
hhmi
Howard Hughes Medical Institute
HARVARD
Origins of Life
INITIATIVE
NASA
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1
00:00:04,070 --> 00:00:02,790
hello it's great to speak at grad count

2
00:00:06,550 --> 00:00:04,080
this year

3
00:00:08,070 --> 00:00:06,560
ultimately all of us at this meeting

4
00:00:10,150 --> 00:00:08,080
have the same goal

5
00:00:11,509 --> 00:00:10,160
to figure out how inanimate matter

6
00:00:15,190 --> 00:00:11,519
organized itself

7
00:00:17,269 --> 00:00:15,200
to form cellular life today i'll try to

8
00:00:18,310 --> 00:00:17,279
show you how rna could have played a

9
00:00:21,269 --> 00:00:18,320
pivotal role

10
00:00:22,550 --> 00:00:21,279
in bridging the worlds of chemistry and

11
00:00:24,550 --> 00:00:22,560
biology

12
00:00:26,710 --> 00:00:24,560
we may never accurately retrace the

13
00:00:29,589 --> 00:00:26,720

steps back to the origin of life

14
00:00:31,429 --> 00:00:29,599
but looking at life as we know it the

15
00:00:33,910 --> 00:00:31,439
worlds of chemistry and biology

16
00:00:35,510 --> 00:00:33,920
must have been bridged by a primitive

17
00:00:37,670 --> 00:00:35,520
cellular system

18
00:00:39,350 --> 00:00:37,680
generated by the self-assembly of

19
00:00:41,830 --> 00:00:39,360
inanimate matter

20
00:00:42,950 --> 00:00:41,840
that exhibited the emerging properties

21
00:00:46,069 --> 00:00:42,960
of life

22
00:00:49,029 --> 00:00:46,079
um such a primitive cell or a protocell

23
00:00:50,150 --> 00:00:49,039
would minimally be a sack of genes and

24
00:00:52,310 --> 00:00:50,160
enzymes

25
00:00:53,350 --> 00:00:52,320
and this is further simplified by the

26
00:00:55,830 --> 00:00:53,360
fact that both

27
00:00:56,790 --> 00:00:55,840
genetic and enzymatic functions can be

28
00:01:00,310 --> 00:00:56,800
embodied

29
00:01:01,830 --> 00:01:00,320
by rna so considering the potentially

30
00:01:04,549 --> 00:01:01,840
central role of rna

31
00:01:05,270 --> 00:01:04,559
in the origin and evolution of early

32
00:01:07,910 --> 00:01:05,280
life

33
00:01:09,190 --> 00:01:07,920
i'm trying to develop experimental

34
00:01:12,149 --> 00:01:09,200
models to demonstrate

35
00:01:13,910 --> 00:01:12,159
some of the major chemical transitions

36
00:01:16,870 --> 00:01:13,920
that are only had to go through

37
00:01:17,510 --> 00:01:16,880
before the emergence of rna-based uh

38
00:01:20,789 --> 00:01:17,520

cellular

39
00:01:22,789 --> 00:01:20,799
life of course it all started with a

40
00:01:24,149 --> 00:01:22,799
chaotic collection of chemicals and then

41
00:01:27,190 --> 00:01:24,159
we somehow

42
00:01:27,910 --> 00:01:27,200
ended up with this vast diversity of

43
00:01:30,950 --> 00:01:27,920
life

44
00:01:32,310 --> 00:01:30,960
so the question here is what happened in

45
00:01:34,310 --> 00:01:32,320
between

46
00:01:35,830 --> 00:01:34,320
uh prebiotic chemistry produced the

47
00:01:37,830 --> 00:01:35,840
building blocks of rna

48
00:01:39,590 --> 00:01:37,840
and these building blocks had to be

49
00:01:41,510 --> 00:01:39,600
chemically activated

50
00:01:43,069 --> 00:01:41,520
so that they could assemble into longer

51
00:01:45,990 --> 00:01:43,079
rna molecules

52
00:01:47,910 --> 00:01:46,000
non-enzymatically we recently discovered

53
00:01:51,270 --> 00:01:47,920
that two amino imidazole or

54
00:01:52,030 --> 00:01:51,280
2ai as we call it is a great activating

55
00:01:55,190 --> 00:01:52,040
group for

56
00:01:57,109 --> 00:01:55,200
non-enzymatic rna assembly and it is

57
00:01:59,749 --> 00:01:57,119
probiotically relevant as well

58
00:02:00,149 --> 00:01:59,759
which makes it quite attractive for us

59
00:02:02,389 --> 00:02:00,159
so

60
00:02:04,230 --> 00:02:02,399
when activated these building blocks

61
00:02:07,190 --> 00:02:04,240
would self-assemble into

62
00:02:07,990 --> 00:02:07,200
longer rnas which would then when

63
00:02:10,869 --> 00:02:08,000

sufficiently

64
00:02:13,270 --> 00:02:10,879
long fold up into complex structures in

65
00:02:16,470 --> 00:02:13,280
three dimensions and perhaps even show

66
00:02:17,510 --> 00:02:16,480
catalytic function and this rna assembly

67
00:02:19,910 --> 00:02:17,520
process would be

68
00:02:21,670 --> 00:02:19,920
turbocharged when some of these longer

69
00:02:25,350 --> 00:02:21,680
rna molecules would start

70
00:02:27,110 --> 00:02:25,360
to behave as rna enzymes or ribozymes

71
00:02:29,990 --> 00:02:27,120
that would use the building blocks of

72
00:02:33,430 --> 00:02:30,000
non-enzymatic assembly as substrates

73
00:02:36,710 --> 00:02:33,440
for enzymatic rna assembly so these

74
00:02:37,670 --> 00:02:36,720
ribozymes would be evolutionary links

75
00:02:41,110 --> 00:02:37,680
between

76
00:02:42,550 --> 00:02:41,120
non-enzymatic and enzymatic rna assembly

77
00:02:44,710 --> 00:02:42,560
processes

78
00:02:46,390 --> 00:02:44,720
now it is important to note here that

79
00:02:49,190 --> 00:02:46,400
for all of this to happen

80
00:02:51,270 --> 00:02:49,200
these ribozymes needed to be compatible

81
00:02:53,670 --> 00:02:51,280
with the prebiotic chemistry

82
00:02:54,550 --> 00:02:53,680
that generated activated rna building

83
00:02:57,110 --> 00:02:54,560
blocks

84
00:02:57,750 --> 00:02:57,120
and finally at some point in this

85
00:02:59,710 --> 00:02:57,760
journey

86
00:03:01,430 --> 00:02:59,720
rna catalysis would have to be

87
00:03:03,350 --> 00:03:01,440
compartmentalized where

88
00:03:04,710 --> 00:03:03,360

ribozymes would take care of early

89
00:03:07,110 --> 00:03:04,720
metabolism and

90
00:03:08,309 --> 00:03:07,120
trigger growth and division and perhaps

91
00:03:10,550 --> 00:03:08,319
even invent

92
00:03:12,149 --> 00:03:10,560
darwinian evolution in these uh

93
00:03:14,470 --> 00:03:12,159
protocellular systems

94
00:03:15,190 --> 00:03:14,480
so for today's talk i will use rna

95
00:03:18,630 --> 00:03:15,200
ligation

96
00:03:21,830 --> 00:03:18,640
as a model uh for prebiotic rna assembly

97
00:03:23,350 --> 00:03:21,840
to describe some of these transitions

98
00:03:25,110 --> 00:03:23,360
so let's look at the first major

99
00:03:27,990 --> 00:03:25,120
transition which is

100
00:03:28,949 --> 00:03:28,000
the emergence of rna enzymes that

101
00:03:31,350 --> 00:03:28,959
utilize

102
00:03:32,070 --> 00:03:31,360
the building blocks of non-enzymatic rna

103
00:03:35,110 --> 00:03:32,080
assembly

104
00:03:35,830 --> 00:03:35,120
to make longer rnas so we use the

105
00:03:38,630 --> 00:03:35,840
technique called

106
00:03:40,149 --> 00:03:38,640
in vitro selection to identify rna

107
00:03:42,390 --> 00:03:40,159
enzymes that join

108
00:03:43,270 --> 00:03:42,400
two pieces of rna in this case with the

109
00:03:45,830 --> 00:03:43,280
second

110
00:03:47,430 --> 00:03:45,840
piece activated with the two amino

111
00:03:49,750 --> 00:03:47,440
imidazole group

112
00:03:52,229 --> 00:03:49,760
in brief we started with a combinatorial

113
00:03:53,110 --> 00:03:52,239

rna library that contained a billion

114
00:03:55,910 --> 00:03:53,120
billion

115
00:03:57,110 --> 00:03:55,920
rna molecules and the first rna piece to

116
00:03:59,750 --> 00:03:57,120
be joined was

117
00:04:02,390 --> 00:03:59,760
actually equivalently linked to each of

118
00:04:04,470 --> 00:04:02,400
the sequences in in the library

119
00:04:06,070 --> 00:04:04,480
and then we challenged this library with

120
00:04:09,110 --> 00:04:06,080
a biotin tagged

121
00:04:11,750 --> 00:04:09,120
two immunomedical activated substrate

122
00:04:13,670 --> 00:04:11,760
uh sequences that were able to catalyze

123
00:04:14,630 --> 00:04:13,680
this ligation reaction between these two

124
00:04:17,189 --> 00:04:14,640
pieces

125
00:04:19,349 --> 00:04:17,199
would get joined to the biotinylated

126
00:04:22,790 --> 00:04:19,359
substrate and therefore be tagged

127
00:04:25,430 --> 00:04:22,800
with the biotin themselves we use

128
00:04:26,629 --> 00:04:25,440
magnetic beads coated with streptavidin

129
00:04:29,670 --> 00:04:26,639
to capture these

130
00:04:31,909 --> 00:04:29,680
sequences because streptavidin binds

131
00:04:34,150 --> 00:04:31,919
to biotin very strongly so these

132
00:04:36,150 --> 00:04:34,160
captured rna sequences on the beads

133
00:04:37,270 --> 00:04:36,160
were reversed transcribed to dna and

134
00:04:40,070 --> 00:04:37,280
amplified by

135
00:04:41,189 --> 00:04:40,080
pcr so by repeating this cycle we were

136
00:04:43,909 --> 00:04:41,199
able to identify

137
00:04:45,830 --> 00:04:43,919
several distinct classes of ligase

138
00:04:48,310 --> 00:04:45,840

ribosomes

139
00:04:50,550 --> 00:04:48,320
this slide summarizes some of the

140
00:04:53,350 --> 00:04:50,560
properties of these rna enzymes

141
00:04:54,390 --> 00:04:53,360
so the image on the top left shows you a

142
00:04:57,430 --> 00:04:54,400
denaturing

143
00:04:59,670 --> 00:04:57,440
gel which was used to separate the

144
00:05:00,469 --> 00:04:59,680
the products of this ligation reaction

145
00:05:04,070 --> 00:05:00,479
that have

146
00:05:06,310 --> 00:05:04,080
a slower gel mobility which once again

147
00:05:08,390 --> 00:05:06,320
uh establishes that these ribozymes are

148
00:05:10,870 --> 00:05:08,400
indeed ligase ribozymes

149
00:05:11,670 --> 00:05:10,880
ribozymes that join pieces of rna

150
00:05:14,390 --> 00:05:11,680
together

151
00:05:15,590 --> 00:05:14,400
and then the image on the top uh center

152
00:05:18,870 --> 00:05:15,600
shows you how

153
00:05:20,870 --> 00:05:18,880
uh catalytic activity was enriched

154
00:05:22,469 --> 00:05:20,880
across these different rounds of

155
00:05:25,430 --> 00:05:22,479
selection uh

156
00:05:26,469 --> 00:05:25,440
from us our selection protocol and then

157
00:05:28,870 --> 00:05:26,479
we observed

158
00:05:29,909 --> 00:05:28,880
uh about a thousand fold rate

159
00:05:32,710 --> 00:05:29,919
accelerations

160
00:05:33,270 --> 00:05:32,720
uh by these selected uh ribozymes which

161
00:05:36,230 --> 00:05:33,280
is of course

162
00:05:38,550 --> 00:05:36,240
great we also confirmed that uh this

163
00:05:41,510 --> 00:05:38,560

catalytic ligation reaction required

164
00:05:42,469 --> 00:05:41,520
a template which could be either rna or

165
00:05:45,830 --> 00:05:42,479
dna

166
00:05:48,629 --> 00:05:45,840
and a two amino imidazole activation on

167
00:05:49,270 --> 00:05:48,639
the substrate this was important uh

168
00:05:51,110 --> 00:05:49,280
since the

169
00:05:52,870 --> 00:05:51,120
two millimeters was activation on the

170
00:05:53,830 --> 00:05:52,880
substrate was an essential feature of

171
00:05:56,629 --> 00:05:53,840
this reaction

172
00:05:57,110 --> 00:05:56,639
the next obvious question is how did

173
00:06:02,950 --> 00:05:57,120
these

174
00:06:04,790 --> 00:06:02,960
activated on early earth now an

175
00:06:05,830 --> 00:06:04,800
interesting chemistry is suggested by

176
00:06:08,950 --> 00:06:05,840
john sutherland's

177
00:06:09,670 --> 00:06:08,960
group in the uk has used isocyanide

178
00:06:12,309 --> 00:06:09,680
aldehyde

179
00:06:13,110 --> 00:06:12,319
and two amino amino dissolve to activate

180
00:06:15,350 --> 00:06:13,120
nucleoside

181
00:06:17,270 --> 00:06:15,360
monophosphates so we thought that we

182
00:06:20,390 --> 00:06:17,280
could use this chemistry to activate

183
00:06:23,670 --> 00:06:20,400
oligomeric rna and more importantly

184
00:06:25,270 --> 00:06:23,680
we wanted to test if uh these ligase

185
00:06:27,430 --> 00:06:25,280
ribozymes could still

186
00:06:30,390 --> 00:06:27,440
function under uh the conditions of

187
00:06:33,029 --> 00:06:30,400
probiotic rna activation

188
00:06:34,469 --> 00:06:33,039

now before we went into our main

189
00:06:37,590 --> 00:06:34,479
experiments we wanted

190
00:06:40,629 --> 00:06:37,600
uh activation and

191
00:06:44,230 --> 00:06:40,639
ribozymatic ligation to happen

192
00:06:45,909 --> 00:06:44,240
in one part right so since unactivated

193
00:06:47,670 --> 00:06:45,919
substrates in the reaction would

194
00:06:49,589 --> 00:06:47,680
bind to the template and therefore

195
00:06:50,629 --> 00:06:49,599
inhibit ligation we wanted to first

196
00:06:53,430 --> 00:06:50,639
maximize

197
00:06:55,110 --> 00:06:53,440
uh the activation yields so we optimized

198
00:06:56,629 --> 00:06:55,120
each of the three components in this

199
00:06:59,510 --> 00:06:56,639
activation reaction

200
00:07:01,350 --> 00:06:59,520
and collectively we got about 50 percent

201
00:07:02,629 --> 00:07:01,360
activated substrate which we thought

202
00:07:05,670 --> 00:07:02,639
would be sufficient

203
00:07:06,629 --> 00:07:05,680
uh to drive this reaction uh so this is

204
00:07:09,270 --> 00:07:06,639
the experiment

205
00:07:10,230 --> 00:07:09,280
we added unactivated substrate to the

206
00:07:13,189 --> 00:07:10,240
ribozyme

207
00:07:13,830 --> 00:07:13,199
and template under activation conditions

208
00:07:16,710 --> 00:07:13,840
and then

209
00:07:17,830 --> 00:07:16,720
we observed catalytic ligation which

210
00:07:20,870 --> 00:07:17,840
means that these

211
00:07:23,749 --> 00:07:20,880
unactivated rnas got activated

212
00:07:25,749 --> 00:07:23,759
in situ in the same part and then these

213
00:07:28,070 --> 00:07:25,759

could now act as substrates

214
00:07:29,589 --> 00:07:28,080
for ribozymatic ligation so this

215
00:07:32,309 --> 00:07:29,599
preliminary result

216
00:07:33,830 --> 00:07:32,319
shows that probiotic chemistry and rna

217
00:07:35,830 --> 00:07:33,840
catalyzed rna assembly

218
00:07:38,870 --> 00:07:35,840
can work together which is how it would

219
00:07:41,110 --> 00:07:38,880
have happened on earlier

220
00:07:43,270 --> 00:07:41,120
so with rna enzymes available that can

221
00:07:45,110 --> 00:07:43,280
stitch together pieces of rna

222
00:07:47,670 --> 00:07:45,120
activated with this prebiotically

223
00:07:50,309 --> 00:07:47,680
relevant two-amino imidazole group

224
00:07:51,029 --> 00:07:50,319
we are now ready to take the next step

225
00:07:52,589 --> 00:07:51,039
which is

226
00:07:54,150 --> 00:07:52,599
to model the emergence of

227
00:07:57,189 --> 00:07:54,160
compartmentalized

228
00:07:58,869 --> 00:07:57,199
rna catalyzed rna assembly

229
00:08:00,309 --> 00:07:58,879
so first how to make a probiotic

230
00:08:02,309 --> 00:08:00,319
compartment uh

231
00:08:04,070 --> 00:08:02,319
some of us know that simple short-chain

232
00:08:05,909 --> 00:08:04,080
fatty acids which are of course the main

233
00:08:08,230 --> 00:08:05,919
component of phospholipids are

234
00:08:09,430 --> 00:08:08,240
attractive candidates for primitive cell

235
00:08:11,749 --> 00:08:09,440
membranes as

236
00:08:13,270 --> 00:08:11,759
they can be made biotically and

237
00:08:15,189 --> 00:08:13,280
interestingly fatty acids

238
00:08:16,550 --> 00:08:15,199

have also been found in carbonaceous

239
00:08:19,189 --> 00:08:16,560
chondrites which is

240
00:08:19,670 --> 00:08:19,199
quite exciting but most importantly

241
00:08:21,589 --> 00:08:19,680
these

242
00:08:23,189 --> 00:08:21,599
molecules can self-assemble into

243
00:08:25,749 --> 00:08:23,199
spherical vesicles

244
00:08:27,110 --> 00:08:25,759
that can encapsulate rna among other

245
00:08:30,150 --> 00:08:27,120
molecules

246
00:08:32,389 --> 00:08:30,160
okay so ribozymes making long rnas

247
00:08:33,509 --> 00:08:32,399
within fatty acid vesicles appear to be

248
00:08:35,829 --> 00:08:33,519
an exciting model

249
00:08:37,029 --> 00:08:35,839
for primitive cells right but the

250
00:08:40,389 --> 00:08:37,039
seemingly simple

251
00:08:41,990 --> 00:08:40,399
model has not been realized yet

252
00:08:43,670 --> 00:08:42,000
because of a nagging problem in the

253
00:08:46,310 --> 00:08:43,680
field which is that most

254
00:08:49,269 --> 00:08:46,320
ribozymes need medium to high

255
00:08:52,550 --> 00:08:49,279
concentrations of magnesium to function

256
00:08:54,710 --> 00:08:52,560
but fatty acid vesicles start to leak at

257
00:08:56,790 --> 00:08:54,720
those concentrations so

258
00:08:59,269 --> 00:08:56,800
the bottom line is you either have

259
00:09:00,710 --> 00:08:59,279
stable compartments or you have active

260
00:09:02,630 --> 00:09:00,720
ribozymes

261
00:09:04,070 --> 00:09:02,640
but it's kind of hard to get both

262
00:09:06,790 --> 00:09:04,080
together

263
00:09:07,750 --> 00:09:06,800

so one of the ways by which we solve

264
00:09:10,870 --> 00:09:07,760
this problem

265
00:09:14,150 --> 00:09:10,880
is by identifying a ligase or ribozyme

266
00:09:16,870 --> 00:09:14,160
that worked at sub millimolar magnesium

267
00:09:18,790 --> 00:09:16,880
right so under these conditions fatty

268
00:09:20,389 --> 00:09:18,800
acid vesicles would be stable

269
00:09:22,550 --> 00:09:20,399
ribozymes would also function which

270
00:09:24,790 --> 00:09:22,560
means that this provides an exciting

271
00:09:27,990 --> 00:09:24,800
opportunity to constitute the first

272
00:09:31,190 --> 00:09:28,000
instance of rna catalyzed rna ligation

273
00:09:33,110 --> 00:09:31,200
within prebiotic fatty acid compartments

274
00:09:34,389 --> 00:09:33,120
uh but before i show you the results for

275
00:09:36,310 --> 00:09:34,399
this experiment i

276
00:09:39,030 --> 00:09:36,320
i would like to play devil's advocate

277
00:09:41,590 --> 00:09:39,040
here so it's obvious that these these

278
00:09:44,389 --> 00:09:41,600
unique ribosomes that work at some

279
00:09:47,350 --> 00:09:44,399
millimolar magnesium would be quite rare

280
00:09:49,750 --> 00:09:47,360
in the in the rna sequence space so

281
00:09:53,030 --> 00:09:49,760
perhaps we must look for a more

282
00:09:55,990 --> 00:09:53,040
general systems based approach

283
00:09:57,509 --> 00:09:56,000
to solve this magnesium problem so

284
00:09:59,990 --> 00:09:57,519
according to the chase

285
00:10:01,750 --> 00:10:00,000
uh i discovered that small molecules

286
00:10:04,310 --> 00:10:01,760
like ethylene glycol or

287
00:10:05,509 --> 00:10:04,320
d ribose that would have been present on

288
00:10:07,269 --> 00:10:05,519

early earth

289
00:10:09,269 --> 00:10:07,279
and may have even played important roles

290
00:10:10,389 --> 00:10:09,279
in in probiotic synthesis of rna

291
00:10:13,509 --> 00:10:10,399
building blocks

292
00:10:15,990 --> 00:10:13,519
could dramatically stimulate uh

293
00:10:17,829 --> 00:10:16,000
ligase ribozyme function at one

294
00:10:19,350 --> 00:10:17,839
millimolar magnesium

295
00:10:21,430 --> 00:10:19,360
so primitive cells of course would

296
00:10:24,470 --> 00:10:21,440
contain these molecules within them

297
00:10:25,430 --> 00:10:24,480
right in addition to rna so we could

298
00:10:28,110 --> 00:10:25,440
then generate

299
00:10:30,069 --> 00:10:28,120
these crowded protocells with

300
00:10:33,430 --> 00:10:30,079
encapsulated rna

301
00:10:36,470 --> 00:10:33,440
and d ribose in this case now

302
00:10:39,269 --> 00:10:36,480
what we saw was this again helped uh

303
00:10:40,230 --> 00:10:39,279
to constitute rna catalyzed rna ligation

304
00:10:42,790 --> 00:10:40,240
within these

305
00:10:44,310 --> 00:10:42,800
fatty acid vesicles and in addition to

306
00:10:47,030 --> 00:10:44,320
helping catalysis

307
00:10:49,750 --> 00:10:47,040
we found that ribose stabilized these

308
00:10:52,710 --> 00:10:49,760
fatty acid compartments and minimized

309
00:10:54,069 --> 00:10:52,720
rna leakage even in the presence of

310
00:10:55,829 --> 00:10:54,079
magnesium as you can see

311
00:10:57,590 --> 00:10:55,839
even after three hours in the presence

312
00:11:01,269 --> 00:10:57,600
of three millimolar magnesium

313
00:11:04,150 --> 00:11:01,279

there's almost no leakage from these

314
00:11:05,509 --> 00:11:04,160
fatty acid vesicles if you have d ribose

315
00:11:08,710 --> 00:11:05,519
within them

316
00:11:11,590 --> 00:11:08,720
okay so with that here are these

317
00:11:13,670 --> 00:11:11,600
vesicles with fluorescent labeled rna

318
00:11:15,829 --> 00:11:13,680
in them healthy and handsome in the

319
00:11:19,110 --> 00:11:15,839
presence of three millimolar magnesium

320
00:11:20,389 --> 00:11:19,120
even after three hours uh so we put our

321
00:11:23,430 --> 00:11:20,399
ligase ribozyme

322
00:11:25,590 --> 00:11:23,440
template and the activated substrate

323
00:11:27,750 --> 00:11:25,600
within these vesicles and then we added

324
00:11:27,990 --> 00:11:27,760
magnesium to the outside to initiate

325
00:11:30,389 --> 00:11:28,000
this

326
00:11:32,550 --> 00:11:30,399
reaction and then we broke open these

327
00:11:35,509 --> 00:11:32,560
vesicles at various time points

328
00:11:36,150 --> 00:11:35,519
uh to analyze the contents and to our

329
00:11:37,910 --> 00:11:36,160
delight

330
00:11:39,590 --> 00:11:37,920
we observed ligation within these

331
00:11:40,710 --> 00:11:39,600
compartments with eels that were

332
00:11:44,230 --> 00:11:40,720
comparable

333
00:11:47,230 --> 00:11:44,240
to ligation in solution so this is a

334
00:11:48,389 --> 00:11:47,240
first step toward our goal of developing

335
00:11:50,710 --> 00:11:48,399
self-replicating

336
00:11:52,470 --> 00:11:50,720
protocells where ribozymes would make

337
00:11:55,590 --> 00:11:52,480
copies of themselves

338
00:11:57,509 --> 00:11:55,600

within prebiotic compartments this of

339
00:11:58,069 --> 00:11:57,519
course has profound implications in the

340
00:12:00,230 --> 00:11:58,079
field

341
00:12:02,310 --> 00:12:00,240
so say you have two protocells that have

342
00:12:05,269 --> 00:12:02,320
slightly different ribozymes

343
00:12:06,870 --> 00:12:05,279
you know one with the better ribozyme

344
00:12:09,110 --> 00:12:06,880
will make more rna

345
00:12:10,470 --> 00:12:09,120
and then of course grow fat and make

346
00:12:12,470 --> 00:12:10,480
more babies faster

347
00:12:15,030 --> 00:12:12,480
and ultimately these are the cells that

348
00:12:16,470 --> 00:12:15,040
would take over the entire population

349
00:12:18,069 --> 00:12:16,480
right so this would represent the

350
00:12:20,389 --> 00:12:18,079
spontaneous emergence

351
00:12:22,069 --> 00:12:20,399
of a rather primitive version of

352
00:12:24,550 --> 00:12:22,079
darwinian evolution

353
00:12:25,269 --> 00:12:24,560
in systems put together from non-living

354
00:12:27,110 --> 00:12:25,279
matter

355
00:12:29,269 --> 00:12:27,120
uh of course we are far from achieving

356
00:12:32,150 --> 00:12:29,279
this but meetings such as this

357
00:12:33,190 --> 00:12:32,160
make me hopeful uh okay so that's all i

358
00:12:35,269 --> 00:12:33,200
have for today

359
00:12:37,829 --> 00:12:35,279
uh i'd like to quickly thank the shostak

360
00:12:39,750 --> 00:12:37,839
lab um jack of course and especially

361
00:12:41,990 --> 00:12:39,760
grad student stephanie jung who i

362
00:12:43,350 --> 00:12:42,000
collaborated with for some of the work

363
00:12:45,670 --> 00:12:43,360

that i discussed here

364
00:12:46,949 --> 00:12:45,680
and thanks a lot for listening i'd be