1
00:00:00,329 --> 00:00:02,912
(gentle music)

2
00:00:09,450 --> 00:00:12,560
- Hi, and welcome to
Conversations at the Perimeter.

3
00:00:12,560 --> 00:00:14,340
Today, Colin and I are excited

4
00:00:14,340 --> 00:00:17,350
to share with you our
conversation with Tim Shay.

5
00:00:17,350 --> 00:00:19,550
Tim is a research faculty member here

6
00:00:19,550 --> 00:00:22,130
at Perimeter Institute to
for Theoretical Physics.

7
00:00:22,130 --> 00:00:25,060
And his work is at the
intersection of quantum information

8
00:00:25,060 --> 00:00:26,290
and quantum matter.

9
00:00:26,290 --> 00:00:28,610
- And it was such a fascinating
conversation to have

10
00:00:28,610 --> 00:00:31,460
with Tim 'cause we talked
not only about quantum matter

11
00:00:31,460 --> 00:00:32,293
and quantum science,

12
00:00:32,293 --> 00:00:33,740
but we talked about his childhood,

13
00:00:33,740 --> 00:00:35,320
growing up in Los Angeles,

14
00:00:35,320 --> 00:00:37,520
and competing in the physics Olympiad

15
00:00:37,520 --> 00:00:40,210
and coming to Perimeter
Institute as a teenager

16
00:00:40,210 --> 00:00:42,860
for the International Summer
School for Young Physicists.

17
00:00:42,860 --> 00:00:45,110
And we also got into his newest adventure,

18
00:00:45,110 --> 00:00:46,010
which is fatherhood.

19
00:00:46,010 --> 00:00:48,840
So it was a fascinating
conversation about science,

20
00:00:48,840 --> 00:00:50,120
life, and just about everything.

21
00:00:50,120 --> 00:00:52,400
- I know, you're all gonna
enjoy this conversation.

22
00:00:52,400 --> 00:00:55,170
Let's step inside the perimeter.

23
00:00:55,170 --> 00:00:58,100

Tim, thanks so much for joining us today.

24
00:00:58,100 --> 00:00:59,950
- Yeah, sure, my pleasure.

25
00:00:59,950 --> 00:01:02,470
- So I wanted to start by
asking you a little bit about

26
00:01:02,470 --> 00:01:04,440
the area you work in, in your research.

27
00:01:04,440 --> 00:01:06,050
I was reading that your work

28
00:01:06,050 --> 00:01:08,760
is at the intersection
of quantum information

29
00:01:08,760 --> 00:01:10,190
and condensed matter.

30
00:01:10,190 --> 00:01:13,477
So I'm curious what draws you
to that specific intersection

31
00:01:13,477 --> 00:01:16,580
and why you like to
combine those two fields?

32
00:01:16,580 --> 00:01:18,310
- Basically I'm most
interested in what happens

33
00:01:18,310 --> 00:01:21,046
when you have, like many
quantum degrees of freedom

34
00:01:21,046 --> 00:01:24,200

that are all kind of
interacting with each other

35
00:01:24,200 --> 00:01:26,530
and what type of new phenomenon can arise

36
00:01:26,530 --> 00:01:28,520
from such a big system?

37
00:01:28,520 --> 00:01:29,860
You know, it's kind of different

38
00:01:29,860 --> 00:01:31,670
from the usual philosophy of physics,

39
00:01:31,670 --> 00:01:34,890
which has basically been like
a reductionist philosophy

40
00:01:34,890 --> 00:01:37,440
where we start with the big
universe as a whole, right?

41
00:01:37,440 --> 00:01:40,260
And then we try to break it down into

42
00:01:40,260 --> 00:01:44,290
smaller building blocks,
like our atoms into

43
00:01:44,290 --> 00:01:48,010
electrons, protons, neutrons,
and then even smaller pieces.

44
00:01:48,010 --> 00:01:50,840
You know, that has had
crazy amount of success

45
00:01:50,840 --> 00:01:52,550

culminating in the standard model.

46
00:01:52,550 --> 00:01:55,430
But this other philosophy
of looking at this

47
00:01:55,430 --> 00:01:58,830
emergent approach of
physics is kind of like

48
00:01:58,830 --> 00:01:59,663
the other way around.

49
00:01:59,663 --> 00:02:02,660
Like we know the basic building blocks,

50
00:02:02,660 --> 00:02:04,530
let's say we have some electrons.

51
00:02:04,530 --> 00:02:06,630
And then now the question is not trying to

52
00:02:06,630 --> 00:02:09,390
reduce it further, but trying
to put them all together

53
00:02:09,390 --> 00:02:11,660
and see what types of
new physics can arise

54
00:02:11,660 --> 00:02:12,870
from this collection.

55
00:02:12,870 --> 00:02:16,380
Not reducing, but building
up from the bottom up.

56
00:02:16,380 --> 00:02:18,300
- A colleague of mine

wrote an article about you.

57
00:02:18,300 --> 00:02:21,060
And she said it was like
a quantum form of Legos.

58
00:02:21,060 --> 00:02:21,980
- Yeah, yeah, exactly.

59
00:02:21,980 --> 00:02:23,180
- That metaphor that we're starting

60
00:02:23,180 --> 00:02:25,560
with individual building
blocks and then seeing

61
00:02:25,560 --> 00:02:27,280
what we can build out of it.

62
00:02:27,280 --> 00:02:28,880
- Yeah, yeah, that's right.

63
00:02:28,880 --> 00:02:31,200
- I have to ask, were you a Lego kid?

64
00:02:31,200 --> 00:02:33,570
- I was, I was a big Lego fan.

65
00:02:33,570 --> 00:02:35,540
- Were you building complex objects

66
00:02:35,540 --> 00:02:37,790
out of simple building blocks even then?

67
00:02:37,790 --> 00:02:40,310
- I was most definitely
throwing away the manuals

68

00:02:40,310 --> 00:02:43,630
and just trying to do things myself.

69
00:02:43,630 --> 00:02:46,990
That's indeed what draws me
to this approach to physics,

70
00:02:46,990 --> 00:02:51,070
because it really allows you
a lot of freedom of creativity

71
00:02:51,070 --> 00:02:53,930
to try to engineer all
sorts of new phenomenon

72
00:02:53,930 --> 00:02:55,500
that you would never have expected

73
00:02:55,500 --> 00:02:58,070
just by looking at each
piece individually.

74
00:02:58,070 --> 00:03:00,090
- How does quantum
computing factor into this

75
00:03:00,090 --> 00:03:01,403
or quantum information?

76
00:03:02,270 --> 00:03:04,660
- So quantum computing you can think of as

77
00:03:04,660 --> 00:03:07,210
a large collection of
these degrees of freedom

78
00:03:07,210 --> 00:03:10,500
called cubits, which you
can realize physically

79
00:03:10,500 --> 00:03:12,040
in many different ways.

80
00:03:12,040 --> 00:03:15,440
So a quantum computer
would be an example of

81
00:03:15,440 --> 00:03:19,280
such a big collection of
quantum degrees of freedom

82
00:03:19,280 --> 00:03:23,580
that we are manipulating in a
way to perform useful things.

83
00:03:23,580 --> 00:03:27,290
A quantum computer, you can
think of it as a particularly

84
00:03:27,290 --> 00:03:29,970
useful phenomenon emerging from this

85
00:03:29,970 --> 00:03:32,740
large collection of quantum particles.

86
00:03:32,740 --> 00:03:36,890
- Are you also interested in
some not so useful products?

87
00:03:36,890 --> 00:03:39,120
- Yeah, it depends on what
do you mean by useful.

88
00:03:39,120 --> 00:03:40,790
And as a physicist to me,

89
00:03:40,790 --> 00:03:43,960
one of the most appealing
applications of quantum computers

90
00:03:43,960 --> 00:03:46,760
is to simulate quantum systems

91
00:03:46,760 --> 00:03:48,280
that if we didn't have a quantum computer,

92
00:03:48,280 --> 00:03:49,750
it would be hard to simulate.

93
00:03:49,750 --> 00:03:51,810
So basically using our
classical computers,

94
00:03:51,810 --> 00:03:53,790
we would struggle with understanding.

95
00:03:53,790 --> 00:03:56,320
There are a lot of intractable models

96
00:03:56,320 --> 00:03:58,470
that we run into problems
either with pen and paper

97
00:03:58,470 --> 00:04:00,770
or with our current computers.

98
00:04:00,770 --> 00:04:02,610
However, if you had a quantum computer,

99
00:04:02,610 --> 00:04:06,390
you would be able to simulate
these intractable models,

100
00:04:06,390 --> 00:04:08,270
do measurements on your quantum computer

101
00:04:08,270 --> 00:04:11,830

to read out answers that you
would not have access to.

102
00:04:11,830 --> 00:04:15,760
So it's that type of not
so practically useful

103
00:04:15,760 --> 00:04:19,600
on a day to day basis, but as
a physicist, very meaningful.

104
00:04:19,600 --> 00:04:20,433
- And I guess of course,

105
00:04:20,433 --> 00:04:22,350
if something is not useful immediately,

106
00:04:22,350 --> 00:04:24,923
it doesn't mean that it
couldn't be useful some-

107
00:04:24,923 --> 00:04:26,088
- That's right, that's right.

108
00:04:26,088 --> 00:04:27,593
- It could be useful.
- Yeah.

109
00:04:27,593 --> 00:04:30,110
- Another question I have
'cause you started talking about

110
00:04:30,110 --> 00:04:33,920
simulation and can you help
us understand that word?

111
00:04:33,920 --> 00:04:35,620
And also maybe what's the difference

112

00:04:35,620 --> 00:04:38,453
between a quantum computer
and a quantum simulator.

113
00:04:39,437 --> 00:04:43,710
- A quantum computer is kind
of a all purpose device,

114
00:04:43,710 --> 00:04:46,120
So the idea is that you
have some quantum particles

115
00:04:46,120 --> 00:04:48,180
that you can carry out operations on

116
00:04:48,180 --> 00:04:51,160
and you can carry out like
a arbitrary operation.

117
00:04:51,160 --> 00:04:54,090
It's kind of like our
current classical computers.

118
00:04:54,090 --> 00:04:56,520
You can pretty much
carry out any algorithm

119
00:04:56,520 --> 00:04:58,640
you want on your current computer.

120
00:04:58,640 --> 00:05:00,840
However, a quantum simulator,

121
00:05:00,840 --> 00:05:03,680
maybe you can think of as
a more restricted version

122
00:05:03,680 --> 00:05:04,513
of a quantum computer,

123
00:05:04,513 --> 00:05:08,090
where you don't have full access
to all possible operations,

124
00:05:08,090 --> 00:05:09,440
maybe only a subset,

125
00:05:09,440 --> 00:05:13,670
but that subset of operations
may still be something beyond

126
00:05:13,670 --> 00:05:16,300
the current reach of classical computers.

127
00:05:16,300 --> 00:05:17,960
For example, in condensed matter,

128
00:05:17,960 --> 00:05:20,110
there are these famously
hard models to solve

129
00:05:20,110 --> 00:05:21,480
like a Hubbard model,

130
00:05:21,480 --> 00:05:23,090
which is supposed to just the phenomenon

131
00:05:23,090 --> 00:05:24,790
of high temperature superconductivity.

132
00:05:24,790 --> 00:05:27,690
these particular models
that can be implemented

133
00:05:27,690 --> 00:05:29,690
in quantum simulators.

134
00:05:29,690 --> 00:05:31,720

These simulators cannot do everything,

135
00:05:31,720 --> 00:05:34,520
but they may be able to
implement specific models

136
00:05:34,520 --> 00:05:35,970
that we can still learn from.

137
00:05:36,900 --> 00:05:39,460
- You mentioned just now high
temperature superconductivity.

138
00:05:39,460 --> 00:05:42,047
I hear that mentioned a
lot around quantum matter

139
00:05:42,047 --> 00:05:43,100
and quantum materials.

140
00:05:43,100 --> 00:05:44,700
Could you explain a bit about what that is

141
00:05:44,700 --> 00:05:47,680
and why it's a goal that we're chasing.

142
00:05:47,680 --> 00:05:51,070
- Superconductivity is a
very well known phenomenon

143
00:05:51,070 --> 00:05:52,300
in condensed matter physics.

144
00:05:52,300 --> 00:05:55,020
It dates all the way
back to, I think 1911,

145
00:05:55,020 --> 00:05:57,420
it's a fascinating

phenomenon to which basically

146
00:05:57,420 --> 00:06:00,740
the resistivity of the
material drops to zero

147
00:06:00,740 --> 00:06:02,390
below like a certain temperature.

148
00:06:02,390 --> 00:06:04,063
- Is that a resistance in terms of like

149
00:06:04,063 --> 00:06:05,770
carrying electrical current?

150
00:06:05,770 --> 00:06:07,390
- Yeah, that's right, that's right.

151
00:06:07,390 --> 00:06:10,760
So you could pass current
through this superconductor

152
00:06:10,760 --> 00:06:13,930
without any dissipation,
without any like energy loss.

153
00:06:13,930 --> 00:06:17,290
- Without a superconductor,
much, much energy is lost.

154
00:06:17,290 --> 00:06:18,123
- That's right.

155
00:06:18,123 --> 00:06:20,290
So, you know, like when
we pass current through

156
00:06:20,290 --> 00:06:23,820
typical metals that, you

know, are not superconducting,

157
00:06:23,820 --> 00:06:25,090
there's heat loss,

158
00:06:25,090 --> 00:06:29,480
and that's a major problem
for like energy transport.

159
00:06:29,480 --> 00:06:31,960
- Superconductivity is possible,

160
00:06:31,960 --> 00:06:33,550
but at super low temperatures.

161
00:06:33,550 --> 00:06:37,420
- Exactly, so they're actually
not super low at this point,

162
00:06:37,420 --> 00:06:39,130
they've gotten higher and higher

163
00:06:39,130 --> 00:06:41,180
as the years has progressed,

164
00:06:41,180 --> 00:06:44,760
but they're still relatively
low on everyday human scales.

165
00:06:44,760 --> 00:06:48,240
They're on the order of
several Kelvin, usually.

166
00:06:48,240 --> 00:06:49,400
- That seems extremely low.

167
00:06:49,400 --> 00:06:50,233
- That's right, but-

168
00:06:50,233 --> 00:06:51,970
- But this is the difference
between everyday scales.

169
00:06:51,970 --> 00:06:53,307
- Yeah, yeah, exactly, right.

170
00:06:53,307 --> 00:06:56,990
And so the holy grails to
have like a room temperature

171
00:06:56,990 --> 00:07:00,060
superconductor, where you
wouldn't have to bring in

172
00:07:00,060 --> 00:07:02,610
a doer of liquid helium to cool down.

173
00:07:02,610 --> 00:07:04,980
You could just operate that
at ambient environment,

174
00:07:04,980 --> 00:07:07,220
and that would clearly be very useful.

175
00:07:07,220 --> 00:07:09,720
- It'd be useful for energy transmission?

176
00:07:09,720 --> 00:07:10,553
- Yes.

177
00:07:10,553 --> 00:07:12,330
- I've seen the
superconducting levitating.

178
00:07:12,330 --> 00:07:14,480
- Yeah, the maglev trains.
- Right.

179
00:07:14,480 --> 00:07:15,780
They use it super cooled?

180
00:07:15,780 --> 00:07:19,217
- Presumably the temperature
they need is still pretty low.

181
00:07:19,217 --> 00:07:21,010
- Why is it such a challenge

182
00:07:21,010 --> 00:07:24,223
to achieve superconductivity
at higher temperatures?

183
00:07:25,100 --> 00:07:28,010
- I don't think there's
any like known recipe

184
00:07:28,010 --> 00:07:31,470
at making this critical
temperature higher and higher.

185
00:07:31,470 --> 00:07:34,020
Like it's a very complex phenomenon.

186
00:07:34,020 --> 00:07:36,220
The models of superconductors

187
00:07:36,220 --> 00:07:39,320
with relatively high temperature,
people can write it down,

188
00:07:39,320 --> 00:07:42,430
but making analytical or
even numerical progress on it

189
00:07:42,430 --> 00:07:43,700
is hard, right.

190
00:07:43,700 --> 00:07:45,640
So if we can't really tackle the models,

191
00:07:45,640 --> 00:07:48,110
it's hard to understand
why certain materials

192
00:07:48,110 --> 00:07:49,810
have higher TC than others.

193
00:07:49,810 --> 00:07:52,627
And so it's hard to engineer higher TC.

194
00:07:52,627 --> 00:07:54,530
- You said that it's sort of a holy grail.

195
00:07:54,530 --> 00:07:58,560
That the technological
offshoots of high temperature

196
00:07:58,560 --> 00:08:01,520
superconductivity could yeah,
have all sorts of effects

197
00:08:01,520 --> 00:08:02,870
in practical life.

198
00:08:02,870 --> 00:08:05,630
What about it in your
specific research area?

199
00:08:05,630 --> 00:08:07,430
What are the specific challenges

200
00:08:07,430 --> 00:08:10,530
that you are tackling in quantum matter?

201
00:08:10,530 --> 00:08:13,040

- I've been very interested
in this feedback loop

202
00:08:13,040 --> 00:08:14,690
between quantum materials,

203
00:08:14,690 --> 00:08:18,550
which might be useful for
building quantum computers

204
00:08:18,550 --> 00:08:20,400
and then using quantum computers

205
00:08:20,400 --> 00:08:23,240
to understand those
quantum materials better.

206
00:08:23,240 --> 00:08:26,090
You may think of it as a bit
of a chicken and egg problem.

207
00:08:26,090 --> 00:08:27,270
But the hope is that, you know,

208
00:08:27,270 --> 00:08:30,210
some quantum computers might not require

209
00:08:30,210 --> 00:08:32,000
such quantum materials to build.

210
00:08:32,000 --> 00:08:33,570
Like there are many different approaches

211
00:08:33,570 --> 00:08:34,810
at building quantum computers.

212
00:08:34,810 --> 00:08:38,460
And so then given, you know,
a functional quantum computer,

213
00:08:38,460 --> 00:08:39,920
like what can we do with it

214
00:08:39,920 --> 00:08:42,560
to learn more about
these quantum materials

215
00:08:42,560 --> 00:08:44,340
that we have trouble understanding.

216
00:08:44,340 --> 00:08:46,430
I'm interested in both directions, right?

217
00:08:46,430 --> 00:08:49,390
Like how can we leverage
existing quantum matter

218
00:08:49,390 --> 00:08:50,400
to build these things,

219
00:08:50,400 --> 00:08:53,850
and how to do interesting things
on these quantum computers

220
00:08:53,850 --> 00:08:55,110
to learn about quantum matter.

221
00:08:55,110 --> 00:08:58,183
- And I think a lot of
people can find it confusing

222
00:08:58,183 --> 00:09:00,469
when we start talking
about quantum computing

223
00:09:00,469 --> 00:09:03,127
or quantum simulations,
because for certain things,

224
00:09:03,127 --> 00:09:06,430
we actually need to
have a quantum computer,

225
00:09:06,430 --> 00:09:09,470
but then there are some
properties of quantum systems

226
00:09:09,470 --> 00:09:12,580
we can actually study
on a classical computer.

227
00:09:12,580 --> 00:09:13,413
- Yeah, indeed.

228
00:09:13,413 --> 00:09:16,830
It turns out that for some
approaches of quantum computing,

229
00:09:16,830 --> 00:09:17,930
there are some operations

230
00:09:17,930 --> 00:09:20,810
that are relatively easy to carry out.

231
00:09:20,810 --> 00:09:23,420
However, it turns out
that one can simulate

232
00:09:23,420 --> 00:09:27,490
those operations on a regular
classical computer already.

233
00:09:27,490 --> 00:09:28,950
That's why it's so important.

234
00:09:28,950 --> 00:09:31,860
It's so important for the

field to establish the notion

235
00:09:31,860 --> 00:09:33,720
of quantum advantage,

236
00:09:33,720 --> 00:09:37,390
where a quantum computer
can do something, you know,

237
00:09:37,390 --> 00:09:40,160
beyond the capabilities
of a classical computer.

238
00:09:40,160 --> 00:09:42,760
But this is a very subtle question

239
00:09:42,760 --> 00:09:45,470
because we don't know for
sure some of the boundaries

240
00:09:45,470 --> 00:09:47,890
of classical computing itself.

241
00:09:47,890 --> 00:09:51,270
Like for example, even like
factoring a large number,

242
00:09:51,270 --> 00:09:53,980
we believe it's a very hard problem

243
00:09:53,980 --> 00:09:55,570
just based on our experience,

244
00:09:55,570 --> 00:09:58,440
like, we don't have any
good classical algorithms

245
00:09:58,440 --> 00:09:59,273
to do that.

246
00:09:59,273 --> 00:10:02,124
But proving that it's really
hard is not that easy either.

247
00:10:02,124 --> 00:10:04,530
- Proving that nobody will ever come up

248
00:10:04,530 --> 00:10:05,440
with a good way of doing that.

249
00:10:05,440 --> 00:10:07,500
- Yeah, that's right, that's right.

250
00:10:07,500 --> 00:10:09,960
So there's this interesting
interplay between,

251
00:10:09,960 --> 00:10:14,720
kind of pushing the boundaries
of our classical approaches.

252
00:10:14,720 --> 00:10:16,090
Yeah, like pushing the boundaries

253
00:10:16,090 --> 00:10:17,150
of our classical approaches

254
00:10:17,150 --> 00:10:20,010
until they reach what a
quantum computer is able to do.

255
00:10:20,010 --> 00:10:22,873
And this boundary is very
mysterious at this moment.

256
00:10:22,873 --> 00:10:25,610
It's not very well defined at the moment.

257
00:10:25,610 --> 00:10:27,700
- Are there some problems,

258
00:10:27,700 --> 00:10:29,300
maybe the boundary is hard to define,

259
00:10:29,300 --> 00:10:30,655
but are there some things that are clearly

260
00:10:30,655 --> 00:10:32,060
on one side or the other?

261
00:10:32,060 --> 00:10:33,720
- Yeah, so as I was saying before,

262
00:10:33,720 --> 00:10:36,620
there are some operations
that are relatively easy to do

263
00:10:36,620 --> 00:10:37,623
on some quantum computers

264
00:10:37,623 --> 00:10:41,500
that we can simulate on
our classical computers.

265
00:10:41,500 --> 00:10:44,180
It turns out that kind of
upgrade these operations

266
00:10:44,180 --> 00:10:48,170
to a fully universal mode in
which the quantum computer

267
00:10:48,170 --> 00:10:49,660
can do everything.

268
00:10:49,660 --> 00:10:50,536

It turns out to do that,

269
00:10:50,536 --> 00:10:53,990
we need this resource called magic,

270
00:10:53,990 --> 00:10:56,491
which is, you know,
actually a technical term

271
00:10:56,491 --> 00:10:58,090
in quantum information.

272
00:10:58,090 --> 00:11:00,660
- I love it, I love that
there's a technical term.

273
00:11:00,660 --> 00:11:02,360
- Who came up with this term?

274
00:11:02,360 --> 00:11:04,520
- Ah, I think originally
it was Sergey Bravyi

275
00:11:04,520 --> 00:11:05,440
and Alexei Kitaev.

276
00:11:05,440 --> 00:11:07,230
You can think of it as like a resource,

277
00:11:07,230 --> 00:11:10,190
so some special quantum states

278
00:11:10,190 --> 00:11:13,150
that if your quantum
computer has access to,

279
00:11:13,150 --> 00:11:16,010
then it can really do everything.

280
00:11:16,010 --> 00:11:17,740
You can carry out operations like

281
00:11:17,740 --> 00:11:20,960
well beyond what our classical
computers can simulate.

282
00:11:20,960 --> 00:11:23,070
- Is this still largely theoretical work

283
00:11:23,070 --> 00:11:26,500
or is it beginning to turn
into technological achievement?

284
00:11:26,500 --> 00:11:28,600
You know, are we building
quantum computers?

285
00:11:28,600 --> 00:11:31,640
You mentioned the example
of factoring large numbers,

286
00:11:31,640 --> 00:11:33,330
that's the example I often hear,

287
00:11:33,330 --> 00:11:35,650
a problem that classical
computers struggle with,

288
00:11:35,650 --> 00:11:37,460
but quantum computers, thanks to,

289
00:11:37,460 --> 00:11:40,080
was it Shor's algorithm
20 something years ago,

290
00:11:40,080 --> 00:11:42,590
that maybe a quantum
computer could do this.

291
00:11:42,590 --> 00:11:45,770
And can you explain
some of those challenges

292
00:11:45,770 --> 00:11:49,000
that we think quantum computers
will be able to tackle

293
00:11:49,000 --> 00:11:50,720
and those that might maybe

294
00:11:50,720 --> 00:11:52,760
in the realm of classical forever?

295
00:11:52,760 --> 00:11:55,660
- The problem I mentioned
of factoring large integers,

296
00:11:55,660 --> 00:11:57,770
that that's one famous example

297
00:11:57,770 --> 00:12:00,020
of what a quantum computer
can do efficiently,

298
00:12:00,020 --> 00:12:03,050
but that a classical computer
can do inefficiently.

299
00:12:03,050 --> 00:12:05,280
I think other examples of, you know,

300
00:12:05,280 --> 00:12:07,570
where we can get a major quantum advantage

301
00:12:07,570 --> 00:12:09,920
are in quantum simulation.

302
00:12:09,920 --> 00:12:13,210
Like looking at the dynamics
of a quantum system,

303
00:12:13,210 --> 00:12:15,810
of like a many body quantum system.

304
00:12:15,810 --> 00:12:18,870
It's typically hard to
simulate such things

305
00:12:18,870 --> 00:12:19,860
on our current computers.

306
00:12:19,860 --> 00:12:21,410
But for quantum simulators,

307
00:12:21,410 --> 00:12:23,660
you just have the thing right there

308
00:12:23,660 --> 00:12:25,140
and you just let it evolve in time.

309
00:12:25,140 --> 00:12:28,300
It itself is the object
of interest, right?

310
00:12:28,300 --> 00:12:31,410
And so you just read out whatever
you want to know about it

311
00:12:31,410 --> 00:12:33,560
from this system itself.

312
00:12:33,560 --> 00:12:36,350
- And so are you working
largely theoretically

313

00:12:36,350 --> 00:12:39,000
and you're working with experimentalists?

314
00:12:39,000 --> 00:12:40,600
how does it work in terms of going

315
00:12:40,600 --> 00:12:45,000
from pure theoretical
ideas to possibly a device?

316
00:12:45,000 --> 00:12:47,810
- I guess what I've been
doing in the past couple years

317
00:12:47,810 --> 00:12:51,621
is proposing some interesting protocols

318
00:12:51,621 --> 00:12:56,290
that can be carried out on
existing quantum computers,

319
00:12:56,290 --> 00:12:59,460
that are in the spirit of
this quantum simulation.

320
00:12:59,460 --> 00:13:02,100
So basically in condensed matter,

321
00:13:02,100 --> 00:13:05,260
we have many interesting states
that we have yet to realize

322
00:13:05,260 --> 00:13:08,590
in actual like solid
state quantum materials.

323
00:13:08,590 --> 00:13:11,180
And yet now with these quantum devices,

324

00:13:11,180 --> 00:13:14,960
you can imagine just building
these states directly,

325
00:13:14,960 --> 00:13:18,670
as opposed to having to find
it in like a piece of rock.

326
00:13:18,670 --> 00:13:22,484
- I hear states, my
layman interpretation is

327
00:13:22,484 --> 00:13:24,400
liquid, solid, gas.

328
00:13:24,400 --> 00:13:26,260
Am I right in thinking that that's just

329
00:13:26,260 --> 00:13:27,300
the tip of the iceberg when you...

330
00:13:27,300 --> 00:13:29,810
- Indeed, that that's a good analogy.

331
00:13:29,810 --> 00:13:31,530
So liquids and solids,

332
00:13:31,530 --> 00:13:34,710
these are examples of
classical phases of matter.

333
00:13:34,710 --> 00:13:37,870
You can think of them as
states that are robust

334
00:13:37,870 --> 00:13:40,150
to some imperfections, right?

335
00:13:40,150 --> 00:13:42,150

So for example, like a solid,

336
00:13:42,150 --> 00:13:44,280
if you tune the temperature a little bit,

337
00:13:44,280 --> 00:13:45,410
it's still a solid.

338
00:13:45,410 --> 00:13:46,530
Or a liquid or gas,

339
00:13:46,530 --> 00:13:47,730
if you tune the temperature a little bit,

340
00:13:47,730 --> 00:13:49,160
it's still the same phase of matter.

341
00:13:49,160 --> 00:13:51,670
There's some degree of robustness

342
00:13:51,670 --> 00:13:54,120
implied by the definition of phase.

343
00:13:54,120 --> 00:13:55,388
On the flip side, you can
have phase transitions

344
00:13:55,388 --> 00:13:58,197
between them, like, if you
tune the temperature too high,

345
00:13:58,197 --> 00:14:01,070
you know, you can have a
solid to a gas transition.

346
00:14:01,070 --> 00:14:04,030
What we deal with is
quantum phases of matter,

347
00:14:04,030 --> 00:14:07,610
where again, you have some
degree of robustness implied,

348
00:14:07,610 --> 00:14:11,210
but now the tuning parameter
is no longer temperature,

349
00:14:11,210 --> 00:14:13,870
but some extent of quantum fluctuation.

350
00:14:13,870 --> 00:14:15,950
So you can have like zero temperature

351
00:14:15,950 --> 00:14:19,320
quantum phases of matter
that are tuned from one phase

352
00:14:19,320 --> 00:14:21,120
to another, not by temperature,

353
00:14:21,120 --> 00:14:24,110
but by some parameter in your system

354
00:14:24,110 --> 00:14:25,873
that controls quantum fluctuations.

355
00:14:27,070 --> 00:14:29,620
- So I guess superconductivity
would be an example of-

356
00:14:29,620 --> 00:14:31,420
- Exactly.
- Of these quantum phases

357
00:14:31,420 --> 00:14:33,570
are there other examples?

358

00:14:33,570 --> 00:14:35,066
- So for example, you could think of like

359
00:14:35,066 --> 00:14:39,140
a ferromagnet and paramagnet

360
00:14:39,140 --> 00:14:41,663
as two different quantum phases of matter.

361
00:14:41,663 --> 00:14:44,200
So basically, you know, you
can imagine that your system

362
00:14:44,200 --> 00:14:47,510
is some collection of magnetic moments.

363
00:14:47,510 --> 00:14:50,520
In one phase, the ferromagnetic
phase, they all align.

364
00:14:50,520 --> 00:14:51,353
Whereas in the paramagnetic phase,

365
00:14:51,353 --> 00:14:54,820
they're all disordered
and highly fluctuating.

366
00:14:54,820 --> 00:14:58,440
So that's another example
of quantum phases.

367
00:14:58,440 --> 00:15:00,697
- Do some of those quantum phases

368
00:15:00,697 --> 00:15:03,728
have this quantum magic
that you were talking about?

369
00:15:03,728 --> 00:15:04,760

- Yes, yeah.

370
00:15:04,760 --> 00:15:08,100
One thing we did recently
was basically connect

371
00:15:08,100 --> 00:15:11,360
this concept of magic,
this resource that you need

372
00:15:11,360 --> 00:15:15,190
to upgrade your quantum
computer to be fully universal.

373
00:15:15,190 --> 00:15:17,630
What we did was connect
this magic resource

374
00:15:17,630 --> 00:15:20,530
to the study of quantum phases of matter.

375
00:15:20,530 --> 00:15:22,870
So my collaborators and
I found that certain

376
00:15:22,870 --> 00:15:26,210
topological phases of matter
are guaranteed to possess

377
00:15:26,210 --> 00:15:27,740
this resource magic.

378
00:15:27,740 --> 00:15:29,863
- And what's a topological
phase of matter?

379
00:15:29,863 --> 00:15:30,696
- Yes, thank you.

380

00:15:30,696 --> 00:15:31,529
- Yes, that's a good question.

381
00:15:31,529 --> 00:15:34,620
So a topological phase of
matter is kind of an unusual

382
00:15:34,620 --> 00:15:35,453
quantum phase of matter.

383
00:15:35,453 --> 00:15:38,450
So the example I gave earlier
of quantum phases of matter,

384
00:15:38,450 --> 00:15:39,900
this ferromagnet,

385
00:15:39,900 --> 00:15:42,510
is something with like
a local order parameter.

386
00:15:42,510 --> 00:15:46,550
It's something where if you
look locally at the system,

387
00:15:46,550 --> 00:15:48,670
you see that all your magnetic moments

388
00:15:48,670 --> 00:15:50,563
are aligned in a particular
direction, right?

389
00:15:50,563 --> 00:15:53,210
So it's something that
you can identify locally.

390
00:15:53,210 --> 00:15:55,410
However, a topological phase of matter

391

00:15:55,410 --> 00:15:59,270
is still distinct from a
completely disordered phase,

392
00:15:59,270 --> 00:16:01,651
the paramagnet, but it
cannot be identified

393
00:16:01,651 --> 00:16:04,620
by such local order parameters.

394
00:16:04,620 --> 00:16:08,860
You need to look at some more
global property of the system,

395
00:16:08,860 --> 00:16:11,580
for example, some entanglement
property of the system

396
00:16:11,580 --> 00:16:14,140
or some property of the
boundary of the system,

397
00:16:14,140 --> 00:16:16,780
it's that, that distinguishes
topological phase

398
00:16:16,780 --> 00:16:18,280
from the paramagnet

399
00:16:18,280 --> 00:16:21,070
- Is it really sort of parallel
to the idea of typology,

400
00:16:21,070 --> 00:16:24,160
thinking of the, you know,
the shape of the mountains

401
00:16:24,160 --> 00:16:25,257
and valleys of the earth?

402
00:16:25,257 --> 00:16:27,260
You're looking at something
in a broader picture

403
00:16:27,260 --> 00:16:28,730
rather than an individual...?

404
00:16:28,730 --> 00:16:30,307
- Yeah, yeah, exactly, exactly.

405
00:16:30,307 --> 00:16:33,930
The idea behind typology
is that you have some

406
00:16:33,930 --> 00:16:35,730
robust property of the system,

407
00:16:35,730 --> 00:16:39,151
that any local deformation cannot change.

408
00:16:39,151 --> 00:16:40,750
So, you know, you have like a torus,

409
00:16:40,750 --> 00:16:43,830
but if you like pinch it
locally, it's still a torus.

410
00:16:43,830 --> 00:16:46,670
And so it's that kind of global notion

411
00:16:46,670 --> 00:16:49,230
that characterizes a topological phase

412
00:16:49,230 --> 00:16:51,730
as opposed to a local order parameter,

413
00:16:51,730 --> 00:16:53,370

as in the ferromagnet.

414
00:16:53,370 --> 00:16:54,750
- You're a co-leader of

415
00:16:54,750 --> 00:16:58,010
the Clay Riddell Center for
Quantum Matter at Perimeter.

416
00:16:58,010 --> 00:16:59,740
Can you explain what that is and what you

417
00:16:59,740 --> 00:17:02,266
and your colleagues sort
of broadly are trying to do

418
00:17:02,266 --> 00:17:04,360
with quantum matter here at Perimeter?

419
00:17:04,360 --> 00:17:06,860
- The Center for Quantum
Matter is kind of built

420
00:17:06,860 --> 00:17:09,140
from the foundations of three fields.

421
00:17:09,140 --> 00:17:11,470
I would say quantum materials,
quantum information,

422
00:17:11,470 --> 00:17:13,140
and quantum gravity.

423
00:17:13,140 --> 00:17:16,710
These fields actually
have a lot in common.

424
00:17:16,710 --> 00:17:17,980
All of us are pretty much interested

425
00:17:17,980 --> 00:17:21,820
in this question that we
be began the podcast on,

426
00:17:21,820 --> 00:17:24,800
which is what happens when you put many

427
00:17:24,800 --> 00:17:26,750
quantum degrees of freedom together

428
00:17:26,750 --> 00:17:28,700
and allow them to interact strongly?

429
00:17:28,700 --> 00:17:31,217
Like what can come out of this
many bodied quantum system?

430
00:17:31,217 --> 00:17:34,170
And it's this underlying
question that kind of drives

431
00:17:34,170 --> 00:17:36,610
all three of these areas of our center.

432
00:17:36,610 --> 00:17:38,350
- So a truth about quantum gravity,

433
00:17:38,350 --> 00:17:39,980
about what happens in extreme gravity

434
00:17:39,980 --> 00:17:43,290
could relate to building
a quantum computer,

435
00:17:43,290 --> 00:17:44,850
there could be parallels there?

436

00:17:44,850 --> 00:17:47,620
- Yeah, I think more
specifically in quantum gravity,

437
00:17:47,620 --> 00:17:49,750
there's this notion of holography

438
00:17:49,750 --> 00:17:53,980
where a strongly interacting
many bodied quantum system

439
00:17:53,980 --> 00:17:56,050
is actually equivalent in some sense,

440
00:17:56,050 --> 00:17:59,860
to a theory of gravity
in one higher dimension.

441
00:17:59,860 --> 00:18:03,530
And so there, it's a
very striking phenomenon

442
00:18:03,530 --> 00:18:07,530
of gravity that has emerged
from this many body system.

443
00:18:07,530 --> 00:18:10,700
But gravity is just one
extremely interesting instance

444
00:18:10,700 --> 00:18:12,030
of something emerging.

445
00:18:12,030 --> 00:18:14,770
- Gravity is considered an
emergent phenomenon in...

446
00:18:14,770 --> 00:18:17,130
- Yeah, from this picture, yes.

447
00:18:17,130 --> 00:18:20,180
- The result of many,
many smaller, complex...

448
00:18:20,180 --> 00:18:21,013
- That's right.

449
00:18:21,013 --> 00:18:24,900
And so that may give you
some insight into how ideas

450
00:18:24,900 --> 00:18:27,851
from quantum information
can be used to shed light

451
00:18:27,851 --> 00:18:30,060
on this holographic correspondence,

452
00:18:30,060 --> 00:18:32,250
and similarly ideas in quantum fruition

453
00:18:32,250 --> 00:18:35,300
shed light on quantum
materials for similar reasons.

454
00:18:35,300 --> 00:18:37,297
- That's amazing to me
that think that people

455
00:18:37,297 --> 00:18:39,590
who are examining how the universe works

456
00:18:39,590 --> 00:18:40,720
on the largest scales, you know,

457
00:18:40,720 --> 00:18:42,500
the quantum gravity theorists

458

00:18:42,500 --> 00:18:44,690
have a common language
with people who are...

459
00:18:44,690 --> 00:18:46,220
- That's right, that's right, yeah.

460
00:18:46,220 --> 00:18:48,768
- Ion traps or other
quantum computing devices.

461
00:18:48,768 --> 00:18:50,220
- Right, right, exactly.

462
00:18:50,220 --> 00:18:52,630
- Really connects the huge to the small.

463
00:18:52,630 --> 00:18:54,730
- These three areas that have
this philosophy in common,

464
00:18:54,730 --> 00:18:56,440
that the center is built on.

465
00:18:56,440 --> 00:18:59,000
So it aims to facilitate collaborations

466
00:18:59,000 --> 00:19:02,600
between these three
areas and make progress.

467
00:19:02,600 --> 00:19:04,920
- Would they typically
connect to each other

468
00:19:04,920 --> 00:19:06,270
or is that the point of the center,

469
00:19:06,270 --> 00:19:08,350

to make them find those?

470
00:19:08,350 --> 00:19:09,880
- I would say in the past decade,

471
00:19:09,880 --> 00:19:11,870
there's been more and more momentum

472
00:19:11,870 --> 00:19:14,313
in kinda unifying these three areas.

473
00:19:14,313 --> 00:19:16,600
And the Center for Quantum
Matter is kind of like, yeah,

474
00:19:16,600 --> 00:19:19,170
it's like a reflection
of all this momentum

475
00:19:19,170 --> 00:19:20,090
toward unification.

476
00:19:20,090 --> 00:19:22,510
- I wanna go back to asking
you something about this paper

477
00:19:22,510 --> 00:19:24,210
that you mentioned on magic.

478
00:19:24,210 --> 00:19:26,730
I think it's called symmetry
protected sign problem

479
00:19:26,730 --> 00:19:29,150
and magic in quantum phases of matter.

480
00:19:29,150 --> 00:19:33,500
I took a look at this paper
before our discussion today,

481
00:19:33,500 --> 00:19:35,753
and I couldn't help but
notice that the word symmetry

482
00:19:35,753 --> 00:19:38,050
comes up a lot in the paper.

483
00:19:38,050 --> 00:19:41,930
So actually just in the first
sentence of the abstract,

484
00:19:41,930 --> 00:19:43,173
it's there three times.

485
00:19:44,208 --> 00:19:46,903
So the first sentence is
we introduced the concepts

486
00:19:46,903 --> 00:19:49,890
of a symmetry protected sign problem,

487
00:19:49,890 --> 00:19:51,500
and symmetry protected magic

488
00:19:51,500 --> 00:19:54,160
to study the complexity
of symmetry protected

489
00:19:54,160 --> 00:19:55,700
topological phases of matter.

490
00:19:55,700 --> 00:19:57,850
So can you tell us a
little bit about symmetry

491
00:19:57,850 --> 00:20:00,440
and how that plays a
role in quantum matter

492
00:20:00,440 --> 00:20:02,850
or maybe specifically in this work?

493
00:20:02,850 --> 00:20:05,620
- Yeah, I think symmetry has
played a fundamental role

494
00:20:05,620 --> 00:20:08,280
in quantum phases of matter
from the very beginning.

495
00:20:08,280 --> 00:20:10,110
The first example I mentioned of this,

496
00:20:10,110 --> 00:20:12,640
this ferromagnet versus a paramagnet,

497
00:20:12,640 --> 00:20:15,990
that's an example where one of the phases

498
00:20:15,990 --> 00:20:18,770
has broken asymmetry.

499
00:20:18,770 --> 00:20:19,980
You know, I was talking about this system

500
00:20:19,980 --> 00:20:21,447
where you have many local moments.

501
00:20:21,447 --> 00:20:24,160
In one of these phases,
the symmetry is preserved.

502
00:20:24,160 --> 00:20:27,600
Like if you rotate these local
moments, nothing happens.

503

00:20:27,600 --> 00:20:28,890
However, in the ferromagnetic phase,

504
00:20:28,890 --> 00:20:30,840
in which they're all aligned,

505
00:20:30,840 --> 00:20:33,370
they've spontaneously
picked out one direction.

506
00:20:33,370 --> 00:20:37,340
So the symmetry, this ability
to do a rotation is broken.

507
00:20:37,340 --> 00:20:38,370
- The symmetry, essentially,

508
00:20:38,370 --> 00:20:40,970
like no matter which way you
turn something, it's the same.

509
00:20:40,970 --> 00:20:43,093
- Exactly, so symmetry,
the principle of symmetry

510
00:20:43,093 --> 00:20:46,730
and symmetry breaking
has been a key concept

511
00:20:46,730 --> 00:20:49,360
in just even defining
different phases of matter.

512
00:20:49,360 --> 00:20:51,980
It's only until recently that
people have started thinking

513
00:20:51,980 --> 00:20:53,330
about topological phases of matter,

514
00:20:53,330 --> 00:20:55,569
which are not necessarily characterized

515
00:20:55,569 --> 00:20:57,720
by symmetry breaking anymore.

516
00:20:57,720 --> 00:20:59,500
And so that's why they're characterized

517
00:20:59,500 --> 00:21:02,370
by more complicated
things like entanglement

518
00:21:02,370 --> 00:21:04,790
or phenomena at the
boundary of the system.

519
00:21:04,790 --> 00:21:08,790
However, symmetry has continued
to play an important role

520
00:21:08,790 --> 00:21:11,290
even in these topological
phases of matter.

521
00:21:11,290 --> 00:21:13,137
And that's because of the
discovery of these things

522
00:21:13,137 --> 00:21:16,640
called symmetry protected
topological phases.

523
00:21:16,640 --> 00:21:19,710
These topological phases
of matter are characterized

524
00:21:19,710 --> 00:21:22,133
by some interesting phenomena

525
00:21:22,133 --> 00:21:25,010
at the boundary of their system.

526
00:21:25,010 --> 00:21:26,930
There's these things called
topological insulators,

527
00:21:26,930 --> 00:21:29,133
whose bulk properties are insulating,

528
00:21:29,133 --> 00:21:33,160
and yet their surfaces
conduct, so they're metals.

529
00:21:33,160 --> 00:21:34,890
What make this non-trivial
phases of matter

530
00:21:34,890 --> 00:21:38,050
is this connection between
this metallic boundary

531
00:21:38,050 --> 00:21:39,430
and the bulk insulator.

532
00:21:39,430 --> 00:21:40,760
These are symmetry
protected in the sense that

533
00:21:40,760 --> 00:21:42,970
if you break the symmetry,

534
00:21:42,970 --> 00:21:47,140
then you lose this property
of the metallic boundary.

535
00:21:47,140 --> 00:21:48,870
That's why it's symmetry protected

536
00:21:48,870 --> 00:21:51,030
because to maintain this correspondence

537
00:21:51,030 --> 00:21:53,230
between this metal or the boundary,

538
00:21:53,230 --> 00:21:54,900
you need to preserve the symmetry.

539
00:21:54,900 --> 00:21:57,420
- And how do you make sure
that you preserve a symmetry?

540
00:21:57,420 --> 00:21:59,887
- In practice, you never
strictly preserve it.

541
00:21:59,887 --> 00:22:02,070
It can be weakly broken.

542
00:22:02,070 --> 00:22:04,110
For example, in these
topological insulators,

543
00:22:04,110 --> 00:22:06,470
they're protected by
time reversal (unclear).

544
00:22:06,470 --> 00:22:08,850
Earth's magnetic field,
you can't really turn off,

545
00:22:08,850 --> 00:22:10,020
but it's very small.

546
00:22:10,020 --> 00:22:11,920
And it turns out that it's so small

547
00:22:11,920 --> 00:22:15,720
that its effect on breaking
these nice properties

548
00:22:15,720 --> 00:22:17,510
is very small.

549
00:22:17,510 --> 00:22:21,130
If you can respect the symmetry,
within some small error,

550
00:22:21,130 --> 00:22:22,090
you're fine.

551
00:22:22,090 --> 00:22:24,810
- As a nonscientist myself,
I'm fascinated by this,

552
00:22:24,810 --> 00:22:26,930
but it's making my brain throb a little.

553
00:22:26,930 --> 00:22:28,780
So I wanna go back a little bit

554
00:22:28,780 --> 00:22:32,020
and just ask, like, how did you
get into cutting edge stuff?

555
00:22:32,020 --> 00:22:34,600
How did you find your way
into doing this for a living?

556
00:22:34,600 --> 00:22:36,770
- As a young kid, I was very interested

557
00:22:36,770 --> 00:22:39,500
in just problem solving
in general, from Legos,

558
00:22:39,500 --> 00:22:42,870
or just, you know, some small
like physics or math problems.

559
00:22:42,870 --> 00:22:44,960
And I think that's what
motivated me enough

560
00:22:44,960 --> 00:22:47,770
to learn about the basics of physics.

561
00:22:47,770 --> 00:22:51,343
It's really just a drive to
understand everyday phenomenon

562
00:22:51,343 --> 00:22:53,820
at the most basic level.

563
00:22:53,820 --> 00:22:55,250
- Was that always a drive for you?

564
00:22:55,250 --> 00:22:56,430
Were you always looking around saying,

565
00:22:56,430 --> 00:22:58,460
how does that work or what is this?

566
00:22:58,460 --> 00:23:02,020
- I think it was that
Lego philosophy of just

567
00:23:02,020 --> 00:23:05,630
first going down to the
most basic building blocks

568
00:23:05,630 --> 00:23:08,050
before like assembling it all together.

569

00:23:08,050 --> 00:23:10,350
- What is the most complex
structure you built with Lego?

570
00:23:10,350 --> 00:23:13,730
- There were some crazy
spaceships, that's yeah.

571
00:23:13,730 --> 00:23:15,430
- You grew up in Los Angeles, right?

572
00:23:15,430 --> 00:23:16,280
- Yeah, that's right.

573
00:23:16,280 --> 00:23:18,800
- I think most people have
a picture in their head

574
00:23:18,800 --> 00:23:21,440
of what Los Angeles is, 'cause
of pop culture, we all know.

575
00:23:21,440 --> 00:23:23,460
But can you tell us what
was Los Angeles like

576
00:23:23,460 --> 00:23:24,730
for you to grow up in?

577
00:23:24,730 --> 00:23:27,380
What were you doing as
a child in Los Angeles?

578
00:23:27,380 --> 00:23:29,650
- One of the most appealing features of LA

579
00:23:29,650 --> 00:23:32,370
as a kid was the musical elements.

580

00:23:32,370 --> 00:23:34,070
I started violin at a very early age

581
00:23:34,070 --> 00:23:37,570
and performed solo violin
and chamber ensembles

582
00:23:37,570 --> 00:23:40,910
and orchestra, LA was just great for that.

583
00:23:40,910 --> 00:23:43,800
- You started out in like youth
orchestras in Los Angeles?

584
00:23:43,800 --> 00:23:45,610
- Yeah, yeah, exactly.

585
00:23:45,610 --> 00:23:46,443
- You're being humble,

586
00:23:46,443 --> 00:23:48,720
you haven't mentioned yet that
you've played Carnegie Hall.

587
00:23:48,720 --> 00:23:51,470
- My orchestra fortunately
had the opportunity

588
00:23:51,470 --> 00:23:54,790
to go to Carnegie Hall
when I was in high school.

589
00:23:54,790 --> 00:23:57,480
And so that indeed was
a wonderful experience.

590
00:23:57,480 --> 00:23:58,940
- Were you interested
in physics at the time

591
00:23:58,940 --> 00:24:00,360
or was it all music first

592
00:24:00,360 --> 00:24:02,170
and then you discovered science later?

593
00:24:02,170 --> 00:24:04,820
- I was definitely interested
in physics at the time.

594
00:24:04,820 --> 00:24:06,950
So that same year that
we went to Carnegie,

595
00:24:06,950 --> 00:24:09,430
I had the other good fortune of competing

596
00:24:09,430 --> 00:24:11,890
in the US Physics Olympiad.

597
00:24:11,890 --> 00:24:15,420
And there, I made it to
this national training camp,

598
00:24:15,420 --> 00:24:18,600
that was another, I
think, major milestone.

599
00:24:18,600 --> 00:24:19,480
- I'm so curious.

600
00:24:19,480 --> 00:24:21,920
I've never seen a Physics Olympiad.

601
00:24:21,920 --> 00:24:23,561
In my head, I'm picturing
physicists running

602

00:24:23,561 --> 00:24:25,900
around a track and doing high jump,

603
00:24:25,900 --> 00:24:26,920
but I know that's not it.

604
00:24:26,920 --> 00:24:28,820
What are the challenges
that you do as a kid

605
00:24:28,820 --> 00:24:31,690
at a Physics Olympiad and
how did you approach it?

606
00:24:31,690 --> 00:24:35,740
- It's very similar to the
usual athletic competitions,

607
00:24:35,740 --> 00:24:37,673
except everything is in your head.

608
00:24:37,673 --> 00:24:39,084
- I like.

609
00:24:39,084 --> 00:24:41,148
- Whether or not it's fun,

610
00:24:41,148 --> 00:24:43,460
this is another question, I guess.

611
00:24:43,460 --> 00:24:46,410
Well, yeah, it's basically
just a lot of problem solving

612
00:24:46,410 --> 00:24:48,250
of very, very interesting questions

613
00:24:48,250 --> 00:24:51,870
in classical mechanics

or electromagnetism.

614
00:24:51,870 --> 00:24:53,080
- And there's various teams

615
00:24:53,080 --> 00:24:55,529
and whoever gets the most right answers

616
00:24:55,529 --> 00:24:58,070
or does it the fastest, how does it work?

617
00:24:58,070 --> 00:25:00,120
- Back then, like speed
was not the problem.

618
00:25:00,120 --> 00:25:04,440
You have like several hours to
work through these problems.

619
00:25:04,440 --> 00:25:06,500
At the of the day, it is a competition,

620
00:25:06,500 --> 00:25:08,770
I think, between various
different countries,

621
00:25:08,770 --> 00:25:13,000
basically who can solve the
most problems most completely.

622
00:25:13,000 --> 00:25:14,880
- And you were how old at the time?

623
00:25:14,880 --> 00:25:16,010
- My junior year of high school,

624
00:25:16,010 --> 00:25:19,430
I think probably around like 14, 15.

625
00:25:19,430 --> 00:25:21,970
- Okay, you got to compete nationally?

626
00:25:21,970 --> 00:25:23,110
- Yeah, that's right, that's right.

627
00:25:23,110 --> 00:25:24,590
- Do you remember what kind of challenges

628
00:25:24,590 --> 00:25:25,730
you were faced with?

629
00:25:25,730 --> 00:25:28,690
- That was the first time in which I saw

630
00:25:28,690 --> 00:25:31,593
how smart people can be.

631
00:25:33,050 --> 00:25:36,890
So as you grow up, you're
only exposed to so many people

632
00:25:36,890 --> 00:25:40,200
and yet on this national stage,

633
00:25:40,200 --> 00:25:43,880
you really see like how
skilled people can be,

634
00:25:43,880 --> 00:25:46,700
like how fast they can think,
how well they can think.

635
00:25:46,700 --> 00:25:48,440
And that to me was really

636
00:25:48,440 --> 00:25:51,040
a humbling and exciting experience.

637
00:25:51,040 --> 00:25:55,093
Because it really sets a
bar that you can aspire to.

638
00:25:56,004 --> 00:25:58,070
- Are you still in touch
with anyone from that time

639
00:25:58,070 --> 00:26:00,103
or did any of them go on to be...?

640
00:26:00,103 --> 00:26:02,357
- Yeah, yeah, I know
several people on the team,

641
00:26:02,357 --> 00:26:04,120
I've kept in touch with them.

642
00:26:04,120 --> 00:26:06,180
Some have become experimental physicists,

643
00:26:06,180 --> 00:26:09,140
some have gone on into it to other fields

644
00:26:09,140 --> 00:26:10,490
like applied mathematics.

645
00:26:10,490 --> 00:26:12,230
We've all gone our different ways,

646
00:26:12,230 --> 00:26:15,480
but I'm sure that
training was very useful,

647
00:26:15,480 --> 00:26:17,000
no matter which discipline.

648

00:26:17,000 --> 00:26:18,160
- And shortly after that

649
00:26:18,160 --> 00:26:20,530
was when you first came to Perimeter

650
00:26:20,530 --> 00:26:23,406
for the International Summer
School for Young Physicists.

651
00:26:23,406 --> 00:26:24,239
- Right, right.

652
00:26:24,239 --> 00:26:25,770
- Can you tell us a little bit about that

653
00:26:25,770 --> 00:26:28,630
and maybe what stands out
when you look back on time.

654
00:26:28,630 --> 00:26:31,650
- So at the culmination of
this Olympiad training camp,

655
00:26:31,650 --> 00:26:34,859
they advertised, a relatively
new program at Perimeter.

656
00:26:34,859 --> 00:26:37,190
ISSYP, it sounded great.

657
00:26:37,190 --> 00:26:39,100
The summer after I graduated high school,

658
00:26:39,100 --> 00:26:39,963
I attended ISSYP.

659
00:26:40,850 --> 00:26:42,510
And I think that that was

the first time in which

660
00:26:42,510 --> 00:26:46,600
I really learned some basic
concepts in quantum mechanics.

661
00:26:46,600 --> 00:26:49,290
- After all those Physics
Olympiads, those were more...

662
00:26:49,290 --> 00:26:50,400
- All the Physics Olympiads

663
00:26:50,400 --> 00:26:54,350
were primarily classical
physics, mechanics, and ENM.

664
00:26:54,350 --> 00:26:57,250
I only had some vague
notions of quantum mechanics

665
00:26:57,250 --> 00:26:58,510
at the time.

666
00:26:58,510 --> 00:27:00,670
ISSYP really opened my eyes further.

667
00:27:00,670 --> 00:27:02,880
And, you know, allowed me to really see

668
00:27:02,880 --> 00:27:07,100
some of the counterintuitive
aspects of quantum mechanics.

669
00:27:07,100 --> 00:27:09,640
- Plus I assume you were
there with other teenagers

670
00:27:09,640 --> 00:27:11,246

who were sort of just like you,

671
00:27:11,246 --> 00:27:14,240
had been probably doing
their own physics contests

672
00:27:14,240 --> 00:27:16,800
and physics enthusiasts.

673
00:27:16,800 --> 00:27:17,890
I imagine you were surrounded

674
00:27:17,890 --> 00:27:19,690
by sort of like-minded individuals.

675
00:27:19,690 --> 00:27:20,650
- That's right, that's right.

676
00:27:20,650 --> 00:27:22,070
- You remember what
that experience was like

677
00:27:22,070 --> 00:27:23,950
as a teenager to come to Canada

678
00:27:23,950 --> 00:27:24,880
and meet these new people

679
00:27:24,880 --> 00:27:28,030
and spend a couple weeks
just immersed in physics?

680
00:27:28,030 --> 00:27:28,863
- It was really great.

681
00:27:28,863 --> 00:27:32,720
I think at the time, probably
even now at the ISSYP,

682
00:27:32,720 --> 00:27:35,870
they break the group into
several smaller groups

683
00:27:35,870 --> 00:27:38,080
that can work together,

684
00:27:38,080 --> 00:27:39,640
work through these hard problems

685
00:27:39,640 --> 00:27:41,140
in quantum mechanics or otherwise.

686
00:27:41,140 --> 00:27:43,380
And yeah, I distinctly remember

687
00:27:43,380 --> 00:27:46,960
many of these team experiences
that were really fun.

688
00:27:46,960 --> 00:27:48,530
- So you came here in high school

689
00:27:48,530 --> 00:27:49,537
and now you're here at Perimeter

690
00:27:49,537 --> 00:27:51,610
- Right, right.
- A Faculty member,

691
00:27:51,610 --> 00:27:52,890
what happened in between,

692
00:27:52,890 --> 00:27:55,440
what are some of the milestone steps

693
00:27:55,440 --> 00:27:59,420
that kind of, you went,

you took until you...

694
00:27:59,420 --> 00:28:02,272
- Well, I guess the short
answer is I learned a lot more

695
00:28:02,272 --> 00:28:06,630
quantum mechanics, to the
extent that I was able to

696
00:28:06,630 --> 00:28:09,207
actually use it in a constructive way.

697
00:28:09,207 --> 00:28:11,616
- One of the leaders of the
Quantum Matter center now.

698
00:28:11,616 --> 00:28:13,180
- Right, right, right.

699
00:28:13,180 --> 00:28:15,187
- When you got that first
exposure to quantum science

700
00:28:15,187 --> 00:28:17,381
and quantum mechanics,
what did you think of it?

701
00:28:17,381 --> 00:28:19,950
These concepts are not terribly intuitive.

702
00:28:19,950 --> 00:28:23,180
- It's just very exciting
because our day to day experience

703
00:28:23,180 --> 00:28:25,130
are consistent with classical physics.

704
00:28:25,130 --> 00:28:28,520

And so these counterintuitive
ideas of like entanglement,

705
00:28:28,520 --> 00:28:30,980
superposition in quantum mechanics

706
00:28:30,980 --> 00:28:33,250
are just something that
you can almost think of it

707
00:28:33,250 --> 00:28:35,690
as like a dreamland, as like a,

708
00:28:35,690 --> 00:28:37,170
it's not an alternative universe,

709
00:28:37,170 --> 00:28:41,060
because it describes
the microscopic nature

710
00:28:41,060 --> 00:28:43,620
of our current universe,
but it's so different

711
00:28:43,620 --> 00:28:46,353
that it's almost like going
to a different universe

712
00:28:46,353 --> 00:28:48,020
and playing around there.

713
00:28:48,020 --> 00:28:49,560
So that's what really fascinated me.

714
00:28:49,560 --> 00:28:50,393
- I like that.

715
00:28:50,393 --> 00:28:51,720
And your enthusiasm talking,

716
00:28:51,720 --> 00:28:52,590
I can tell you enjoy this stuff.

717
00:28:52,590 --> 00:28:54,560
- Yeah, yeah.
- You light up talking about

718
00:28:54,560 --> 00:28:56,800
quantum superposition and entanglement.

719
00:28:56,800 --> 00:28:59,300
Are you still sort of fascinated by it?

720
00:28:59,300 --> 00:29:01,370
Is that what keeps you going?

721
00:29:01,370 --> 00:29:04,920
- Yeah, I mean, the thing is
if you think really deeply

722
00:29:04,920 --> 00:29:06,867
about quantum mechanics
and its foundations,

723
00:29:06,867 --> 00:29:10,830
eventually you realize
that philosophically,

724
00:29:10,830 --> 00:29:13,280
it's not that complete yet.

725
00:29:13,280 --> 00:29:15,140
- Is that why it's so
counterintuitive to us

726
00:29:15,140 --> 00:29:16,890
'cause it's not yet complete

727
00:29:16,890 --> 00:29:19,150
or because we haven't
developed our intuition

728
00:29:19,150 --> 00:29:19,983
for this stuff yet?

729
00:29:19,983 --> 00:29:23,530
- Well, I think even
things that are, you know,

730
00:29:23,530 --> 00:29:26,100
solidly in the foundation
of quantum mechanics

731
00:29:26,100 --> 00:29:28,320
are already counterintuitive,

732
00:29:28,320 --> 00:29:31,570
but there's this additional
aspect that the theory,

733
00:29:31,570 --> 00:29:33,570
even while being counterintuitive,

734
00:29:33,570 --> 00:29:37,360
is not like aesthetically
that satisfying at times.

735
00:29:37,360 --> 00:29:40,340
So for example, in
basic quantum mechanics,

736
00:29:40,340 --> 00:29:43,930
you first learned that there
are two types of operations

737
00:29:43,930 --> 00:29:48,320
of just the unitary evolution

of a system and measurement,

738
00:29:48,320 --> 00:29:50,950
and these two things, in
your most basic course,

739
00:29:50,950 --> 00:29:54,420
you learn that they're just
two separate operations

740
00:29:54,420 --> 00:29:56,450
that are allowed in quantum mechanics.

741
00:29:56,450 --> 00:29:59,390
And later maybe in a more
sophisticated course,

742
00:29:59,390 --> 00:30:03,360
you learn that this idea of
measurement can be incorporated

743
00:30:03,360 --> 00:30:06,670
within unitary evolution
of a bigger system

744
00:30:06,670 --> 00:30:09,344
in which you treat the
object of measurement

745
00:30:09,344 --> 00:30:12,920
and the measuring device
as a joint system.

746
00:30:12,920 --> 00:30:14,660
- Talk a little bit more
about measurement here,

747
00:30:14,660 --> 00:30:17,040
because I think it's a
word that a lot of people

748
00:30:17,040 --> 00:30:18,180
would use pretty often,

749
00:30:18,180 --> 00:30:21,610
and they're using more of
a classical definition.

750
00:30:21,610 --> 00:30:25,040
So why is measurement maybe more subtle

751
00:30:25,040 --> 00:30:27,420
or what are kind of
some of those subtleties

752
00:30:27,420 --> 00:30:29,970
when we're talking about
it in quantum mechanics?

753
00:30:29,970 --> 00:30:31,840
- Yeah, measurement is
subtle in quantum mechanics

754
00:30:31,840 --> 00:30:33,400
because in quantum mechanics

755
00:30:33,400 --> 00:30:35,500
you can have basically a superposition

756
00:30:35,500 --> 00:30:37,140
of many different states.

757
00:30:37,140 --> 00:30:41,260
And when you do a measurement
in the most basic description,

758
00:30:41,260 --> 00:30:43,720
you're collapsing that big superposition

759
00:30:43,720 --> 00:30:47,550
into one branch of the superposition,

760
00:30:47,550 --> 00:30:49,420
into one component of it.

761
00:30:49,420 --> 00:30:52,400
That's why, again, in a
most basic description,

762
00:30:52,400 --> 00:30:55,770
this measurement is some operation

763
00:30:55,770 --> 00:31:00,770
that supplements the usual
dynamics of the superposition.

764
00:31:01,050 --> 00:31:02,320
You know, our superposition,

765
00:31:02,320 --> 00:31:05,790
it's supposed to evolve
under a Schrödinger equation.

766
00:31:05,790 --> 00:31:08,450
And yet to describe the
actual measurement process,

767
00:31:08,450 --> 00:31:12,420
you need to say, okay,
there's this weird operation

768
00:31:12,420 --> 00:31:15,740
where it can also collapse
into one component only.

769
00:31:15,740 --> 00:31:17,500
And so it's this tension

770
00:31:17,500 --> 00:31:19,680
between these two types of operation,

771
00:31:19,680 --> 00:31:22,820
this coherent evolution
with Schrödinger equation,

772
00:31:22,820 --> 00:31:26,380
and this drastic that
collapse to one component,

773
00:31:26,380 --> 00:31:27,850
that is very subtle.

774
00:31:27,850 --> 00:31:30,730
How the two can be reconciled, if at all,

775
00:31:30,730 --> 00:31:33,760
I think is still a open question.

776
00:31:33,760 --> 00:31:35,921
- Measurement means that it causes

777
00:31:35,921 --> 00:31:37,410
that collapse to it.

778
00:31:37,410 --> 00:31:38,890
- Yeah, yeah, right.

779
00:31:38,890 --> 00:31:41,152
- You can't look at a superposition,

780
00:31:41,152 --> 00:31:43,770
once you look you've forced it to...

781
00:31:43,770 --> 00:31:45,110
- That's right, that's right.

782
00:31:45,110 --> 00:31:48,840
The kind of paradox is
that your measuring device,

783
00:31:48,840 --> 00:31:50,540
and the thing being measured

784
00:31:50,540 --> 00:31:53,530
are just also some big
collections of particles,

785
00:31:53,530 --> 00:31:56,976
that are evolving under the
laws of quantum mechanics.

786
00:31:56,976 --> 00:31:58,832
So in principle, they
should just be evolving

787
00:31:58,832 --> 00:32:01,690
under the description of
the Schrödinger equation.

788
00:32:01,690 --> 00:32:03,690
So then why did I need to introduce

789
00:32:03,690 --> 00:32:06,450
this extra concept of collapse?

790
00:32:06,450 --> 00:32:09,870
It's this type of subtlety
that is quite fascinating.

791
00:32:09,870 --> 00:32:12,790
- And I know some of your
work involves even now

792
00:32:12,790 --> 00:32:15,590
exploring some of the

subtleties of this measurement

793
00:32:15,590 --> 00:32:18,870
and you're looking at
these quantum systems,

794
00:32:18,870 --> 00:32:20,520
these large quantum systems,

795
00:32:20,520 --> 00:32:21,660
you can do these measurements

796
00:32:21,660 --> 00:32:23,540
on maybe different parts of the system,

797
00:32:23,540 --> 00:32:26,440
or you could do it at
different rates, very often,

798
00:32:26,440 --> 00:32:27,410
or maybe spread apart.

799
00:32:27,410 --> 00:32:30,440
What are some of the
interesting dynamics or features

800
00:32:30,440 --> 00:32:34,110
that you can observe by
adjusting how you measure?

801
00:32:34,110 --> 00:32:35,960
- Yeah, so indeed what we were discussing

802
00:32:35,960 --> 00:32:38,640
about the more philosophical
aspect of measurement,

803
00:32:38,640 --> 00:32:41,503
one can just kind of sweep

it under the rug for now

804
00:32:41,503 --> 00:32:45,090
and adopt the shut up
and calculate philosophy

805
00:32:45,970 --> 00:32:46,950
of quantum mechanics, right?

806
00:32:46,950 --> 00:32:48,914
Where you just accept it as the way it is

807
00:32:48,914 --> 00:32:50,750
and kind of run with it.

808
00:32:50,750 --> 00:32:54,720
And indeed, that's what I, and
many other condensed matter

809
00:32:54,720 --> 00:32:56,260
physicists have been doing.

810
00:32:56,260 --> 00:32:59,910
What we were doing is kind
of motivated by recent use

811
00:32:59,910 --> 00:33:01,860
of measurement as not something you do

812
00:33:01,860 --> 00:33:03,330
at the end of an experiment,

813
00:33:03,330 --> 00:33:06,510
but as something you can
do during the experiment

814
00:33:06,510 --> 00:33:09,050
to create some interesting dynamics.

815
00:33:09,050 --> 00:33:11,280
As I said, you can think
of quantum mechanics

816
00:33:11,280 --> 00:33:12,960
as having these two operations.

817
00:33:12,960 --> 00:33:16,460
One is unitary evolution
with Schrödinger equation,

818
00:33:16,460 --> 00:33:17,850
and one with measurement,

819
00:33:17,850 --> 00:33:20,290
these collapse of the
wave functions, right?

820
00:33:20,290 --> 00:33:22,544
And so previously most of
the dynamics we considered

821
00:33:22,544 --> 00:33:27,544
only involve one kind, this
Schrödinger equation evolution.

822
00:33:27,550 --> 00:33:29,460
However, when you put the two together,

823
00:33:29,460 --> 00:33:32,710
it turns out that you can
have very interesting dynamics

824
00:33:32,710 --> 00:33:36,213
leading to dynamical phase transitions.

825
00:33:37,090 --> 00:33:38,860
I've been very interested in recently

826
00:33:38,860 --> 00:33:40,930
is exploring this dynamics

827
00:33:40,930 --> 00:33:43,410
involving both of these operations.

828
00:33:43,410 --> 00:33:45,690
And these operations
kind of want to compete

829
00:33:45,690 --> 00:33:46,850
with each other.

830
00:33:46,850 --> 00:33:51,850
So this Schrödinger equation
evolution or unitary evolution,

831
00:33:52,470 --> 00:33:54,550
it tends to want to create entanglement.

832
00:33:54,550 --> 00:33:57,050
It wants to entangle
many particles together.

833
00:33:57,050 --> 00:33:59,640
Whereas this measurement operation,

834
00:33:59,640 --> 00:34:02,060
it wants to disentangle particles

835
00:34:02,060 --> 00:34:05,910
and just collapse things
locally to definite states.

836
00:34:05,910 --> 00:34:07,000
So there there's this competition

837
00:34:07,000 --> 00:34:10,720

between entangling dynamics
and disentangling dynamics.

838
00:34:10,720 --> 00:34:13,210
At a critical balance between the two,

839
00:34:13,210 --> 00:34:15,160
you have this phase transition,

840
00:34:15,160 --> 00:34:18,010
and it's this type of interesting dynamics

841
00:34:18,010 --> 00:34:19,460
we've been playing around with.

842
00:34:19,460 --> 00:34:22,380
- And so one of the phases on
one side of that transition

843
00:34:22,380 --> 00:34:23,213
would have more entanglement

844
00:34:23,213 --> 00:34:25,140
and the other one would have less.

845
00:34:25,140 --> 00:34:27,680
- It's not even necessarily
the amount of entanglement,

846
00:34:27,680 --> 00:34:31,640
it's how the entanglement
scales with the system size.

847
00:34:31,640 --> 00:34:33,480
So basically in one phase,

848
00:34:33,480 --> 00:34:36,690
the entanglement is very short range.

849
00:34:36,690 --> 00:34:38,520
If you divide your system into two pieces,

850
00:34:38,520 --> 00:34:41,630
you only have entanglement
locally across the partition.

851
00:34:41,630 --> 00:34:44,360
However, in another phase the
entanglement is long range.

852
00:34:44,360 --> 00:34:45,210
Across the partition,

853
00:34:45,210 --> 00:34:49,010
you have entanglement between
particles on all scales.

854
00:34:49,010 --> 00:34:51,961
- You sort of joked that
when you finished ISSYP

855
00:34:51,961 --> 00:34:54,820
here at Perimeter, and
then came back later,

856
00:34:54,820 --> 00:34:57,440
in between you just learned a
bunch more quantum mechanics.

857
00:34:57,440 --> 00:34:59,430
I think that's a nice way of saying

858
00:34:59,430 --> 00:35:02,220
that you did a lot of
schooling, you went to MIT

859
00:35:02,220 --> 00:35:05,200
for your PhD, and a

postdoc at Kavli Institute

860
00:35:05,200 --> 00:35:06,033
in California.

861
00:35:06,033 --> 00:35:08,246
I want to focus on the
MIT bit for a second

862
00:35:08,246 --> 00:35:11,140
because I discovered a very interesting,

863
00:35:11,140 --> 00:35:14,300
cool connection between your musical life

864
00:35:14,300 --> 00:35:15,750
and your scientific life.

865
00:35:15,750 --> 00:35:19,391
Can you tell us a bit
about this composition?

866
00:35:19,391 --> 00:35:21,210
Let's actually just play a little bit

867
00:35:21,210 --> 00:35:23,278
and then tell is what it was.

868
00:35:23,278 --> 00:35:26,028
(violin playing)

869
00:35:36,285 --> 00:35:37,180
So that's you on violin.

870
00:35:37,180 --> 00:35:39,280
- Right, that's the Bach.

871
00:35:39,280 --> 00:35:40,970

One of my friends at MIT figured

872
00:35:40,970 --> 00:35:43,888
that this is a very nice
piece of music to juxtapose

873
00:35:43,888 --> 00:35:46,780
with one of Frank Wilczek's lectures.

874
00:35:46,780 --> 00:35:49,244
- Frank Wilczek being the
Nobel prize winning physicist.

875
00:35:49,244 --> 00:35:50,123
- That's right, that's right.

876
00:35:50,123 --> 00:35:53,570
I think that year I had
been taking a reading course

877
00:35:53,570 --> 00:35:56,330
with Frank in the Center
for Theoretical Physics.

878
00:35:56,330 --> 00:35:58,110
I should've realized
that it was pretty cool

879
00:35:58,110 --> 00:36:00,930
to put this together
with Frank's lectures.

880
00:36:00,930 --> 00:36:03,500
- Yeah, it's this beautiful
collection of footage of,

881
00:36:03,500 --> 00:36:05,470
it looks a lot like Perimeter actually,

882

00:36:05,470 --> 00:36:09,000
because of the close ups
of chalk on a blackboard

883
00:36:09,000 --> 00:36:10,520
and people in a classroom,

884
00:36:10,520 --> 00:36:14,030
all the while it's you playing
violin in the background.

885
00:36:14,030 --> 00:36:17,590
It's this beautiful
combination of art and music.

886
00:36:17,590 --> 00:36:20,260
I encourage everybody to
Google it, to find it on,

887
00:36:20,260 --> 00:36:21,280
I found it out in Vimeo.

888
00:36:21,280 --> 00:36:23,510
What did you get out of doing that?

889
00:36:23,510 --> 00:36:25,990
- Well, I think it just
made a lot of sense to me

890
00:36:25,990 --> 00:36:28,650
because I think both music such as Bach

891
00:36:29,720 --> 00:36:32,490
and quantum mechanics,

892
00:36:32,490 --> 00:36:35,040
they're all these beautiful structures,

893
00:36:35,040 --> 00:36:39,240

these beautiful rules that
kind of reflect each other.

894
00:36:39,240 --> 00:36:40,220
- I can sort of see that.

895
00:36:40,220 --> 00:36:43,010
Have you found that doing
one helps you do the other,

896
00:36:43,010 --> 00:36:45,950
doing music and science
sort of go hand in hand?

897
00:36:45,950 --> 00:36:49,300
- As a kid, I definitely
found that performing music

898
00:36:49,300 --> 00:36:52,760
by practicing, I definitely
developed the discipline

899
00:36:52,760 --> 00:36:56,120
and concentration to do physics well.

900
00:36:56,120 --> 00:36:57,580
I guess at that practical level,

901
00:36:57,580 --> 00:37:00,440
there was already a
connection when I was a kid.

902
00:37:00,440 --> 00:37:03,830
Now I just view one as like
a way to escape the other

903
00:37:03,830 --> 00:37:06,220
when I get, you know,
really tired of doing one.

904
00:37:06,220 --> 00:37:08,140
- Well, in that way, they'd
be complimentary as well.

905
00:37:08,140 --> 00:37:09,060
- Yeah, yeah.

906
00:37:09,060 --> 00:37:09,990
- Yeah, that's interesting.

907
00:37:09,990 --> 00:37:12,680
I hadn't thought that
they both were based on

908
00:37:12,680 --> 00:37:16,010
sort of their own language
and their own rule book.

909
00:37:16,010 --> 00:37:18,110
- And I guess it also goes
back to this philosophy

910
00:37:18,110 --> 00:37:20,090
of emergent phenomenon.

911
00:37:20,090 --> 00:37:22,710
Because you know, in music
you have notes, right.

912
00:37:22,710 --> 00:37:27,020
You have these basic notes, chords, right,

913
00:37:27,020 --> 00:37:28,330
and the way you put them together,

914
00:37:28,330 --> 00:37:31,290
you can get stuff you really
wouldn't have imagined before.

915
00:37:31,290 --> 00:37:33,830
- You can put notes together
and you get chaos and noise.

916
00:37:33,830 --> 00:37:34,663
- Yeah, yeah.

917
00:37:34,663 --> 00:37:36,810
- You can put it together
enough harmony and melody and...

918
00:37:36,810 --> 00:37:37,940
- Right, right, right.

919
00:37:37,940 --> 00:37:41,020
- And that chord that
comes up is quite different

920
00:37:41,020 --> 00:37:42,843
than just playing each note one at a time.

921
00:37:42,843 --> 00:37:44,150
- Exactly, exactly.

922
00:37:44,150 --> 00:37:46,070
- Music is an emergent
phenomenon. I like that.

923
00:37:46,070 --> 00:37:47,850
- Yeah, yeah, that's right.

924
00:37:48,710 --> 00:37:51,533
- Well, Tim, we also ask for
questions from some students

925
00:37:51,533 --> 00:37:53,170
or some listeners.

926

00:37:53,170 --> 00:37:54,920
So we have a couple that were sent in.

927
00:37:54,920 --> 00:37:58,590
The first one is from a
student here in Waterloo.

928
00:37:58,590 --> 00:38:01,540
- This is Matt Duchene, a
student at IQC and Perimeter.

929
00:38:01,540 --> 00:38:03,440
I'm wondering what has been
your most memorable moment

930
00:38:03,440 --> 00:38:04,890
of your career so far,

931
00:38:04,890 --> 00:38:06,850
maybe either something
that's happened to you

932
00:38:06,850 --> 00:38:08,170
or a breakthrough or a lecture

933
00:38:08,170 --> 00:38:09,900
or something that you've witnessed.

934
00:38:09,900 --> 00:38:12,842
- So the question is what
is the most difficult?

935
00:38:12,842 --> 00:38:15,730
- Most memorable.
- Oh, most memorable.

936
00:38:15,730 --> 00:38:17,570
- It could be memorable
because it's difficult.

937
00:38:17,570 --> 00:38:19,430
- That's true, that's true, that's true.

938
00:38:19,430 --> 00:38:23,350
I would say the most
memorable moment was my time

939
00:38:23,350 --> 00:38:26,040
at the Kavli Institute as a postdoc.

940
00:38:26,040 --> 00:38:28,040
Those three years as a postdoc at KITP

941
00:38:28,040 --> 00:38:31,310
were probably the most
influential in my career, I feel.

942
00:38:31,310 --> 00:38:34,220
Allowing me to get the
confidence to tackle problems

943
00:38:34,220 --> 00:38:37,410
that I formulated and can solve on my own.

944
00:38:37,410 --> 00:38:40,090
It was also just the environment at Kavli

945
00:38:40,090 --> 00:38:41,920
with all these people going through,

946
00:38:41,920 --> 00:38:44,500
the fantastic conferences they had,

947
00:38:44,500 --> 00:38:47,383
the brilliant postdocs and faculty there

948
00:38:47,383 --> 00:38:50,670
that really made for a very intense

949
00:38:50,670 --> 00:38:52,280
and gratifying experience.

950
00:38:52,280 --> 00:38:54,840
- Is that where you felt
sort of you transitioned

951
00:38:54,840 --> 00:38:56,570
from student to scientist?

952
00:38:56,570 --> 00:38:57,960
- Yeah, yeah, exactly.

953
00:38:57,960 --> 00:39:00,350
Presumably that's true for many postdocs,

954
00:39:00,350 --> 00:39:01,720
you know, that's precisely the period

955
00:39:01,720 --> 00:39:03,690
in which that transition occurs.

956
00:39:03,690 --> 00:39:06,435
But for me, the KITP was
particularly special, I think,

957
00:39:06,435 --> 00:39:09,950
due to it's unique conference environment,

958
00:39:09,950 --> 00:39:11,050
I guess Santa Barbara is great.

959
00:39:11,050 --> 00:39:12,900
- Yeah, not too far from your home.

960
00:39:12,900 --> 00:39:14,160
- Yeah, yeah, that's right.

961
00:39:14,160 --> 00:39:16,000
- Santa Barbara's a nice
place to do some physics.

962
00:39:16,000 --> 00:39:17,630
You can do just about anything probably.

963
00:39:17,630 --> 00:39:18,500
- Yeah, yeah.

964
00:39:18,500 --> 00:39:21,690
- I've also often thought
that beginning a postdoc

965
00:39:21,690 --> 00:39:23,490
must be very challenging.

966
00:39:23,490 --> 00:39:25,140
I guess it's exciting,
but also challenging,

967
00:39:25,140 --> 00:39:28,120
because as a PhD student,
you have an advisor

968
00:39:28,120 --> 00:39:30,870
that can maybe help you decide
what problems to work on.

969
00:39:30,870 --> 00:39:32,330
And then as a postdoc, it's really,

970
00:39:32,330 --> 00:39:35,230
you have to become much more independent.

971
00:39:35,230 --> 00:39:38,670
Was it difficult to choose what
to focus on in your postdoc?

972
00:39:38,670 --> 00:39:42,260
- Yeah, it was definitely
pretty challenging

973
00:39:42,260 --> 00:39:44,930
just trying to survive on your own,

974
00:39:44,930 --> 00:39:46,593
floating in the open sea.

975
00:39:47,570 --> 00:39:49,370
But I think what helped
me the most was just

976
00:39:49,370 --> 00:39:52,120
having these other postdocs around that

977
00:39:52,120 --> 00:39:55,040
were great to talk to, bounce ideas off,

978
00:39:55,040 --> 00:39:57,490
give feedback on, it's that environment

979
00:39:57,490 --> 00:39:58,750
that was really special.

980
00:39:58,750 --> 00:40:01,000
- And then what drew you back to Perimeter

981
00:40:01,000 --> 00:40:03,410
to continue your career after the postdoc?

982
00:40:03,410 --> 00:40:06,890
- Perimeter and KTP actually
have a lot in common,

983
00:40:06,890 --> 00:40:08,357

weather not withstanding..

984
00:40:09,230 --> 00:40:12,200
But in terms of the
philosophy and activity,

985
00:40:12,200 --> 00:40:14,190
it's quite similar.

986
00:40:14,190 --> 00:40:17,560
Perimeter also has a great
throughput of visitors,

987
00:40:17,560 --> 00:40:18,900
at least before the pandemic.

988
00:40:18,900 --> 00:40:20,320
This idea of having all these conferences

989
00:40:20,320 --> 00:40:22,690
in different areas, that
you can just listen to,

990
00:40:22,690 --> 00:40:24,930
that are well outside your own specialty

991
00:40:24,930 --> 00:40:27,860
was also one of the
most appealing factors.

992
00:40:27,860 --> 00:40:29,760
The other thing is just
the spirit of Perimeter

993
00:40:29,760 --> 00:40:33,720
seems to be to tackle
very fundamental problems

994
00:40:33,720 --> 00:40:38,000

in unique ways, that other
people haven't even considered.

995
00:40:38,000 --> 00:40:41,110
And I think that that
approach of doing physics

996
00:40:41,110 --> 00:40:43,080
that also drew me to here.

997
00:40:43,080 --> 00:40:45,590
- And also combining people
maybe from different areas

998
00:40:45,590 --> 00:40:46,423
like you were saying.

999
00:40:46,423 --> 00:40:48,570
- Yeah, yeah, that's right, that's right,

1000
00:40:48,570 --> 00:40:51,000
all branches of theoretical physics.

1001
00:40:51,000 --> 00:40:52,870
- You've recently started to tackle

1002
00:40:52,870 --> 00:40:57,870
another very challenging, let's
say another big challenge,

1003
00:40:57,880 --> 00:40:58,713
fatherhood.

1004
00:40:58,713 --> 00:40:59,640
- Right, right.

1005
00:40:59,640 --> 00:41:00,500
- How is that going for you?

1006
00:41:00,500 --> 00:41:02,580
- You know, I think
from that point of view,

1007
00:41:02,580 --> 00:41:04,280
the physics is actually very easy,

1008
00:41:05,743 --> 00:41:09,667
You know, physics, at least
there's some predictable laws

1009
00:41:10,730 --> 00:41:13,274
that you can use to calculate.

1010
00:41:13,274 --> 00:41:16,880
But yeah, for fatherhood,
it's at the same time,

1011
00:41:16,880 --> 00:41:19,730
you know, very tiring,
but also very exciting,

1012
00:41:19,730 --> 00:41:21,720
in part due to this unpredictability.

1013
00:41:21,720 --> 00:41:24,840
You have this complex many body system

1014
00:41:24,840 --> 00:41:29,840
that is just absorbing and
emitting information that...

1015
00:41:32,543 --> 00:41:35,550
Yeah, it's just, you know,
impossible to predict.

1016
00:41:35,550 --> 00:41:38,418
It's also at the same
time, like fascinating.

1017
00:41:38,418 --> 00:41:41,350
- Does it help you see your work or life

1018
00:41:41,350 --> 00:41:44,290
or everything through a different lens?

1019
00:41:44,290 --> 00:41:46,860
- Yeah, I think having a kid
has definitely motivated me

1020
00:41:46,860 --> 00:41:49,920
even more to think outside of the box.

1021
00:41:49,920 --> 00:41:51,810
This baby is just, you know, again,

1022
00:41:51,810 --> 00:41:54,950
taking in all this
information in her own way

1023
00:41:54,950 --> 00:41:57,750
and trying to make her own sense

1024
00:41:57,750 --> 00:42:00,350
of this mysterious world out there.

1025
00:42:00,350 --> 00:42:02,940
And I think it's this kind
of first principles approach

1026
00:42:02,940 --> 00:42:06,350
at looking at the world
that helps one make

1027
00:42:06,350 --> 00:42:08,840
very original research progress.

1028

00:42:08,840 --> 00:42:10,540
So I think this has
definitely motivated me

1029
00:42:10,540 --> 00:42:13,493
to think even more outside
the box and be more creative.

1030
00:42:14,400 --> 00:42:15,960
- And Tim, we have one more question.

1031
00:42:15,960 --> 00:42:19,580
This one was sent in by
Nayeli Rodríguez Briones

1032
00:42:19,580 --> 00:42:20,810
and she's a postdoc

1033
00:42:20,810 --> 00:42:23,050
at the University of California Berkeley.

1034
00:42:23,050 --> 00:42:24,220
She wrote in this question,

1035
00:42:24,220 --> 00:42:27,230
she asked what has been
the most surprising

1036
00:42:27,230 --> 00:42:30,060
or intriguing result
that you have obtained

1037
00:42:30,060 --> 00:42:32,390
in your research so far?

1038
00:42:32,390 --> 00:42:35,713
- Something I did while postdoc at KITP,

1039
00:42:35,713 --> 00:42:40,713

this is basically a way to kind
of upgrade a phase of matter

1040
00:42:41,030 --> 00:42:44,100
by coupling to auxiliary system.

1041
00:42:44,100 --> 00:42:44,933
In phases of matter,

1042
00:42:44,933 --> 00:42:47,270
you can have various
degrees of complexity.

1043
00:42:47,270 --> 00:42:49,730
You know, I mentioned these
topological phases of matter,

1044
00:42:49,730 --> 00:42:53,000
but there are different
degrees of how exotic

1045
00:42:53,000 --> 00:42:54,660
that phase can be.

1046
00:42:54,660 --> 00:42:56,900
So for example, there exists things like

1047
00:42:56,900 --> 00:42:59,850
topological insulators
already in real materials,

1048
00:42:59,850 --> 00:43:01,330
like bismuth selenide.

1049
00:43:01,330 --> 00:43:05,310
These, I would say are the
slightly less exotic version.

1050
00:43:05,310 --> 00:43:07,520

However, there more exotic versions

1051
00:43:07,520 --> 00:43:10,230
where you can have this
phenomenon of fractionalization

1052
00:43:10,230 --> 00:43:12,860
where individual degrees
of freedom fractionalize

1053
00:43:12,860 --> 00:43:16,200
into excitations that
gain a life of their own

1054
00:43:16,200 --> 00:43:18,210
in this weird phase of matter.

1055
00:43:18,210 --> 00:43:21,930
And so what we found was
like a way to kind of upgrade

1056
00:43:21,930 --> 00:43:26,740
from the less exotic to this
more exotic fractionalization

1057
00:43:26,740 --> 00:43:29,320
by just coupling to a auxiliary system.

1058
00:43:29,320 --> 00:43:31,360
- And was this different
than what you were expecting

1059
00:43:31,360 --> 00:43:33,833
to find when you started
working on this project?

1060
00:43:33,833 --> 00:43:37,170
- It kind of arose from an
earlier project of mine,

1061
00:43:37,170 --> 00:43:39,520
in which I found that if you just couple

1062
00:43:39,520 --> 00:43:42,840
a topological phase of matter
to same degrees of freedom,

1063
00:43:42,840 --> 00:43:44,980
you can kind of clone that phase.

1064
00:43:44,980 --> 00:43:47,970
Like you can kind of duplicate
it in the auxiliary system.

1065
00:43:47,970 --> 00:43:50,040
We call this topological proximity effect.

1066
00:43:50,040 --> 00:43:54,480
You're kind of inducing the
order on a nearby system.

1067
00:43:54,480 --> 00:43:57,710
This work dimension before
this upgrading of the phase

1068
00:43:57,710 --> 00:43:59,505
arose and we realized that if you couple

1069
00:43:59,505 --> 00:44:01,070
to different degrees of freedom,

1070
00:44:01,070 --> 00:44:05,000
you can actually kind of clone
it in a very different way.

1071
00:44:05,000 --> 00:44:06,867
You can impart the non-trivialness

1072

00:44:06,867 --> 00:44:09,100
of the first system onto the second one,

1073
00:44:09,100 --> 00:44:11,880
but twist it in a more complicated way

1074
00:44:11,880 --> 00:44:15,060
and make a even more
intriguing phase of matter.

1075
00:44:15,060 --> 00:44:17,460
- It seems exciting to
be doing all these things

1076
00:44:17,460 --> 00:44:19,522
because you're doing them
essentially for the first time,

1077
00:44:19,522 --> 00:44:23,090
it's uncharted territory,
you're combining things,

1078
00:44:23,090 --> 00:44:25,918
and then looking for something
that nobody's seen before.

1079
00:44:25,918 --> 00:44:26,955
- Yeah, yeah.

1080
00:44:26,955 --> 00:44:29,681
- There's a nice
exploratory element to that.

1081
00:44:29,681 --> 00:44:33,440
Does it keep you curious
and keep you energized

1082
00:44:33,440 --> 00:44:35,540
because you don't know
exactly what's gonna....?

1083
00:44:35,540 --> 00:44:36,830
- Yeah, yeah, definitely, definitely.

1084
00:44:36,830 --> 00:44:39,050
I think that that's, you
know, part of the whole,

1085
00:44:39,050 --> 00:44:40,940
the beauty of quantum mechanics, right?

1086
00:44:40,940 --> 00:44:43,605
You have this space of possibilities

1087
00:44:43,605 --> 00:44:45,780
that's exponentially large.

1088
00:44:45,780 --> 00:44:47,263
There are all these
possibilities out there.

1089
00:44:47,263 --> 00:44:50,600
Many of them that are probably
not terribly physical,

1090
00:44:50,600 --> 00:44:52,600
but a large portion are surely physical.

1091
00:44:52,600 --> 00:44:56,020
And we have yet to reach
those portions of space.

1092
00:44:56,020 --> 00:44:57,930
So that definitely keeps me going,

1093
00:44:57,930 --> 00:45:00,290
this wide space of possibility.

1094

00:45:00,290 --> 00:45:03,150
- Your enthusiasm really comes across,

1095
00:45:03,150 --> 00:45:07,100
it's so fun to talk to people
who are working on things

1096
00:45:07,100 --> 00:45:08,580
that I don't fully understand,

1097
00:45:08,580 --> 00:45:11,200
but I can see that they just love it.

1098
00:45:11,200 --> 00:45:12,960
And that there's so
much possibility there,

1099
00:45:12,960 --> 00:45:15,030
that you're always
exploring something new,

1100
00:45:15,030 --> 00:45:15,863
it's fascinating.
- Right.

1101
00:45:15,863 --> 00:45:17,720
- Tim, Well, thank you
so much for sitting down

1102
00:45:17,720 --> 00:45:18,553
with us today,

1103
00:45:18,553 --> 00:45:20,228
this has been really fascinating and it-

1104
00:45:20,228 --> 00:45:21,290
- Yeah, thanks.
- And really a pleasure

1105

00:45:21,290 --> 00:45:23,421
to talk to you.
- No problem, my pleasure.

1106
00:45:23,421 --> 00:45:26,088
(upbeat music)

1107
00:45:26,940 --> 00:45:29,290
- Thanks for stepping
inside the Perimeter.

1108
00:45:29,290 --> 00:45:30,770
Please, help us out.

1109
00:45:30,770 --> 00:45:33,019
- You can rate, review and subscribe.

1110
00:45:33,019 --> 00:45:36,230
- And please be sure to tell two friends.

1111
00:45:36,230 --> 00:45:39,160
- It's important that
you tell two and not one,

1112
00:45:39,160 --> 00:45:41,240
because that way exponential growth

1113
00:45:41,240 --> 00:45:44,690
will get us to billions
of listeners in no time.

1114
00:45:44,690 --> 00:45:45,998
- Science.

1115
00:45:45,998 --> 00:45:48,665
(upbeat music)