

ACKNOWLEDGEMENTS

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1
00:00:04,910 --> 00:00:03,590
hello my name is lena vincent i'm a phd

2
00:00:06,309 --> 00:00:04,920
candidate at the university of

3
00:00:07,909 --> 00:00:06,319
wisconsin-madison

4
00:00:09,669 --> 00:00:07,919
and in this presentation i'm going to

5
00:00:10,310 --> 00:00:09,679
share some of the work our lab has been

6
00:00:11,990 --> 00:00:10,320
doing

7
00:00:14,070 --> 00:00:12,000
to try to understand how systems

8
00:00:16,070 --> 00:00:14,080
displaying life's key processes like

9
00:00:17,750 --> 00:00:16,080
self-propagation and evolution might

10
00:00:19,670 --> 00:00:17,760
have arisen in the absence of a prior

11
00:00:21,189 --> 00:00:19,680
living process

12
00:00:22,710 --> 00:00:21,199
our lab has been using theory and

13
00:00:23,349 --> 00:00:22,720

experiments to try to resolve this

14

00:00:24,870 --> 00:00:23,359

mystery

15

00:00:26,470 --> 00:00:24,880

and to do this we've developed a

16

00:00:28,390 --> 00:00:26,480

framework to try to explain how

17

00:00:29,429 --> 00:00:28,400

ecosystems of interacting chemical

18

00:00:31,429 --> 00:00:29,439

cycles

19

00:00:33,910 --> 00:00:31,439

could self-organize into systems capable

20

00:00:35,430 --> 00:00:33,920

of self-propagation and evolution

21

00:00:37,350 --> 00:00:35,440

and how those systems might further

22

00:00:38,549 --> 00:00:37,360

complexify and eventually give rise to

23

00:00:40,150 --> 00:00:38,559

cellular life

24

00:00:42,069 --> 00:00:40,160

and our hope is that this framework will

25

00:00:45,590 --> 00:00:42,079

yield insights into the origins of life

26

00:00:47,190 --> 00:00:45,600

from simple chemical precursors

27

00:00:49,190 --> 00:00:47,200

now we believe that the ability to

28

00:00:50,950 --> 00:00:49,200

self-propagate and build complexity

29

00:00:52,630 --> 00:00:50,960

through adaptive evolution are two

30

00:00:54,549 --> 00:00:52,640

essential features of life

31

00:00:55,750 --> 00:00:54,559

and to understand the origins of life we

32

00:00:57,910 --> 00:00:55,760

have to try to explain

33

00:00:59,430 --> 00:00:57,920

if and how these processes can emerge

34

00:01:01,029 --> 00:00:59,440

independently of their specific

35

00:01:03,110 --> 00:01:01,039

biochemical constituents

36

00:01:05,030 --> 00:01:03,120

including compartments polymer-based

37

00:01:06,469 --> 00:01:05,040

genetics and even specific metabolic

38

00:01:08,230 --> 00:01:06,479

pathways

39

00:01:09,910 --> 00:01:08,240

now conventional approaches to studying

40

00:01:11,670 --> 00:01:09,920

the origins of life have historically

41

00:01:13,109 --> 00:01:11,680

focused on explaining the origins of

42

00:01:15,030 --> 00:01:13,119

these specific features

43

00:01:16,550 --> 00:01:15,040

but as a whole they failed to explain

44

00:01:17,670 --> 00:01:16,560

how those features could have arisen

45

00:01:19,590 --> 00:01:17,680

spontaneously

46

00:01:21,109 --> 00:01:19,600

in the absence of a prior living process

47

00:01:23,109 --> 00:01:21,119

like evolution

48

00:01:24,390 --> 00:01:23,119

as an alternative the chemical ecology

49

00:01:25,510 --> 00:01:24,400

model which is the one i'm going to

50

00:01:27,109 --> 00:01:25,520

present here

51
00:01:28,870 --> 00:01:27,119
suggests that self-propagation and

52
00:01:29,749 --> 00:01:28,880
evolution could arise in chemical

53
00:01:31,749 --> 00:01:29,759
ecosystems

54
00:01:34,069 --> 00:01:31,759
independently of polymer-based genetics

55
00:01:36,390 --> 00:01:34,079
and even compartments

56
00:01:37,910 --> 00:01:36,400
so what is this chemical ecology model

57
00:01:40,230 --> 00:01:37,920
so to start we define

58
00:01:41,990 --> 00:01:40,240
chemical ecosystems as sets of

59
00:01:42,870 --> 00:01:42,000
interacting auto catalytic chemical

60
00:01:44,950 --> 00:01:42,880
cycles

61
00:01:46,630 --> 00:01:44,960
and an autocatalytic cycle is simply a

62
00:01:47,510 --> 00:01:46,640
chemical reaction or sequence of

63
00:01:49,429 --> 00:01:47,520

reactions

64

00:01:51,270 --> 00:01:49,439

where at least one chemical species is

65

00:01:51,910 --> 00:01:51,280

present both as a reactant and as a

66

00:01:55,830 --> 00:01:51,920

product

67

00:01:57,670 --> 00:01:55,840

reactant side and that's key

68

00:01:59,350 --> 00:01:57,680

now we call these member chemicals

69

00:02:01,270 --> 00:01:59,360

denoted as m or mu

70

00:02:02,789 --> 00:02:01,280

in the diagrams i'm going to show you

71

00:02:04,789 --> 00:02:02,799

and these cycles also require

72

00:02:05,910 --> 00:02:04,799

food or f which are present only on the

73

00:02:07,990 --> 00:02:05,920

reactant side

74

00:02:10,229 --> 00:02:08,000

and generate waste w which are only

75

00:02:12,390 --> 00:02:10,239

present on the product side

76

00:02:13,270 --> 00:02:12,400

now our lab in an effort led by postdoc

77

00:02:15,430 --> 00:02:13,280

shen peng

78

00:02:17,510 --> 00:02:15,440

has simulated reaction cycles of varying

79

00:02:18,229 --> 00:02:17,520

complexity exposed to constant flux of

80

00:02:19,990 --> 00:02:18,239

food

81

00:02:21,910 --> 00:02:20,000

and found that the behavior of even the

82

00:02:23,670 --> 00:02:21,920

simplest autocatalytic cycles can be

83

00:02:24,470 --> 00:02:23,680

approximated using logistic growth

84

00:02:25,910 --> 00:02:24,480

models

85

00:02:27,430 --> 00:02:25,920

which basically just means that they

86

00:02:30,390 --> 00:02:27,440

behave much like populations of

87

00:02:32,470 --> 00:02:30,400

biological species

88

00:02:34,550 --> 00:02:32,480

even more interestingly when there are

89

00:02:35,750 --> 00:02:34,560

pairs of interacting cycles that behave

90

00:02:38,150 --> 00:02:35,760

either as competitors

91

00:02:39,830 --> 00:02:38,160

mutualists or even predator and prey the

92

00:02:40,710 --> 00:02:39,840

systems begin to display dynamic

93

00:02:42,710 --> 00:02:40,720

behaviors

94

00:02:44,869 --> 00:02:42,720

that resemble ecological interactions

95

00:02:46,550 --> 00:02:44,879

observed in biological populations

96

00:02:48,309 --> 00:02:46,560

and these dynamics can be observed as

97

00:02:50,869 --> 00:02:48,319

changes in the concentration of member

98

00:02:52,710 --> 00:02:50,879

species over time

99

00:02:54,630 --> 00:02:52,720

now a key consequence of this chemical

100

00:02:56,550 --> 00:02:54,640

ecology model is that it suggests that

101
00:02:57,030 --> 00:02:56,560
chemical ecosystems may be able to

102
00:02:58,949 --> 00:02:57,040
evolve

103
00:03:00,710 --> 00:02:58,959
as a result of combinations of different

104
00:03:02,070 --> 00:03:00,720
ecological interactions among many

105
00:03:03,670 --> 00:03:02,080
autocatalytic cycles

106
00:03:05,589 --> 00:03:03,680
as well as random or stochastic

107
00:03:07,990 --> 00:03:05,599
processes like fluctuations of food

108
00:03:09,750 --> 00:03:08,000
species or other environmental factors

109
00:03:11,589 --> 00:03:09,760
so we've also been working to explain

110
00:03:12,630 --> 00:03:11,599
how natural selection among chemical

111
00:03:14,470 --> 00:03:12,640
ecosystems

112
00:03:16,630 --> 00:03:14,480
can take place under plausible prebiotic

113
00:03:18,390 --> 00:03:16,640

scenarios for example in a sea floor or

114

00:03:20,229 --> 00:03:18,400

geothermal pool environment

115

00:03:22,070 --> 00:03:20,239

recognizing that an important component

116

00:03:23,589 --> 00:03:22,080

of these settings are mineral surfaces

117

00:03:25,589 --> 00:03:23,599

which have long been implicated in the

118

00:03:27,509 --> 00:03:25,599

emergence of life as they do things like

119

00:03:28,390 --> 00:03:27,519

readily absorb or stick to organic

120

00:03:31,270 --> 00:03:28,400

compounds

121

00:03:33,270 --> 00:03:31,280

and have important catalytic properties

122

00:03:35,270 --> 00:03:33,280

chemical ecosystems stuck onto mineral

123

00:03:37,509 --> 00:03:35,280

surfaces which we endearingly refer to

124

00:03:38,710 --> 00:03:37,519

as slimes or surface limited molecular

125

00:03:40,550 --> 00:03:38,720

ecosystems

126
00:03:42,710 --> 00:03:40,560
could differentially colonize surfaces

127
00:03:43,670 --> 00:03:42,720
and mutate as a result of rear side

128
00:03:45,430 --> 00:03:43,680
reactions

129
00:03:47,430 --> 00:03:45,440
while the continual turnover of mineral

130
00:03:48,630 --> 00:03:47,440
surfaces can effectively select or

131
00:03:50,630 --> 00:03:48,640
enrich for slimes

132
00:03:52,070 --> 00:03:50,640
that are better able to colonize new

133
00:03:54,309 --> 00:03:52,080
surfaces

134
00:03:56,710 --> 00:03:54,319
so this model shows us how in principle

135
00:03:57,350 --> 00:03:56,720
chemical ecosystems could complexify and

136
00:03:58,949 --> 00:03:57,360
evolve

137
00:04:02,949 --> 00:03:58,959
without implicating polymer-based

138
00:04:06,710 --> 00:04:04,630

now an important part of our research

139

00:04:08,550 --> 00:04:06,720

has been to test this chemical ecology

140

00:04:09,910 --> 00:04:08,560

model empirically and to do this

141

00:04:11,509 --> 00:04:09,920

we've developed an experimental

142

00:04:13,030 --> 00:04:11,519

framework designed to generate and

143

00:04:13,990 --> 00:04:13,040

detect slimes under laboratory

144

00:04:15,830 --> 00:04:14,000

conditions

145

00:04:17,189 --> 00:04:15,840

and we call this chemical ecosystem

146

00:04:19,189 --> 00:04:17,199

selection

147

00:04:21,110 --> 00:04:19,199

the basic principle is really simple it

148

00:04:22,950 --> 00:04:21,120

just involves combining a food-rich

149

00:04:24,710 --> 00:04:22,960

solution with mineral grains

150

00:04:25,990 --> 00:04:24,720

and deploying an analog of experimental

151
00:04:27,350 --> 00:04:26,000
evolution

152
00:04:29,670 --> 00:04:27,360
and to do this we incubate our

153
00:04:31,110 --> 00:04:29,680
ingredients to allow for putative slimes

154
00:04:32,950 --> 00:04:31,120
to establish themselves

155
00:04:35,189 --> 00:04:32,960
and then we transfer small sepsis

156
00:04:36,870 --> 00:04:35,199
colonized grains usually about 10

157
00:04:39,270 --> 00:04:36,880
to a new reaction vessel containing

158
00:04:40,070 --> 00:04:39,280
fresh food and fresh uncolonized mineral

159
00:04:41,990 --> 00:04:40,080
grains

160
00:04:43,749 --> 00:04:42,000
and we repeat this over many generations

161
00:04:45,189 --> 00:04:43,759
to selectively enrich for variants

162
00:04:46,070 --> 00:04:45,199
depicted in different colors here in

163
00:04:47,749 --> 00:04:46,080

this figure

164

00:04:49,189 --> 00:04:47,759

that are better able to get from green

165

00:04:51,909 --> 00:04:49,199

to grain and resist

166

00:04:53,670 --> 00:04:51,919

cereal dilution out of existence now

167

00:04:55,270 --> 00:04:53,680

importantly we also routinely sample

168

00:04:57,510 --> 00:04:55,280

both the bulk solution and the mineral

169

00:04:58,950 --> 00:04:57,520

grains and analyze them to track any

170

00:05:02,629 --> 00:04:58,960

changes that might be occurring in

171

00:05:05,990 --> 00:05:04,230

now the nice thing about this approach

172

00:05:07,670 --> 00:05:06,000

is that it's chemically agnostic

173

00:05:09,510 --> 00:05:07,680

in that it doesn't presuppose any

174

00:05:10,950 --> 00:05:09,520

specific chemistry and can therefore be

175

00:05:12,070 --> 00:05:10,960

used to test virtually any set of

176

00:05:14,070 --> 00:05:12,080

conditions

177

00:05:16,070 --> 00:05:14,080

instead the general principle relies on

178

00:05:17,749 --> 00:05:16,080

the detection of changes in proxy traits

179

00:05:19,270 --> 00:05:17,759

across generations to infer the

180

00:05:20,870 --> 00:05:19,280

existence of slimes

181

00:05:22,469 --> 00:05:20,880

and really the only requirement is that

182

00:05:24,390 --> 00:05:22,479

the proxy trait be related

183

00:05:26,710 --> 00:05:24,400

either directly or indirectly to the

184

00:05:28,390 --> 00:05:26,720

rate of slime propagation

185

00:05:30,629 --> 00:05:28,400

now response to selection here could

186

00:05:32,310 --> 00:05:30,639

manifest as a jump in the value of a

187

00:05:33,270 --> 00:05:32,320

proxy trait over one or several

188

00:05:34,870 --> 00:05:33,280

generations

189

00:05:36,870 --> 00:05:34,880

that is then sustained over further

190

00:05:38,150 --> 00:05:36,880

generations and can be seen here in this

191

00:05:39,990 --> 00:05:38,160

hypothetical figure

192

00:05:41,670 --> 00:05:40,000

representing the rate of propagation of

193

00:05:43,430 --> 00:05:41,680

a slime over time

194

00:05:45,510 --> 00:05:43,440

whereas progressive evolution would be

195

00:05:47,749 --> 00:05:45,520

demonstrated by gradual transitions to

196

00:05:49,830 --> 00:05:47,759

different proxy trait values

197

00:05:51,590 --> 00:05:49,840

so now to give you specific examples of

198

00:05:53,110 --> 00:05:51,600

proxy traits we've been using to track

199

00:05:54,950 --> 00:05:53,120

slime formation in our lab

200

00:05:56,790 --> 00:05:54,960

and illustrate the chemical ecosystem

201
00:05:58,230 --> 00:05:56,800
selection procedure a little bit better

202
00:06:01,749 --> 00:05:58,240
i'm going to show you some results of

203
00:06:03,350 --> 00:06:01,759
experiments we've conducted in our lab

204
00:06:05,270 --> 00:06:03,360
so we've screened several sets of

205
00:06:05,990 --> 00:06:05,280
conditions but for the purposes of this

206
00:06:07,830 --> 00:06:06,000
presentation

207
00:06:10,309 --> 00:06:07,840
i'm going to focus on one specific

208
00:06:12,390 --> 00:06:10,319
recipe we used to validate the approach

209
00:06:14,870 --> 00:06:12,400
and again chemical ecosystem selection

210
00:06:16,390 --> 00:06:14,880
doesn't require any specific inputs

211
00:06:18,230 --> 00:06:16,400
but here we chose ingredients that

212
00:06:19,670 --> 00:06:18,240
replicate what is known about the early

213
00:06:22,150 --> 00:06:19,680

earth in some way

214

00:06:23,029 --> 00:06:22,160

so we used a food rich prebiotic soup

215

00:06:25,110 --> 00:06:23,039

modeled after

216

00:06:26,870 --> 00:06:25,120

spark discharge experiments the recipe

217

00:06:28,309 --> 00:06:26,880

for which can be found in this table

218

00:06:30,469 --> 00:06:28,319

but you'll also notice that we made

219

00:06:32,870 --> 00:06:30,479

additions of compounds like atp

220

00:06:33,909 --> 00:06:32,880

as a chemical energy source although we

221

00:06:35,830 --> 00:06:33,919

acknowledge that atp

222

00:06:38,150 --> 00:06:35,840

is not a realistic prebiotic phosphate

223

00:06:38,790 --> 00:06:38,160

source and for the mineral we used

224

00:06:40,950 --> 00:06:38,800

pyrite

225

00:06:43,110 --> 00:06:40,960

and iron sulfide mineral which we ground

226
00:06:44,790 --> 00:06:43,120
up into powder and cleaned ourselves

227
00:06:47,350 --> 00:06:44,800
and we carried out the experiment under

228
00:06:49,749 --> 00:06:47,360
anoxic or oxygen-free conditions

229
00:06:51,510 --> 00:06:49,759
and we did so on 10 independent lineages

230
00:06:52,629 --> 00:06:51,520
that were exposed to 40 rounds of

231
00:06:54,390 --> 00:06:52,639
transfers

232
00:06:56,870 --> 00:06:54,400
with each generation lasting about two

233
00:06:58,710 --> 00:06:56,880
to three days and then we analyzed the

234
00:07:00,469 --> 00:06:58,720
replicate lineages periodically

235
00:07:02,150 --> 00:07:00,479
with controls that were strategically

236
00:07:03,350 --> 00:07:02,160
set up to only have a single round of

237
00:07:07,110 --> 00:07:03,360
transfer in their history

238
00:07:09,029 --> 00:07:07,120

to isolate the role of these transfers

239

00:07:11,110 --> 00:07:09,039

one of the selected proxy traits we

240

00:07:13,189 --> 00:07:11,120

monitored was the concentration of free

241

00:07:15,110 --> 00:07:13,199

inorganic phosphate in the bulk solution

242

00:07:16,950 --> 00:07:15,120

at the end of each generation to

243

00:07:18,469 --> 00:07:16,960

estimate the amount of atp hydrolysis

244

00:07:19,990 --> 00:07:18,479

that had taken place

245

00:07:21,830 --> 00:07:20,000

and when we did this we observed a

246

00:07:23,350 --> 00:07:21,840

distinct oscillatory pattern in the

247

00:07:25,189 --> 00:07:23,360

amount of free inorganic phosphate

248

00:07:26,710 --> 00:07:25,199

across generations

249

00:07:28,550 --> 00:07:26,720

and there are several ways to interpret

250

00:07:30,309 --> 00:07:28,560

this pattern the simplest being that a

251
00:07:32,150 --> 00:07:30,319
non-linear or autocatalytic chemical

252
00:07:34,150 --> 00:07:32,160
system has arisen in response to the

253
00:07:36,070 --> 00:07:34,160
protocol

254
00:07:37,270 --> 00:07:36,080
and interestingly the theoretical work

255
00:07:39,189 --> 00:07:37,280
our group has done

256
00:07:41,029 --> 00:07:39,199
suggests that these oscillatory patterns

257
00:07:42,710 --> 00:07:41,039
might reflect the presence of predator

258
00:07:44,390 --> 00:07:42,720
prey type dynamics and simulated

259
00:07:45,830 --> 00:07:44,400
chemical ecosystems

260
00:07:47,589 --> 00:07:45,840
hinting at the possibility that

261
00:07:48,950 --> 00:07:47,599
interacting or coupled auto catalytic

262
00:07:50,790 --> 00:07:48,960
cycles might have arisen in our

263
00:07:53,029 --> 00:07:50,800

experiments

264

00:07:54,869 --> 00:07:53,039

now on the mineral side we also observe

265

00:07:57,029 --> 00:07:54,879

distinct fractal structures on the

266

00:07:59,029 --> 00:07:57,039

surfaces of pyrite grains from samples

267

00:08:01,110 --> 00:07:59,039

exposed to many rounds of selection

268

00:08:02,710 --> 00:08:01,120

which are absent or rare in controls

269

00:08:04,070 --> 00:08:02,720

meaning samples that only have one

270

00:08:05,670 --> 00:08:04,080

transfer in their history

271

00:08:07,670 --> 00:08:05,680

and we did these observations by

272

00:08:09,430 --> 00:08:07,680

electron microscopy and you can see some

273

00:08:11,029 --> 00:08:09,440

representative micrographs here

274

00:08:13,189 --> 00:08:11,039

for both experimental and control

275

00:08:14,950 --> 00:08:13,199

samples and while we're still looking to

276

00:08:16,629 --> 00:08:14,960

determine the exact composition of these

277

00:08:18,230 --> 00:08:16,639

structures and their significance

278

00:08:19,830 --> 00:08:18,240

and whether they're related somehow to

279

00:08:21,270 --> 00:08:19,840

the source of oscillatory patterns we

280

00:08:22,790 --> 00:08:21,280

saw in the bulk solution

281

00:08:24,790 --> 00:08:22,800

this just further illustrates the fact

282

00:08:25,990 --> 00:08:24,800

that chemical ecosystem selection can be

283

00:08:28,230 --> 00:08:26,000

used to study complex

284

00:08:31,270 --> 00:08:28,240

spatial temporal dynamics that can arise

285

00:08:33,110 --> 00:08:31,280

in prebiotic mixtures

286

00:08:34,630 --> 00:08:33,120

and while the results i've shown you are

287

00:08:36,550 --> 00:08:34,640

interesting and consistent with the

288

00:08:37,269 --> 00:08:36,560

appearance of interacting autocatalytic

289

00:08:39,269 --> 00:08:37,279

cycles

290

00:08:41,190 --> 00:08:39,279

much more work is needed to determine

291

00:08:42,310 --> 00:08:41,200

whether they constitute true slimes by

292

00:08:43,750 --> 00:08:42,320

our definition

293

00:08:45,990 --> 00:08:43,760

and for this we would really need to

294

00:08:47,590 --> 00:08:46,000

demonstrate evolvability and we plan on

295

00:08:48,870 --> 00:08:47,600

doing this by carrying out experiments

296

00:08:51,190 --> 00:08:48,880

for much longer

297

00:08:53,750 --> 00:08:51,200

at least 100 generations and performing

298

00:08:55,350 --> 00:08:53,760

more in-depth chemical characterization

299

00:08:56,949 --> 00:08:55,360

and on the theory side our group is

300

00:08:59,190 --> 00:08:56,959

working to analyze the effects of

301
00:09:00,790 --> 00:08:59,200
spatial structuring and heterogeneity

302
00:09:02,870 --> 00:09:00,800
to simulate the effects of mineral

303
00:09:03,509 --> 00:09:02,880
surface absorption on chemical ecosystem

304
00:09:05,670 --> 00:09:03,519
dynamics

305
00:09:07,269 --> 00:09:05,680
which will enhance our ability to apply

306
00:09:08,150 --> 00:09:07,279
these models in the interpretation of

307
00:09:10,389 --> 00:09:08,160
results

308
00:09:13,269 --> 00:09:10,399
that we obtain in our chemical ecosystem

309
00:09:14,870 --> 00:09:13,279
selection experiments

310
00:09:16,870 --> 00:09:14,880
so in conclusion we hope that our

311
00:09:17,590 --> 00:09:16,880
chemical ecology model for the emergence

312
00:09:19,269 --> 00:09:17,600
of life

313
00:09:20,870 --> 00:09:19,279

will help advance our understanding of

314

00:09:22,470 --> 00:09:20,880

life as a general phenomenon

315

00:09:24,310 --> 00:09:22,480

and shed light on the origins of key

316

00:09:25,829 --> 00:09:24,320

life processes in relatively simple

317

00:09:27,350 --> 00:09:25,839

chemical systems

318

00:09:29,509 --> 00:09:27,360

and i've shown you that our chemical

319

00:09:31,590 --> 00:09:29,519

ecology model can explain how chemical

320

00:09:32,389 --> 00:09:31,600

ecosystems of interacting autocathetic

321

00:09:33,829 --> 00:09:32,399

cycles

322

00:09:35,590 --> 00:09:33,839

can yield complex dynamics and

323

00:09:38,070 --> 00:09:35,600

potentially evolve without the need for

324

00:09:40,230 --> 00:09:38,080

polymer-based genetics or compartments

325

00:09:41,829 --> 00:09:40,240

and how chemical ecosystem selection

326

00:09:44,230 --> 00:09:41,839

might help us study the emergence of

327

00:09:45,509 --> 00:09:44,240

evolvable autocatalysis under laboratory

328

00:09:47,430 --> 00:09:45,519

conditions

329

00:09:49,350 --> 00:09:47,440

and we've also already identified a set

330

00:09:50,389 --> 00:09:49,360

of conditions that yields promising

331

00:09:52,070 --> 00:09:50,399

results

332

00:09:53,990 --> 00:09:52,080

and so ongoing and future work in our

333

00:09:55,430 --> 00:09:54,000

lab will be aimed at further

334

00:09:57,269 --> 00:09:55,440

understanding and expanding these

335

00:09:59,030 --> 00:09:57,279

theoretical and empirical models

336

00:10:01,110 --> 00:09:59,040

and hopefully help the astrobiology

337

00:10:04,870 --> 00:10:01,120

community as a whole resolve the origins

338

00:10:06,630 --> 00:10:04,880

and fundamental nature of life

339

00:10:08,949 --> 00:10:06,640

and with that i'd just like to thank

340

00:10:09,829 --> 00:10:08,959

past and current members of david baum's

341

00:10:10,949 --> 00:10:09,839

lab at the university of

342

00:10:13,030 --> 00:10:10,959

wisconsin-madison

343

00:10:14,389 --> 00:10:13,040

and wisconsin institute for discovery

344

00:10:17,190 --> 00:10:14,399

all of our collaborators