to

1373

01:09:43,829 --> 01:09:41,529

what was possible on early Earth when we

1374

01:09:45,930 --> 01:09:43,839

think that life was Occident limited may

1375

01:09:48,690 --> 01:09:45,940

be limited to co2 it need not be if you

1376

01:09:50,459 --> 01:09:48,700

have UV that's it right yeah yeah right

1377

01:09:52,740 --> 01:09:50,469

you can generate the oxidant in that

1378

01:09:55,080 --> 01:09:52,750

form it's of course that's right that's

1379

01:09:56,910 --> 01:09:55,090

exactly how it works so I mean I know

1380

01:09:59,700 --> 01:09:56,920

Mike has thought about I mean

1381

01:10:03,170 --> 01:09:59,710

Karen Smith popularize this I guess and

1382

01:10:07,800 --> 01:10:03,180

when he was in Glasgow what 30 years ago

1383

01:10:11,130 --> 01:10:07,810

right so Graham Karen Smith started to

1384

01:10:13,740 --> 01:10:11,140

experiment on on minerals and photo

1385

01:10:17,790 --> 01:10:13,750

oxidation of minerals it's one of these

1386

01:10:19,620 --> 01:10:17,800

things that it's sort of a thin out here

1387

01:10:22,550 --> 01:10:19,630

in geochemistry this isn't

1388

01:10:23,729 --> 01:10:22,560

biogeochemistry is pure geochemistry

1389

01:10:26,279 --> 01:10:23,739

we're

1390

01:10:28,830 --> 01:10:26,289

very very very few people work in this

1391

01:10:31,109 --> 01:10:28,840

area very few and usually there's one

1392

01:10:33,750 --> 01:10:31,119

person that does this for 10 or 15 years

1393

01:10:36,419 --> 01:10:33,760

Martin shounan was the last at Stony

1394

01:10:37,859 --> 01:10:36,429

Brook and then you know he kind of

1395

01:10:41,270 --> 01:10:37,869

retired from science he's now a

1396

01:10:44,040 --> 01:10:41,280

co-director at Brookhaven National Lab

1397

01:10:46,259 --> 01:10:44,050

okay that was interesting and they

1398

01:10:48,000 --> 01:10:46,269

forget about it and it's rediscovered 10

1399

01:10:49,919 --> 01:10:48,010

years later and that's the way it goes

1400

01:10:53,220 --> 01:10:49,929

so we haven't really had a concerted

1401
01:10:55,739 --> 01:10:53,230
effort in understanding how photons can

1402
01:10:57,540 --> 01:10:55,749
transform minerals and ultimately move

1403
01:11:02,189 --> 01:10:57,550
on to become catalysts and I think it's

1404
01:11:04,229 --> 01:11:02,199
time so I tried that but you know it's

1405
01:11:08,100 --> 01:11:04,239
it's one of these things where we'll

1406
01:11:10,410 --> 01:11:08,110
have to do it without funding because it

1407
01:11:13,830 --> 01:11:10,420
was last time out we tried this with an

1408
01:11:17,970 --> 01:11:13,840
nai proposal there it came back it was

1409
01:11:20,220 --> 01:11:17,980
too risky okay I don't know why but

1410
01:11:22,229 --> 01:11:20,230
that's what that was the proposal we got

1411
01:11:24,410 --> 01:11:22,239
we use the rejection to get the money

1412
01:11:26,520 --> 01:11:24,420
from the Gordon and Betty Moore energies

1413
01:11:27,989 --> 01:11:26,530

first time I've used a rejection letter

1414

01:11:31,379 --> 01:11:27,999

we used a rejection letter to get

1415

01:11:33,810 --> 01:11:31,389

something funded but it is an

1416

01:11:38,870 --> 01:11:33,820

interesting problem because if you think

1417

01:11:41,310 --> 01:11:38,880

about it we know a lot a lot in terms of

1418

01:11:45,660 --> 01:11:41,320

calculating anti-bonding orbital's we

1419

01:11:48,299 --> 01:11:45,670

know a lot about basics of quantum

1420

01:11:51,180 --> 01:11:48,309

mechanics we should be able to screen a

1421

01:11:54,810 --> 01:11:51,190

whole series of earth abundant minerals

1422

01:11:57,089 --> 01:11:54,820

than the Archaean period and say how did

1423

01:12:00,359 --> 01:11:57,099

these come to be appropriated to make

1424

01:12:03,060 --> 01:12:00,369

electrons moved catalytically right so

1425

01:12:05,100 --> 01:12:03,070

what could I stick a 12 amino acid

1426

01:12:07,739 --> 01:12:05,110

peptide onto a piece of City right and

1427

01:12:12,270 --> 01:12:07,749

make a catalyst I don't know if I could

1428

01:12:13,500 --> 01:12:12,280

you know that would be very cool sorry I

1429

01:12:15,149 --> 01:12:13,510

was completely with you until the

1430

01:12:16,770 --> 01:12:15,159

questions and that's what made me ask a

1431

01:12:19,649 --> 01:12:16,780

question okay it's sort of your

1432

01:12:21,720 --> 01:12:19,659

dismissal of the why we have animals and

1433

01:12:23,850 --> 01:12:21,730

I love your perspective of the Reynolds

1434

01:12:25,290 --> 01:12:23,860

numbers but they're all the sort of

1435

01:12:26,879 --> 01:12:25,300

traditional things that you can have

1436

01:12:28,950 --> 01:12:26,889

specialization of cells you can avoid

1437

01:12:29,970 --> 01:12:28,960

predation you can you know you can do

1438

01:12:32,790 --> 01:12:29,980

all sorts of things when you're

1439

01:12:35,370 --> 01:12:32,800

multicellular and so it's curious why

1440

01:12:36,750 --> 01:12:35,380

you you sort of ignored that and the

1441

01:12:37,160 --> 01:12:36,760

other thing would be why do you become

1442

01:12:38,540 --> 01:12:37,170

by

1443

01:12:39,830 --> 01:12:38,550

really symmetrical so that you don't

1444

01:12:41,900 --> 01:12:39,840

have your anus in your mouth in the same

1445

01:12:44,360 --> 01:12:41,910

orifice well

1446

01:12:46,880 --> 01:12:44,370

the bilateral symmetrical issue for me

1447

01:12:49,130 --> 01:12:46,890

is a hydrodynamic issue right and that's

1448

01:12:50,930 --> 01:12:49,140

why it's curious well I think about it

1449

01:12:52,790 --> 01:12:50,940

you know I'm trained in biophysics I

1450

01:12:54,350 --> 01:12:52,800

think about it in physics right but from

1451

01:12:56,209 --> 01:12:54,360

metabolic point of view it makes a heck

1452

01:12:59,000 --> 01:12:56,219

of a lot more sense - it won't end at

1453

01:13:00,320 --> 01:12:59,010

one end in a protozoan deuterostome

1454

01:13:01,970 --> 01:13:00,330

issue I mean I'm not going to go down

1455

01:13:06,350 --> 01:13:01,980

that road that's a developmental problem

1456

01:13:09,950 --> 01:13:06,360

but I think that the issue here of the

1457

01:13:13,189 --> 01:13:09,960

fundamental question is scaling

1458

01:13:15,669 --> 01:13:13,199

metabolism - sharing resources between

1459

01:13:17,870 --> 01:13:15,679

cells so that you have shared

1460

01:13:22,030 --> 01:13:17,880

responsibilities to make an organism

1461

01:13:24,320 --> 01:13:22,040

right so that ultimately is a

1462

01:13:27,860 --> 01:13:24,330

fundamental problem in developmental

1463

01:13:31,400 --> 01:13:27,870

biology but it is also not exactly clear

1464

01:13:34,939 --> 01:13:31,410

to me why you had to do this there's no

1465

01:13:36,830 --> 01:13:34,949

we were perfectly fine 42.8 you know

1466

01:13:38,360 --> 01:13:36,840

it's only what we have animals the

1467

01:13:41,240 --> 01:13:38,370

oldest animal that we have on the planet

1468

01:13:46,280 --> 01:13:41,250

I think in the fossil record is 635

1469

01:13:47,630 --> 01:13:46,290

million years old so for you know 85 90

1470

01:13:50,030 --> 01:13:47,640

percent of Earth's history I don't know

1471

01:13:52,760 --> 01:13:50,040

the number I just around 80 percent of

1472

01:13:54,110 --> 01:13:52,770

Earth's history or more microbes had the

1473

01:13:56,060 --> 01:13:54,120

world unto themselves and we're

1474

01:13:57,590 --> 01:13:56,070

perfectly fine and they still are there

1475

01:13:59,479 --> 01:13:57,600

there's still the dominant creatures

1476

01:14:02,120 --> 01:13:59,489

they're still making the planet go

1477

01:14:03,860 --> 01:14:02,130

around I mean animals and plants are

1478

01:14:06,620 --> 01:14:03,870

kind of like you know they're kind of

1479

01:14:08,240 --> 01:14:06,630

decorations as a fellow put pretty soon

1480

01:14:09,830 --> 01:14:08,250

you'd do you know that virtually every

1481

01:14:12,169 --> 01:14:09,840

protists and taxon has multi cellular

1482

01:14:19,080 --> 01:14:12,179

yes I mean you know it's done over and

1483

01:14:19,810 --> 01:14:19,090

over anyway all right okay again

1484

01:14:42,540 --> 01:14:19,820

[Applause]