



George Cody

*The Need for Dynamic Organic Reaction  
Networks & Where to Find Them*

1  
00:00:12,740 --> 00:00:10,600

[Music]

2  
00:00:15,650 --> 00:00:12,750

Thank You Irina

3  
00:00:16,880 --> 00:00:15,660

that's a great question George and so

4  
00:00:18,700 --> 00:00:16,890

what actually they're sort of core of

5  
00:00:20,960 --> 00:00:18,710

what I'm going to try to talk about here

6  
00:00:23,060 --> 00:00:20,970

so I gave this I think it's kinda like a

7  
00:00:24,620 --> 00:00:23,070

Harry Potter s sort of title dynamic

8  
00:00:26,029 --> 00:00:24,630

organic reaction networks and where to

9  
00:00:28,009 --> 00:00:26,039

find them it's kind of like magical

10  
00:00:29,540 --> 00:00:28,019

beasts and how to feed them and I think

11  
00:00:31,099 --> 00:00:29,550

a bunch of different collaborators are a

12  
00:00:33,259 --> 00:00:31,109

highlight show a ohhara I'm going to

13  
00:00:35,720 --> 00:00:33,269

show quite a bit of his work that he did

14

00:00:37,579 --> 00:00:35,730

with along with Vijay that was actually

15

00:00:39,380 --> 00:00:37,589

inspired by some ideas a Harold marwat's

16

00:00:42,080 --> 00:00:39,390

had are very consistent with what we

17

00:00:44,600 --> 00:00:42,090

just heard before really pretty cool

18

00:00:47,150 --> 00:00:44,610

stuff so I think to me a statement of

19

00:00:48,619 --> 00:00:47,160

the obvious is that for life to emerge

20

00:00:49,970 --> 00:00:48,629

on this planet there had to be

21

00:00:52,459 --> 00:00:49,980

environments that we're capable of

22

00:00:55,189 --> 00:00:52,469

continuous synthesis of reactive organic

23

00:00:57,470 --> 00:00:55,199

molecules I think that's probably the

24

00:00:58,880 --> 00:00:57,480

simplest requirement so that's an

25

00:01:00,529 --> 00:00:58,890

obvious question now I'll refer to this

26

00:01:02,270 --> 00:01:00,539

in a very general sense it's dynamic

27

00:01:05,029 --> 00:01:02,280

organic reaction networks I think you're

28

00:01:07,130 --> 00:01:05,039

self-explanatory we get to it what's not

29

00:01:09,080 --> 00:01:07,140

at all obvious from a geochemical

30

00:01:11,510 --> 00:01:09,090

perspective is how and where could these

31

00:01:13,280 --> 00:01:11,520

naturally occur I think this speaks

32

00:01:17,570 --> 00:01:13,290

somewhat to exactly what George was

33

00:01:18,679 --> 00:01:17,580

asking at this stage of what we do we're

34

00:01:20,899 --> 00:01:18,689

generally not worried so much about

35

00:01:23,210 --> 00:01:20,909

yield we're worried about pathway can we

36

00:01:25,999 --> 00:01:23,220

show pathway connectivity between one

37

00:01:27,440 --> 00:01:26,009

state systems to nuts but at some point

38

00:01:28,670 --> 00:01:27,450

we do have to worry about yield in some

39

00:01:33,170 --> 00:01:28,680

way we have to at some point we have to

40

00:01:35,210 --> 00:01:33,180

worry about control functions and I will

41

00:01:36,830 --> 00:01:35,220

point to that so when one puts it

42

00:01:39,050 --> 00:01:36,840

together a talk like this one generally

43

00:01:40,520 --> 00:01:39,060

likes to look at sort of big idea papers

44

00:01:42,050 --> 00:01:40,530

and and you can't really go wrong or I

45

00:01:44,480 --> 00:01:42,060

think you can't go wrong by looking at

46

00:01:45,679 --> 00:01:44,490

big idea of papers from norms sleep

47

00:01:47,810 --> 00:01:45,689

he always has very interesting

48

00:01:49,370 --> 00:01:47,820

perspective so I hadn't read this

49

00:01:51,740 --> 00:01:49,380

particular paper if his but I did just

50

00:01:53,600 --> 00:01:51,750

to kind of get myself energized for

51  
00:01:54,859 --> 00:01:53,610  
putting this talk together and and he

52  
00:01:56,389 --> 00:01:54,869  
says some statements that make me feel

53  
00:01:58,340 --> 00:01:56,399  
really good like life probably

54  
00:02:00,170 --> 00:01:58,350  
originated here and definitely evolved

55  
00:02:03,080 --> 00:02:00,180  
here that's a great statement and if you

56  
00:02:04,999 --> 00:02:03,090  
know norm he he is very very careful

57  
00:02:06,649 --> 00:02:05,009  
about what he says and then I game since

58  
00:02:08,359 --> 00:02:06,659  
I said was probably unproductive to

59  
00:02:11,150 --> 00:02:08,369  
precisely define when auto catalysis

60  
00:02:13,160 --> 00:02:11,160  
became life and from norms perspective

61  
00:02:14,870 --> 00:02:13,170  
this an absolutely relevant point

62  
00:02:18,170 --> 00:02:14,880  
because he's focused on life on Earth

63  
00:02:19,460 --> 00:02:18,180

and the evolution of both life and the

64

00:02:21,770 --> 00:02:19,470

earth in

65

00:02:23,330 --> 00:02:21,780

interactive sort of way so he he can

66

00:02:26,210 --> 00:02:23,340

take that question off the table

67

00:02:28,490 --> 00:02:26,220

but we can hey we really have to address

68

00:02:30,680 --> 00:02:28,500

this issue about the broader context of

69

00:02:32,570 --> 00:02:30,690

life how that reflects to Swiss self in

70

00:02:35,180 --> 00:02:32,580

an exoplanets and the possibility of

71

00:02:36,860 --> 00:02:35,190

life elsewhere so again going back to

72

00:02:40,400 --> 00:02:36,870

norm sleeps key requirements

73

00:02:42,290 --> 00:02:40,410

he says temperatures key here we really

74

00:02:43,790 --> 00:02:42,300

don't we've got a narrow band of

75

00:02:46,550 --> 00:02:43,800

temperature to play with it has to be

76  
00:02:48,530 --> 00:02:46,560  
warmer than in solid water so you could

77  
00:02:50,300 --> 00:02:48,540  
have Bryan's that are colder than zero

78  
00:02:52,190 --> 00:02:50,310  
but but a certain point waters gonna

79  
00:02:55,220 --> 00:02:52,200  
solidify and it has to be probably he

80  
00:02:56,990 --> 00:02:55,230  
argues less than 122 degrees centigrade

81  
00:02:58,280 --> 00:02:57,000  
and then the second requirement is

82  
00:03:00,440 --> 00:02:58,290  
straightforward there has to be energy

83  
00:03:02,090 --> 00:03:00,450  
and I like the fact that he said there

84  
00:03:03,800 --> 00:03:02,100  
have always been hydrothermal systems to

85  
00:03:05,960 --> 00:03:03,810  
promote this chemical D security regime

86  
00:03:07,580 --> 00:03:05,970  
and the earth throughout Earth history

87  
00:03:09,320 --> 00:03:07,590  
he also argues that then came

88  
00:03:12,230 --> 00:03:09,330

phototropism I think everybody agree

89

00:03:13,820 --> 00:03:12,240

with that so in a norm kind of grounds

90

00:03:15,170 --> 00:03:13,830

the questions rather nicely and both the

91

00:03:18,560 --> 00:03:15,180

requirements that seem very reasonable

92

00:03:21,200 --> 00:03:18,570

to me so then I went off and I said well

93

00:03:22,910 --> 00:03:21,210

you know at this point 2018 we must have

94

00:03:24,740 --> 00:03:22,920

a pretty clear view of what the Earth's

95

00:03:26,600 --> 00:03:24,750

early atmosphere looked like and I was

96

00:03:28,430 --> 00:03:26,610

surprised that the first figure you get

97

00:03:30,290 --> 00:03:28,440

when you google it is very Harold Urey

98

00:03:33,530 --> 00:03:30,300

--is-- sort of view of the earth even in

99

00:03:34,850 --> 00:03:33,540

2018 so don't think that that's

100

00:03:37,400 --> 00:03:34,860

particularly likely so another person

101  
00:03:40,160 --> 00:03:37,410  
that's always kind of fun to go visit is

102  
00:03:41,510 --> 00:03:40,170  
Kevin's on LI and apparently this must

103  
00:03:43,370 --> 00:03:41,520  
have been a really interesting meeting I

104  
00:03:46,370 --> 00:03:43,380  
think Jack szostak put it together at

105  
00:03:47,930 --> 00:03:46,380  
Cold Spring Harbor and what Kevin does

106  
00:03:49,759 --> 00:03:47,940  
of course is he takes her the same

107  
00:03:52,430 --> 00:03:49,769  
perspective that norm does perhaps a

108  
00:03:55,130 --> 00:03:52,440  
little bit more if you know Kevin work

109  
00:03:57,350 --> 00:03:55,140  
Kevin like way it is very complicated

110  
00:03:59,420 --> 00:03:57,360  
diagram the bottom line is is Kevin

111  
00:04:01,310 --> 00:03:59,430  
would argue that that the surface of the

112  
00:04:04,400 --> 00:04:01,320  
earth itself became a very climate place

113  
00:04:06,650 --> 00:04:04,410

for life remarkably quickly so in this

114

00:04:08,449 --> 00:04:06,660

axis of time he would argue that that

115

00:04:11,030 --> 00:04:08,459

oceans had completely started to

116

00:04:13,610 --> 00:04:11,040

condense at about a million years and at

117

00:04:15,650 --> 00:04:13,620

that point like we go on he also argues

118

00:04:18,229 --> 00:04:15,660

against things like an ammoniated or or

119

00:04:21,259 --> 00:04:18,239

methane ated atmosphere atmosphere based

120

00:04:23,630 --> 00:04:21,269

on on photochemistry so so if you you

121

00:04:26,750 --> 00:04:23,640

think Kevin's --only esque way you're

122

00:04:29,060 --> 00:04:26,760

really talking about co2 so that gets us

123

00:04:30,050 --> 00:04:29,070

to ask about Hadean sources of fuels and

124

00:04:32,060 --> 00:04:30,060

oxidants

125

00:04:33,260 --> 00:04:32,070

so we condensed a planet from

126

00:04:34,580 --> 00:04:33,270

interstellar material

127

00:04:36,620 --> 00:04:34,590

course one of those abundant molecules

128

00:04:38,659 --> 00:04:36,630

in in the universe is hydrogen but I

129

00:04:40,490 --> 00:04:38,669

doubt very severely than any of that

130

00:04:42,589 --> 00:04:40,500

hydrogen made it way into the accretion

131

00:04:43,939 --> 00:04:42,599

of the earth that was left so we need

132

00:04:45,290 --> 00:04:43,949

the earth to generate the hydrogen

133

00:04:48,050 --> 00:04:45,300

that's going to be probably the most

134

00:04:50,059 --> 00:04:48,060

dominant fuel this is a model reaction

135

00:04:52,370 --> 00:04:50,069

of certain ization reaction which is a

136

00:04:55,040 --> 00:04:52,380

very efficient hydrogen generator my

137

00:04:58,159 --> 00:04:55,050

Kressel has considered this for many

138

00:05:01,040 --> 00:04:58,169

many years many people do so it's a very

139

00:05:02,510 --> 00:05:01,050

reliable source of a fuel maybe there

140

00:05:04,790 --> 00:05:02,520

was methane maybe there was ammonium

141

00:05:07,430 --> 00:05:04,800

hydrogen sulfides a good fuel that would

142

00:05:09,740 --> 00:05:07,440

be more of a URI asks thing so we

143

00:05:12,980 --> 00:05:09,750

include that for oxidants it would

144

00:05:15,499 --> 00:05:12,990

appear that  $\text{CO}_2$  is really the only solid

145

00:05:17,390 --> 00:05:15,509

oxidant we have things appear to be Mike

146

00:05:19,189 --> 00:05:17,400

could speak to this much more eloquently

147

00:05:20,870 --> 00:05:19,199

and I but but sulfate doesn't seem to be

148

00:05:24,140 --> 00:05:20,880

reasonable in the beginning although

149

00:05:25,040 --> 00:05:24,150

I'll talk to you about this and make

150

00:05:26,420 --> 00:05:25,050

some arguments that there may have been

151

00:05:27,860 --> 00:05:26,430

some other interesting oxidants that we

152

00:05:29,300 --> 00:05:27,870

don't normally take an account so

153

00:05:30,890 --> 00:05:29,310

starting with  $\text{CO}_2$  and hydrogen it's good

154

00:05:34,040 --> 00:05:30,900

place to start with sitting organic

155

00:05:36,170 --> 00:05:34,050

synthesis and life's origins and so the

156

00:05:39,140 --> 00:05:36,180

key is of course  $\text{CO}_2$  reductions we just

157

00:05:40,850 --> 00:05:39,150

heard now thermodynamically carbon

158

00:05:42,770 --> 00:05:40,860

dioxide and hydrogen can do two things

159

00:05:44,930 --> 00:05:42,780

they can do the water gas shift reaction

160

00:05:47,810 --> 00:05:44,940

it's basically a very fast equilibrium

161

00:05:49,820 --> 00:05:47,820

between  $\text{CO}_2$  and hydrogen carbon monoxide

162

00:05:51,560 --> 00:05:49,830

water the problem is almost any

163

00:05:53,959 --> 00:05:51,570

temperature any pressure you can think

164

00:05:56,330 --> 00:05:53,969

of the reaction is always strongly in

165

00:05:58,670 --> 00:05:56,340

charge use chips to the co2 side of

166

00:06:00,409 --> 00:05:58,680

things so so it's it's a fast reaction

167

00:06:02,779 --> 00:06:00,419

it doesn't require a catalyst but it's

168

00:06:04,580 --> 00:06:02,789

it's it's not particularly interesting

169

00:06:06,110 --> 00:06:04,590

as the previous speaker noted carbon

170

00:06:09,140 --> 00:06:06,120

monoxide is a great molecule for

171

00:06:11,270 --> 00:06:09,150

chemistry co2 is not now the methanogens

172

00:06:12,890 --> 00:06:11,280

this reaction is very very strongly

173

00:06:14,959 --> 00:06:12,900

thermodynamically driven at low

174

00:06:17,749 --> 00:06:14,969

temperatures so co2 plus hydrogen goes

175

00:06:19,760 --> 00:06:17,759

to methane and water so this is a great

176

00:06:21,439 --> 00:06:19,770

game and it senses start at least it's

177

00:06:23,709 --> 00:06:21,449

not making carbon-carbon bonds but it's

178

00:06:26,270 --> 00:06:23,719

a start for basically building something

179

00:06:27,950 --> 00:06:26,280

however it's interesting to go back

180

00:06:29,420 --> 00:06:27,960

through the literature particularly

181

00:06:31,010 --> 00:06:29,430

amongst experimental geochemist they

182

00:06:32,240 --> 00:06:31,020

were quickly surprised when they started

183

00:06:33,529 --> 00:06:32,250

studying this reaction that they could

184

00:06:35,559 --> 00:06:33,539

never see any methane even though

185

00:06:38,330 --> 00:06:35,569

thermodynamically it was the most stable

186

00:06:41,269 --> 00:06:38,340

species by far and they didn't recognize

187

00:06:43,909 --> 00:06:41,279

at the time that that without a catalyst

188

00:06:46,610 --> 00:06:43,919

you'll form no methane so you can verify

189

00:06:49,360 --> 00:06:46,620

that yourself in fact when you do seem

190

00:06:52,219 --> 00:06:49,370

Thayne using gold reactors where gold is

191

00:06:53,840 --> 00:06:52,229

effectively non catalytic you'll find

192

00:06:55,310 --> 00:06:53,850

that it's due to trace metal

193

00:06:57,200 --> 00:06:55,320

contaminants in the gold because there's

194

00:06:58,670 --> 00:06:57,210

always you know entropy will never allow

195

00:07:00,350 --> 00:06:58,680

you to have pure gold pure words you

196

00:07:01,909 --> 00:07:00,360

might think it might be will always be a

197

00:07:03,980 --> 00:07:01,919

little bit platinum iridium and some

198

00:07:06,200 --> 00:07:03,990

kind of sicyon so any methane that you

199

00:07:09,050 --> 00:07:06,210

do generate can be attributed we had a

200

00:07:11,409 --> 00:07:09,060

postdoc in my lab who did a very careful

201  
00:07:13,310 --> 00:07:11,419  
experiment showing just that fact and

202  
00:07:15,890 --> 00:07:13,320  
important but not particularly exciting

203  
00:07:17,420 --> 00:07:15,900  
so we do the reaction and this is this

204  
00:07:19,580 --> 00:07:17,430  
is scaled so that you can see all the

205  
00:07:21,110 --> 00:07:19,590  
products but you get mostly methane you

206  
00:07:23,900 --> 00:07:21,120  
get a subordinate amount of ethane

207  
00:07:25,520 --> 00:07:23,910  
that's the two-threes propane you get

208  
00:07:29,420 --> 00:07:25,530  
your butane and your pentane and your

209  
00:07:30,590 --> 00:07:29,430  
hexane so this is fine I'll talk about

210  
00:07:32,510 --> 00:07:30,600  
the kinetics but I'll highlight one

211  
00:07:34,820 --> 00:07:32,520  
thing you do form a bunch of other

212  
00:07:37,159 --> 00:07:34,830  
little molecules and it turns out these

213  
00:07:38,840 --> 00:07:37,169

are really going to be the source atom

214

00:07:40,610 --> 00:07:38,850

utley if your dynamic organic reaction

215

00:07:42,320 --> 00:07:40,620

networks so these are branched and

216

00:07:43,879 --> 00:07:42,330

partially unsaturated but they're very

217

00:07:48,110 --> 00:07:43,889

subordinate to to the main reduce

218

00:07:51,200 --> 00:07:48,120

products now kinetics you know this is a

219

00:07:53,060 --> 00:07:51,210

if theoretically if you had homogeneous

220

00:07:55,129 --> 00:07:53,070

kinetics you'd predict this sort of

221

00:07:57,500 --> 00:07:55,139

behavior decay of co<sub>2</sub> so we're starting

222

00:08:00,950 --> 00:07:57,510

with formic acid so you only form 25%

223

00:08:02,810 --> 00:08:00,960

methane so co<sub>2</sub> and hydrogen decay

224

00:08:05,629 --> 00:08:02,820

exponentially and then one minus

225

00:08:07,100 --> 00:08:05,639

exponent production of water and methane

226

00:08:09,650 --> 00:08:07,110

is what is expected but of course I said

227

00:08:12,350 --> 00:08:09,660

you can't do this without a catalyst so

228

00:08:14,719 --> 00:08:12,360

with heterogeneous catalysis you end up

229

00:08:16,640 --> 00:08:14,729

with essentially 0th order kinetics so

230

00:08:18,680 --> 00:08:16,650

this is what you would predict to see if

231

00:08:20,480 --> 00:08:18,690

you did this reaction as a function of

232

00:08:23,240 --> 00:08:20,490

time and that little blue box shows you

233

00:08:26,420 --> 00:08:23,250

why you get 0th order kinetics in fact

234

00:08:29,000 --> 00:08:26,430

we can show this in a really funny

235

00:08:30,860 --> 00:08:29,010

reaction for chemists because we did a

236

00:08:32,870 --> 00:08:30,870

reaction to butane Thyle which is one of

237

00:08:35,000 --> 00:08:32,880

the most foul-smelling molecules could

238

00:08:37,550 --> 00:08:35,010

possibly imagine except for the product

239

00:08:39,199 --> 00:08:37,560

of the reaction which is pentanoic or

240

00:08:41,449 --> 00:08:39,209

villi Eric acid which is about the most

241

00:08:43,730 --> 00:08:41,459

horrendously smelly compound you can so

242

00:08:45,920 --> 00:08:43,740

it's like gifs go for bad too costly

243

00:08:51,050 --> 00:08:45,930

worse but it shows beautiful 0th order

244

00:08:53,810 --> 00:08:51,060

kinetics and its yield so so what we saw

245

00:08:56,060 --> 00:08:53,820

in this reaction this is a funny story

246

00:08:57,530 --> 00:08:56,070

to this so I wasn't particularly

247

00:08:59,810 --> 00:08:57,540

interested in this reaction but I had a

248

00:09:00,540 --> 00:08:59,820

summer research intern and I wanted to

249

00:09:02,070 --> 00:09:00,550

give them a

250

00:09:04,110 --> 00:09:02,080

experiment to do and I wanted to get

251  
00:09:05,820 --> 00:09:04,120  
them from bothering me so I thought I

252  
00:09:06,900 --> 00:09:05,830  
could teach them how to weld gold tubes

253  
00:09:09,240 --> 00:09:06,910  
and I would give this very simple

254  
00:09:11,130 --> 00:09:09,250  
reaction I said just take form of gas to

255  
00:09:13,410 --> 00:09:11,140  
decompose it over iron and gold tubes

256  
00:09:16,320 --> 00:09:13,420  
and just show me that  $\text{CO}_2$  is decaying

257  
00:09:18,060 --> 00:09:16,330  
linearly and hydrogens decaying linearly

258  
00:09:19,440 --> 00:09:18,070  
and methane is increasing linearly and

259  
00:09:21,600 --> 00:09:19,450  
then you'll be done for your summer

260  
00:09:26,519 --> 00:09:21,610  
research and so he came back in and he

261  
00:09:27,840 --> 00:09:26,529  
and he showed me this plot and I said

262  
00:09:29,819 --> 00:09:27,850  
that's ridiculous to go back and do it

263  
00:09:31,440 --> 00:09:29,829

again this doesn't make any sense and so

264

00:09:33,139 --> 00:09:31,450

he did it over and over again so of

265

00:09:35,550 --> 00:09:33,149

course this is what we predicted and

266

00:09:38,579 --> 00:09:35,560

this is what we see that in the first

267

00:09:41,009 --> 00:09:38,589

couple hours there's no co2 at all co2

268

00:09:42,360 --> 00:09:41,019

is just disappears from the system half

269

00:09:43,740 --> 00:09:42,370

of the hydrogen you'd expect to see is

270

00:09:46,139 --> 00:09:43,750

there and it just sort of floats there

271

00:09:48,150 --> 00:09:46,149

and then miraculously about four to six

272

00:09:51,960 --> 00:09:48,160

hours also there's an explosion of co2

273

00:09:53,910 --> 00:09:51,970

and product hydrocarbons this is the

274

00:09:55,769 --> 00:09:53,920

distribution I showed you so again it

275

00:09:58,769 --> 00:09:55,779

looks very Fischer troph like in its

276

00:10:00,780 --> 00:09:58,779

distribution so methane propane is

277

00:10:02,550 --> 00:10:00,790

abundant over at more abundant of ethane

278

00:10:03,930 --> 00:10:02,560

and so on and so forth but a decay and

279

00:10:06,120 --> 00:10:03,940

the relative yield as a function of

280

00:10:10,050 --> 00:10:06,130

chain length the blue are branched

281

00:10:11,610 --> 00:10:10,060

compounds and when you do a mass balance

282

00:10:13,199 --> 00:10:11,620

you see the carbon budget doesn't make

283

00:10:15,530 --> 00:10:13,209

any sense so for the first four hours

284

00:10:18,180 --> 00:10:15,540

100% of your carbon is just not

285

00:10:19,920 --> 00:10:18,190

detectable analytically it's there right

286

00:10:22,010 --> 00:10:19,930

it's in a sealed gold tube but but you

287

00:10:26,100 --> 00:10:22,020

just can't see it using gas phase

288

00:10:27,960 --> 00:10:26,110

analysis headspace-gc similarly it

289

00:10:29,970 --> 00:10:27,970

reappears about four hours but it's now

290

00:10:32,100 --> 00:10:29,980

quite important the black line down

291

00:10:33,300 --> 00:10:32,110

below is about the amount of hydrocarbon

292

00:10:34,740 --> 00:10:33,310

so you would predict you have made so

293

00:10:36,449 --> 00:10:34,750

you're making more hydrocarbons and you

294

00:10:37,680 --> 00:10:36,459

had hydrogen to make with so it tells

295

00:10:39,630 --> 00:10:37,690

you that you've got hydrogen generation

296

00:10:43,530 --> 00:10:39,640

going on that's not a surprise the

297

00:10:45,150 --> 00:10:43,540

hydrogen budget also and then we did we

298

00:10:47,730 --> 00:10:45,160

looked at stable isotopes and again you

299

00:10:49,860 --> 00:10:47,740

can see at low times the co2 both the

300

00:10:51,569 --> 00:10:49,870

co2 and methane are actually more

301  
00:10:52,920 --> 00:10:51,579  
depleted relative to the starting

302  
00:10:54,689 --> 00:10:52,930  
material which is the dashed line which

303  
00:10:56,189 --> 00:10:54,699  
is just the carbon your four mate so

304  
00:11:00,269 --> 00:10:56,199  
that's your missing carbon reservoir

305  
00:11:01,829 --> 00:11:00,279  
somewhere and the same thing happens

306  
00:11:04,560 --> 00:11:01,839  
over here there's a bottom line what I'm

307  
00:11:05,939 --> 00:11:04,570  
saying is so then interact Sharma was

308  
00:11:07,500 --> 00:11:05,949  
working out loud and he's very handy

309  
00:11:09,120 --> 00:11:07,510  
with a hydrothermal diamond anvil cell

310  
00:11:10,710 --> 00:11:09,130  
which is a beautiful device to allow you

311  
00:11:12,660 --> 00:11:10,720  
to look into the reactor to see what's

312  
00:11:13,980 --> 00:11:12,670  
actually going on and what you can see

313  
00:11:15,630 --> 00:11:13,990

is complete mayhem

314

00:11:19,170 --> 00:11:15,640

so you're seeing all sorts of different

315

00:11:20,880 --> 00:11:19,180

phases here the absolute cake phases are

316

00:11:23,370 --> 00:11:20,890

your residual iron there's at least two

317

00:11:25,050 --> 00:11:23,380

different liquids but apparently even

318

00:11:27,420 --> 00:11:25,060

three different liquid phases that are

319

00:11:29,220 --> 00:11:27,430

immiscible and if you look closely in

320

00:11:31,380 --> 00:11:29,230

the rommel inspector you see abundant

321

00:11:33,660 --> 00:11:31,390

transition metal carbonyls so the bottom

322

00:11:36,360 --> 00:11:33,670

line is in this particular super simple

323

00:11:39,240 --> 00:11:36,370

system or organometallic chemistry x' is

324

00:11:41,220 --> 00:11:39,250

very abundant it highlights the fact

325

00:11:43,620 --> 00:11:41,230

that even simple experiments are rarely

326

00:11:45,300 --> 00:11:43,630

simple and the hidden mineral chemistry

327

00:11:46,890 --> 00:11:45,310

that drives the system towards sorts

328

00:11:50,220 --> 00:11:46,900

very rapid Hodge a thermo-pile

329

00:11:52,050 --> 00:11:50,230

hydrocarbon synthesis the kinetics are

330

00:11:53,370 --> 00:11:52,060

completely unusual we don't really quite

331

00:11:55,530 --> 00:11:53,380

understand them there they're almost

332

00:11:56,790 --> 00:11:55,540

explosive so you know you would have

333

00:11:58,380 --> 00:11:56,800

thought I would have thought the system

334

00:12:00,480 --> 00:11:58,390

would have established one state or the

335

00:12:02,400 --> 00:12:00,490

other what special at four or six hours

336

00:12:03,720 --> 00:12:02,410

it causes a system to all us and shift

337

00:12:07,440 --> 00:12:03,730

from one state to another

338

00:12:08,610 --> 00:12:07,450

is not at all obvious to us I don't know

339

00:12:10,520 --> 00:12:08,620

if it's a profitable thing to really

340

00:12:12,930 --> 00:12:10,530

worry about but it's very reproducible

341

00:12:15,300 --> 00:12:12,940

but either way I wanted to highlight for

342

00:12:17,340 --> 00:12:15,310

this talk that even though we can do

343

00:12:19,890 --> 00:12:17,350

very easily all this carbon-carbon bond

344

00:12:22,020 --> 00:12:19,900

formation simple hydrocarbons are not

345

00:12:24,030 --> 00:12:22,030

reactive and are not capable of

346

00:12:25,440 --> 00:12:24,040

sustaining a dynamic organic reaction

347

00:12:27,780 --> 00:12:25,450

network so even though this is how you

348

00:12:29,700 --> 00:12:27,790

have to start the system the main

349

00:12:32,010 --> 00:12:29,710

product distribution is not something

350

00:12:36,180 --> 00:12:32,020

that's going to be in my view beneficial

351  
00:12:38,010 --> 00:12:36,190  
for a emergent living system as George

352  
00:12:42,120 --> 00:12:38,020  
talked about this morning and others

353  
00:12:43,290 --> 00:12:42,130  
have talked about so just this figure is

354  
00:12:45,030 --> 00:12:43,300  
kind of screwed up but obviously there's

355  
00:12:47,550 --> 00:12:45,040  
a carbon valence state from minus 4 to

356  
00:12:51,350 --> 00:12:47,560  
plus 4 and then hydrogen redox over here

357  
00:12:54,000 --> 00:12:51,360  
and it highlights the fact that if you

358  
00:12:56,610 --> 00:12:54,010  
if you're just making simple

359  
00:13:00,090 --> 00:12:56,620  
hydrocarbons as a macro moly ethylenes

360  
00:13:02,820 --> 00:13:00,100  
and alkanes through -4 minus 2 or

361  
00:13:04,650 --> 00:13:02,830  
methane Thyle which is a molecule that's

362  
00:13:06,990 --> 00:13:04,660  
fine but all of life exists essentially

363  
00:13:10,140 --> 00:13:07,000

much more at sort of a carbon neutral

364

00:13:13,980 --> 00:13:10,150

valence state and if our Trebor were

365

00:13:17,010 --> 00:13:13,990

here he would go on quite convincingly

366

00:13:18,630 --> 00:13:17,020

and and I think rightly so and the

367

00:13:19,920 --> 00:13:18,640

benefit of being at around 0 valence

368

00:13:21,630 --> 00:13:19,930

carbon for the kind of chemistry you

369

00:13:23,400 --> 00:13:21,640

want to do but the bottom line is you

370

00:13:25,260 --> 00:13:23,410

see all amino acids are sort of sitting

371

00:13:26,910 --> 00:13:25,270

back and forth around the zero valence

372

00:13:27,630 --> 00:13:26,920

state and all the T C intermediates are

373

00:13:31,080 --> 00:13:27,640

relatively

374

00:13:32,610 --> 00:13:31,090

sighs when it comes to organic

375

00:13:34,470 --> 00:13:32,620

polymerization which is something we're

376

00:13:36,420 --> 00:13:34,480

always interested in this becomes

377

00:13:38,010 --> 00:13:36,430

critical so even if you if you wanted to

378

00:13:39,870 --> 00:13:38,020

make a compelling physical argument that

379

00:13:41,550 --> 00:13:39,880

polyethylene was your polymer of choice

380

00:13:44,040 --> 00:13:41,560

for emergence systems I don't think

381

00:13:46,410 --> 00:13:44,050

anybody would the problem is is that

382

00:13:48,060 --> 00:13:46,420

this catalytic chemistry is is strongly

383

00:13:50,130 --> 00:13:48,070

quenched by the presence of water and

384

00:13:51,510 --> 00:13:50,140

and so you're not going to go very far

385

00:13:54,120 --> 00:13:51,520

with regards to the activity water

386

00:13:56,580 --> 00:13:54,130

before if things fall apart now my

387

00:13:59,130 --> 00:13:56,590

colleague Irina she does some beautiful

388

00:14:00,930 --> 00:13:59,140

work with you know cyclic drying heating

389

00:14:03,480 --> 00:14:00,940

wetting drying wetting drying white

390

00:14:05,160 --> 00:14:03,490

wedding to do polymerization but she

391

00:14:06,600 --> 00:14:05,170

would also agree at a certain point the

392

00:14:08,550 --> 00:14:06,610

activity of water is going to shut

393

00:14:10,890 --> 00:14:08,560

things down just simple thermodynamics

394

00:14:12,990 --> 00:14:10,900

condensation and that's the beauty is

395

00:14:14,730 --> 00:14:13,000

art Weber would talk to you about is the

396

00:14:16,500 --> 00:14:14,740

idea of what sugars can do in aldol

397

00:14:18,630 --> 00:14:16,510

polymerization so they're not

398

00:14:20,490 --> 00:14:18,640

condensation polymerization and and in

399

00:14:22,650 --> 00:14:20,500

fact you can show that sugars will

400

00:14:24,780 --> 00:14:22,660

polymerize themselves I'll be it into a

401  
00:14:27,480 --> 00:14:24,790  
mess so there's your messy chemistry

402  
00:14:29,190 --> 00:14:27,490  
like that but but it you know you can go

403  
00:14:30,450 --> 00:14:29,200  
down to millimolar concentrations and

404  
00:14:32,130 --> 00:14:30,460  
give it enough time and the stuff will

405  
00:14:34,650 --> 00:14:32,140  
polymerize and precipitate out I'll show

406  
00:14:36,030 --> 00:14:34,660  
you an example of that so so there's

407  
00:14:37,560 --> 00:14:36,040  
something to be said is what I'm getting

408  
00:14:40,140 --> 00:14:37,570  
at maybe the core of this entire

409  
00:14:42,480 --> 00:14:40,150  
argument is getting a system to sit

410  
00:14:48,630 --> 00:14:42,490  
around sort of equivalently carbon 0

411  
00:14:50,850 --> 00:14:48,640  
valence so we kind of got re-energized

412  
00:14:53,960 --> 00:14:50,860  
by this ism it's a different difficult

413  
00:14:55,920 --> 00:14:53,970

segue to make but I'm going to it is

414

00:14:57,030 --> 00:14:55,930

independent of this I've been studying

415

00:14:58,380 --> 00:14:57,040

the organic matter and carbonaceous

416

00:15:00,180 --> 00:14:58,390

chondrite meteorites and I've been

417

00:15:01,530 --> 00:15:00,190

focusing on the in cell insoluble

418

00:15:03,750 --> 00:15:01,540

organic matter and I'm not going to talk

419

00:15:05,160 --> 00:15:03,760

about that specifically but others have

420

00:15:07,530 --> 00:15:05,170

a dominantly been focusing on small

421

00:15:09,000 --> 00:15:07,540

molecules they can extract now the neat

422

00:15:10,650 --> 00:15:09,010

thing about carbonaceous chondrites

423

00:15:12,690 --> 00:15:10,660

is they tell you about chemistry and

424

00:15:15,270 --> 00:15:12,700

planet parent body interiors these are

425

00:15:17,340 --> 00:15:15,280

planetesimals that existed for tens to

426

00:15:20,640 --> 00:15:17,350

hundreds of millions of years they had

427

00:15:22,710 --> 00:15:20,650

interesting disequilibrium systems that

428

00:15:24,690 --> 00:15:22,720

were warm but not hot they were wet but

429

00:15:25,860 --> 00:15:24,700

not soaked they initially started very

430

00:15:28,200 --> 00:15:25,870

far from equilibrium

431

00:15:30,270 --> 00:15:28,210

very rich in carbon predominantly  $\text{CO}_2$

432

00:15:32,150 --> 00:15:30,280

and perhaps some carbon monoxide and

433

00:15:36,900 --> 00:15:32,160

catalytic phases iron nickel metal

434

00:15:39,330 --> 00:15:36,910

kamacite and correlate as a iron

435

00:15:40,950 --> 00:15:39,340

sulphide is very very abundant

436

00:15:41,519 --> 00:15:40,960

relatively speaking and potentially

437

00:15:43,530 --> 00:15:41,529

millions

438

00:15:45,809 --> 00:15:43,540

years of mild hydrothermal reaction and

439

00:15:49,170 --> 00:15:45,819

the possibility perhaps of chemical

440

00:15:50,850 --> 00:15:49,180

evolution so but up to this point most

441

00:15:52,499 --> 00:15:50,860

people have focused on amino acids there

442

00:15:53,699 --> 00:15:52,509

been detection of nucleobases there's

443

00:15:56,929 --> 00:15:53,709

certainly some interesting chemistry in

444

00:16:01,710 --> 00:15:56,939

there George Cooper published a paper in

445

00:16:03,600 --> 00:16:01,720

2011 which astounded me he is a very

446

00:16:06,660 --> 00:16:03,610

careful analyst and he's been studying

447

00:16:09,030 --> 00:16:06,670

the Murchison meteorite and he detected

448

00:16:10,920 --> 00:16:09,040

and on the biggest identified all sorts

449

00:16:12,360 --> 00:16:10,930

of interesting compounds that are very

450

00:16:17,610 --> 00:16:12,370

familiar to us as metabolic

451

00:16:21,360 --> 00:16:17,620

intermediates and so he finds pyruvate

452

00:16:22,980 --> 00:16:21,370

and citrate and alpha ketoglutarate and

453

00:16:27,059 --> 00:16:22,990

some and so forth lactic acids over

454

00:16:28,679 --> 00:16:27,069

there alanine glycolic acid and some and

455

00:16:30,449 --> 00:16:28,689

so forth there's even a can con at eight

456

00:16:33,989 --> 00:16:30,459

somewhere here

457

00:16:35,429 --> 00:16:33,999

yeah down in the corner and but he's you

458

00:16:37,350 --> 00:16:35,439

know he focuses primarily at doing

459

00:16:39,449 --> 00:16:37,360

really precise analytical chemistry and

460

00:16:42,809 --> 00:16:39,459

using isotopic analysis to verify the

461

00:16:45,449 --> 00:16:42,819

you know JIT a'mma C of these compounds

462

00:16:47,100 --> 00:16:45,459

with respect to their origin but when it

463

00:16:48,809 --> 00:16:47,110

came time to proposing what their

464

00:16:51,360 --> 00:16:48,819

formation mechanism was he said well

465

00:16:54,119 --> 00:16:51,370

maybe they came from Keene and we get to

466

00:16:56,069 --> 00:16:54,129

pyruvate and then we can add potassium

467

00:17:00,119 --> 00:16:56,079

cyanide to the system and all this

468

00:17:01,920 --> 00:17:00,129

chemistry occur and you know possibly

469

00:17:07,350 --> 00:17:01,930

possibly that's okay

470

00:17:09,630 --> 00:17:07,360

but the thing that struck me was if you

471

00:17:12,090 --> 00:17:09,640

looked at all his molecules citric acid

472

00:17:13,919 --> 00:17:12,100

and the previous speaker highlighted his

473

00:17:16,110 --> 00:17:13,929

early study I did looking at the hydro

474

00:17:18,809 --> 00:17:16,120

thermal decomposition such a gas is a

475

00:17:20,250 --> 00:17:18,819

fairly tough molecule it's it's you have

476

00:17:21,929 --> 00:17:20,260

to go to temperatures on the order of

477

00:17:24,720 --> 00:17:21,939

about 200 Gries centigrade to start to

478

00:17:26,360 --> 00:17:24,730

see it decompose in a reasonable way you

479

00:17:28,710 --> 00:17:26,370

know at a hundred degrees I haven't

480

00:17:30,990 --> 00:17:28,720

bothered to determine what the half-life

481

00:17:33,029 --> 00:17:31,000

is as a function of temperature but it's

482

00:17:34,169 --> 00:17:33,039

it's a tough molecule in fact one of the

483

00:17:35,639 --> 00:17:34,179

reasons that people got interested in

484

00:17:37,680 --> 00:17:35,649

getting rid of it is it turns out that

485

00:17:39,240 --> 00:17:37,690

it's a byproduct of the molasses

486

00:17:41,070 --> 00:17:39,250

industry and we generate more citric

487

00:17:42,419 --> 00:17:41,080

acid than we know what to do with and if

488

00:17:43,649 --> 00:17:42,429

you could find an easy way of getting

489

00:17:45,659 --> 00:17:43,659

rid of it this would be a really good

490

00:17:48,899 --> 00:17:45,669

thing to do so it's tough enough that

491

00:17:51,539 --> 00:17:48,909

people worry about this toughness but

492

00:17:53,370 --> 00:17:51,549

nevertheless it will go away and if you

493

00:17:55,020 --> 00:17:53,380

give something like 10 to 100 million

494

00:17:57,300 --> 00:17:55,030

years of hydrothermal chemistry

495

00:17:58,530 --> 00:17:57,310

a hundred to even maybe fifty two

496

00:18:00,690 --> 00:17:58,540

hundred great it's gonna decompose

497

00:18:01,860 --> 00:18:00,700

here's just showing the decomposition a

498

00:18:04,020 --> 00:18:01,870

two hundred grease integrated and within

499

00:18:06,240 --> 00:18:04,030

two hours you dropped a concentration of

500

00:18:09,630 --> 00:18:06,250

citric acid by three orders of magnitude

501  
00:18:12,450 --> 00:18:09,640  
which tells you so good something even

502  
00:18:14,730 --> 00:18:12,460  
as robust as citric acid less a million

503  
00:18:16,050 --> 00:18:14,740  
years not possible and that's probably

504  
00:18:17,130 --> 00:18:16,060  
one of the toughest molecules and all

505  
00:18:20,460 --> 00:18:17,140  
the molecules that George Cooper

506  
00:18:21,750 --> 00:18:20,470  
detected so the key here is that none of

507  
00:18:24,570 --> 00:18:21,760  
the molecules that George Cooper

508  
00:18:26,760 --> 00:18:24,580  
identified have ever been proposed to

509  
00:18:28,770 --> 00:18:26,770  
form prior to planetesimals accretion

510  
00:18:30,510 --> 00:18:28,780  
alright so so these things had to form

511  
00:18:32,760 --> 00:18:30,520  
in the parent body due to whatever

512  
00:18:34,110 --> 00:18:32,770  
process of occurring and he said many of

513  
00:18:36,090 --> 00:18:34,120

these molecules have not all of them are

514

00:18:38,760 --> 00:18:36,100

academic acid if you don't freeze it

515

00:18:39,720 --> 00:18:38,770

decomposes on the shelf right so so

516

00:18:41,070 --> 00:18:39,730

there's no way you're gonna have a

517

00:18:42,990 --> 00:18:41,080

commit a gas for the last thing for a

518

00:18:44,460 --> 00:18:43,000

couple of days let alone you know a

519

00:18:46,950 --> 00:18:44,470

millions of years in wet water

520

00:18:49,050 --> 00:18:46,960

conditions so so these things will not

521

00:18:50,670 --> 00:18:49,060

suffice oh we require in my view that

522

00:18:52,260 --> 00:18:50,680

the only way you could find these things

523

00:18:54,990 --> 00:18:52,270

in a meteorite if they were continuously

524

00:18:57,540 --> 00:18:55,000

regenerated and so in essence George

525

00:18:59,610 --> 00:18:57,550

Cooper detected the core evidence we

526

00:19:01,830 --> 00:18:59,620

were hoping to find and probably try to

527

00:19:03,720 --> 00:19:01,840

do in a laboratory of a natural dynamic

528

00:19:06,150 --> 00:19:03,730

organic reaction operating in

529

00:19:07,680 --> 00:19:06,160

planetesimals interiors so it raises the

530

00:19:10,920 --> 00:19:07,690

question how did this start and how did

531

00:19:12,660 --> 00:19:10,930

it operate so key here is planetesimals

532

00:19:14,490 --> 00:19:12,670

in crete from rapid collation of

533

00:19:16,470 --> 00:19:14,500

ice-covered interstellar silicate grains

534

00:19:18,210 --> 00:19:16,480

and ice is predominantly water that's

535

00:19:20,820 --> 00:19:18,220

why we call it ice but there's a fair

536

00:19:22,460 --> 00:19:20,830

amount of co2 carbon monoxide methanol

537

00:19:24,810 --> 00:19:22,470

formaldehyde my favorite molecule

538

00:19:27,150 --> 00:19:24,820

ammonia h<sub>2</sub>s and all about the same

539

00:19:29,550 --> 00:19:27,160

abundance and the silicates are in Hydra

540

00:19:31,940 --> 00:19:29,560

iron hydras hi I'm bearing silicates and

541

00:19:34,590 --> 00:19:31,950

amorphous iron bearing classes

542

00:19:35,940 --> 00:19:34,600

radiogenic elements provide the heat so

543

00:19:37,350 --> 00:19:35,950

in the core of a reasonably sized

544

00:19:39,180 --> 00:19:37,360

planetesimals and will get warm enough

545

00:19:41,580 --> 00:19:39,190

to melt the ices and start to react the

546

00:19:43,020 --> 00:19:41,590

iron to generate hydrogen so you have an

547

00:19:45,210 --> 00:19:43,030

environment that's capable of producing

548

00:19:47,340 --> 00:19:45,220

fuels and it has the oxidants you might

549

00:19:51,420 --> 00:19:47,350

like to do but what else has struck me

550

00:19:53,310 --> 00:19:51,430

about George Cooper's work is that all

551

00:19:56,160 --> 00:19:53,320

of these compounds much like our

552

00:19:57,480 --> 00:19:56,170

previous speaker was showing we've been

553

00:19:58,890 --> 00:19:57,490

able to make in our hydrothermal

554

00:20:01,710 --> 00:19:58,900

experiments in our laboratories so

555

00:20:04,350 --> 00:20:01,720

everyone in blue we made now the pathway

556

00:20:05,970 --> 00:20:04,360

unlike George's pathway coming from from

557

00:20:08,700 --> 00:20:05,980

this key team to to pyruvate and

558

00:20:11,370 --> 00:20:08,710

everywhere else the pathway we saw it

559

00:20:13,889 --> 00:20:11,380

doing something more like that in terms

560

00:20:16,470 --> 00:20:13,899

of connectivity of molecular species

561

00:20:19,230 --> 00:20:16,480

micro species and I highlight the methyl

562

00:20:21,210 --> 00:20:19,240

cyclic acid there so this really struck

563

00:20:23,250 --> 00:20:21,220

me because these molecules we can make

564

00:20:23,909 --> 00:20:23,260

in our little gold reactors and we see

565

00:20:25,380 --> 00:20:23,919

them all the time

566

00:20:27,240 --> 00:20:25,390

however we had never been able to make

567

00:20:29,880 --> 00:20:27,250

fumaric acid and we never could find a

568

00:20:31,560 --> 00:20:29,890

pathway to that alpha keto glue turret

569

00:20:33,960 --> 00:20:31,570

and so that really intrigued me that

570

00:20:37,769 --> 00:20:33,970

clearly this is occurring at Murchison

571

00:20:39,149 --> 00:20:37,779

how come we can't do it now one of the

572

00:20:40,710 --> 00:20:39,159

things we've always been focusing on not

573

00:20:42,539 --> 00:20:40,720

worrying at all about yields but we're

574

00:20:44,519 --> 00:20:42,549

just worrying about topology pathways

575

00:20:46,049 --> 00:20:44,529

--is is how would you start with co2 and

576

00:20:48,480 --> 00:20:46,059

hydrogen get to interesting molecules

577

00:20:51,299 --> 00:20:48,490

and so the pathway we like is going say

578

00:20:52,980 --> 00:20:51,309

through propane to acrylic acid through

579

00:20:55,950 --> 00:20:52,990

a carbonyl addition reaction and so and

580

00:20:57,899 --> 00:20:55,960

so forth level by level up the core to

581

00:20:59,669 --> 00:20:57,909

this chemistry is I'll show you later is

582

00:21:01,350 --> 00:20:59,679

that you can't just do this in a

583

00:21:03,180 --> 00:21:01,360

reductive sense you have to be playing

584

00:21:07,740 --> 00:21:03,190

both oxidative and reductive chemistry

585

00:21:10,019 --> 00:21:07,750

simultaneously which is tricky so a bit

586

00:21:12,630 --> 00:21:10,029

of history we got involved in this game

587

00:21:14,580 --> 00:21:12,640

when Harold Warwick's came to our lab 20

588

00:21:16,769 --> 00:21:14,590

years ago and he asked if I could do an

589

00:21:19,590 --> 00:21:16,779

experiment adding  $\text{CO}_2$  to pyruvic acid to

590

00:21:21,210 --> 00:21:19,600

make oxaloacetate and I didn't think

591

00:21:23,580 --> 00:21:21,220

that that would work at the time and it

592

00:21:25,139 --> 00:21:23,590

didn't and I thought would happen would

593

00:21:27,389 --> 00:21:25,149

be nothing but trouble and I was right

594

00:21:29,730 --> 00:21:27,399

is that the pyruvate would just react

595

00:21:31,889 --> 00:21:29,740

with itself forming this gooey tar which

596

00:21:34,200 --> 00:21:31,899

is what it does and or it just

597

00:21:38,340 --> 00:21:34,210

spontaneously decomposes to acetate

598

00:21:39,810 --> 00:21:38,350

releasing his reductive potential there

599

00:21:41,460 --> 00:21:39,820

are some interesting intermediates but

600

00:21:43,049 --> 00:21:41,470

but if you did this reactions as we did

601  
00:21:45,029 --> 00:21:43,059  
them in water that they're very low

602  
00:21:46,620 --> 00:21:45,039  
abundance but the only product that you

603  
00:21:48,750 --> 00:21:46,630  
do detected sort of builds up in the

604  
00:21:54,510 --> 00:21:48,760  
system is methyl 6na so I was really

605  
00:21:56,010 --> 00:21:54,520  
struck in when when it George Cooper

606  
00:21:57,570 --> 00:21:56,020  
called that out because that again

607  
00:22:02,450 --> 00:21:57,580  
looked like a lot of our aldol

608  
00:22:10,620 --> 00:22:08,430  
so any case so but that was as far as we

609  
00:22:13,380 --> 00:22:10,630  
went with the aldol reaction effect I

610  
00:22:15,419 --> 00:22:13,390  
used to say I know I'm sort of a little

611  
00:22:17,010 --> 00:22:15,429  
jet lag here I apologize for this one of

612  
00:22:20,250 --> 00:22:17,020  
the things I like about this system is

613  
00:22:22,410 --> 00:22:20,260

the power of the retro aldol component

614

00:22:23,880 --> 00:22:22,420

to give you reactive compound

615

00:22:25,590 --> 00:22:23,890

when and possibly you need it so for

616

00:22:28,470 --> 00:22:25,600

example on the right side Citroen malic

617

00:22:30,300 --> 00:22:28,480

acid turned out to be the best pyruvic

618

00:22:32,700 --> 00:22:30,310

acid generator I've ever seen and so in

619

00:22:35,850 --> 00:22:32,710

terms of high yield for example if you

620

00:22:37,620 --> 00:22:35,860

have ammonia and pyruvate as its own

621

00:22:40,710 --> 00:22:37,630

self reductant you can get almost the

622

00:22:42,420 --> 00:22:40,720

full yield of alanine one to one out of

623

00:22:45,480 --> 00:22:42,430

sitri moly under a aquatherm oolitic

624

00:22:47,760 --> 00:22:45,490

conditions i contrast that with my first

625

00:22:49,680 --> 00:22:47,770

and only first author science paper

626

00:22:51,810 --> 00:22:49,690

where I made some yield at point zero

627

00:22:54,360 --> 00:22:51,820

one percent pyruvate over Iron Mountain

628

00:22:55,920 --> 00:22:54,370

sulfate sulphide and at the time and we

629

00:22:57,210 --> 00:22:55,930

were really excited about that but but

630

00:22:59,310 --> 00:22:57,220

when you can see what you can do with

631

00:23:01,680 --> 00:22:59,320

the retro aldol reaction with something

632

00:23:03,180 --> 00:23:01,690

like Citra malate it's just incredible

633

00:23:05,940 --> 00:23:03,190

it's almost a hundred percent of the

634

00:23:10,860 --> 00:23:05,950

potential pyruvate generation will give

635

00:23:13,110 --> 00:23:10,870

you and so in keys but Harold had been

636

00:23:16,890 --> 00:23:13,120

starting to read some interesting papers

637

00:23:20,030 --> 00:23:16,900

by I wouldn't say his wasn't his nemesis

638

00:23:25,350 --> 00:23:23,550

but Leslie or gal it was the chemist

639

00:23:27,420 --> 00:23:25,360

chemist if my view in this business and

640

00:23:29,010 --> 00:23:27,430

and Harold as a biophysicist who was

641

00:23:31,290 --> 00:23:29,020

coming into this and just throwing out

642

00:23:33,770 --> 00:23:31,300

possible ideas and it I used to drive I

643

00:23:37,530 --> 00:23:33,780

think's fair to say Leslie a little bit

644

00:23:38,640 --> 00:23:37,540

crazy and so Harold came to me one time

645

00:23:41,040 --> 00:23:38,650

he said you know I just was reading

646

00:23:43,230 --> 00:23:41,050

Leslie's book on on ligand theory he

647

00:23:44,370 --> 00:23:43,240

says it's really very very good we

648

00:23:46,140 --> 00:23:44,380

should just start working with

649

00:23:47,430 --> 00:23:46,150

transition metal cations search as

650

00:23:50,420 --> 00:23:47,440

you've seen the previous talk turned out

651  
00:23:53,220 --> 00:23:50,430  
to be very fortuitous and so fine so

652  
00:23:55,860 --> 00:23:53,230  
showy O Hara and VJ who was a postdoc

653  
00:23:57,870 --> 00:23:55,870  
with Harold at the time we're in my lab

654  
00:24:00,840 --> 00:23:57,880  
and they just had a bunch of different

655  
00:24:02,700 --> 00:24:00,850  
transition metal chlorides and decided

656  
00:24:04,140 --> 00:24:02,710  
they'd start with they said well we've

657  
00:24:05,220 --> 00:24:04,150  
got to build something from something so

658  
00:24:07,020 --> 00:24:05,230  
it's gonna have to be the alwah

659  
00:24:09,120 --> 00:24:07,030  
condensation so they started with

660  
00:24:11,160 --> 00:24:09,130  
glyoxylate and pyruvate moderate

661  
00:24:13,290 --> 00:24:11,170  
conditions so on and so forth and some

662  
00:24:15,540 --> 00:24:13,300  
really really cool pathways emerged so

663  
00:24:17,460 --> 00:24:15,550

they found a not particularly high yield

664

00:24:21,150 --> 00:24:17,470

but a very elegant pathway to alpha key

665

00:24:23,010 --> 00:24:21,160

to glue to rate unambiguously and due to

666

00:24:25,170 --> 00:24:23,020

some other issues we reran all these

667

00:24:27,770 --> 00:24:25,180

experiments Irena reran all of them to

668

00:24:30,450 --> 00:24:27,780

verify that you know it wasn't just

669

00:24:32,250 --> 00:24:30,460

magic that show hey Vijay could do that

670

00:24:34,050 --> 00:24:32,260

it's magic that anybody can do well not

671

00:24:36,780 --> 00:24:34,060

anybody but Irene Irene

672

00:24:38,640 --> 00:24:36,790

I had no problem doing this they also

673

00:24:40,350 --> 00:24:38,650

found a really novel pathway to

674

00:24:42,690 --> 00:24:40,360

isocitrate I was intrigued by the

675

00:24:44,520 --> 00:24:42,700

previous talk because we had tried to

676

00:24:47,520 --> 00:24:44,530

look at the conversion of citrate to

677

00:24:49,380 --> 00:24:47,530

isocitrate and we could easily get the

678

00:24:50,760 --> 00:24:49,390

conversion from isocitrate to citrate

679

00:24:53,460 --> 00:24:50,770

but we could never get around the

680

00:24:55,110 --> 00:24:53,470

Markoff knockoffs or propensity to put

681

00:24:57,990 --> 00:24:55,120

the hydroxyl on that particular carbon

682

00:25:00,090 --> 00:24:58,000

so it's isocitrate instantaneously goes

683

00:25:02,400 --> 00:25:00,100

to citrate but we couldn't get the

684

00:25:06,210 --> 00:25:02,410

slightest amount of isocitrate to form

685

00:25:08,190 --> 00:25:06,220

in the opposite direction but here you

686

00:25:10,170 --> 00:25:08,200

can form isocitrate in a very novel way

687

00:25:11,550 --> 00:25:10,180

so if you take glass light and succinate

688

00:25:13,650 --> 00:25:11,560

the way you think it might work nothing

689

00:25:15,390 --> 00:25:13,660

happens but if you take black slate now

690

00:25:17,420 --> 00:25:15,400

if a key to glitter 8 you go through

691

00:25:19,860 --> 00:25:17,430

this pathway generate co<sub>2</sub> and hydrogen

692

00:25:22,620 --> 00:25:19,870

it's really slick Toledo's yields are

693

00:25:24,060 --> 00:25:22,630

not particularly low now if you just

694

00:25:26,370 --> 00:25:24,070

start with your product alpha-keto

695

00:25:29,460 --> 00:25:26,380

glitter 8 and in the presence of cobalt

696

00:25:32,520 --> 00:25:29,470

nickel or st. cation you form

697

00:25:34,410 --> 00:25:32,530

Arisa some succinate through the metal

698

00:25:37,190 --> 00:25:34,420

producted you know and control the cells

699

00:25:41,670 --> 00:25:37,200

to produced oxidative decarboxylation

700

00:25:44,250 --> 00:25:41,680

glittery but if you put iron and copper

701  
00:25:46,710 --> 00:25:44,260  
in the system you get considerable loss

702  
00:25:49,350 --> 00:25:46,720  
at off key to glue rate any form malate

703  
00:25:51,930 --> 00:25:49,360  
and oxalate and fumarate and ultimately

704  
00:25:55,350 --> 00:25:51,940  
pyruvate and then a lot of acetate is a

705  
00:25:57,150 --> 00:25:55,360  
product so so some interesting things

706  
00:25:59,730 --> 00:25:57,160  
are going on in the system as a previous

707  
00:26:03,840 --> 00:25:59,740  
speaker talked it's it's almost like a

708  
00:26:05,310 --> 00:26:03,850  
classic Maxwell demon you you the

709  
00:26:07,800 --> 00:26:05,320  
frustrating thing about this chemistry

710  
00:26:09,390 --> 00:26:07,810  
is you you really I can't convey man

711  
00:26:11,520 --> 00:26:09,400  
Eric Smith used to sit we would sit

712  
00:26:13,170 --> 00:26:11,530  
there in discuss what might become

713  
00:26:16,400 --> 00:26:13,180

possible going on at the molecular level

714

00:26:20,160 --> 00:26:16,410

and it's it's really tricky business

715

00:26:22,140 --> 00:26:20,170

but what it is tricky or not is it turns

716

00:26:23,700 --> 00:26:22,150

out that these different metals are do a

717

00:26:25,560 --> 00:26:23,710

lot of interesting different things I

718

00:26:27,450 --> 00:26:25,570

think at the molecular level what's

719

00:26:30,180 --> 00:26:27,460

actually going on is hyper complex and

720

00:26:32,400 --> 00:26:30,190

perhaps unknowable at the core level but

721

00:26:35,840 --> 00:26:32,410

clearly these metal cations are doing

722

00:26:38,010 --> 00:26:35,850

some very interesting molecular

723

00:26:39,930 --> 00:26:38,020

coordination based chemistry that

724

00:26:43,230 --> 00:26:39,940

enhances certain aldol polymerization

725

00:26:46,080 --> 00:26:43,240

suppresses other net reactions minimizes

726

00:26:47,799 --> 00:26:46,090

almost no polymerization and as clearly

727

00:26:50,200 --> 00:26:47,809

as I would say physical chemical

728

00:26:53,349 --> 00:26:50,210

it's a very high loss system but it's a

729

00:26:55,659 --> 00:26:53,359

very dynamic system and so for example

730

00:26:58,299 --> 00:26:55,669

you can start with glyoxylate pyruvate

731

00:27:00,339 --> 00:26:58,309

up here you can wander along you can get

732

00:27:01,359 --> 00:27:00,349

as far as Auto key of glue to rate you

733

00:27:04,180 --> 00:27:01,369

can go from alpha ketoglutarate

734

00:27:06,459 --> 00:27:04,190

isocitrate and so on and so forth but

735

00:27:08,589 --> 00:27:06,469

you can also start to fall backwards

736

00:27:11,379 --> 00:27:08,599

through oxidation reactions to Foom rate

737

00:27:13,149 --> 00:27:11,389

back to malate hydration Mount alight

738

00:27:14,649 --> 00:27:13,159

over Docs I'll acetates and ultimately

739

00:27:16,659 --> 00:27:14,659

decomposition very rapid decomposition

740

00:27:18,909 --> 00:27:16,669

regenerating pyruvate here and

741

00:27:21,789 --> 00:27:18,919

generating or regenerating glyoxylate

742

00:27:28,119 --> 00:27:21,799

there in all cases acetate becomes your

743

00:27:30,009 --> 00:27:28,129

predominant product so where I'm getting

744

00:27:31,989 --> 00:27:30,019

with this is that as I said in the

745

00:27:33,430 --> 00:27:31,999

beginning it seems like all life

746

00:27:35,829 --> 00:27:33,440

chemistry and the interesting chemistry

747

00:27:38,469 --> 00:27:35,839

where you want to go with this sits at

748

00:27:42,009 --> 00:27:38,479

around sort of the zero valence carbon

749

00:27:44,379 --> 00:27:42,019

level equivalent yet you're started you

750

00:27:46,419 --> 00:27:44,389

start out with a system that tends to

751

00:27:48,940 --> 00:27:46,429

give you a predominance of methane

752

00:27:51,310 --> 00:27:48,950

followed by propane than ethane and then

753

00:27:54,849 --> 00:27:51,320

so on and so forth really far away from

754

00:27:55,599 --> 00:27:54,859

that and if everything this previous

755

00:27:57,249 --> 00:27:55,609

talk

756

00:28:00,159 --> 00:27:57,259

presents brilliantly and then it gets

757

00:28:01,629 --> 00:28:00,169

factors into what also Leslie Orgel and

758

00:28:03,729 --> 00:28:01,639

Dave Ross were talking about right that

759

00:28:05,289 --> 00:28:03,739

the idea of if you got a system that's

760

00:28:07,029 --> 00:28:05,299

really great for reductive chemistry

761

00:28:09,519 --> 00:28:07,039

you're gonna get stuck this has always

762

00:28:11,619 --> 00:28:09,529

been our concern and so it cruelly came

763

00:28:13,869 --> 00:28:11,629

clear to us and actually in that 2001

764

00:28:15,609 --> 00:28:13,879

paper we had identified an area where

765

00:28:17,829 --> 00:28:15,619

you had a couple reduction and then

766

00:28:19,839 --> 00:28:17,839

partial oxidation that you have to have

767

00:28:21,779 --> 00:28:19,849

both going on and and the question for

768

00:28:23,709 --> 00:28:21,789

us became and how how could that be

769

00:28:25,089 --> 00:28:23,719

particularly in the early Earth where

770

00:28:29,109 --> 00:28:25,099

everybody would presume that things were

771

00:28:32,079 --> 00:28:29,119

so reducing how am i doing time was you

772

00:28:34,839 --> 00:28:32,089

just I'm almost done okay I'm rocketing

773

00:28:36,759 --> 00:28:34,849

along with Hostin the simple fact that

774

00:28:37,810 --> 00:28:36,769

is DNA source was two scoops again in

775

00:28:40,060 --> 00:28:37,820

our lab was doing an interesting

776

00:28:41,289 --> 00:28:40,070

experiment and this is a complicated

777

00:28:43,509 --> 00:28:41,299

diagram so I won't waste time with it

778

00:28:45,219 --> 00:28:43,519

but the point is if you think in

779

00:28:49,349 --> 00:28:45,229

equilibrium considerations and

780

00:28:52,180 --> 00:28:49,359

particularly in hydrogen oxidation then

781

00:28:54,549 --> 00:28:52,190

you don't worry things too much but but

782

00:28:56,979 --> 00:28:54,559

it turns out hot water you see the

783

00:28:58,239 --> 00:28:56,989

equilibrium from  $\text{H}_2\text{O}$  goes to  $\text{H}_2$  plus  $\text{O}$

784

00:29:00,669 --> 00:28:58,249

$\text{H}_2$  is favored at higher and higher

785

00:29:01,210 --> 00:29:00,679

temperatures and when you start to

786

00:29:02,770 --> 00:29:01,220

quench that

787

00:29:04,000 --> 00:29:02,780

hot water down the actually the

788

00:29:06,190 --> 00:29:04,010

oxidation kinetics could be pretty

789

00:29:08,500 --> 00:29:06,200

sluggish and so you can have situations

790

00:29:11,919 --> 00:29:08,510

where in fact hydrogen and oxygen will

791

00:29:14,830 --> 00:29:11,929

persist even an in height in a you know

792

00:29:18,490 --> 00:29:14,840

a net redox neutral systems where I'm

793

00:29:21,549 --> 00:29:18,500

getting at so ultimately what we're

794

00:29:23,919 --> 00:29:21,559

doing is saying if you can get a dynamic

795

00:29:25,720 --> 00:29:23,929

or functional dynamic organic reaction

796

00:29:27,909 --> 00:29:25,730

network to occur you can get an awful

797

00:29:29,799 --> 00:29:27,919

lot from a little so this is an example

798

00:29:31,090 --> 00:29:29,809

is just playing around on paper but if

799

00:29:33,909 --> 00:29:31,100

you start with something like butanoic

800

00:29:35,380 --> 00:29:33,919

acid and IC butanoic acid and you allow

801  
00:29:37,330 --> 00:29:35,390  
for these following reactions to occur

802  
00:29:39,580 --> 00:29:37,340  
and every one of these has been verified

803  
00:29:42,310 --> 00:29:39,590  
right so carbonyl certain partial

804  
00:29:44,230 --> 00:29:42,320  
oxidation Retro aldol aldol lamination

805  
00:29:46,980 --> 00:29:44,240  
and reductive amination you can easily

806  
00:29:49,620 --> 00:29:46,990  
generate over 350 different molecules

807  
00:29:51,970 --> 00:29:49,630  
starting with saturated and olefinic

808  
00:29:53,890 --> 00:29:51,980  
including a broad range of things so the

809  
00:29:57,220 --> 00:29:53,900  
question is but to get to that you'd

810  
00:29:58,510 --> 00:29:57,230  
have to have unusual controls but the

811  
00:30:00,250 --> 00:29:58,520  
bigger problem and this is the very end

812  
00:30:02,140 --> 00:30:00,260  
of the talk is the following said if you

813  
00:30:04,000 --> 00:30:02,150

start out with a system and catalysts

814

00:30:07,149 --> 00:30:04,010

where you can go from carbon dioxide

815

00:30:08,740 --> 00:30:07,159

hydrogen most your products are going to

816

00:30:10,360 --> 00:30:08,750

be very reduced methane and alkanes

817

00:30:12,310 --> 00:30:10,370

you're going to produce a small amount

818

00:30:13,630 --> 00:30:12,320

of these potentially reactive molecules

819

00:30:16,390 --> 00:30:13,640

that are going to be your dynamic

820

00:30:18,789 --> 00:30:16,400

organic rational network that system is

821

00:30:20,289 --> 00:30:18,799

a very efficient acetate generator so

822

00:30:22,600 --> 00:30:20,299

carbon is just going to flux through

823

00:30:24,880 --> 00:30:22,610

there into an acetate and some of it is

824

00:30:28,149 --> 00:30:24,890

going to polymerize and the bottom line

825

00:30:29,409 --> 00:30:28,159

is that's going to grow and that's going

826

00:30:30,760 --> 00:30:29,419

to grow and this is going to say the

827

00:30:32,440 --> 00:30:30,770

same so everything that you don't want

828

00:30:35,320 --> 00:30:32,450

is going to grow but the dynamic or get

829

00:30:37,990 --> 00:30:35,330

organic reaction network does not now

830

00:30:40,750 --> 00:30:38,000

this is just a picture of the polymer

831

00:30:42,610 --> 00:30:40,760

that you can make very easily so what

832

00:30:44,799 --> 00:30:42,620

you want to do is you want to find a way

833

00:30:46,060 --> 00:30:44,809

of doing this so one of these you want

834

00:30:48,669 --> 00:30:46,070

to see a system that can direct

835

00:30:49,960 --> 00:30:48,679

catalytically co<sub>2</sub> directly into the into

836

00:30:52,600 --> 00:30:49,970

the dynamic organic reaction that we're

837

00:30:54,909 --> 00:30:52,610

suppressing methane and alkanes you'd

838

00:30:56,529 --> 00:30:54,919

like to find a way of using your acetate

839

00:30:59,110 --> 00:30:56,539

so it isn't constantly being rejected

840

00:31:00,669 --> 00:30:59,120

from the system and you don't mind the

841

00:31:02,110 --> 00:31:00,679

organic polymer growing because I might

842

00:31:03,430 --> 00:31:02,120

be useful you don't mind the dynamic

843

00:31:05,230 --> 00:31:03,440

organic reaction that we're growing

844

00:31:06,899 --> 00:31:05,240

because that's what you want so the

845

00:31:09,070 --> 00:31:06,909

question is how in the world to do that

846

00:31:09,639 --> 00:31:09,080

this is where we get into a complete

847

00:31:12,580 --> 00:31:09,649

fantasy

848

00:31:14,169 --> 00:31:12,590

but perhaps the cord all of this is the

849

00:31:14,740 --> 00:31:14,179

idea of start thinking about reactive

850

00:31:16,810 --> 00:31:14,750

Nano and

851  
00:31:18,580 --> 00:31:16,820  
and one of the areas is to actually move

852  
00:31:21,909 --> 00:31:18,590  
your dynamic organic reaction Network

853  
00:31:25,270 --> 00:31:21,919  
and your entire system into the organic

854  
00:31:27,070 --> 00:31:25,280  
polymer system so now you have a system

855  
00:31:29,529 --> 00:31:27,080  
that's generating all of this and

856  
00:31:31,120 --> 00:31:29,539  
everything is growing the acetate is

857  
00:31:34,960 --> 00:31:31,130  
following the dynamic organic reaction

858  
00:31:36,820 --> 00:31:34,970  
Network and so the problem is is solved

859  
00:31:38,350 --> 00:31:36,830  
if you could do it so what I'm getting

860  
00:31:40,120 --> 00:31:38,360  
at is that the problem of life's origins

861  
00:31:41,830 --> 00:31:40,130  
is not in my mind a chemistry problem

862  
00:31:42,970 --> 00:31:41,840  
the chemistry is not the problem we know

863  
00:31:44,440 --> 00:31:42,980

how to do that kind of see the question

864

00:31:46,570 --> 00:31:44,450

is how to harness that chemistry were to

865

00:31:48,430 --> 00:31:46,580

direct that chemistry through some sort

866

00:31:50,799 --> 00:31:48,440

of control function and we'll hear more

867

00:31:53,260 --> 00:31:50,809

about that in Christophe lambs talk and

868

00:31:56,529 --> 00:31:53,270

and this is where I think theory really

869

00:31:58,120 --> 00:31:56,539

has to jump into this so the question is

870

00:32:00,250 --> 00:31:58,130

what a special environment so so key

871

00:32:01,450 --> 00:32:00,260

here is we need an environment the only

872

00:32:02,919 --> 00:32:01,460

way you're gonna get acetate back in the

873

00:32:04,899 --> 00:32:02,929

systems you have to activate it the

874

00:32:07,480 --> 00:32:04,909

simplest way of activating it is through

875

00:32:08,799 --> 00:32:07,490

phosphorylation there's nothing

876

00:32:10,390 --> 00:32:08,809

difficult about doing it if you can get

877

00:32:11,740 --> 00:32:10,400

the activity in pyrophosphate high

878

00:32:13,210 --> 00:32:11,750

enough how do you do that you can do

879

00:32:14,289 --> 00:32:13,220

that in a nano environment you can't do

880

00:32:15,820 --> 00:32:14,299

that in open water

881

00:32:18,010 --> 00:32:15,830

the same is true we have to affect

882

00:32:19,299 --> 00:32:18,020

enhance the control of ammonia activity

883

00:32:21,430 --> 00:32:19,309

and this is again if you dilute

884

00:32:23,860 --> 00:32:21,440

everything and George Whitesides to do

885

00:32:26,770 --> 00:32:23,870

critically nothing's going to happen so

886

00:32:28,240 --> 00:32:26,780

so at some level environments have to

887

00:32:29,919 --> 00:32:28,250

develop and these environments are not

888

00:32:31,149 --> 00:32:29,929

living systems but in my view our

889

00:32:33,610 --> 00:32:31,159

systems where you can start to control

890

00:32:35,380 --> 00:32:33,620

the activities of things you have to

891

00:32:36,760 --> 00:32:35,390

control oxidative decarboxylation you

892

00:32:38,740 --> 00:32:36,770

don't if you keep throwing away your

893

00:32:40,539 --> 00:32:38,750

Redoute potential and you have to

894

00:32:44,230 --> 00:32:40,549

control partial oxidation if you don't

895

00:32:46,180 --> 00:32:44,240

have some oxidation nothing interesting

896

00:32:48,220 --> 00:32:46,190

is going to occur but it has to be

897

00:32:51,010 --> 00:32:48,230

balanced with the idea of high loss to

898

00:32:52,690 --> 00:32:51,020

the system so the requirement of a

899

00:32:54,909 --> 00:32:52,700

dynamic organic reaction I think remains

900

00:32:57,610 --> 00:32:54,919

obvious precisely where and how it

901  
00:32:59,620 --> 00:32:57,620  
occurs I don't know potential for at

902  
00:33:01,450 --> 00:32:59,630  
least a stable dynamic organic reaction

903  
00:33:03,310 --> 00:33:01,460  
network is I would argue probably proven

904  
00:33:06,070 --> 00:33:03,320  
for chondritic environments so it works

905  
00:33:09,220 --> 00:33:06,080  
I think that's a remarkable result and I

906  
00:33:10,690 --> 00:33:09,230  
and I just got me really excited re

907  
00:33:13,120 --> 00:33:10,700  
excited if you will about this entire

908  
00:33:14,799 --> 00:33:13,130  
field so experimental evidence supports

909  
00:33:16,750 --> 00:33:14,809  
the potential chemical topology that

910  
00:33:18,130 --> 00:33:16,760  
would do this but both redox and

911  
00:33:20,350 --> 00:33:18,140  
oxidative chemistry have to operate

912  
00:33:21,700 --> 00:33:20,360  
simultaneously this is not classically

913  
00:33:23,440 --> 00:33:21,710

the kind of chemistry that you might

914

00:33:24,789 --> 00:33:23,450

think about doing in the laboratory but

915

00:33:26,710 --> 00:33:24,799

it may be that we have to start thinking

916

00:33:28,420 --> 00:33:26,720

about that perhaps chemistry along

917

00:33:30,430 --> 00:33:28,430

gradients and so on and so forth

918

00:33:32,110 --> 00:33:30,440

and a true lab demonstration of a

919

00:33:33,550 --> 00:33:32,120

dynamic organic reaction network I would

920

00:33:35,530 --> 00:33:33,560

say remains elusive

921

00:33:37,600 --> 00:33:35,540

but we saw snapshots of pictures and

922

00:33:39,130 --> 00:33:37,610

pieces of what you can be done by

923

00:33:42,400 --> 00:33:39,140

setting up a system that actually would

924

00:33:44,800 --> 00:33:42,410

grow would be the de facto it's not a

925

00:33:46,600 --> 00:33:44,810

criteria for life but it is a criteria

926

00:33:49,270 --> 00:33:46,610

that I would say would be very very

927

00:33:57,490 --> 00:33:49,280

interesting to see and that's all I have

928

00:34:04,720 --> 00:33:57,500

to say on that topic got a little jet

929

00:34:06,790 --> 00:34:04,730

lag either you with the blue box already

930

00:34:08,740 --> 00:34:06,800

to do this twice but I want to ask about

931

00:34:10,300 --> 00:34:08,750

a general theme because this morning in

932

00:34:12,399 --> 00:34:10,310

George Whitesides is talk one of the

933

00:34:15,100 --> 00:34:12,409

conceptual pillars he brought up was the

934

00:34:16,570 --> 00:34:15,110

essential role of kinetic traps and in

935

00:34:18,460 --> 00:34:16,580

biochemistry that's clear this is the

936

00:34:21,399 --> 00:34:18,470

thing ever it has emphasized in

937

00:34:22,330 --> 00:34:21,409

geochemical contexts for ever you know

938

00:34:26,860 --> 00:34:22,340

forever

939

00:34:27,760 --> 00:34:26,870

yeah apologies but it's been hard to get

940

00:34:31,600 --> 00:34:27,770

out systematically

941

00:34:33,190 --> 00:34:31,610

so if I look at what Joseph showed by

942

00:34:35,680 --> 00:34:33,200

controlling for the fact that when you

943

00:34:37,149 --> 00:34:35,690

scrub you can find these complexity

944

00:34:38,530 --> 00:34:37,159

generating intermediates but if you put

945

00:34:42,430 --> 00:34:38,540

them into the solution you get nothing

946

00:34:45,060 --> 00:34:42,440

and then your black hole for carbon

947

00:34:48,159 --> 00:34:45,070

which then suddenly comes up right I

948

00:34:50,530 --> 00:34:48,169

think ok it looks like we have surface

949

00:34:53,350 --> 00:34:50,540

associated traps we have something that

950

00:34:55,780 --> 00:34:53,360

is has a time lag it's in a transition

951  
00:34:58,390 --> 00:34:55,790  
from being a metal to being an oxide and

952  
00:35:00,280 --> 00:34:58,400  
it's in that intermediate State it's

953  
00:35:01,420 --> 00:35:00,290  
band structure is changing its site

954  
00:35:03,910 --> 00:35:01,430  
density on the surface is changing

955  
00:35:05,830 --> 00:35:03,920  
possibly its morphology is changing and

956  
00:35:07,930 --> 00:35:05,840  
we have overwhelming evidence that it's

957  
00:35:09,550 --> 00:35:07,940  
a kinetic trap that's crucial to the

958  
00:35:10,600 --> 00:35:09,560  
distinction between going into one of

959  
00:35:12,790 --> 00:35:10,610  
these dead ends and going into

960  
00:35:14,530 --> 00:35:12,800  
complexity how do we study that

961  
00:35:17,650 --> 00:35:14,540  
systematically that is the grand

962  
00:35:18,910 --> 00:35:17,660  
challenge because what we want to see so

963  
00:35:20,410 --> 00:35:18,920

getting back to the idea of this being a

964

00:35:21,700 --> 00:35:20,420

constraint at all and I think in some

965

00:35:23,170 --> 00:35:21,710

ways the best we could hope for right

966

00:35:25,270 --> 00:35:23,180

now I was talking to George this morning

967

00:35:27,400 --> 00:35:25,280

you know in the nice thing about this

968

00:35:28,720 --> 00:35:27,410

field this is so wide open and it's so

969

00:35:31,210 --> 00:35:28,730

wide open because we're so close all

970

00:35:32,200 --> 00:35:31,220

ignorant we can't we have difficulties I

971

00:35:33,940 --> 00:35:32,210

think George's talked this morning

972

00:35:36,700 --> 00:35:33,950

perfect week we can't even really

973

00:35:38,470 --> 00:35:36,710

clarify what we think is life what is

974

00:35:39,470 --> 00:35:38,480

semi life of what is dead and was semi

975

00:35:42,500 --> 00:35:39,480

dead

976

00:35:44,570 --> 00:35:42,510

so so we at least I feel that we can try

977

00:35:46,100 --> 00:35:44,580

to play some emphasis on constraints and

978

00:35:48,830 --> 00:35:46,110

that's where the geochemistry becomes so

979

00:35:52,250 --> 00:35:48,840

critical because it evidently occurred

980

00:35:54,410 --> 00:35:52,260

on this planet subject to the laws of

981

00:35:57,380 --> 00:35:54,420

chemistry has defined by this planet at

982

00:36:01,160 --> 00:35:57,390

the same token there's a lot that has to

983

00:36:02,420 --> 00:36:01,170

happen so for example this explosive

984

00:36:04,040 --> 00:36:02,430

effect that you saw in this one

985

00:36:06,140 --> 00:36:04,050

so-called simple experiment I showed

986

00:36:08,090 --> 00:36:06,150

that as a demonstration of that that

987

00:36:09,920 --> 00:36:08,100

simple experiments aren't simple but I

988

00:36:12,860 --> 00:36:09,930

also had to say that if that was a

989

00:36:14,240 --> 00:36:12,870

useful state then you'd have to say on

990

00:36:17,510 --> 00:36:14,250

this planet would have to be a

991

00:36:18,950 --> 00:36:17,520

continuously regenerating state so so

992

00:36:20,630 --> 00:36:18,960

what one this is two always been the

993

00:36:22,550 --> 00:36:20,640

problem whatever one experiment we set

994

00:36:23,960 --> 00:36:22,560

up is set up in a sense intrinsically

995

00:36:25,910 --> 00:36:23,970

thermodynamically to move in the

996

00:36:27,650 --> 00:36:25,920

direction thermodynamics required to go

997

00:36:29,590 --> 00:36:27,660

and it goes as far as the energy

998

00:36:31,730 --> 00:36:29,600

available to it does and then it stops

999

00:36:34,180 --> 00:36:31,740

but we know that that's not sufficient

1000

00:36:36,230 --> 00:36:34,190

to get us for where we need to go I

1001  
00:36:37,280 --> 00:36:36,240  
don't know if I'm articulated as well so

1002  
00:36:39,650 --> 00:36:37,290  
that's why I got so interested about

1003  
00:36:41,420 --> 00:36:39,660  
George Cooper's results because clearly

1004  
00:36:44,000 --> 00:36:41,430  
in this planetesimals

1005  
00:36:46,310 --> 00:36:44,010  
somehow this system was able to make

1006  
00:36:48,890 --> 00:36:46,320  
pyruvate it went away makes it again it

1007  
00:36:50,720 --> 00:36:48,900  
goes away make aconite and you know and

1008  
00:36:52,700 --> 00:36:50,730  
it makes it enough so finally when the

1009  
00:36:54,470 --> 00:36:52,710  
system freezes out it's able to freeze

1010  
00:36:56,120 --> 00:36:54,480  
out at least some signature that those

1011  
00:36:59,360 --> 00:36:56,130  
molecules were being regenerated from

1012  
00:37:01,220 --> 00:36:59,370  
millions of years so constantly I'm

1013  
00:37:02,390 --> 00:37:01,230

trying to think about what's experiment

1014

00:37:05,330 --> 00:37:02,400

and getting back to what George was

1015

00:37:07,370 --> 00:37:05,340

asking if you could do the experiment

1016

00:37:10,370 --> 00:37:07,380

you could start to show the components

1017

00:37:12,830 --> 00:37:10,380

of the network growing in perhaps

1018

00:37:14,660 --> 00:37:12,840

through cycles that you could develop

1019

00:37:17,150 --> 00:37:14,670

and this is where Christophe lambs

1020

00:37:21,350 --> 00:37:17,160

approach is critical here I don't know

1021

00:37:23,300 --> 00:37:21,360

yet how I want to control the system and

1022

00:37:26,480 --> 00:37:23,310

whether so he might look at this network

1023

00:37:27,830 --> 00:37:26,490

idea answer to say as you said knobs and

1024

00:37:29,540 --> 00:37:27,840

buttons and things like this that's K

1025

00:37:31,580 --> 00:37:29,550

and start playing around with them and

1026  
00:37:34,280 --> 00:37:31,590  
then can you find that geochemical set

1027  
00:37:36,380 --> 00:37:34,290  
of conditions that allow you to tweak

1028  
00:37:37,610 --> 00:37:36,390  
the knobs in a way that makes sense such

1029  
00:37:39,620 --> 00:37:37,620  
that the chemical system you're

1030  
00:37:42,650 --> 00:37:39,630  
interested in grows as opposed to decays

1031  
00:37:44,960 --> 00:37:42,660  
and what I tried to show you was I why

1032  
00:37:48,080 --> 00:37:44,970  
we see the topology this network growing

1033  
00:37:49,700 --> 00:37:48,090  
it's it's a lossy system right most of

1034  
00:37:50,450 --> 00:37:49,710  
the stuff is going to acetate so fast

1035  
00:37:50,950 --> 00:37:50,460  
make your head spin

1036  
00:37:51,940 --> 00:37:50,960  
so

1037  
00:37:54,310 --> 00:37:51,950  
nothing that we've done in the

1038  
00:37:56,920 --> 00:37:54,320

laboratory shows us anything other than

1039

00:37:59,260 --> 00:37:56,930

the connectivity of molecular states and

1040

00:38:01,450 --> 00:37:59,270

we have to go that next level of playing

1041

00:38:03,760 --> 00:38:01,460

around with the knobs in a dynamical

1042

00:38:08,460 --> 00:38:03,770

system and then seeing does that take us

1043

00:38:17,010 --> 00:38:12,730

you mentioned dhunda has been proven for

1044

00:38:20,860 --> 00:38:17,020

kinetic planetesimals to me yes yeah

1045

00:38:25,450 --> 00:38:20,870

yeah I'd believe that but I also want to

1046

00:38:29,110 --> 00:38:25,460

point out Don may also be a proven for

1047

00:38:32,140 --> 00:38:29,120

this small moon of Saturn this Enceladus

1048

00:38:35,980 --> 00:38:32,150

because from the prune we can measure

1049

00:38:39,520 --> 00:38:35,990

this array of organics which are

1050

00:38:43,180 --> 00:38:39,530

obviously be manufactured and inside and

1051  
00:38:45,070 --> 00:38:43,190  
they have been preserved over certainly

1052  
00:38:49,330 --> 00:38:45,080  
the over long period of times like

1053  
00:38:51,220 --> 00:38:49,340  
millions of years yes I agree with you

1054  
00:38:52,570 --> 00:38:51,230  
actually in solid solidus is becoming

1055  
00:38:54,820 --> 00:38:52,580  
one of the more interesting objects in

1056  
00:38:59,350 --> 00:38:54,830  
our solar system and I hope we study it

1057  
00:39:00,940 --> 00:38:59,360  
much more closely yes a question that

1058  
00:39:03,670 --> 00:39:00,950  
comes up listening to the several

1059  
00:39:07,360 --> 00:39:03,680  
fascinating last talks and listening to

1060  
00:39:10,240 --> 00:39:07,370  
my colleagues I formed no judgments

1061  
00:39:13,570 --> 00:39:10,250  
publicly at least is that the kind of

1062  
00:39:15,540 --> 00:39:13,580  
chemistry that you do is you know Co

1063  
00:39:18,460 --> 00:39:15,550

hydrogen high temperature

1064

00:39:21,190 --> 00:39:18,470

hydroformylation that kind of thing and

1065

00:39:24,310 --> 00:39:21,200

what many of my colleagues think is that

1066

00:39:26,050 --> 00:39:24,320

it's all done in space it's HCN and co

1067

00:39:28,420 --> 00:39:26,060

and stuff that forms there and

1068

00:39:30,550 --> 00:39:28,430

particularly HCN maybe acetylene and

1069

00:39:33,280 --> 00:39:30,560

sano acetylene so you've done all the

1070

00:39:34,900 --> 00:39:33,290

reactivation chemistry there right and

1071

00:39:36,880 --> 00:39:34,910

so there's that approach there's also

1072

00:39:38,800 --> 00:39:36,890

the approach that says why work with co2

1073

00:39:40,930 --> 00:39:38,810

which is a horrible reaction for

1074

00:39:42,760 --> 00:39:40,940

anything except nucleophiles work with

1075

00:39:45,580 --> 00:39:42,770

cs2 because there's an enormous amount

1076

00:39:47,260 --> 00:39:45,590

of cs2 around and there's h2s and

1077

00:39:50,110 --> 00:39:47,270

there's a lot of h2s and that's a great

1078

00:39:52,030 --> 00:39:50,120

nucleophile in an activating agent or do

1079

00:39:54,280 --> 00:39:52,040

you consider these as independent themes

1080

00:39:57,670 --> 00:39:54,290

or is one going to turn out to be better

1081

00:40:00,760 --> 00:39:57,680

than the others well that's that's an

1082

00:40:02,080 --> 00:40:00,770

excellent question so HCN is a fantastic

1083

00:40:04,150 --> 00:40:02,090

molecule in chemistry

1084

00:40:09,310 --> 00:40:04,160

and I don't have anything against it

1085

00:40:11,620 --> 00:40:09,320

personally but you're laughing but but

1086

00:40:13,600 --> 00:40:11,630

but it does have a problem which is it

1087

00:40:15,190 --> 00:40:13,610

hydrolyzes really quickly so I recall

1088

00:40:16,770 --> 00:40:15,200

when people were worried about terrorist

1089

00:40:19,120 --> 00:40:16,780

threats and things like this and I I

1090

00:40:20,560 --> 00:40:19,130

knew Quabbin Reservoir really well and

1091

00:40:21,970 --> 00:40:20,570

people say well oh my god what if

1092

00:40:24,520 --> 00:40:21,980

somebody sneaks up one night and they

1093

00:40:26,770 --> 00:40:24,530

dump you know tons of potassium cyanide

1094

00:40:28,720 --> 00:40:26,780

in Quabbin Reservoir and people like

1095

00:40:32,020 --> 00:40:28,730

well we'll have a lot of formate then

1096

00:40:35,800 --> 00:40:32,030

because it hydrolyzes so quickly so in

1097

00:40:37,480 --> 00:40:35,810

my view and this is partly my bias in

1098

00:40:42,040 --> 00:40:37,490

terms of trying to place constraints on

1099

00:40:42,910 --> 00:40:42,050

my own set of questions for you to get

1100

00:40:44,440 --> 00:40:42,920

to the point where you have a dynamic

1101

00:40:46,900 --> 00:40:44,450

organic reaction network you know

1102

00:40:48,070 --> 00:40:46,910

carbonaceous chondrite whatever hydrogen

1103

00:40:50,290 --> 00:40:48,080

cyanide might have done for you in the

1104

00:40:52,420 --> 00:40:50,300

very beginning has been over printed by

1105

00:40:54,820 --> 00:40:52,430

millions of years of hydrothermal

1106

00:40:56,680 --> 00:40:54,830

recurrence so unless you have a

1107

00:40:59,260 --> 00:40:56,690

mechanism in the interior of the planet

1108

00:41:01,600 --> 00:40:59,270

to regenerate some of these interstellar

1109

00:41:03,790 --> 00:41:01,610

molecules I would take a lot of them off

1110

00:41:05,890 --> 00:41:03,800

the table I love carbonyl carbon

1111

00:41:07,870 --> 00:41:05,900

disulphide but it also is it's very

1112

00:41:10,570 --> 00:41:07,880

strongly prone to hydrolysis to  $\text{CO}_2$

1113

00:41:13,690 --> 00:41:10,580

ultimately it's a great molecule or

1114

00:41:15,010 --> 00:41:13,700

Leslie or gal I was sitting a meeting he

1115

00:41:16,690 --> 00:41:15,020

was getting really really excited and

1116

00:41:18,370 --> 00:41:16,700

kept asking me have you ever worked with

1117

00:41:20,080 --> 00:41:18,380

carbonyl sulfide carbon eel sulfide and

1118

00:41:22,300 --> 00:41:20,090

it turns out it became a wonderful

1119

00:41:23,440 --> 00:41:22,310

polymerization reagent for amino acids

1120

00:41:27,280 --> 00:41:23,450

for the work that he did with Reis

1121

00:41:31,780 --> 00:41:27,290

Agadir so these are great molecules but

1122

00:41:33,730 --> 00:41:31,790

I fear that so I looted to this so there

1123

00:41:36,670 --> 00:41:33,740

is a big problem with ammonia and the

1124

00:41:39,670 --> 00:41:36,680

problem is the following if you allow me

1125

00:41:42,790 --> 00:41:39,680

all the ammonia or equivalent ammonia

1126

00:41:44,830 --> 00:41:42,800

equivalent that I could have then making

1127

00:41:46,720 --> 00:41:44,840

things like nucleobases is very very

1128

00:41:49,300 --> 00:41:46,730

easy to do and I can do them in the

1129

00:41:55,090 --> 00:41:49,310

laboratory I like urea which is

1130

00:41:56,980 --> 00:41:55,100

equivalently ammonia plus CO<sub>2</sub> but the

1131

00:42:00,010 --> 00:41:56,990

biggest race I have when I do this for

1132

00:42:01,180 --> 00:42:00,020

example making uracil very easy to do

1133

00:42:02,320 --> 00:42:01,190

the yields are really low the only

1134

00:42:04,780 --> 00:42:02,330

reason the yields are low is because

1135

00:42:06,910 --> 00:42:04,790

it's I'm competing with hydrolysis urea

1136

00:42:09,880 --> 00:42:06,920

as fast as I'm making the uracil

1137

00:42:11,200 --> 00:42:09,890

it's just it hydrolyzes so quickly if I

1138

00:42:14,740 --> 00:42:11,210

could crank that so I don't know how to

1139

00:42:15,670 --> 00:42:14,750

deal with that that and there so it's a

1140

00:42:18,040 --> 00:42:15,680

really getting back

1141

00:42:19,510 --> 00:42:18,050

it's really interesting I think I don't

1142

00:42:20,950 --> 00:42:19,520

have to worry about HCN I think I don't

1143

00:42:22,630 --> 00:42:20,960

have to worry about carbonyl sulfide I

1144

00:42:25,059 --> 00:42:22,640

know I have to worry about ammonia it

1145

00:42:26,740 --> 00:42:25,069

just doesn't seem to be a easy way of

1146

00:42:29,020 --> 00:42:26,750

generating enough ammonia or keeping the

1147

00:42:30,880 --> 00:42:29,030

activity high enough and this again I

1148

00:42:34,809 --> 00:42:30,890

think factors into the idea that that

1149

00:42:37,599 --> 00:42:34,819

one has to have some sort of nano

1150

00:42:40,120 --> 00:42:37,609

environment where you can enhance the

1151

00:42:42,670 --> 00:42:40,130

effective molarity of ammonia way higher

1152

00:42:44,799 --> 00:42:42,680

than perhaps the ambient would be and I

1153

00:42:46,329 --> 00:42:44,809

like the idea Polly electrolyte gels or

1154

00:42:48,790 --> 00:42:46,339

probably electrolyte polymers that might

1155

00:42:51,069 --> 00:42:48,800

actually enhance the the molar

1156

00:42:52,599 --> 00:42:51,079

concentration of ammonia even if it's an

1157

00:42:54,400 --> 00:42:52,609

equilibrium with less concentration

1158

00:42:57,520 --> 00:42:54,410

ammonium in a solution it's an

1159

00:43:01,359 --> 00:42:57,530

equilibrium with it's like effective

1160

00:43:05,109 --> 00:43:01,369

molarity with proteins may be similar

1161

00:43:07,270 --> 00:43:05,119

questions so thank you for the very

1162

00:43:12,640 --> 00:43:07,280

interesting alpha ketoglutarate since

1163

00:43:15,250 --> 00:43:12,650

this reaction my question is that if the

1164

00:43:18,099 --> 00:43:15,260

green oxalate is replaced though is

1165

00:43:20,200 --> 00:43:18,109

hollom hardline so for my heart height

1166

00:43:23,349 --> 00:43:20,210

and pyruvate reaction what happens so

1167

00:43:26,680 --> 00:43:23,359

this is why probably so formal

1168

00:43:29,140 --> 00:43:26,690

aldehyde would be much more abundant in

1169

00:43:34,539 --> 00:43:29,150

solar system compared with gree oxide

1170

00:43:36,609 --> 00:43:34,549

right we mean my god so long for from

1171

00:43:39,400 --> 00:43:36,619

aldehyde it's very abundant molecules is

1172

00:43:42,430 --> 00:43:39,410

one from a library hundred waters it's

1173

00:43:45,880 --> 00:43:42,440

like what's the other calamari hide on

1174

00:43:48,400 --> 00:43:45,890

pyruvate oh oh yeah from a time far away

1175

00:43:50,650 --> 00:43:48,410

versus glyoxylate power of eight if

1176

00:43:54,760 --> 00:43:50,660

you're saying yes the problem is from

1177

00:43:56,710 --> 00:43:54,770

aldehyde is it's a great molecule to so

1178

00:43:59,410 --> 00:43:56,720

then that's we're getting back to

1179

00:44:02,799 --> 00:43:59,420

George's question formaldehyde is stable

1180

00:44:07,089 --> 00:44:02,809

enough that it can hang around and

1181

00:44:08,230 --> 00:44:07,099

polymerize now usually there are great

1182

00:44:09,099 --> 00:44:08,240

stories and all these things I remember

1183

00:44:10,539 --> 00:44:09,109

the first time I was trying to do

1184

00:44:12,819 --> 00:44:10,549

formaldehyde polymerization and it just

1185

00:44:15,039 --> 00:44:12,829

never worked and I was on a train with

1186

00:44:16,120 --> 00:44:15,049

Leslie Orgel and I asked him why you

1187

00:44:17,920 --> 00:44:16,130

know why doesn't this work and he said

1188

00:44:19,539 --> 00:44:17,930

it's because you're doing it right he

1189

00:44:20,920 --> 00:44:19,549

said if you do it right it doesn't work

1190

00:44:22,690 --> 00:44:20,930

they said the trick to making it

1191

00:44:24,069 --> 00:44:22,700

polymerizes you you give it some glycol

1192

00:44:27,069 --> 00:44:24,079

and hide and then the thing takes off

1193

00:44:28,510 --> 00:44:27,079

very Auto catalytically and so so the

1194

00:44:29,500 --> 00:44:28,520

trick is let's say fortunately we can

1195

00:44:31,810 --> 00:44:29,510

say there's glycol

1196

00:44:33,070 --> 00:44:31,820

in these interstellar ices as well it

1197

00:44:34,840 --> 00:44:33,080

turns out and this I'm not going to

1198

00:44:36,070 --> 00:44:34,850

divulge I'm very bad at showing data

1199

00:44:37,420 --> 00:44:36,080

before I publish it so I'm not gonna

1200

00:44:39,340 --> 00:44:37,430

mention what we have found a way of

1201  
00:44:41,290 --> 00:44:39,350  
making formaldehyde polymerize with

1202  
00:44:43,120 --> 00:44:41,300  
itself without giving a clack all died

1203  
00:44:45,700 --> 00:44:43,130  
this is really cool and I'm not gonna

1204  
00:44:47,590 --> 00:44:45,710  
say worried about it but but it's

1205  
00:44:50,950 --> 00:44:47,600  
interesting for but formaldehyde will

1206  
00:44:53,080 --> 00:44:50,960  
eventually through the countless our

1207  
00:44:54,670 --> 00:44:53,090  
reaction decomposed so what limits the

1208  
00:44:56,590 --> 00:44:54,680  
yield of polymer that you ultimately get

1209  
00:44:59,380 --> 00:44:56,600  
from from a light anyway is the fact

1210  
00:45:02,200 --> 00:44:59,390  
that it will decompose to form a gas and

1211  
00:45:05,380 --> 00:45:02,210  
methanol and that's an e recoverable

1212  
00:45:07,210 --> 00:45:05,390  
irreversible formaldehyde it's a great

1213  
00:45:09,550 --> 00:45:07,220

molecule I like it because I don't think

1214

00:45:11,770 --> 00:45:09,560

that is no one has ever advocated that

1215

00:45:13,690 --> 00:45:11,780

you could make it hydrothermally it sits

1216

00:45:15,580 --> 00:45:13,700

on the very very top of an energetic

1217

00:45:17,440 --> 00:45:15,590

mountain so there's only two ways to

1218

00:45:19,210 --> 00:45:17,450

know that we make it either do it with

1219

00:45:22,240 --> 00:45:19,220

you know photochemistry

1220

00:45:24,340 --> 00:45:22,250

or you do it with interstellar ices and

1221

00:45:27,490 --> 00:45:24,350

again photochemistry or hi molecule

1222

00:45:33,700 --> 00:45:27,500

reactions so it is sort of the one thing

1223

00:45:35,680 --> 00:45:33,710

that's interstellar I believe thank you

1224

00:45:39,609 --> 00:45:35,690

i I want to go back to your comment

1225

00:45:42,430 --> 00:45:39,619

about ammonia so what how did we make

1226

00:45:44,290 --> 00:45:42,440

ammonium so we you you started off your

1227

00:45:46,000 --> 00:45:44,300

talk with a discussion of early Earth's

1228

00:45:48,640 --> 00:45:46,010

atmosphere and we haven't changed much

1229

00:45:51,609 --> 00:45:48,650

since Yuri but I think that's not true

1230

00:45:54,070 --> 00:45:51,619

yeah I agree me or Yuri advocated for a

1231

00:45:55,690 --> 00:45:54,080

reducing atmosphere that's right I think

1232

00:45:57,670 --> 00:45:55,700

now we think it's more oxidized more

1233

00:46:01,030 --> 00:45:57,680

oxidized so you had you had another

1234

00:46:03,040 --> 00:46:01,040

oxidant you had n<sub>2</sub> gas that's right and

1235

00:46:05,800 --> 00:46:03,050

we don't treat it as an oxidant we

1236

00:46:09,960 --> 00:46:05,810

almost ignore it okay so right and so

1237

00:46:12,340 --> 00:46:09,970

why is it that we get ammonia at

1238

00:46:14,080 --> 00:46:12,350

standard pressure and in fact it was

1239

00:46:16,660 --> 00:46:14,090

point eight bar probably even lower

1240

00:46:18,280 --> 00:46:16,670

pressure and we don't get it from

1241

00:46:21,580 --> 00:46:18,290

hydrothermal vents nope

1242

00:46:25,780 --> 00:46:21,590

so how do we make ammonia on the planet

1243

00:46:27,820 --> 00:46:25,790

before life that is that is very much in

1244

00:46:29,470 --> 00:46:27,830

my view in elephant Mike Mike Mike this

1245

00:46:31,450 --> 00:46:29,480

so the simplest way to do it that I

1246

00:46:34,090 --> 00:46:31,460

could you know if he said George you

1247

00:46:36,160 --> 00:46:34,100

know I'm holding a gun to you what I

1248

00:46:38,200 --> 00:46:36,170

would say said well he wants nitrate so

1249

00:46:39,370 --> 00:46:38,210

so nitrate is the easiest way to do and

1250

00:46:41,500 --> 00:46:39,380

the easiest way to get nitrate is

1251  
00:46:43,300 --> 00:46:41,510  
through Auto chemistry with water and

1252  
00:46:46,150 --> 00:46:43,310  
die nitrogen in the upper atmosphere and

1253  
00:46:49,870 --> 00:46:46,160  
you rain it out then then hydrate then

1254  
00:46:52,420 --> 00:46:49,880  
you can make very high quantitative

1255  
00:46:53,920 --> 00:46:52,430  
yields if you take that off the table I

1256  
00:46:55,930 --> 00:46:53,930  
think you've got a real problem so I

1257  
00:46:57,430 --> 00:46:55,940  
don't want to strongly put myself into

1258  
00:46:59,470 --> 00:46:57,440  
what the source is

1259  
00:47:02,380 --> 00:46:59,480  
but I'm strongly advocating that we have

1260  
00:47:04,480 --> 00:47:02,390  
I believe in a nitrogen problem that has

1261  
00:47:06,099 --> 00:47:04,490  
to be solved and currently on earth we

1262  
00:47:08,230 --> 00:47:06,109  
have a nitrogen problem because we are

1263  
00:47:10,240 --> 00:47:08,240

using right we're using more ammonia

1264

00:47:12,970 --> 00:47:10,250

than we can actually fix through

1265

00:47:15,700 --> 00:47:12,980

nitrogenase so it's it's a problem now

1266

00:47:17,500 --> 00:47:15,710

and it was a bigger problem then and so

1267

00:47:19,180 --> 00:47:17,510

I went through this calculation with

1268

00:47:22,060 --> 00:47:19,190

canfield a few years ago in a paper in

1269

00:47:24,880 --> 00:47:22,070

science and and if we appeal to nitrate

1270

00:47:26,740 --> 00:47:24,890

as a source without a molecular oxygen

1271

00:47:28,390 --> 00:47:26,750

in the planet so we're doing it with

1272

00:47:31,120 --> 00:47:28,400

lightning right right

1273

00:47:35,590 --> 00:47:31,130

you all get approximately 10 to the

1274

00:47:38,290 --> 00:47:35,600

minus tenth molar concentration 10 to

1275

00:47:40,300 --> 00:47:38,300

the minus 10 this is I mean your sub

1276

00:47:42,340 --> 00:47:40,310

nano molar oh yeah it's really really

1277

00:47:44,950 --> 00:47:42,350

really low it's it's a huge so that's

1278

00:47:47,470 --> 00:47:44,960

why I was saying that again I think we

1279

00:47:50,710 --> 00:47:47,480

all know this in too intellectually this

1280

00:47:52,630 --> 00:47:50,720

idea of I think John barrows pointed

1281

00:47:55,210 --> 00:47:52,640

initially that one kilometer cell the

1282

00:47:56,800 --> 00:47:55,220

idea that that that life as a system

1283

00:48:00,490 --> 00:47:56,810

could ever have been occurring in a

1284

00:48:02,500 --> 00:48:00,500

dilute ocean is impossible so one has to

1285

00:48:04,720 --> 00:48:02,510

say okay even that tiny amount of

1286

00:48:06,580 --> 00:48:04,730

ammonia if you could find a physical

1287

00:48:10,960 --> 00:48:06,590

chemical mechanism by which you could

1288

00:48:12,520 --> 00:48:10,970

concentrate it in a way that doesn't you

1289

00:48:14,950 --> 00:48:12,530

know violate the laws of physics and

1290

00:48:16,540 --> 00:48:14,960

particularly the loss of entropy the

1291

00:48:17,230 --> 00:48:16,550

best way I can think of doing that is

1292

00:48:22,200 --> 00:48:17,240

through

1293

00:48:25,990 --> 00:48:24,609

might about thesis and cult chemistry

1294

00:48:27,940 --> 00:48:26,000

strangely enough and one of the things I

1295

00:48:29,770 --> 00:48:27,950

do is I would automatically dilate calls

1296

00:48:32,560 --> 00:48:29,780

to measure viscoelastic properties and

1297

00:48:34,030 --> 00:48:32,570

what happens there is that you achieve a

1298

00:48:36,160 --> 00:48:34,040

thermodynamic equilibrium where the

1299

00:48:39,190 --> 00:48:36,170

molarity of your compounds can be very

1300

00:48:41,740 --> 00:48:39,200

high inside this gel relative to their

1301  
00:48:44,890 --> 00:48:41,750  
concentration in a medium stay outside

1302  
00:48:46,630 --> 00:48:44,900  
so it was kind of where I was leading

1303  
00:48:48,250 --> 00:48:46,640  
people I think that you have to be able

1304  
00:48:50,530 --> 00:48:48,260  
to create micro environments that at

1305  
00:48:52,480 --> 00:48:50,540  
least locally take a small amount of

1306  
00:48:55,030 --> 00:48:52,490  
ammonia and Hance that to the point

1307  
00:48:56,230 --> 00:48:55,040  
where you can start to because the way I

1308  
00:48:58,690 --> 00:48:56,240  
like you know the way I look at it

1309  
00:49:01,690 --> 00:48:58,700  
living system right so for example ATP

1310  
00:49:03,250 --> 00:49:01,700  
synthesis synthesis from a living system

1311  
00:49:05,470 --> 00:49:03,260  
point of view it's just a mechanical way

1312  
00:49:07,030 --> 00:49:05,480  
of locally getting the concentration of

1313  
00:49:10,240 --> 00:49:07,040

phosphates so high that making the

1314

00:49:12,130 --> 00:49:10,250

phosphate diester banas is cost you

1315

00:49:13,300 --> 00:49:12,140

nothing right but then you then you send

1316

00:49:14,920 --> 00:49:13,310

it off to a system where else and that's

1317

00:49:24,820 --> 00:49:14,930

not the case and now you got a really

1318

00:49:27,940 --> 00:49:24,830

energetic molecule I agree I completely

1319

00:49:29,680 --> 00:49:27,950

agree it's a huge problem yeah I hate to

1320

00:49:32,050 --> 00:49:29,690

be the one to interrupt this all this

1321

00:49:32,920 --> 00:49:32,060

fascinating debate which we do need to

1322

00:49:36,410 --> 00:49:32,930

move on

1323

00:49:55,160 --> 00:49:36,420

[Applause]