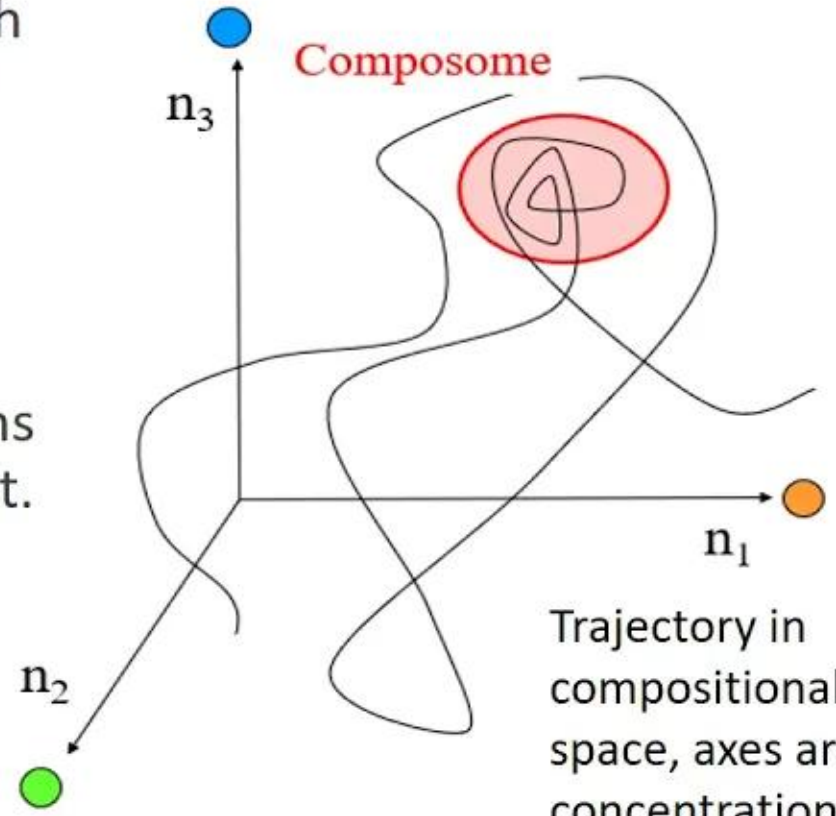
Self-reproduction is rare

- Micellar reproduction dynamics is studied with the GARD model, a rigorous chemistry model with nature-like parameters.
- Composome – a rare compositional state in which the assembly is able to self-reproduce.
- Despite their low probability, GARD simulations tend to reach composome states relatively fast.
- We performed new analyses and formally proved that composomes are dynamic attractors.



Trajectory in compositional space, axes are concentrations

Lancet, D., Zidovetzki, R., & Markovitch, O. (2018), "Systems protobiology: origin of life in lipid catalytic networks", *Journal of The Royal Society Interface*.

1
00:00:05,269 --> 00:00:02,950
hi my name is amit kahana and i'm a

2
00:00:07,190 --> 00:00:05,279
student of professor doran lancet

3
00:00:08,390 --> 00:00:07,200
from the weizmann institute of science

4
00:00:10,150 --> 00:00:08,400
in israel

5
00:00:11,830 --> 00:00:10,160
and today i'd like to talk to you about

6
00:00:14,230 --> 00:00:11,840
compositional attractors

7
00:00:16,710 --> 00:00:14,240
and why we think they are so important

8
00:00:19,990 --> 00:00:16,720
for the study of the origin of life

9
00:00:22,550 --> 00:00:20,000
we in the lancet group approach

10
00:00:23,269 --> 00:00:22,560
the origin of life from a systems

11
00:00:26,710 --> 00:00:23,279
chemistry

12
00:00:29,750 --> 00:00:26,720
perspective and specifically we believe

13
00:00:31,509 --> 00:00:29,760

in the lipid first scenario

14
00:00:33,270 --> 00:00:31,519
a scenario that we have developed and

15
00:00:35,990 --> 00:00:33,280
promoted over the years

16
00:00:37,430 --> 00:00:36,000
and so i'd like to first start by

17
00:00:40,069 --> 00:00:37,440
describing it to you

18
00:00:40,549 --> 00:00:40,079
so you'll get the principles of how we

19
00:00:43,590 --> 00:00:40,559
think

20
00:00:46,069 --> 00:00:43,600
life has emerged so

21
00:00:47,190 --> 00:00:46,079
imagine a primordial setting in which we

22
00:00:49,430 --> 00:00:47,200
have lipids

23
00:00:50,470 --> 00:00:49,440
simple amphiphiles of many different

24
00:00:53,510 --> 00:00:50,480
types

25
00:00:55,430 --> 00:00:53,520
that can spontaneously self-assemble to

26
00:00:58,229 --> 00:00:55,440
generate micelles

27
00:01:00,790 --> 00:00:58,239
nanoscopic lipid assemblies of many many

28
00:01:03,110 --> 00:01:00,800
different compositions

29
00:01:04,229 --> 00:01:03,120
some assemblies would have unique

30
00:01:07,429 --> 00:01:04,239
compositions

31
00:01:09,990 --> 00:01:07,439
that could be preserved over time

32
00:01:10,950 --> 00:01:10,000
this is due to the mutually catalytic

33
00:01:13,990 --> 00:01:10,960
interactions

34
00:01:17,590 --> 00:01:14,000
between constituent lipids

35
00:01:23,030 --> 00:01:17,600
and the composition would be

36
00:01:26,149 --> 00:01:23,040
retained overgrowth and split events

37
00:01:28,230 --> 00:01:26,159
from which progeny is generated with

38
00:01:31,190 --> 00:01:28,240

some compositional mutations

39
00:01:33,109 --> 00:01:31,200
that underlie selection and further

40
00:01:34,870 --> 00:01:33,119
evolution

41
00:01:37,109 --> 00:01:34,880
now this cycle of compositional

42
00:01:39,429 --> 00:01:37,119
reproduction can be repeated

43
00:01:41,830 --> 00:01:39,439
again and again and down the road it

44
00:01:44,149 --> 00:01:41,840
will produce more elaborate protocells

45
00:01:45,190 --> 00:01:44,159
such as the consensual model of a

46
00:01:48,630 --> 00:01:45,200
protocell that we

47
00:01:51,830 --> 00:01:48,640
in the community adhere to

48
00:01:52,789 --> 00:01:51,840
and you can read more about uh the

49
00:01:55,030 --> 00:01:52,799
chemistry

50
00:01:56,149 --> 00:01:55,040
and the principles of our models and

51
00:01:58,950 --> 00:01:56,159
scenario

52
00:02:00,310 --> 00:01:58,960
in our papers specifically in our nature

53
00:02:04,230 --> 00:02:00,320
reviews chemistry

54
00:02:06,709 --> 00:02:04,240
that hopefully will be published soon

55
00:02:08,389 --> 00:02:06,719
and what is very interesting to us and

56
00:02:12,309 --> 00:02:08,399
specifically in this project

57
00:02:15,350 --> 00:02:12,319
is the notion of homeostatic growth

58
00:02:19,589 --> 00:02:15,360
what makes a

59
00:02:23,030 --> 00:02:19,599
an assembly retains its composition

60
00:02:25,990 --> 00:02:23,040
overgrowth and split events

61
00:02:26,470 --> 00:02:26,000
this is a crucial aspect of the lipid

62
00:02:30,070 --> 00:02:26,480
first

63
00:02:31,750 --> 00:02:30,080

scenario and this is exactly what we are

64
00:02:34,390 --> 00:02:31,760
researching in the lab

65
00:02:36,550 --> 00:02:34,400
using the guard model a rigorous

66
00:02:38,470 --> 00:02:36,560
chemistry kinetics formalism

67
00:02:40,309 --> 00:02:38,480
that's highly based on nature-like

68
00:02:43,030 --> 00:02:40,319
parameters

69
00:02:44,470 --> 00:02:43,040
what we do is simulate assemblies

70
00:02:47,830 --> 00:02:44,480
starting from

71
00:02:48,390 --> 00:02:47,840
random compositions and just let them

72
00:02:52,630 --> 00:02:48,400
run

73
00:02:55,990 --> 00:02:52,640
and see what emergent properties we find

74
00:02:59,030 --> 00:02:56,000
now curiously these assemblies

75
00:03:02,070 --> 00:02:59,040
reach a composome state

76
00:03:05,110 --> 00:03:02,080
in which they can self-reproduce

77
00:03:07,670 --> 00:03:05,120
very very fast which is

78
00:03:08,309 --> 00:03:07,680
quite strange because these compositions

79
00:03:11,589 --> 00:03:08,319
are very

80
00:03:13,030 --> 00:03:11,599
rare in compositional space and yet the

81
00:03:16,470 --> 00:03:13,040
simulations

82
00:03:18,470 --> 00:03:16,480
again and again reach them very fast

83
00:03:21,670 --> 00:03:18,480
and this has been bothering us for a

84
00:03:25,110 --> 00:03:21,680
while so we performed some new analysis

85
00:03:26,550 --> 00:03:25,120
and formally proved that these composome

86
00:03:29,190 --> 00:03:26,560
states

87
00:03:32,550 --> 00:03:29,200
are actually dynamic attractors in

88
00:03:35,190 --> 00:03:32,560

compositional space

89
00:03:36,390 --> 00:03:35,200
so what are dynamic attractors let's run

90
00:03:39,190 --> 00:03:36,400
through the definition

91
00:03:40,309 --> 00:03:39,200
an attractor is an area or section in

92
00:03:43,589 --> 00:03:40,319
our space

93
00:03:46,229 --> 00:03:43,599
in our example compositional space

94
00:03:48,869 --> 00:03:46,239
towards which a system tends to progress

95
00:03:51,910 --> 00:03:48,879
or evolve

96
00:03:52,949 --> 00:03:51,920
now it means that we can start in many

97
00:03:56,070 --> 00:03:52,959
different

98
00:03:58,550 --> 00:03:56,080
random initial conditions

99
00:04:00,149 --> 00:03:58,560
and no matter where we start from the

100
00:04:04,070 --> 00:04:00,159
system tends to progress

101
00:04:07,350 --> 00:04:04,080
and reach the basin of attraction

102
00:04:08,309 --> 00:04:07,360
and that once it is within the basin of

103
00:04:12,550 --> 00:04:08,319
attraction

104
00:04:16,629 --> 00:04:12,560
it is less susceptible to perturbations

105
00:04:21,749 --> 00:04:16,639
which means that it tends to not escape

106
00:04:29,670 --> 00:04:25,830
so we come to the question are composums

107
00:04:31,909 --> 00:04:29,680
dynamic attractors as it turns out

108
00:04:33,830 --> 00:04:31,919
they are and this is an analysis that

109
00:04:36,870 --> 00:04:33,840
can illustrate that

110
00:04:37,909 --> 00:04:36,880
this is a phase diagram a visualization

111
00:04:41,430 --> 00:04:37,919
that scientists

112
00:04:45,189 --> 00:04:41,440
use to portray attraction

113
00:04:46,870 --> 00:04:45,199

and it depicts one simulation run

114
00:04:48,390 --> 00:04:46,880
the different colors here are the

115
00:04:51,510 --> 00:04:48,400
different generations

116
00:04:52,950 --> 00:04:51,520
the micelle grow and divide and upon

117
00:04:55,430 --> 00:04:52,960
each division event

118
00:04:56,790 --> 00:04:55,440
a new generation begins so you can

119
00:04:59,270 --> 00:04:56,800
follow the

120
00:05:02,070 --> 00:04:59,280
entire trajectory of the micellar

121
00:05:08,629 --> 00:05:05,270
now the axes are similarity measures

122
00:05:10,790 --> 00:05:08,639
the y-axis is a measure of similarity

123
00:05:13,990 --> 00:05:10,800
between the current composition

124
00:05:17,029 --> 00:05:14,000
of the assembly and its flux which

125
00:05:19,830 --> 00:05:17,039
influences the the next

126
00:05:21,590 --> 00:05:19,840
move of the assembly in compositional

127
00:05:24,550 --> 00:05:21,600
space

128
00:05:25,590 --> 00:05:24,560
for us this is a temporal compositional

129
00:05:27,430 --> 00:05:25,600
stability

130
00:05:28,629 --> 00:05:27,440
measure because the higher the

131
00:05:30,469 --> 00:05:28,639
similarity the more

132
00:05:33,110 --> 00:05:30,479
the assembly tends to preserve its

133
00:05:35,830 --> 00:05:33,120
composition

134
00:05:36,790 --> 00:05:35,840
now the x-axis is a similarity measure

135
00:05:39,430 --> 00:05:36,800
between

136
00:05:40,870 --> 00:05:39,440
the current composition of the assembly

137
00:05:44,230 --> 00:05:40,880
and the combo type

138
00:05:45,110 --> 00:05:44,240

the exact composition at which uh the

139
00:05:47,590 --> 00:05:45,120
assembly

140
00:05:49,270 --> 00:05:47,600
attains self-reproduction capacity and

141
00:05:52,469 --> 00:05:49,280
this is why we treat it

142
00:05:55,590 --> 00:05:52,479
as a reproduction capacity measure

143
00:05:58,390 --> 00:05:55,600
so you can see how the assembly starts

144
00:06:01,909 --> 00:05:58,400
at a random place

145
00:06:04,230 --> 00:06:01,919
goes to a

146
00:06:06,070 --> 00:06:04,240
place where it attains a high temporal

147
00:06:08,390 --> 00:06:06,080
compositional stability

148
00:06:10,150 --> 00:06:08,400
for a few generations before it escapes

149
00:06:13,350 --> 00:06:10,160
from that small haven

150
00:06:15,749 --> 00:06:13,360
and then rapidly

151
00:06:19,350 --> 00:06:15,759
merge with the compo type at the top

152
00:06:22,870 --> 00:06:19,360
right corner of the phase diagram

153
00:06:24,150 --> 00:06:22,880
now interestingly this pattern is highly

154
00:06:27,510 --> 00:06:24,160
reproducible

155
00:06:30,870 --> 00:06:27,520
you can see it in many many runs of our

156
00:06:34,629 --> 00:06:30,880
guard simulations

157
00:06:36,390 --> 00:06:34,639
so here for example we have 20 such runs

158
00:06:38,629 --> 00:06:36,400
and again you can see how they start in

159
00:06:39,350 --> 00:06:38,639
different random places in compositional

160
00:06:42,790 --> 00:06:39,360
space

161
00:06:46,550 --> 00:06:42,800
compositions

162
00:06:49,749 --> 00:06:46,560
um stay for a bit at different places

163
00:06:52,309 --> 00:06:49,759

but then quickly coalesce

164
00:06:53,189 --> 00:06:52,319
towards the top right corner where the

165
00:06:57,110 --> 00:06:53,199
combo type

166
00:06:58,790 --> 00:06:57,120
lies in a team's composable state

167
00:07:00,390 --> 00:06:58,800
and this is a major dynamic attractor

168
00:07:04,950 --> 00:07:00,400
you can see how all

169
00:07:07,430 --> 00:07:04,960
the runs just rapidly

170
00:07:08,629 --> 00:07:07,440
go towards that corner and even when

171
00:07:10,550 --> 00:07:08,639
they reach there

172
00:07:11,830 --> 00:07:10,560
there's still fluctuations there's still

173
00:07:15,510 --> 00:07:11,840
a place for high

174
00:07:17,909 --> 00:07:15,520
variation in the composition but

175
00:07:19,430 --> 00:07:17,919
the compositions are still within the

176
00:07:21,270 --> 00:07:19,440
basin of attraction

177
00:07:22,950 --> 00:07:21,280
so no matter how much they fluctuate

178
00:07:29,029 --> 00:07:22,960
they still

179
00:07:35,430 --> 00:07:32,150
so you may ask why do we care

180
00:07:38,309 --> 00:07:35,440
about the tractors and the answer is

181
00:07:41,589 --> 00:07:38,319
that attractors have many advantages

182
00:07:44,550 --> 00:07:41,599
specifically for the origin of life

183
00:07:45,909 --> 00:07:44,560
first and foremost dynamic detractors

184
00:07:49,189 --> 00:07:45,919
allow

185
00:07:52,230 --> 00:07:49,199
assemblies of different

186
00:07:52,869 --> 00:07:52,240
random initial compositions to fastly

187
00:07:55,990 --> 00:07:52,879
reach

188
00:07:59,430 --> 00:07:56,000

a surf reproduction state

189
00:08:02,950 --> 00:07:59,440
in other words self-reproduction

190
00:08:06,629 --> 00:08:02,960
is attractive to chemical systems

191
00:08:09,830 --> 00:08:06,639
this is important because it means that

192
00:08:10,950 --> 00:08:09,840
the emergence of lives becomes much more

193
00:08:17,270 --> 00:08:10,960
probable

194
00:08:21,749 --> 00:08:19,830
attractors also assist the assemblies to

195
00:08:23,110 --> 00:08:21,759
reach self-reproduction in the face of

196
00:08:26,150 --> 00:08:23,120
the many challenges

197
00:08:28,469 --> 00:08:26,160
that come with a probiotic setting

198
00:08:29,909 --> 00:08:28,479
among them the high environmental

199
00:08:32,949 --> 00:08:29,919
molecular diversity

200
00:08:36,469 --> 00:08:32,959
of the different lipids that surrounding

201
00:08:38,870 --> 00:08:36,479
the assemblies the uneven

202
00:08:41,190 --> 00:08:38,880
or fluctuating concentrations of these

203
00:08:44,389 --> 00:08:41,200
lipids

204
00:08:47,110 --> 00:08:44,399
and the varied levels of catalysis high

205
00:08:49,110 --> 00:08:47,120
catalysis locators and anything in

206
00:08:51,030 --> 00:08:49,120
between

207
00:08:54,949 --> 00:08:51,040
these are parameters that we are

208
00:08:58,150 --> 00:08:54,959
exploring in our project currently

209
00:09:00,389 --> 00:08:58,160
and a more theoretical thought we see

210
00:09:03,910 --> 00:09:00,399
systems in which there are

211
00:09:05,509 --> 00:09:03,920
many combo types not only one

212
00:09:07,269 --> 00:09:05,519
and that we see transitions between

213
00:09:09,750 --> 00:09:07,279

compotypes

214
00:09:10,790 --> 00:09:09,760
and these transitions are governed by

215
00:09:14,070 --> 00:09:10,800
the attraction

216
00:09:16,949 --> 00:09:14,080
of each of the compotype state

217
00:09:17,910 --> 00:09:16,959
and so we can describe the evolutionary

218
00:09:19,750 --> 00:09:17,920
routes

219
00:09:21,670 --> 00:09:19,760
the transition between the combo types

220
00:09:21,990 --> 00:09:21,680
based on their attraction which i think

221
00:09:27,509 --> 00:09:22,000
is

222
00:09:29,590 --> 00:09:27,519
conclusions and take-home messages

223
00:09:31,590 --> 00:09:29,600
about the project and about why i think

224
00:09:34,230 --> 00:09:31,600
attractors are cool and are important

225
00:09:37,110 --> 00:09:34,240
for the study of the origin of life

226
00:09:37,990 --> 00:09:37,120
so first we discovered that mixed

227
00:09:39,750 --> 00:09:38,000
micelles

228
00:09:41,590 --> 00:09:39,760
can self-reproduce and that their

229
00:09:45,430 --> 00:09:41,600
self-reproduction state

230
00:09:47,269 --> 00:09:45,440
is a dynamic attractor this means and i

231
00:09:49,990 --> 00:09:47,279
will iterate this point

232
00:09:52,230 --> 00:09:50,000
that self-reproduction is attractive to

233
00:09:54,630 --> 00:09:52,240
chemical systems

234
00:09:56,630 --> 00:09:54,640
we further explored and found that the

235
00:09:58,470 --> 00:09:56,640
attraction stems from the inherent

236
00:10:00,550 --> 00:09:58,480
mutually catalytic interactions

237
00:10:02,550 --> 00:10:00,560
between the constituent lipids of the

238
00:10:05,750 --> 00:10:02,560

assemblies the different

239
00:10:08,310 --> 00:10:05,760
simple molecules in the system and that

240
00:10:10,230 --> 00:10:08,320
the attraction towards self-reproduction

241
00:10:11,910 --> 00:10:10,240
actually helps to mitigate the

242
00:10:13,990 --> 00:10:11,920
challenges of existing

243
00:10:16,829 --> 00:10:14,000
in a probiotic setting as i have

244
00:10:20,949 --> 00:10:19,030
additionally for assemblies that exist

245
00:10:22,790 --> 00:10:20,959
within the basin of attraction

246
00:10:24,949 --> 00:10:22,800
there's still room for compositional

247
00:10:26,710 --> 00:10:24,959
variation and optimization as we've seen

248
00:10:29,670 --> 00:10:26,720
in the phase diagrams

249
00:10:31,990 --> 00:10:29,680
and this is necessary for selection and

250
00:10:33,670 --> 00:10:32,000
further evolution towards life as we

251
00:10:36,550 --> 00:10:33,680
know it

252
00:10:37,750 --> 00:10:36,560
and perhaps the most important point

253
00:10:40,630 --> 00:10:37,760
attractors

254
00:10:41,910 --> 00:10:40,640
as a notion could help us explore

255
00:10:44,949 --> 00:10:41,920
chemical space

256
00:10:46,630 --> 00:10:44,959
to find the roots of the origin of life

257
00:10:49,590 --> 00:10:46,640
we don't need to look for specific

258
00:10:51,350 --> 00:10:49,600
molecules or even specific compositions

259
00:10:53,910 --> 00:10:51,360
we need to generate different

260
00:10:57,750 --> 00:10:53,920
compositions in different environments

261
00:11:00,949 --> 00:10:57,760
and see toward what states the systems

262
00:11:02,790 --> 00:11:00,959
tend to evolve and this would really

263
00:11:04,949 --> 00:11:02,800

help us define the attractors

264
00:11:06,550 --> 00:11:04,959
and define the states in which systems

265
00:11:08,470 --> 00:11:06,560
can self-reproduce

266
00:11:10,389 --> 00:11:08,480
and this is why i think attractors are

267
00:11:11,430 --> 00:11:10,399
so so important not only to understand

268
00:11:16,069 --> 00:11:11,440
the origin of life

269
00:11:18,230 --> 00:11:16,079
but also to search and explore it

270
00:11:19,750 --> 00:11:18,240
i quickly want to thank my mentor

271
00:11:21,990 --> 00:11:19,760
professor dawn lansette our

272
00:11:24,069 --> 00:11:22,000
collaborators in this project

273
00:11:25,030 --> 00:11:24,079
here is my email you can contact me with

274
00:11:27,590 --> 00:11:25,040
any question

275
00:11:28,790 --> 00:11:27,600
or comment or just speak to me during

276
00:11:31,269 --> 00:11:28,800
this conference

277
00:11:32,870 --> 00:11:31,279
and read our papers engage with our

278
00:11:35,350 --> 00:11:32,880
science