1
00:00:00,136 --> 00:00:03,636
(gentle electronic music)

2
00:00:08,960 --> 00:00:12,310
- Hi, and welcome to
"Conversations at the Perimeter."

3
00:00:12,310 --> 00:00:15,220
Today we're excited to share
with you this conversation

4
00:00:15,220 --> 00:00:16,570
with Ray Laflamme.

5
00:00:16,570 --> 00:00:19,960
Ray is a researcher at the
Institute for Quantum Computing

6
00:00:19,960 --> 00:00:21,620
and the Perimeter Institute,

7
00:00:21,620 --> 00:00:23,850
and he's an expert on everything related

8
00:00:23,850 --> 00:00:25,340
to quantum information.

9
00:00:25,340 --> 00:00:27,760
- I was so excited to have
this conversation with Ray.

10
00:00:27,760 --> 00:00:29,950
I've been looking forward
to it for a long time

11
00:00:29,950 --> 00:00:33,420
'cause I've known Ray for about
12 years 'cause he hired me.

12
00:00:33,420 --> 00:00:35,830
He was my boss at the
Institute for Quantum Computing

13
00:00:35,830 --> 00:00:37,390
when I worked in communications,

14
00:00:37,390 --> 00:00:38,760
and he's really responsible

15
00:00:38,760 --> 00:00:41,130
for teaching me the things I first learned

16
00:00:41,130 --> 00:00:42,330
about quantum computing

17
00:00:42,330 --> 00:00:45,210
by showing me around and
taking me to the labs.

18
00:00:45,210 --> 00:00:48,410
And his passion and his dedication

19
00:00:48,410 --> 00:00:50,270
to the science is really infectious.

20
00:00:50,270 --> 00:00:53,260
And as you'll hear, he's
a wonderful storyteller.

21
00:00:53,260 --> 00:00:56,750
And he told us stories about
his early days studying

22
00:00:56,750 --> 00:00:59,080
under Stephen Hawking at Cambridge

23
00:00:59,080 --> 00:01:01,920

and then working at Los
Alamos National Laboratory

24
00:01:01,920 --> 00:01:04,560
and then more recently, his
struggle with lung cancer

25
00:01:04,560 --> 00:01:06,320
and how that's shaped his perspectives

26
00:01:06,320 --> 00:01:07,920
on life in the future.

27
00:01:07,920 --> 00:01:09,470
- I really loved hearing his stories

28
00:01:09,470 --> 00:01:10,757
about how quantum computing

29
00:01:10,757 --> 00:01:13,550
and quantum technology
has evolved over the years

30
00:01:13,550 --> 00:01:16,140
and also what we can
expect for the future.

31
00:01:16,140 --> 00:01:18,953
So let's step inside the
perimeter with Ray Laflamme.

32
00:01:22,600 --> 00:01:24,530
- Ray, Laflamme, thank you
so much for being here.

33
00:01:24,530 --> 00:01:25,790
It's great to see you.

34
00:01:25,790 --> 00:01:26,760

- You're welcome.

35
00:01:26,760 --> 00:01:28,130
- I wanna start with a big question.

36
00:01:28,130 --> 00:01:29,360
How's life?

37
00:01:29,360 --> 00:01:30,723
- Life is really good.

38
00:01:30,723 --> 00:01:33,730
Definitely after a pandemic of two years,

39
00:01:33,730 --> 00:01:37,020
life seems to pick up
again of seeing people.

40
00:01:37,020 --> 00:01:41,670
And then I think that pandemic
has made us enjoy the kind

41
00:01:41,670 --> 00:01:44,080
of precious moment even
more than we did before,

42
00:01:44,080 --> 00:01:46,220
realizing that there are things

43
00:01:46,220 --> 00:01:48,720
that goes in different ways as life goes,

44
00:01:48,720 --> 00:01:49,900
and then you adapt to them,

45
00:01:49,900 --> 00:01:53,660
and then suddenly you realize
kind of what are the diamonds

46
00:01:53,660 --> 00:01:56,010
that kind of before, you
were kind of neglecting.

47
00:01:56,010 --> 00:01:56,970
- This is part of the reason

48
00:01:56,970 --> 00:01:58,310
I was so excited to talk to you.

49
00:01:58,310 --> 00:01:59,870
I've known you now, I did the math,

50
00:01:59,870 --> 00:02:02,520
I think it's been about 12
years since we first met

51
00:02:02,520 --> 00:02:03,870
because you hired me to work

52
00:02:03,870 --> 00:02:06,220
at the Institute for Quantum
Computing in Waterloo,

53
00:02:06,220 --> 00:02:07,770
where you were the director.

54
00:02:07,770 --> 00:02:09,980
And I still remember the
first thing you said to me

55
00:02:09,980 --> 00:02:11,720
on the first day of the job.

56
00:02:11,720 --> 00:02:13,180
I bet you don't remember this.

57
00:02:13,180 --> 00:02:14,013

I remember it clearly.

58
00:02:14,013 --> 00:02:14,900
I walked into your office.

59
00:02:14,900 --> 00:02:17,670
You said, "Hello," and
you said, "Lose the tie,"

60
00:02:17,670 --> 00:02:19,252
because I was wearing a tie.

61
00:02:19,252 --> 00:02:21,310
And I thought, "Oh,
okay, I like this guy."

62
00:02:21,310 --> 00:02:23,730
And then you were such a mentor to me.

63
00:02:23,730 --> 00:02:26,090
I had come out of a journalism career,

64
00:02:26,090 --> 00:02:28,477
and I knew practically nothing
about quantum computing

65
00:02:28,477 --> 00:02:29,650
and quantum information.

66
00:02:29,650 --> 00:02:31,960
So you showed me around this Institute

67
00:02:31,960 --> 00:02:33,050
for Quantum Computing.

68
00:02:33,050 --> 00:02:35,420
Could you tell our
listeners what the Institute

69
00:02:35,420 --> 00:02:37,660
for Quantum Computing
is, how you got involved,

70
00:02:37,660 --> 00:02:38,703
and what it's for?

71
00:02:39,570 --> 00:02:41,800
- The Institute for Quantum
Computing is an Institute

72
00:02:41,800 --> 00:02:43,620
at the University of Waterloo

73
00:02:43,620 --> 00:02:47,440
whose aim is to develop the
science of quantum information.

74
00:02:47,440 --> 00:02:51,140
And that includes quantum
computing, quantum communication,

75
00:02:51,140 --> 00:02:53,330
quantum metrology, or quantum sensors,

76
00:02:53,330 --> 00:02:56,390
and some materials that are essential

77
00:02:56,390 --> 00:02:59,590
to build devices that
use quantum mechanics.

78
00:02:59,590 --> 00:03:03,700
So it's an institute whose first
goal is to do the research,

79
00:03:03,700 --> 00:03:06,850
the basic research related
to quantum information,

80
00:03:06,850 --> 00:03:11,210
the second one to train
a generation of students

81
00:03:11,210 --> 00:03:15,550
and scientists and
engineers who think quantum.

82
00:03:15,550 --> 00:03:18,000
We all kind of grow up,

83
00:03:18,000 --> 00:03:21,290
and you are learning Newton's mechanics

84
00:03:21,290 --> 00:03:22,630
or classical mechanics.

85
00:03:22,630 --> 00:03:24,230
Even if most people
don't call it that way,

86
00:03:24,230 --> 00:03:27,460
that's the way we understand
how to control our car,

87
00:03:27,460 --> 00:03:31,020
using our bicycle or whatever,
flying in an airplane.

88
00:03:31,020 --> 00:03:32,520
But really, the world

89
00:03:32,520 --> 00:03:36,930
at its very fundamental
part behaves differently,

90
00:03:36,930 --> 00:03:39,640
like atoms and molecules and electrons

91
00:03:39,640 --> 00:03:42,810
and protons has a different set of rules.

92
00:03:42,810 --> 00:03:45,970
And then we want to use these rules

93
00:03:45,970 --> 00:03:48,280
to manipulate information.

94
00:03:48,280 --> 00:03:50,200
- Could you give us
maybe an example of one

95
00:03:50,200 --> 00:03:52,470
or two of those uniquely quantum rules

96
00:03:52,470 --> 00:03:53,520
that you're trying to exploit

97
00:03:53,520 --> 00:03:55,870
and why harness these properties?

98
00:03:55,870 --> 00:03:58,720
- I'm happy you say why harness these

99
00:03:58,720 --> 00:04:00,730
instead of why do they behave that way

100
00:04:00,730 --> 00:04:03,290
because we just don't know
why they behave that way.

101
00:04:03,290 --> 00:04:05,640
The world is built in some way,

102
00:04:05,640 --> 00:04:08,330
and maybe there's a fundamental reason

103
00:04:08,330 --> 00:04:13,210
that one day we will discover
that it cannot be otherwise.

104
00:04:13,210 --> 00:04:14,580
It had to be this way.

105
00:04:14,580 --> 00:04:17,630
But right now, we just
kind of explore the world

106
00:04:17,630 --> 00:04:20,800
and try to understand how it works

107
00:04:20,800 --> 00:04:23,040
and not necessarily why it works that way.

108
00:04:23,040 --> 00:04:25,690
So one of these properties
of quantum mechanics

109
00:04:25,690 --> 00:04:28,110
is called the superposition principle.

110
00:04:28,110 --> 00:04:32,030
In the physics of Newton or
what I call classical physics,

111
00:04:32,030 --> 00:04:35,520
we think of objects made of particles,

112
00:04:35,520 --> 00:04:37,190
and particles are little things

113
00:04:37,190 --> 00:04:41,110
that are at a given position in time

114

00:04:41,110 --> 00:04:43,650
and at a given velocity.

115
00:04:43,650 --> 00:04:46,490
This works very well to
describe most of the world

116
00:04:46,490 --> 00:04:49,070
that we interact with in day to day,

117
00:04:49,070 --> 00:04:51,070
except people like me and my students

118
00:04:51,070 --> 00:04:53,440
and my colleagues who suddenly go in labs

119
00:04:53,440 --> 00:04:55,430
and isolate these particles very well

120
00:04:55,430 --> 00:04:56,937
and try to see how they work.

121
00:04:56,937 --> 00:04:58,900
And what we find is there's something

122
00:04:58,900 --> 00:05:00,490
called a superposition principle.

123
00:05:00,490 --> 00:05:03,220
These fundamental
particle of nature can be

124
00:05:03,220 --> 00:05:05,400
at more than one place at a given time.

125
00:05:05,400 --> 00:05:09,610
So a single system can be here
and there at the same time.

126
00:05:09,610 --> 00:05:12,620
We are trying to use this property,

127
00:05:12,620 --> 00:05:15,650
the superposition principle,
and use it to compute.

128
00:05:15,650 --> 00:05:18,700
And so we kind of discovered

129
00:05:18,700 --> 00:05:22,130
that if we use these properties,
we can build computers,

130
00:05:22,130 --> 00:05:24,480
or we are attempting to
build these computers.

131
00:05:24,480 --> 00:05:26,460
We're still kind of early in that stage.

132
00:05:26,460 --> 00:05:28,590
Although we have some
really good prototypes

133
00:05:28,590 --> 00:05:30,790
that shows that the science is okay

134
00:05:30,790 --> 00:05:32,770
and kind of things are working the way

135
00:05:32,770 --> 00:05:34,480
that we're thinking they should work.

136
00:05:34,480 --> 00:05:36,770
And so we found that by using the rules

137
00:05:36,770 --> 00:05:38,400

of quantum mechanics,

138
00:05:38,400 --> 00:05:41,830
the theory that described
this kind of very small part

139
00:05:41,830 --> 00:05:42,663
of the world,

140
00:05:42,663 --> 00:05:46,160
if we use the rules of
quantum mechanics to compute,

141
00:05:46,160 --> 00:05:49,190
we can solve problems which
seems to be intractable

142
00:05:49,190 --> 00:05:51,170
with classical computers.

143
00:05:51,170 --> 00:05:55,150
And suddenly it tells us
that if we can do that,

144
00:05:55,150 --> 00:05:58,990
there's a wild world of information

145
00:05:58,990 --> 00:06:01,640
that will open to us that we haven't,

146
00:06:01,640 --> 00:06:06,640
which is totally surprising
because it is mind-boggling

147
00:06:06,660 --> 00:06:10,550
what we've seen in the last
50 years with the computing

148
00:06:10,550 --> 00:06:13,550

or information revolution.

149
00:06:13,550 --> 00:06:16,590
Before people were
having to jump on a horse

150
00:06:16,590 --> 00:06:18,510
to tell the story to somebody else

151
00:06:18,510 --> 00:06:21,070
in the 16th, 17th, 18th century.

152
00:06:21,070 --> 00:06:23,470
And suddenly people invented the telegraph

153
00:06:23,470 --> 00:06:27,143
where we can send things,
short waves to send messages.

154
00:06:28,090 --> 00:06:32,160
This turned into computers
in the 1970s and '80s

155
00:06:32,160 --> 00:06:35,090
and to cellular phone that we have today.

156
00:06:35,090 --> 00:06:36,840
When we look at our kids,

157
00:06:36,840 --> 00:06:38,530
if you want to give them a hard time,

158
00:06:38,530 --> 00:06:39,820
you take their cell phone off.

159
00:06:39,820 --> 00:06:43,510
It's like the end of the world,
like they cannot connect.

160
00:06:43,510 --> 00:06:46,410
You and me have grown up
where we had neighbors,

161
00:06:46,410 --> 00:06:48,650
and our friends were neighbors.

162
00:06:48,650 --> 00:06:53,550
Our kids grow up where their
friends can be in France

163
00:06:53,550 --> 00:06:57,150
or in Japan or in South America.

164
00:06:57,150 --> 00:07:00,390
Instead of having a little local village,

165
00:07:00,390 --> 00:07:04,560
the earth is a global village,
all putting this together.

166
00:07:04,560 --> 00:07:07,660
That changed the way that
people think, how we behave,

167
00:07:07,660 --> 00:07:10,170
and what we think about the future,

168
00:07:10,170 --> 00:07:13,700
so this incredible change
of how we conceive the world

169
00:07:13,700 --> 00:07:15,940
because of this information revolution.

170
00:07:15,940 --> 00:07:17,380
And suddenly quantum mechanics comes in

171

00:07:17,380 --> 00:07:20,830
and tells us things can
be very, very different.

172
00:07:20,830 --> 00:07:24,070
We can evaluate even so
much more information

173
00:07:24,070 --> 00:07:26,230
that these classical computers cannot do.

174
00:07:26,230 --> 00:07:27,357
So, there it is.

175
00:07:27,357 --> 00:07:30,003
And this is what the Institute
for Quantum Computing,

176
00:07:30,003 --> 00:07:31,930
I would say the Perimeter also,

177
00:07:31,930 --> 00:07:33,100
are investigating these pieces

178
00:07:33,100 --> 00:07:35,090
and trying to put all of this together.

179
00:07:35,090 --> 00:07:36,850
- So as you've alluded to,

180
00:07:36,850 --> 00:07:39,360
this field and the related technology,

181
00:07:39,360 --> 00:07:42,060
it's really very quickly
growing and changing.

182
00:07:42,060 --> 00:07:44,840
So I would assume that

would mean the goals

183
00:07:44,840 --> 00:07:46,260
of a place like the Institute

184
00:07:46,260 --> 00:07:48,350
for Quantum Computing
would also have to evolve.

185
00:07:48,350 --> 00:07:50,030
Can you tell us a little bit

186
00:07:50,030 --> 00:07:52,550
about how those goals have changed

187
00:07:52,550 --> 00:07:54,950
throughout the time
that you've been there?

188
00:07:54,950 --> 00:07:57,490
- Yes, I'm kind of thinking of this

189
00:07:57,490 --> 00:07:59,930
and kind of putting myself back 20 years

190
00:07:59,930 --> 00:08:01,970
when I first came to Waterloo.

191
00:08:01,970 --> 00:08:06,970
At the time, the goal was
mostly to convince people around

192
00:08:07,100 --> 00:08:09,647
that this idea of quantum
computing was not totally crazy,

193
00:08:09,647 --> 00:08:12,330
and I say not totally crazy
because we don't have them yet.

194
00:08:12,330 --> 00:08:14,520
And me as a scientist,

195
00:08:14,520 --> 00:08:16,500
as a scientist, you shouldn't
kind of believe something

196
00:08:16,500 --> 00:08:18,380
until you see all the goods.

197
00:08:18,380 --> 00:08:21,120
We don't have a full-fledged
quantum computer today,

198
00:08:21,120 --> 00:08:24,530
and until we have one, you
should have a little skepticism.

199
00:08:24,530 --> 00:08:26,730
Although I really
believe we will have one,

200
00:08:26,730 --> 00:08:29,100
but this is a belief and
not the scientific data,

201
00:08:29,100 --> 00:08:31,363
and quite a distinction between the two.

202
00:08:32,340 --> 00:08:34,710
In the 2000s, a lot of the work

203
00:08:34,710 --> 00:08:38,030
of the director of the
institute was to convince people

204
00:08:38,030 --> 00:08:40,920
that this was really an important field.

205
00:08:40,920 --> 00:08:42,560
And we seem to have done a very good job

206
00:08:42,560 --> 00:08:45,530
because people now are,

207
00:08:45,530 --> 00:08:49,210
there's investment from
government, industry,

208
00:08:49,210 --> 00:08:51,140
many universities across Canada

209
00:08:51,140 --> 00:08:54,570
and around the world have
group of quantum information.

210
00:08:54,570 --> 00:08:55,680
Now this is different.

211
00:08:55,680 --> 00:09:00,500
Now a lot of the work is really
to develop these ideas to

212
00:09:00,500 --> 00:09:03,480
in part better understand where the power

213
00:09:03,480 --> 00:09:04,980
of quantum computing comes in,

214
00:09:04,980 --> 00:09:07,750
find new class of algorithms

215
00:09:07,750 --> 00:09:10,337
that kind of quantum computing could help

216
00:09:10,337 --> 00:09:12,710

and kind of make more efficient

217
00:09:12,710 --> 00:09:16,850
and then turn into how do
we rebuild these devices

218
00:09:16,850 --> 00:09:17,720
and building them.

219
00:09:17,720 --> 00:09:21,010
So maybe 20 years ago,
we were really asking

220
00:09:21,010 --> 00:09:23,110
how can we really build these things?

221
00:09:23,110 --> 00:09:25,930
Now we have a bunch of blueprints,

222
00:09:25,930 --> 00:09:29,510
and people are in lab trying
to show them, and industry.

223
00:09:29,510 --> 00:09:32,110
Building quantum computers
has become complex enough

224
00:09:32,110 --> 00:09:35,040
that it is hard to make
this in a university,

225
00:09:35,040 --> 00:09:37,330
in part because it takes a long time

226
00:09:37,330 --> 00:09:41,370
to go from the first steps to
the device that we have today.

227
00:09:41,370 --> 00:09:44,680

A generation of grad students
are three, four, five years,

228
00:09:44,680 --> 00:09:47,580
and that's all too short to
kind of keep things going.

229
00:09:47,580 --> 00:09:50,160
So we can make proof of principle

230
00:09:50,160 --> 00:09:54,140
of certain mechanism or certain things,

231
00:09:54,140 --> 00:09:58,330
but it is really the
IBM, Googles, and Xanadu

232
00:09:58,330 --> 00:10:00,680
and those that are really kind of putting

233
00:10:00,680 --> 00:10:02,460
all the engineering together

234
00:10:02,460 --> 00:10:06,070
and kind of developing
these ideas to get devices.

235
00:10:06,070 --> 00:10:09,150
And indeed, they are producing devices,

236
00:10:09,150 --> 00:10:11,300
not the one what we finally want,

237
00:10:11,300 --> 00:10:13,280
but enough to give us confidence

238
00:10:13,280 --> 00:10:14,720
that we are on the right track.

239
00:10:14,720 --> 00:10:17,550
- Takes a lot of pieces and a
lot of collaboration, I guess.

240
00:10:17,550 --> 00:10:19,640
- Yes, a lot of pieces,
a lot of collaboration,

241
00:10:19,640 --> 00:10:21,140
a lot of stamina,

242
00:10:21,140 --> 00:10:24,140
lot also of understanding
where the problems

243
00:10:24,140 --> 00:10:27,207
and the challenges are and get over them

244
00:10:27,207 --> 00:10:28,993
and kind of moving forward.

245
00:10:30,359 --> 00:10:33,050
- You said that your primary job

246
00:10:33,050 --> 00:10:34,400
as director of the institute

247
00:10:34,400 --> 00:10:37,480
for the first 10, 15 years
or so was convincing people

248
00:10:37,480 --> 00:10:39,760
that this wasn't a crazy idea.

249
00:10:39,760 --> 00:10:41,830
Was there a time when you
needed to be convinced

250

00:10:41,830 --> 00:10:43,470
that it wasn't a crazy idea?

251
00:10:43,470 --> 00:10:46,010
Were you a skeptic about quantum computing

252
00:10:46,010 --> 00:10:48,003
before you were a preacher about it?

253
00:10:48,840 --> 00:10:51,400
- Yes, my first piece of
work on quantum computing was

254
00:10:51,400 --> 00:10:55,203
to try to prove that they
would never work, and I failed.

255
00:10:56,530 --> 00:11:00,150
- You failed and succeeded,
I'd say, in an equal measure.

256
00:11:00,150 --> 00:11:04,390
- So after my PhD, I went to Vancouver,

257
00:11:04,390 --> 00:11:07,550
and I worked with a
physicist called Bill Unruh.

258
00:11:07,550 --> 00:11:10,370
And Bill is an incredibly good physicist,

259
00:11:10,370 --> 00:11:14,200
and he has this tendency of,
he really likes to argue.

260
00:11:14,200 --> 00:11:15,910
And as a post-doctoral fellow,

261
00:11:15,910 --> 00:11:18,520

it turns out that
sometimes it was very hard

262
00:11:18,520 --> 00:11:22,660
to work with him because
every time I had a new idea,

263
00:11:22,660 --> 00:11:24,100
I would tell him black,

264
00:11:24,100 --> 00:11:26,320
and as a person who really likes to argue

265
00:11:26,320 --> 00:11:28,750
and sharpen your ideas,
he would say white.

266
00:11:28,750 --> 00:11:30,360
We'd would argue for black and then black,

267
00:11:30,360 --> 00:11:33,150
and then he would kind of
poke holes at my arguments,

268
00:11:33,150 --> 00:11:35,610
which, after a while,
it gets really tiring,

269
00:11:35,610 --> 00:11:38,540
every time you have a new idea
that you kind of get poked.

270
00:11:38,540 --> 00:11:41,350
It is really good
scientifically to do this,

271
00:11:41,350 --> 00:11:43,890
but as a human being trying to do research

272

00:11:43,890 --> 00:11:46,890
and trying to make your name
with kind of being poked.

273
00:11:46,890 --> 00:11:49,320
But I learned that it was important.

274
00:11:49,320 --> 00:11:51,190
Probably 10 years after,

275
00:11:51,190 --> 00:11:52,750
I started to work on quantum computing.

276
00:11:52,750 --> 00:11:54,800
I went, in fact, to a
conference in San Fe.

277
00:11:54,800 --> 00:11:58,310
My mentor at Los Alamos
National Lab, Wojciech Zurek,

278
00:11:58,310 --> 00:11:59,580
told me there was this conference

279
00:11:59,580 --> 00:12:00,950
on the physics of information.

280
00:12:00,950 --> 00:12:02,900
And I initially said, "I
don't want to go there

281
00:12:02,900 --> 00:12:03,880
because I don't know anything

282
00:12:03,880 --> 00:12:05,830
about the physics of information."

283
00:12:05,830 --> 00:12:09,410
And Wojciech told me there's

really neat people going there.

284
00:12:09,410 --> 00:12:10,840
Like, what is it?

285
00:12:10,840 --> 00:12:12,290
It'll take two days.

286
00:12:12,290 --> 00:12:14,940
And it is kind of 45 minutes
away from Los Alamos.

287
00:12:14,940 --> 00:12:17,570
Says, "Just go," and so
I said, "Okay, I'll go."

288
00:12:17,570 --> 00:12:19,540
And it turns out that was
the first time I heard

289
00:12:19,540 --> 00:12:22,490
about this algorithm called
the Shor's algorithm,

290
00:12:22,490 --> 00:12:24,280
which is crucial for quantum computing.

291
00:12:24,280 --> 00:12:26,680
It's related to factoring numbers

292
00:12:26,680 --> 00:12:30,020
which are product of primes
using a quantum computer,

293
00:12:30,020 --> 00:12:33,093
which turns out to be an
algorithm on which cryptography,

294
00:12:33,950 --> 00:12:36,780

in fact, most of today's
world cryptography is based

295
00:12:36,780 --> 00:12:39,900
on the difficulty of factoring numbers

296
00:12:39,900 --> 00:12:41,230
which are products of primes.

297
00:12:41,230 --> 00:12:42,730
- Cryptography being the stuff

298
00:12:42,730 --> 00:12:44,560
that keeps our information safe?

299
00:12:44,560 --> 00:12:47,460
- Absolutely. When you use your cell

300
00:12:47,460 --> 00:12:50,680
or your computer to log into your bank,

301
00:12:50,680 --> 00:12:52,630
the cryptography that is set up

302
00:12:52,630 --> 00:12:55,070
so that it is private is based,

303
00:12:55,070 --> 00:12:57,440
like breaking the
cryptography is equivalent

304
00:12:57,440 --> 00:13:00,230
of finding the factors of a number

305
00:13:00,230 --> 00:13:01,370
which is the product of prime.

306
00:13:01,370 --> 00:13:04,800

So I went there, and so
this computer scientist,

307
00:13:04,800 --> 00:13:08,010
Umesh Vazirani, explained this algorithm,

308
00:13:08,010 --> 00:13:11,110
and in fact, he started
with a very funny story.

309
00:13:11,110 --> 00:13:13,690
Umesh is a really smart guy.

310
00:13:13,690 --> 00:13:15,297
He always has great ideas, all this.

311
00:13:15,297 --> 00:13:17,317
And he started this talk by saying,

312
00:13:17,317 --> 00:13:20,630
"I haven't done anything
interesting in the last two years."

313
00:13:20,630 --> 00:13:21,463
What?

314
00:13:21,463 --> 00:13:25,363
And usually scientists are very,
all of them are not humble.

315
00:13:26,750 --> 00:13:28,170
- That was put politely.

316
00:13:28,170 --> 00:13:31,100
- So that was a little surprising to hear.

317
00:13:31,100 --> 00:13:33,560
And he said, "But I've
heard about this algorithm,"

318
00:13:33,560 --> 00:13:35,690
which was going to be
called Shor's algorithm.

319
00:13:35,690 --> 00:13:38,010
And he says, "From this
guy called Peter Shor

320
00:13:38,010 --> 00:13:39,900
to factor numbers which
are product of prime."

321
00:13:39,900 --> 00:13:41,863
And there was a buzz in the conference

322
00:13:41,863 --> 00:13:43,540
that this was really important,

323
00:13:43,540 --> 00:13:45,060
and people were talking about it.

324
00:13:45,060 --> 00:13:46,140
At the time, I didn't know,

325
00:13:46,140 --> 00:13:48,280
I knew very little about cryptography.

326
00:13:48,280 --> 00:13:51,150
So it was very hard for me
to really assess everything.

327
00:13:51,150 --> 00:13:56,150
But there was really a
coherence in that conference.

328
00:13:57,770 --> 00:13:59,310
For those who know physics,

329
00:13:59,310 --> 00:14:03,010
it was like Bose condensation
of human beings' thoughts

330
00:14:03,010 --> 00:14:07,070
of kind of suddenly, wow,
something's happening here.

331
00:14:07,070 --> 00:14:10,610
I came back to the lab,
and I started the thing.

332
00:14:10,610 --> 00:14:11,840
I was working on something

333
00:14:11,840 --> 00:14:13,527
which was called quantum decoherence.

334
00:14:13,527 --> 00:14:16,260
And I said, "Oh, this quantum decoherence

335
00:14:16,260 --> 00:14:19,407
is gonna be an obstacle
to quantum computers."

336
00:14:19,407 --> 00:14:23,530
And I started to use little
kind of simple models

337
00:14:23,530 --> 00:14:26,420
to show that if there would
be quantum decoherence,

338
00:14:26,420 --> 00:14:27,850
quantum computers would not work.

339
00:14:27,850 --> 00:14:29,720
And so I kind of put things together.

340
00:14:29,720 --> 00:14:32,900
Not everything was tight and clean,

341
00:14:32,900 --> 00:14:35,590
but I was pushing the idea
that quantum computers

342
00:14:35,590 --> 00:14:36,567
would never work.

343
00:14:36,567 --> 00:14:39,350
And one day, there is this
thing called the archive

344
00:14:39,350 --> 00:14:41,890
where we get pre-prints for
everybody around the world.

345
00:14:41,890 --> 00:14:45,440
I look at the archive, and
there's a paper by Bill Unruh

346
00:14:45,440 --> 00:14:48,460
on quantum decoherence
and quantum computers

347
00:14:48,460 --> 00:14:49,610
giving exactly my method.

348
00:14:49,610 --> 00:14:53,593
So I was pretty miffed.
(all laugh)

349
00:14:54,640 --> 00:14:58,210
And then I said, "Oh, it's
pretty much the idea that I had."

350
00:14:58,210 --> 00:15:02,390
So, okay, my last couple

of months of work,

351
00:15:02,390 --> 00:15:04,550
it kind of goes in the garbage.

352
00:15:04,550 --> 00:15:09,550
But then I said, "Oh, Bill
always asked me to argue white

353
00:15:10,570 --> 00:15:13,780
when somebody says black,
and the other way around."

354
00:15:13,780 --> 00:15:16,770
So I started to work
to demolish his paper,

355
00:15:16,770 --> 00:15:18,690
and I tried to poke holes at it.

356
00:15:18,690 --> 00:15:20,210
- Which was essentially poking holes

357
00:15:20,210 --> 00:15:21,480
in your own ideas as well, right?

358
00:15:21,480 --> 00:15:22,620
- Absolutely.

359
00:15:24,560 --> 00:15:25,870
- Well, as a scientist,
- Idea?

360
00:15:25,870 --> 00:15:27,950
- You have to look at both sides.

361
00:15:27,950 --> 00:15:29,640
You don't know where the truth is.

362
00:15:29,640 --> 00:15:33,190
We have ideas, and you never
know if these ideas are right

363
00:15:33,190 --> 00:15:35,870
or wrong until you go
through the whole details

364
00:15:35,870 --> 00:15:38,570
of the mathematical
models and all of this.

365
00:15:38,570 --> 00:15:41,040
So I was poking the other way around

366
00:15:41,040 --> 00:15:43,080
to try to kind of demolish his idea.

367
00:15:43,080 --> 00:15:45,040
Then I didn't have to say to other people

368
00:15:45,040 --> 00:15:46,270
that I had the same idea.

369
00:15:46,270 --> 00:15:48,413
I can say, oh, this guy was wrong.

370
00:15:49,780 --> 00:15:54,780
So by doing this, I stumbled
into quantum error correction,

371
00:15:55,040 --> 00:15:59,230
which shows that not all errors

372
00:15:59,230 --> 00:16:01,410
will be kind of deadly
for quantum computers.

373

00:16:01,410 --> 00:16:05,460
There's family of models of
errors that if they happen,

374
00:16:05,460 --> 00:16:09,150
there's ways to take care of them.

375
00:16:09,150 --> 00:16:11,300
At that time, many physicists thought

376
00:16:11,300 --> 00:16:13,990
that this was impossible.

377
00:16:13,990 --> 00:16:16,140
- Because decoherence
causes too many errors

378
00:16:16,140 --> 00:16:18,330
and makes your computation worthless?

379
00:16:18,330 --> 00:16:21,460
- Yes, and quantum
mechanics has this property,

380
00:16:21,460 --> 00:16:23,160
it's called unitary.

381
00:16:23,160 --> 00:16:25,800
That is, if you make
a computation forward,

382
00:16:25,800 --> 00:16:28,890
if it is quantum mechanical,
it should go backward also.

383
00:16:28,890 --> 00:16:31,050
If noise comes in naively,

384
00:16:31,050 --> 00:16:33,200

it seems that you cannot
go backward again.

385
00:16:33,200 --> 00:16:36,640
So they would say it's just
not going to be possible

386
00:16:36,640 --> 00:16:38,100
to do this.

387
00:16:38,100 --> 00:16:40,150
The idea at first level seemed to be okay,

388
00:16:40,150 --> 00:16:42,870
but if you start to think
about it very carefully,

389
00:16:42,870 --> 00:16:44,030
it is not really correct.

390
00:16:44,030 --> 00:16:47,150
And this is what quantum error
correction is really about,

391
00:16:47,150 --> 00:16:49,550
is to find a way to be able to go forward

392
00:16:49,550 --> 00:16:51,600
and backward in your quantum computation,

393
00:16:51,600 --> 00:16:53,340
even if noise comes in.

394
00:16:53,340 --> 00:16:56,360
- So you essentially
demonstrated the opposite

395
00:16:56,360 --> 00:16:59,230
of what you thought, that

quantum computing is possible.

396
00:16:59,230 --> 00:17:00,890
- I think we should have to,

397
00:17:00,890 --> 00:17:04,200
I should be a little bit more precise.

398
00:17:04,200 --> 00:17:07,620
It didn't show that quantum
computation was possible

399
00:17:07,620 --> 00:17:09,160
because we don't have them yet.

400
00:17:09,160 --> 00:17:10,600
So we still don't know.

401
00:17:10,600 --> 00:17:14,220
It shows that noise
and quantum decoherence

402
00:17:14,220 --> 00:17:18,113
are not a fundamental objection
to get quantum computers.

403
00:17:19,200 --> 00:17:21,190
- And we also have to think
about error correction

404
00:17:21,190 --> 00:17:22,850
in classical computers, right?

405
00:17:22,850 --> 00:17:25,190
So can you tell us a little
bit about the difference,

406
00:17:25,190 --> 00:17:27,600
really, the fundamental

differences between classical

407
00:17:27,600 --> 00:17:29,580
and quantum error correction?

408
00:17:29,580 --> 00:17:30,910
- Now that becomes a little bit more,

409
00:17:30,910 --> 00:17:32,460
could become a little bit more technical.

410
00:17:32,460 --> 00:17:35,120
So I'll try not to be too technical.

411
00:17:35,120 --> 00:17:40,120
The idea is first related to
the type of noise that we have.

412
00:17:40,980 --> 00:17:42,570
In classical computers,

413
00:17:42,570 --> 00:17:45,680
all the information is encoded
in bits of information.

414
00:17:45,680 --> 00:17:48,610
Bits in information is the
smallest unit of information

415
00:17:48,610 --> 00:17:52,610
that we have typically encoded
in a system with two levels.

416
00:17:52,610 --> 00:17:53,850
And we call them zero or one,

417
00:17:53,850 --> 00:17:58,080
like something which is either
pointing up or pointing down,

418
00:17:58,080 --> 00:17:59,980
that little kind of magnetic moment,

419
00:17:59,980 --> 00:18:03,630
or a pulse of light which
is there or not there,

420
00:18:03,630 --> 00:18:05,870
or a switch on or off.

421
00:18:05,870 --> 00:18:07,777
So all the information is encoded in this.

422
00:18:07,777 --> 00:18:12,010
And the type of noise that
we have is called a bit flip.

423
00:18:12,010 --> 00:18:13,260
You have one bit.

424
00:18:13,260 --> 00:18:15,690
Let's say you want to send it to me.

425
00:18:15,690 --> 00:18:17,550
If it is zero, we'd get zero,

426
00:18:17,550 --> 00:18:20,000
but suddenly there's
noise between you and me.

427
00:18:20,000 --> 00:18:22,970
And then it gets flipped to
one, and I get the wrong answer.

428
00:18:22,970 --> 00:18:24,960
The idea of classical error correction

429

00:18:24,960 --> 00:18:28,380
is not send your bit one by one,

430
00:18:28,380 --> 00:18:32,860
but to encode them so that
instead of sending zero or one,

431
00:18:32,860 --> 00:18:36,530
you'll send me zero, zero,
zero, or one, one, one,

432
00:18:36,530 --> 00:18:38,650
three bit for the one.

433
00:18:38,650 --> 00:18:40,770
And if one of them flips,

434
00:18:40,770 --> 00:18:42,500
you can still recover the information

435
00:18:42,500 --> 00:18:44,330
just by taking the majority.

436
00:18:44,330 --> 00:18:48,220
If there's two errors, then
it's gonna fail, that process.

437
00:18:48,220 --> 00:18:50,340
But the process here will take care

438
00:18:50,340 --> 00:18:53,000
of the one-bit error that comes in,

439
00:18:53,000 --> 00:18:54,640
which would not have been taken care of

440
00:18:54,640 --> 00:18:56,260
if you sent it single bit.

441
00:18:56,260 --> 00:18:59,180
So now when you try to translate
this for quantum computing,

442
00:18:59,180 --> 00:19:01,980
there were fundamental objections
that this would happen.

443
00:19:01,980 --> 00:19:06,063
First, the noise in quantum
mechanics is not discrete

444
00:19:06,063 --> 00:19:10,150
like a zero, one, but it
could look like continuous.

445
00:19:10,150 --> 00:19:12,420
The second one is that it seems

446
00:19:12,420 --> 00:19:15,520
that when we have taken a bit, zero,

447
00:19:15,520 --> 00:19:19,480
and encoded it in zero, zero,
zero, we've copied it twice.

448
00:19:19,480 --> 00:19:20,860
And quantum mechanics tells us

449
00:19:20,860 --> 00:19:23,033
that we cannot copy quantum information.

450
00:19:24,080 --> 00:19:26,160
And the last thing is that when we try

451
00:19:26,160 --> 00:19:28,233
to make this majority voting,

452

00:19:29,070 --> 00:19:31,020
then we have to measure the bits.

453
00:19:31,020 --> 00:19:32,620
Another property of quantum mechanics

454
00:19:32,620 --> 00:19:34,200
that I could have mentioned

455
00:19:34,200 --> 00:19:36,290
at the beginning of this podcast,

456
00:19:36,290 --> 00:19:37,540
when you measure it,

457
00:19:37,540 --> 00:19:41,070
you kill the superposition
of zeros and one.

458
00:19:41,070 --> 00:19:44,790
By doing this, then you kill
the quantum information.

459
00:19:44,790 --> 00:19:48,240
So the question was how to get over this

460
00:19:48,240 --> 00:19:50,220
and these three objections.

461
00:19:50,220 --> 00:19:53,560
And the three ways now seems obvious

462
00:19:53,560 --> 00:19:55,170
once you know how it works,

463
00:19:55,170 --> 00:19:57,830
but it wasn't around the 1990s.

464

00:19:57,830 --> 00:20:01,430
And I'm not gonna go into
all details how it happens,

465
00:20:01,430 --> 00:20:03,520
but maybe I'll mention one thing.

466
00:20:03,520 --> 00:20:05,640
So, type of noise,

467
00:20:05,640 --> 00:20:08,470
it turns out that although
the noise can be thought

468
00:20:08,470 --> 00:20:09,430
to be continuous,

469
00:20:09,430 --> 00:20:12,360
there's a way also of
thinking it as being discrete.

470
00:20:12,360 --> 00:20:16,210
And the type of quantum
noise can be simplified

471
00:20:16,210 --> 00:20:19,260
to have either bit flips,
the classical noise,

472
00:20:19,260 --> 00:20:21,080
or what is called a phase flip.

473
00:20:21,080 --> 00:20:22,540
So when we have superposition,

474
00:20:22,540 --> 00:20:24,220
there's something called a phase,

475
00:20:24,220 --> 00:20:27,360

and this phase get changed
from plus to minus.

476
00:20:27,360 --> 00:20:30,660
So we certainly have two
types of discrete noise.

477
00:20:30,660 --> 00:20:32,970
And the combination of the two

478
00:20:32,970 --> 00:20:34,480
makes the type of noise that we have.

479
00:20:34,480 --> 00:20:37,900
So the continuous noise that
we have can be thought of

480
00:20:37,900 --> 00:20:39,750
as a discrete piece,

481
00:20:39,750 --> 00:20:43,170
and then we can get over
that first objection.

482
00:20:43,170 --> 00:20:44,880
And the last two are a
little bit more complex,

483
00:20:44,880 --> 00:20:47,210
so I'm not gonna mention
exactly how it works,

484
00:20:47,210 --> 00:20:48,480
but there's a way to go through.

485
00:20:48,480 --> 00:20:51,590
So there is a theory of
quantum error correction,

486

00:20:51,590 --> 00:20:53,330
and it turns out that
classical error correction

487
00:20:53,330 --> 00:20:56,760
is like a subset of
quantum error correction.

488
00:20:56,760 --> 00:20:58,100
It's quantum error correction

489
00:20:58,100 --> 00:20:59,840
when we don't have phase errors.

490
00:20:59,840 --> 00:21:01,780
We have only bit flip errors.

491
00:21:01,780 --> 00:21:04,733
And then in that case,
things are lot, lot simpler.

492
00:21:05,820 --> 00:21:08,690
- And these considerations
about noise and copying,

493
00:21:08,690 --> 00:21:11,180
they are challenges that
you need to overcome

494
00:21:11,180 --> 00:21:12,690
when you're doing
quantum error correction,

495
00:21:12,690 --> 00:21:15,070
but are they also kind of advantages

496
00:21:15,070 --> 00:21:16,770
when we're trying to encrypt data?

497

00:21:17,760 --> 00:21:18,780
- Well, the advantage is

498
00:21:18,780 --> 00:21:21,630
that you can keep these superpositions

499
00:21:21,630 --> 00:21:24,470
that we don't care in the classical world

500
00:21:24,470 --> 00:21:26,860
because your bits are either zero or one.

501
00:21:26,860 --> 00:21:29,040
In quantum mechanics, and
maybe I should have said this

502
00:21:29,040 --> 00:21:30,380
at the beginning of this podcast,

503
00:21:30,380 --> 00:21:33,660
that the bits in quantum
information are called qubits

504
00:21:33,660 --> 00:21:37,620
or quantum bits, a name
coined by Ben Schumacher.

505
00:21:37,620 --> 00:21:40,690
And these quantum bits
can be in a superposition

506
00:21:40,690 --> 00:21:42,410
of being in zero and one.

507
00:21:42,410 --> 00:21:45,090
There's one way of kind of
having a picture of this.

508
00:21:45,090 --> 00:21:47,260

You can take the surface of the sphere

509
00:21:47,260 --> 00:21:51,730
as the kind of quantum state
that one qubit can have.

510
00:21:51,730 --> 00:21:54,370
The classical bits are the
north and the south pole.

511
00:21:54,370 --> 00:21:56,130
We'll call them zero and one.

512
00:21:56,130 --> 00:21:59,090
But if you are anywhere
else on the sphere,

513
00:21:59,090 --> 00:22:03,090
then you are in zero and
one at the same time.

514
00:22:03,090 --> 00:22:05,560
And so these different
kind of states allows you

515
00:22:05,560 --> 00:22:06,871
to do something different.

516
00:22:06,871 --> 00:22:08,790
In fact, the transformation
to go from zero

517
00:22:08,790 --> 00:22:12,070
to a superposition of zeros and ones

518
00:22:12,070 --> 00:22:15,650
is something that classical
computers cannot do.

519

00:22:15,650 --> 00:22:18,610
And so by having a quantum computer,

520
00:22:18,610 --> 00:22:20,320
suddenly you have different types

521
00:22:20,320 --> 00:22:24,240
of transformation you can
do with your information.

522
00:22:24,240 --> 00:22:27,890
And the hope initially
was to find shortcuts,

523
00:22:27,890 --> 00:22:28,960
that there would be shortcuts

524
00:22:28,960 --> 00:22:30,620
that if you had different transformation,

525
00:22:30,620 --> 00:22:33,340
if you can do some things
that your peer cannot do,

526
00:22:33,340 --> 00:22:36,660
maybe you can kind of find a
shortcut to go somewhere else.

527
00:22:36,660 --> 00:22:37,830
And indeed, quantum mechanics

528
00:22:37,830 --> 00:22:39,273
and quantum algorithms are exactly this.

529
00:22:39,273 --> 00:22:42,140
They are shortcut to get to the answer.

530
00:22:42,140 --> 00:22:43,570
- When you showed me around the Institute

531
00:22:43,570 --> 00:22:45,230
for Quantum Computing for the first time

532
00:22:45,230 --> 00:22:46,600
and showed me what the labs were,

533
00:22:46,600 --> 00:22:49,050
and then I would give tours
to visitors around the labs,

534
00:22:49,050 --> 00:22:50,620
and you would see in one lab,

535
00:22:50,620 --> 00:22:53,070
it would be all dark
with lasers and mirrors.

536
00:22:53,070 --> 00:22:55,930
And you'd see these lasers
bouncing off of things.

537
00:22:55,930 --> 00:22:57,890
And you go to the next
lab, and there's a big,

538
00:22:57,890 --> 00:23:00,170
the nuclear magnetic resonance can.

539
00:23:00,170 --> 00:23:02,820
I don't know what you
call it, this super cool,

540
00:23:02,820 --> 00:23:05,690
your quantum computer
prototype in one lab.

541
00:23:05,690 --> 00:23:08,290
And then another lab has ion traps.

542
00:23:08,290 --> 00:23:10,910
There's all these different approaches.

543
00:23:10,910 --> 00:23:12,880
Are they sort of different attempts

544
00:23:12,880 --> 00:23:15,040
to find the right way
to do quantum computing,

545
00:23:15,040 --> 00:23:17,870
or are they all sort of
part of the same effort

546
00:23:17,870 --> 00:23:19,800
at harnessing quantum information?

547
00:23:19,800 --> 00:23:23,800
- They're all different
blueprints for quantum computers,

548
00:23:23,800 --> 00:23:26,560
and it's not clear yet
which one is the winner

549
00:23:26,560 --> 00:23:28,020
in all of this.

550
00:23:28,020 --> 00:23:33,020
People are making bets of
which one will be the best one.

551
00:23:33,120 --> 00:23:35,210
Different companies have different ideas

552
00:23:35,210 --> 00:23:37,010
of which one will end.

553
00:23:37,010 --> 00:23:39,350
What they have in common
is that they all want

554
00:23:39,350 --> 00:23:40,970
to manipulate quantum information,

555
00:23:40,970 --> 00:23:45,340
and they have different
physical implementation

556
00:23:45,340 --> 00:23:47,120
of how to do this.

557
00:23:47,120 --> 00:23:49,250
In some sense, we can think of,

558
00:23:49,250 --> 00:23:52,780
in classical computers
today who have all chips

559
00:23:52,780 --> 00:23:54,240
will all look the same.

560
00:23:54,240 --> 00:23:58,977
But if you do classical computing,
you could have an abacus.

561
00:23:58,977 --> 00:24:01,940
An abacus is a way of
manipulating information,

562
00:24:01,940 --> 00:24:03,750
and you can have a slide rule

563
00:24:03,750 --> 00:24:06,075
which tells you how to calculate, also.

564

00:24:06,075 --> 00:24:07,550
There are different ways of doing this.

565
00:24:07,550 --> 00:24:09,880
Now, I'm not gonna compare
the different implementation

566
00:24:09,880 --> 00:24:13,100
to the slide rule and
today's kind of modern,

567
00:24:13,100 --> 00:24:15,850
which one is a slide rule, which
one is the modern computer.

568
00:24:15,850 --> 00:24:18,990
I'm gonna kind of say
nothing about this exactly,

569
00:24:18,990 --> 00:24:22,560
but the different
implementations are aiming

570
00:24:22,560 --> 00:24:25,170
to be the quantum computer.

571
00:24:25,170 --> 00:24:28,210
And maybe it's possible that
there could be more than one

572
00:24:28,210 --> 00:24:29,370
that kind of works.

573
00:24:29,370 --> 00:24:32,670
Maybe one will work better
for certain applications.

574
00:24:32,670 --> 00:24:35,310
Another one works better for
some other type of things.

575
00:24:35,310 --> 00:24:39,380
And so investigating those
right now are all kind

576
00:24:39,380 --> 00:24:41,730
of worthwhile endeavor to do.

577
00:24:41,730 --> 00:24:42,910
And there's also, I would say,

578
00:24:42,910 --> 00:24:45,400
a spinoff of having these
different implementation,

579
00:24:45,400 --> 00:24:48,430
which relates to not
necessarily quantum computing,

580
00:24:48,430 --> 00:24:50,050
but to quantum sensors.

581
00:24:50,050 --> 00:24:51,790
So quantum sensors are sensors

582
00:24:51,790 --> 00:24:54,240
which use, again, rules
of quantum mechanics

583
00:24:54,240 --> 00:24:56,220
to better sense certain phenomena.

584
00:24:56,220 --> 00:24:58,120
It could be better sense
the electric field.

585
00:24:58,120 --> 00:25:01,480
It could be a better to sense
the gravitational field.

586
00:25:01,480 --> 00:25:04,690
It could be better to field
some different properties

587
00:25:04,690 --> 00:25:06,000
that we have around.

588
00:25:06,000 --> 00:25:11,000
And by studying either
atoms or ions or light,

589
00:25:11,650 --> 00:25:14,860
then, in that case, they
can be more appropriate

590
00:25:14,860 --> 00:25:16,900
to certain places.

591
00:25:16,900 --> 00:25:18,950
An example of this is light.

592
00:25:18,950 --> 00:25:21,630
Fundamental difference
between using light as a qubit

593
00:25:21,630 --> 00:25:23,030
and an atom as a qubit

594
00:25:23,030 --> 00:25:25,960
is that light goes at the speed of light.

595
00:25:25,960 --> 00:25:26,793
It doesn't stop.

596
00:25:26,793 --> 00:25:29,960
So you cannot take a
photon and keep it here.

597
00:25:29,960 --> 00:25:31,920
While you're doing something
else on your qubit,

598
00:25:31,920 --> 00:25:33,080
they are gonna move around.

599
00:25:33,080 --> 00:25:34,410
And so you have to find a way

600
00:25:34,410 --> 00:25:37,660
that if you want this photon
to interact with that one,

601
00:25:37,660 --> 00:25:39,010
that even if this one goes around,

602
00:25:39,010 --> 00:25:41,260
that it has come back in the right state

603
00:25:41,260 --> 00:25:42,260
to kind of interact.

604
00:25:42,260 --> 00:25:46,410
With ion, it's easier
because they are in a trap,

605
00:25:46,410 --> 00:25:48,340
and they are there next to each other.

606
00:25:48,340 --> 00:25:50,130
Now, the difference is if you want

607
00:25:50,130 --> 00:25:52,930
to send information
which is in an ion trap,

608
00:25:52,930 --> 00:25:56,490

quantum information to your
partner who's somewhere else,

609
00:25:56,490 --> 00:25:59,430
then you have to use light
to be able to do this.

610
00:25:59,430 --> 00:26:04,100
So you can transfer
information from the other.

611
00:26:04,100 --> 00:26:06,373
from one implementation to another one.

612
00:26:07,520 --> 00:26:09,560
- I remember you describing that

613
00:26:09,560 --> 00:26:12,150
in the early days of
quantum computing's being

614
00:26:12,150 --> 00:26:15,050
somewhat like the early
days of classical computing,

615
00:26:15,050 --> 00:26:17,100
you had to try different techniques.

616
00:26:17,100 --> 00:26:19,680
And there were vacuum
tubes, and that was a step,

617
00:26:19,680 --> 00:26:22,100
and that we don't use vacuum tubes now.

618
00:26:22,100 --> 00:26:24,040
Do you imagine the
future quantum computers

619

00:26:24,040 --> 00:26:26,780
will perhaps use elements
of what we've seen before,

620
00:26:26,780 --> 00:26:29,910
but perhaps things we haven't
even investigated yet?

621
00:26:29,910 --> 00:26:32,190
- Yes, certainly we might stumble

622
00:26:32,190 --> 00:26:35,000
into a better physical implementation

623
00:26:35,000 --> 00:26:37,390
of quantum information which
is more robust to noise.

624
00:26:37,390 --> 00:26:39,960
In fact, I would say the biggest challenge

625
00:26:39,960 --> 00:26:43,060
that we see today trying
to build quantum computers

626
00:26:43,060 --> 00:26:46,530
is the noise and quantum decoherence.

627
00:26:46,530 --> 00:26:49,630
That's why quantum error
correction is really important.

628
00:26:49,630 --> 00:26:52,400
That's the main technique
that we have right now

629
00:26:52,400 --> 00:26:54,310
to have the idea of scaling up.

630

00:26:54,310 --> 00:26:56,030
But I can see this changing.

631
00:26:56,030 --> 00:26:57,730
There's this beautiful quote

632
00:26:57,730 --> 00:27:01,360
from "Popular Mechanics,"
1949, saying the ENIAC,

633
00:27:01,360 --> 00:27:03,900
which was one of the
first classical computer,

634
00:27:03,900 --> 00:27:07,750
the ENIAC had 15,000 vacuum
tube and weighed 30 tons.

635
00:27:07,750 --> 00:27:10,540
And we could imagine the
future having computers

636
00:27:10,540 --> 00:27:11,930
which would weigh only a ton

637
00:27:11,930 --> 00:27:15,210
and have 1,000 vacuum tubes.
(all laugh)

638
00:27:15,210 --> 00:27:16,043
- Dare to dream.

639
00:27:16,043 --> 00:27:18,020
- Yeah, that's it.

640
00:27:18,020 --> 00:27:19,940
And if this would've
been a scientific paper,

641

00:27:19,940 --> 00:27:22,410
you would say, okay,
they tried to be careful,

642
00:27:22,410 --> 00:27:23,840
but that was "Popular Mechanics."

643
00:27:23,840 --> 00:27:26,480
You would give them a
license to kind of dream

644
00:27:26,480 --> 00:27:29,110
and kind of having a wide imagination.

645
00:27:29,110 --> 00:27:31,460
So it does show that suddenly

646
00:27:31,460 --> 00:27:34,580
when transistors were just appearing

647
00:27:34,580 --> 00:27:36,580
in labs, totally disconnected,

648
00:27:36,580 --> 00:27:37,930
and people didn't think they would be used

649
00:27:37,930 --> 00:27:39,930
for computers at the time, appeared.

650
00:27:39,930 --> 00:27:42,660
And this changed things completely.

651
00:27:42,660 --> 00:27:45,170
Maybe the implementation
that we have today

652
00:27:45,170 --> 00:27:47,240
of quantum computers are the ENIAC type.

653
00:27:48,080 --> 00:27:50,130
Suddenly we could find some form

654
00:27:50,130 --> 00:27:54,680
of artificial particle
in material science.

655
00:27:54,680 --> 00:27:56,270
And there are suggestion about this

656
00:27:56,270 --> 00:27:59,490
called topological quantum
computers with anions.

657
00:27:59,490 --> 00:28:03,170
Maybe these things, if we
can make them in the lab,

658
00:28:03,170 --> 00:28:05,510
and they're able to control them,

659
00:28:05,510 --> 00:28:08,720
they would become
naturally robust to noise

660
00:28:08,720 --> 00:28:10,850
and give us a chance to scale up.

661
00:28:10,850 --> 00:28:12,070
This is part of the dream,

662
00:28:12,070 --> 00:28:14,520
and we hope that we see these things.

663
00:28:14,520 --> 00:28:17,660
In fact, it would be very
neat to discover something

664

00:28:17,660 --> 00:28:19,730
that kind of suddenly
makes it a lot easier

665
00:28:19,730 --> 00:28:22,890
because today building quantum
commuters is very hard,

666
00:28:22,890 --> 00:28:24,120
very, very hard.

667
00:28:24,120 --> 00:28:26,270
- On the topic of dreaming in the future,

668
00:28:26,270 --> 00:28:27,610
I think this would be a good place

669
00:28:27,610 --> 00:28:30,350
to play for you a question
that was sent in by a student.

670
00:28:30,350 --> 00:28:33,220
So this one is from Mohamed Hibat-Allah,

671
00:28:33,220 --> 00:28:36,280
and he's a PhD student at
the University of Waterloo

672
00:28:36,280 --> 00:28:38,293
and the Vector Institute in Toronto.

673
00:28:39,200 --> 00:28:41,390
- Thank you for taking my question.

674
00:28:41,390 --> 00:28:45,890
So I'm a physics student at
the University of Waterloo.

675
00:28:45,890 --> 00:28:48,323

My question is related
to quantum computing.

676
00:28:49,260 --> 00:28:50,520
So as we all know,

677
00:28:50,520 --> 00:28:53,430
there is a lot of research
all over the world

678
00:28:53,430 --> 00:28:57,360
for the purpose of building
a useful quantum computer.

679
00:28:57,360 --> 00:28:58,900
So my question is,

680
00:28:58,900 --> 00:29:01,480
what do we need to
build a quantum computer

681
00:29:01,480 --> 00:29:04,900
that is useful to real-world applications?

682
00:29:04,900 --> 00:29:06,590
And what do we need to do

683
00:29:06,590 --> 00:29:09,120
to reach the point where quantum computers

684
00:29:09,120 --> 00:29:12,640
can outperform classical computers?

685
00:29:12,640 --> 00:29:14,270
Thank you.

686
00:29:14,270 --> 00:29:15,887
- That's a very good question

687
00:29:15,887 --> 00:29:17,410
and in bunch of different parts,

688
00:29:17,410 --> 00:29:19,290
so maybe I'll start by the last part

689
00:29:19,290 --> 00:29:21,540
to, like, what do we need
to have a quantum computer

690
00:29:21,540 --> 00:29:25,043
which is more powerful
than classical computers

691
00:29:25,043 --> 00:29:26,520
that we have around.

692
00:29:26,520 --> 00:29:29,290
And it turns out we're pretty much there.

693
00:29:29,290 --> 00:29:32,460
We have quantum computer
prototypes around the world,

694
00:29:32,460 --> 00:29:34,570
one at Google, one at IBM,

695
00:29:34,570 --> 00:29:38,820
that are big enough to do a computation

696
00:29:38,820 --> 00:29:40,660
which classical computers

697
00:29:40,660 --> 00:29:42,620
have incredible difficulty to solve.

698
00:29:42,620 --> 00:29:44,227
So we are just on the border.

699
00:29:44,227 --> 00:29:46,770
And a little bit discussion
of if we're there,

700
00:29:46,770 --> 00:29:49,090
but to me it doesn't really matter.

701
00:29:49,090 --> 00:29:52,510
And so the challenge there
is that these problems

702
00:29:52,510 --> 00:29:55,340
that these quantum computers are solving

703
00:29:55,340 --> 00:29:58,190
are not that interesting
for day-to-day application,

704
00:29:58,190 --> 00:30:00,460
but I think it's quite a milestone.

705
00:30:00,460 --> 00:30:03,090
If I compare this to 10
years or 20 years ago,

706
00:30:03,090 --> 00:30:05,150
then to arrive there,

707
00:30:05,150 --> 00:30:07,020
15 years ago, there were
people who were saying

708
00:30:07,020 --> 00:30:10,650
that we will never be able
to build a quantum computer.

709
00:30:10,650 --> 00:30:12,270
And here we have a prototype today.

710
00:30:12,270 --> 00:30:15,060
We have controlled these
quantum bits well enough

711
00:30:15,060 --> 00:30:16,040
to do a computation

712
00:30:16,040 --> 00:30:18,560
that the classical computer can barely do.

713
00:30:18,560 --> 00:30:22,290
To turn this into a device
which is very useful

714
00:30:22,290 --> 00:30:24,300
for practical application,

715
00:30:24,300 --> 00:30:27,360
then we have to scale the
number of these quantum bits.

716
00:30:27,360 --> 00:30:30,160
And as we scale the
number of quantum bits,

717
00:30:30,160 --> 00:30:33,530
it's very hard to make
them more and more precise.

718
00:30:33,530 --> 00:30:38,110
If you have an error rate
pair operation, which is P,

719
00:30:38,110 --> 00:30:42,870
then as you have N of these qubits,

720
00:30:42,870 --> 00:30:45,580
if the error pair qubit

is P, if you have them,

721
00:30:45,580 --> 00:30:48,270
then the error rate goes like N times P.

722
00:30:48,270 --> 00:30:50,700
So if you have 100 qubits,
it's 100 times higher,

723
00:30:50,700 --> 00:30:53,860
and if you have 10,000
qubits, it's 10,000 higher.

724
00:30:53,860 --> 00:30:56,980
This tells us that we
won't be able to compute

725
00:30:56,980 --> 00:30:58,900
in a way which is fault-tolerant

726
00:30:58,900 --> 00:31:01,350
or to have confidence in the result

727
00:31:01,350 --> 00:31:04,720
if we don't have a mechanism
to take care of these errors.

728
00:31:04,720 --> 00:31:06,830
And again, that's what quantum
error correction tells us,

729
00:31:06,830 --> 00:31:10,080
that we can bring this
NP to some constant value

730
00:31:10,080 --> 00:31:12,060
and compute.

731
00:31:12,060 --> 00:31:13,630

We need to be able to have a device

732
00:31:13,630 --> 00:31:14,760
with quantum error correction.

733
00:31:14,760 --> 00:31:15,950
At least the focus is there.

734
00:31:15,950 --> 00:31:18,070
We don't know how to do this

735
00:31:18,070 --> 00:31:19,960
without quantum error correction.

736
00:31:19,960 --> 00:31:21,310
And so we need to do this.

737
00:31:21,310 --> 00:31:24,890
And that will probably
take another 10 years.

738
00:31:24,890 --> 00:31:27,693
Hopefully I'm wrong,
and it's in three years,

739
00:31:28,990 --> 00:31:32,743
or I hope that I'm not wrong
that they'll be in 50 years.

740
00:31:33,580 --> 00:31:38,040
But the consensus and some
people in industry claim

741
00:31:38,040 --> 00:31:40,980
that probably by the end of
this decade, roughly 10 years,

742
00:31:40,980 --> 00:31:42,420
we should have these devices.

743
00:31:42,420 --> 00:31:45,550
And we'll need many thousands
of qubits to do this.

744
00:31:45,550 --> 00:31:47,960
So the noise has to be thought carefully

745
00:31:47,960 --> 00:31:51,250
and how do we control these qubits also.

746
00:31:51,250 --> 00:31:53,100
Right now, we do this brute force.

747
00:31:53,100 --> 00:31:54,560
We send one little wire

748
00:31:54,560 --> 00:31:57,680
for every of the qubits that we have,

749
00:31:57,680 --> 00:31:59,580
but if we have a million,

750
00:31:59,580 --> 00:32:01,430
how do we kind of link all of this

751
00:32:01,430 --> 00:32:04,800
and make all these wires that
goes into all of the qubits?

752
00:32:04,800 --> 00:32:06,340
It's not totally clear right now.

753
00:32:06,340 --> 00:32:08,650
There's different architectures.

754
00:32:08,650 --> 00:32:12,300
I saw something from

IBM Open Day last week

755
00:32:12,300 --> 00:32:14,850
about making a sandwich of qubits

756
00:32:14,850 --> 00:32:18,250
and having wires to come to
them in kind of different ways,

757
00:32:18,250 --> 00:32:19,960
which I thought fascinating.

758
00:32:19,960 --> 00:32:22,160
And although I've seen
kind of people talking

759
00:32:22,160 --> 00:32:23,580
about (indistinct) architecture,

760
00:32:23,580 --> 00:32:25,263
they had very concrete plans to do this.

761
00:32:25,263 --> 00:32:27,070
So there will be progress

762
00:32:27,070 --> 00:32:28,670
that will happen the years to come.

763
00:32:28,670 --> 00:32:30,400
So that's why the field
is incredibly exciting.

764
00:32:30,400 --> 00:32:32,610
There's new things
every day in this field.

765
00:32:32,610 --> 00:32:34,510
- This field wasn't the original field

766
00:32:34,510 --> 00:32:36,840
that you got into when you
started studying science.

767
00:32:36,840 --> 00:32:38,670
You were more interested in the universe

768
00:32:38,670 --> 00:32:39,930
in its largest scales, right?

769
00:32:39,930 --> 00:32:42,260
You were more into cosmology?

770
00:32:42,260 --> 00:32:43,630
- Yes, I was in cosmology,

771
00:32:43,630 --> 00:32:46,480
but a small branch of cosmology
called quantum cosmology.

772
00:32:46,480 --> 00:32:48,990
What is quantum cosmology?

773
00:32:48,990 --> 00:32:50,900
So the universe is very, very big,

774
00:32:50,900 --> 00:32:52,730
and I've told you a few minutes ago

775
00:32:52,730 --> 00:32:56,250
that quantum mechanics is
what described the world

776
00:32:56,250 --> 00:32:58,230
when it is very, very small.

777
00:32:58,230 --> 00:33:01,150
So these things seem

to be, at first sight,

778
00:33:01,150 --> 00:33:03,290
contradictory in terms,

779
00:33:03,290 --> 00:33:06,373
but the university is very
large, but it is expanding.

780
00:33:07,340 --> 00:33:08,580
Instead of thinking about the future,

781
00:33:08,580 --> 00:33:09,460
if you look at the past,

782
00:33:09,460 --> 00:33:12,280
means that the universe was
a little smaller yesterday,

783
00:33:12,280 --> 00:33:15,290
even smaller the day
before, even smaller before.

784
00:33:15,290 --> 00:33:18,940
And then we can trace back
using Einstein's theory

785
00:33:18,940 --> 00:33:20,490
of relativity.

786
00:33:20,490 --> 00:33:22,350
We can trace back and ask the question,

787
00:33:22,350 --> 00:33:23,183
how long does it take

788
00:33:23,183 --> 00:33:25,730
before the universe is
kind of small to a point?

789
00:33:25,730 --> 00:33:28,320
And it's roughly about 13 billion years.

790
00:33:28,320 --> 00:33:31,890
And at that point, quantum
effects should come out.

791
00:33:31,890 --> 00:33:35,180
What I was studying is how
do we use quantum mechanics

792
00:33:35,180 --> 00:33:36,870
to describe the beginning of the universe?

793
00:33:36,870 --> 00:33:40,140
So I worked in Cambridge with
Professor Stephen Hawking

794
00:33:40,140 --> 00:33:44,490
on a proposal that he had
called the Hartle-Hawking

795
00:33:44,490 --> 00:33:45,960
or the no-boundary proposal.

796
00:33:45,960 --> 00:33:49,110
So he was trying to
understand how this proposal

797
00:33:49,110 --> 00:33:51,890
was kind of fitting what
we observe in the universe

798
00:33:51,890 --> 00:33:53,550
and does it make sense

799
00:33:53,550 --> 00:33:57,290
and try to interpret this wave function.

800
00:33:57,290 --> 00:33:59,280
A wave function is a mathematical tool

801
00:33:59,280 --> 00:34:01,620
which describe everything we can learn

802
00:34:01,620 --> 00:34:04,730
from the quantum system that it represent.

803
00:34:04,730 --> 00:34:06,880
I was trying to understand
how it interpret.

804
00:34:06,880 --> 00:34:09,540
In usual quantum mechanics,
quantum mechanics in the lab,

805
00:34:09,540 --> 00:34:10,720
we interpret the wave function

806
00:34:10,720 --> 00:34:14,810
as it gives us the probability
for something to happen.

807
00:34:14,810 --> 00:34:17,020
And we show that we have
the right wave function

808
00:34:17,020 --> 00:34:20,030
by repeating the experiments
many, many times.

809
00:34:20,030 --> 00:34:21,920
And then you get the
probability distribution

810
00:34:21,920 --> 00:34:23,430
of different events.

811
00:34:23,430 --> 00:34:27,150
And this probability kind of
maps with the wave function.

812
00:34:27,150 --> 00:34:29,440
The problem with this, the universe,

813
00:34:29,440 --> 00:34:31,217
we cannot kind of having
many of these experiments.

814
00:34:31,217 --> 00:34:32,960
We have only one of them.

815
00:34:32,960 --> 00:34:36,280
So how do we use this wave
function to make prediction?

816
00:34:36,280 --> 00:34:41,130
And it turns out that
decoherence is a tool,

817
00:34:41,130 --> 00:34:42,790
or quantum decoherence is a tool

818
00:34:42,790 --> 00:34:45,030
to turn this wave function

819
00:34:45,030 --> 00:34:48,180
into probability of classical events.

820
00:34:48,180 --> 00:34:49,670
I knew this quite well,

821
00:34:49,670 --> 00:34:53,130
and this is part that I learned
while I went to Vancouver

822
00:34:53,130 --> 00:34:54,540
with Bill Unruh.

823
00:34:54,540 --> 00:34:57,280
And it turns out that
when I was at Los Alamos,

824
00:34:57,280 --> 00:34:58,670
my mentor, Wojciech Zurek,

825
00:34:58,670 --> 00:35:01,620
was probably kind of the best known person

826
00:35:01,620 --> 00:35:03,570
in the world working
in quantum decoherence.

827
00:35:03,570 --> 00:35:07,500
And when I went to this talk
about quantum computers,

828
00:35:07,500 --> 00:35:10,100
then I could put the two things together.

829
00:35:10,100 --> 00:35:11,880
Quantum decoherence was an asset

830
00:35:11,880 --> 00:35:14,050
to interpret the wave
function of the universe

831
00:35:14,050 --> 00:35:16,870
but an impediment to
build quantum computers.

832
00:35:16,870 --> 00:35:18,870
But again, it's the same mathematics.

833

00:35:18,870 --> 00:35:20,157
I jumped one to the other,

834
00:35:20,157 --> 00:35:22,200
and at that time I thought,
oh, I'll work a little bit

835
00:35:22,200 --> 00:35:23,750
on quantum computers for a few weeks.

836
00:35:23,750 --> 00:35:26,860
And then I'll come back
to the fundamental issues

837
00:35:26,860 --> 00:35:30,540
of quantum cosmology and
work with the universe.

838
00:35:30,540 --> 00:35:33,943
But I got stuck on quantum
computers for a little while.

839
00:35:34,957 --> 00:35:37,640
- And actually, one of
your current students

840
00:35:37,640 --> 00:35:41,350
sent us a question about
this time in your career.

841
00:35:41,350 --> 00:35:43,167
So maybe we can play that one.

842
00:35:44,830 --> 00:35:46,260
- Hi, Raymond. This is Matt Duschenes,

843
00:35:46,260 --> 00:35:49,150
one of your students at IQC and Perimeter.

844

00:35:49,150 --> 00:35:51,010
Ray, how did your advisor,
Stephen Hawking, react

845
00:35:51,010 --> 00:35:52,550
to your career pivot?

846
00:35:52,550 --> 00:35:54,100
Did you two still discuss science

847
00:35:54,100 --> 00:35:56,030
and quantum gravity topics
after you transitioned

848
00:35:56,030 --> 00:35:57,800
to quantum computing?

849
00:35:57,800 --> 00:35:59,340
- Again, a very good question.

850
00:35:59,340 --> 00:36:01,860
So I had the chance,
after finishing my PhD,

851
00:36:01,860 --> 00:36:03,790
I would bump into Stephen

852
00:36:03,790 --> 00:36:06,130
or kind of go to Cambridge
from time to time.

853
00:36:06,130 --> 00:36:09,590
And Stephen has always
been driven by curiosity.

854
00:36:09,590 --> 00:36:12,720
This is something which has
kind of always puzzled me.

855

00:36:12,720 --> 00:36:16,890
When I was a student, he was
already incredibly disabled.

856
00:36:16,890 --> 00:36:20,410
So he couldn't do pretty
much anything by himself.

857
00:36:20,410 --> 00:36:24,600
When I started as a grad
student, he could speak then,

858
00:36:24,600 --> 00:36:26,490
and he could move a joystick

859
00:36:26,490 --> 00:36:28,250
on his wheelchair to move around,

860
00:36:28,250 --> 00:36:31,440
but he would not be able to put his leg,

861
00:36:31,440 --> 00:36:34,160
or he was barely able to put his leg back

862
00:36:34,160 --> 00:36:37,920
on the little stalls of
his wheelchair by himself.

863
00:36:37,920 --> 00:36:38,930
But he couldn't feed himself,

864
00:36:38,930 --> 00:36:41,120
couldn't go to the bathroom by himself.

865
00:36:41,120 --> 00:36:44,400
And he couldn't kind of lift
himself in his wheelchair,

866
00:36:44,400 --> 00:36:46,340

so, incredibly disabled.

867
00:36:46,340 --> 00:36:47,460
But Stephen was curious,

868
00:36:47,460 --> 00:36:49,460
and he knew an incredible
amount of things.

869
00:36:49,460 --> 00:36:52,500
I always wonder, how
did he learn all of this

870
00:36:52,500 --> 00:36:53,740
if he had to read a book.

871
00:36:53,740 --> 00:36:55,130
Today, we read on the internet.

872
00:36:55,130 --> 00:36:58,260
We just kind of move from
pages to pages or read a book.

873
00:36:58,260 --> 00:37:01,460
He couldn't turn the page
by himself, of a book.

874
00:37:01,460 --> 00:37:04,570
So he had to have somebody
all the time doing this.

875
00:37:04,570 --> 00:37:07,010
Despite all of this, he
had an incredible knowledge

876
00:37:07,010 --> 00:37:10,700
on a broad level and curious
about so many things.

877

00:37:10,700 --> 00:37:13,230
So certainly when he came to Waterloo,

878
00:37:13,230 --> 00:37:16,010
and Stephen did come
to Waterloo many times

879
00:37:16,010 --> 00:37:18,800
in the last 10 years
before he passed away,

880
00:37:18,800 --> 00:37:21,707
he was always curious to
learn different things.

881
00:37:21,707 --> 00:37:23,397
And I remember at some point I asked him,

882
00:37:23,397 --> 00:37:27,220
"Are you interested to
come and visit the labs?"

883
00:37:27,220 --> 00:37:28,380
He's a theoretical physicist,

884
00:37:28,380 --> 00:37:31,490
so I was not totally sure
if that would interest him.

885
00:37:31,490 --> 00:37:33,040
And he was really keen.

886
00:37:33,040 --> 00:37:35,170
He said, "Oh yes, absolutely."

887
00:37:35,170 --> 00:37:37,460
And then I learned that while he was here,

888
00:37:37,460 --> 00:37:40,940

he had gone to SNOLAB in Sudbury.

889
00:37:40,940 --> 00:37:44,330
This is a lab where people
have measured the mass

890
00:37:44,330 --> 00:37:45,590
of the neutrino.

891
00:37:45,590 --> 00:37:47,590
Professor McDonald got a Nobel Prize

892
00:37:47,590 --> 00:37:49,420
for the work that they have done this.

893
00:37:49,420 --> 00:37:50,810
And then it turns out that the lab

894
00:37:50,810 --> 00:37:53,770
to measure this in a mine,

895
00:37:53,770 --> 00:37:57,510
and the mine is still active,
but you can go and visit it.

896
00:37:57,510 --> 00:37:59,950
You go in this kind of elevator.

897
00:37:59,950 --> 00:38:02,750
You go down, I think it's
two miles down the ground,

898
00:38:02,750 --> 00:38:03,810
and then becomes really hot.

899
00:38:03,810 --> 00:38:06,060
You go down there with the miners.

900

00:38:06,060 --> 00:38:08,420
And as you get out of the elevator,

901
00:38:08,420 --> 00:38:09,660
the miners goes to the right,

902
00:38:09,660 --> 00:38:11,420
and scientist goes to the left.

903
00:38:11,420 --> 00:38:14,540
And then you walk for about
half a kilometer down there.

904
00:38:14,540 --> 00:38:17,320
And then you arrive to a
place which is a clean room.

905
00:38:17,320 --> 00:38:19,440
So incredibly, incredibly clean part.

906
00:38:19,440 --> 00:38:22,120
So it's all closed off, sealed off.

907
00:38:22,120 --> 00:38:25,030
You have to get a shower
before going to the other side.

908
00:38:25,030 --> 00:38:27,530
The men and women get
on two different parts.

909
00:38:27,530 --> 00:38:29,610
They're all stripped off,
go through the showers,

910
00:38:29,610 --> 00:38:33,420
go and get dressed, and
then go and observe things.

911

00:38:33,420 --> 00:38:36,090
By the way, if you have
never seen this lab,

912
00:38:36,090 --> 00:38:39,070
and you have a chance in Sudbury, just go.

913
00:38:39,070 --> 00:38:41,030
It's totally amazing place.

914
00:38:41,030 --> 00:38:42,690
But I hear that Stephen was interested,

915
00:38:42,690 --> 00:38:45,170
that he went. (laughs)

916
00:38:45,170 --> 00:38:47,600
And I say, "How was it?"

917
00:38:47,600 --> 00:38:51,860
And he said, "The elevator was great.

918
00:38:51,860 --> 00:38:53,350
It was like free fall."

919
00:38:53,350 --> 00:38:56,010
So for somebody who was
the master of gravity

920
00:38:56,010 --> 00:38:59,790
to be in elevator for that
long and felt like free fall,

921
00:38:59,790 --> 00:39:01,420
he thought it was absolutely fantastic.

922
00:39:01,420 --> 00:39:03,600
So he went to visit there, came back here,

923
00:39:03,600 --> 00:39:05,730
and during the week, he
came and visited the lab.

924
00:39:05,730 --> 00:39:08,900
And at every lab, he had some
really interesting questions.

925
00:39:08,900 --> 00:39:11,020
And you know that he knew some pieces

926
00:39:11,020 --> 00:39:13,530
of all the different parts
that we were talking about,

927
00:39:13,530 --> 00:39:14,860
which totally, I mean it,

928
00:39:14,860 --> 00:39:17,030
I said, "Where does he
get all that knowledge?"

929
00:39:17,030 --> 00:39:18,630
But it was very interesting.

930
00:39:18,630 --> 00:39:21,930
- I remember when he visited
IQC a number of years ago,

931
00:39:21,930 --> 00:39:23,507
we had a gift made for
him that you gave to him,

932
00:39:23,507 --> 00:39:25,530
and it was a wooden boomerang.

933
00:39:25,530 --> 00:39:27,620
Can you explain why we chose a boomerang

934
00:39:27,620 --> 00:39:29,610
as a gift to Stephen Hawking?

935
00:39:29,610 --> 00:39:31,560
- The first project when
I was a graduate student

936
00:39:31,560 --> 00:39:36,560
of Stephen, which was to try
to prove that the wave function

937
00:39:37,820 --> 00:39:41,400
that bear his name, the
Hartle-Hawking wave function,

938
00:39:41,400 --> 00:39:45,030
showed that the arrow
of time would reverse

939
00:39:45,030 --> 00:39:46,930
at the time of maximum expansion.

940
00:39:46,930 --> 00:39:50,150
So the universe got started very small.

941
00:39:50,150 --> 00:39:52,260
We have the big bang,
which is like an explosion.

942
00:39:52,260 --> 00:39:54,090
At that time, the people thought

943
00:39:54,090 --> 00:39:56,900
that the universe would reach
a time of maximum expansion

944
00:39:56,900 --> 00:39:58,490
and re-collapse.

945
00:39:58,490 --> 00:40:00,160
At the beginning of the universe

946
00:40:00,160 --> 00:40:02,050
and at the end of these universes,

947
00:40:02,050 --> 00:40:04,090
there are something called singularities,

948
00:40:04,090 --> 00:40:08,080
places where physical
quantities would go to infinity,

949
00:40:08,080 --> 00:40:09,050
which essentially tells you

950
00:40:09,050 --> 00:40:11,580
that the theory by itself breaks down,

951
00:40:11,580 --> 00:40:14,163
the place where something
different will happen.

952
00:40:15,160 --> 00:40:18,620
Classical relativity,
Einstein's theory of gravity,

953
00:40:18,620 --> 00:40:20,000
would break down there

954
00:40:20,000 --> 00:40:22,080
and should be replaced by something else.

955
00:40:22,080 --> 00:40:23,400
And Stephen had been working

956
00:40:23,400 --> 00:40:25,960
that quantum gravity would

be what would replace

957
00:40:25,960 --> 00:40:28,330
and smooth out these
singularities in some ways

958
00:40:28,330 --> 00:40:32,890
because he want his wave
function that he had picked up,

959
00:40:32,890 --> 00:40:34,040
his quantum wave function,

960
00:40:34,040 --> 00:40:37,370
was smoothing out the
singularity at the beginning.

961
00:40:37,370 --> 00:40:40,730
He thought that it would
smooth it out also at the end.

962
00:40:40,730 --> 00:40:45,730
But today we see entropy or
disorder to increase as we go.

963
00:40:46,000 --> 00:40:48,020
So at some point, this
would have to reverse

964
00:40:48,020 --> 00:40:50,243
and come back so that it
goes to a smooth thing.

965
00:40:50,243 --> 00:40:51,780
That was my first project.

966
00:40:51,780 --> 00:40:52,630
I had to show this.

967

00:40:52,630 --> 00:40:53,990
So he had the idea.

968
00:40:53,990 --> 00:40:57,320
And then he had to show that
the math agrees with the idea.

969
00:40:57,320 --> 00:40:59,770
So we've talked about
this a little bit before.

970
00:40:59,770 --> 00:41:01,090
It's great to have ideas.

971
00:41:01,090 --> 00:41:02,860
Some are right. Some are wrong.

972
00:41:02,860 --> 00:41:04,960
And usually really smart people,

973
00:41:04,960 --> 00:41:06,560
clever people like Stephen,

974
00:41:06,560 --> 00:41:08,213
get them all right straight away.

975
00:41:09,380 --> 00:41:11,340
And I started to work on the math of it,

976
00:41:11,340 --> 00:41:13,200
and I couldn't make it work.

977
00:41:13,200 --> 00:41:15,780
And I would go and see Stephen once a week

978
00:41:15,780 --> 00:41:17,490
and show him my progress.

979

00:41:17,490 --> 00:41:21,340
And he would always pick
apart some of my argument

980
00:41:21,340 --> 00:41:22,997
or my comments, or ask me,

981
00:41:22,997 --> 00:41:24,970
"Have you checked this carefully?"

982
00:41:24,970 --> 00:41:26,470
Well, I was a grad student just starting,

983
00:41:26,470 --> 00:41:27,750
so I had not checked everything.

984
00:41:27,750 --> 00:41:30,903
And I'm sure other grad students
would understand very well

985
00:41:30,903 --> 00:41:33,980
that kind of, you go
and see your supervisor.

986
00:41:33,980 --> 00:41:36,870
You think you have everything neatly done,

987
00:41:36,870 --> 00:41:38,810
but something, oh, there are little pieces

988
00:41:38,810 --> 00:41:42,200
under the carpet there that
kind of you had assumed.

989
00:41:42,200 --> 00:41:46,550
And that's why Stephen would
pick at me all the time.

990
00:41:46,550 --> 00:41:48,780

Fortunately, after a couple of months,

991
00:41:48,780 --> 00:41:52,040
one of his ex-post docs, Don Page, came,

992
00:41:52,040 --> 00:41:53,320
and he asked me what I was working on.

993
00:41:53,320 --> 00:41:56,040
And I told him, and I said,
"I just cannot make it work."

994
00:41:56,040 --> 00:41:57,970
And he said to me, "Oh, it's interesting

995
00:41:57,970 --> 00:42:00,130
because I've been thinking about this.

996
00:42:00,130 --> 00:42:02,610
And also I believe that
it's not gonna work."

997
00:42:02,610 --> 00:42:04,010
So then I felt reassured

998
00:42:04,010 --> 00:42:08,194
because for the last kind of six months,

999
00:42:08,194 --> 00:42:10,483
I thought that I was
the one who was wrong.

1000
00:42:11,340 --> 00:42:16,177
And so Don, who was a
bit older than me, said,

1001
00:42:16,177 --> 00:42:19,860
"Stephen will never agree
if we just go brute force

1002
00:42:19,860 --> 00:42:21,730
and tell him he is wrong.

1003
00:42:21,730 --> 00:42:25,900
What we have to do is slowly
putting the pieces together

1004
00:42:25,900 --> 00:42:29,460
and build our arguments and add
one more piece to the other,

1005
00:42:29,460 --> 00:42:32,510
which each of these little piece don't say

1006
00:42:32,510 --> 00:42:34,910
that the arrow of time will not reverse,

1007
00:42:34,910 --> 00:42:37,597
but kind of all together
will kind of bring."

1008
00:42:37,597 --> 00:42:41,920
And so we did this, and after
about two months of arguing,

1009
00:42:41,920 --> 00:42:45,157
that both of us kind of were
putting, Stephen came and said,

1010
00:42:45,157 --> 00:42:49,010
"It's never gonna work."
(all laugh)

1011
00:42:49,010 --> 00:42:52,350
And then, so you say, "Ah, yeah."

1012
00:42:52,350 --> 00:42:55,777
When I finished my PhD, Stephen

gave me a copy of his book,

1013
00:42:55,777 --> 00:42:57,920
"A Brief History of Time" and, well,

1014
00:42:57,920 --> 00:42:59,407
a quotation at the beginning:

1015
00:42:59,407 --> 00:43:01,150
"To Raymond, who showed me

1016
00:43:01,150 --> 00:43:03,650
that the arrow of time
was not a boomerang.

1017
00:43:03,650 --> 00:43:05,550
Best, Stephen Hawking."

1018
00:43:05,550 --> 00:43:07,030
So when he came to visit here,

1019
00:43:07,030 --> 00:43:09,280
it was kind of 20 years later.

1020
00:43:09,280 --> 00:43:12,240
Then I gave him a boomerang of this.

1021
00:43:12,240 --> 00:43:14,770
And then he had a big smile on his face.

1022
00:43:14,770 --> 00:43:17,910
And interestingly enough,
in the following year,

1023
00:43:17,910 --> 00:43:19,150
there was a documentary on him

1024
00:43:19,150 --> 00:43:22,150

that I was watching at some
point, and it was at his house.

1025
00:43:22,150 --> 00:43:23,850
And I could see in the background,

1026
00:43:24,879 --> 00:43:27,800
the boomerang was there
on the wall, put there.

1027
00:43:27,800 --> 00:43:29,823
So this is the story of the boomerang.

1028
00:43:31,130 --> 00:43:32,240
- Well, this actually leads

1029
00:43:32,240 --> 00:43:34,530
into one more question that we got,

1030
00:43:34,530 --> 00:43:38,050
and this one was from
Nayeli Rodriguez Briones.

1031
00:43:38,050 --> 00:43:40,880
She's a postdoc at the University
of California, Berkeley,

1032
00:43:40,880 --> 00:43:44,320
but she did her PhD
doing some work with you.

1033
00:43:44,320 --> 00:43:46,340
And so she actually wanted to know

1034
00:43:46,340 --> 00:43:48,810
what your fondest memory
is with Stephen Hawking,

1035
00:43:48,810 --> 00:43:50,070

and you've shared a few now,

1036
00:43:50,070 --> 00:43:53,260
but I'm curious, what's the
fondest when you look back

1037
00:43:53,260 --> 00:43:54,210
on all those times?

1038
00:43:55,820 --> 00:43:59,150
- Maybe one piece that
surprised me about Stephen

1039
00:43:59,150 --> 00:44:03,290
is scientists, some of
them are very stubborn.

1040
00:44:03,290 --> 00:44:04,960
Some of them kind of have ideas,

1041
00:44:04,960 --> 00:44:07,890
and they think that all
their ideas are right.

1042
00:44:07,890 --> 00:44:10,510
One thing which really amazed me

1043
00:44:10,510 --> 00:44:14,550
with Stephen is when suddenly he realized

1044
00:44:14,550 --> 00:44:16,970
that he had made a
mistake on this proposal

1045
00:44:16,970 --> 00:44:20,380
on the arrow of time,
he totally turned around

1046
00:44:20,380 --> 00:44:22,910

and said explicitly in conference

1047
00:44:22,910 --> 00:44:25,550
and talked in his book
that he had made a mistake

1048
00:44:25,550 --> 00:44:28,520
and realized that things
were going differently.

1049
00:44:28,520 --> 00:44:31,460
And he gave me a lot of credit for it.

1050
00:44:31,460 --> 00:44:33,930
I thought it was incredibly generous.

1051
00:44:33,930 --> 00:44:36,080
And so that was a part of Stephen

1052
00:44:36,080 --> 00:44:38,653
that I didn't know that much before,

1053
00:44:38,653 --> 00:44:42,513
that he was my boss and
incredibly smart person.

1054
00:44:42,513 --> 00:44:46,340
I was a small graduate
student kind of stumbling

1055
00:44:46,340 --> 00:44:47,400
on this problem.

1056
00:44:47,400 --> 00:44:49,240
- I can't imagine the intimidation factor

1057
00:44:49,240 --> 00:44:50,677
of telling Stephen Hawking,

1058
00:44:50,677 --> 00:44:52,210
"I think you're wrong about that."

1059
00:44:52,210 --> 00:44:53,580
- Yeah, I must admit

1060
00:44:53,580 --> 00:44:58,293
that I never said it explicitly that way.

1061
00:44:59,896 --> 00:45:01,447
I would go to the Blackboard and say,

1062
00:45:01,447 --> 00:45:03,360
"I don't see how this can work,"

1063
00:45:03,360 --> 00:45:05,180
or "I don't see this working."

1064
00:45:05,180 --> 00:45:06,263
And then you would go,

1065
00:45:06,263 --> 00:45:08,160
I would tell him I've done this and this

1066
00:45:08,160 --> 00:45:09,420
and do this calculation.

1067
00:45:09,420 --> 00:45:12,990
And if I look at this, I get this result.

1068
00:45:12,990 --> 00:45:16,290
And so I'm not getting
what you're thinking.

1069
00:45:16,290 --> 00:45:17,913
So a little bit different than saying,

1070

00:45:17,913 --> 00:45:19,647
"You're totally wrong, Stephen."

1071
00:45:21,040 --> 00:45:23,600
Another thing of Stephen which is amazing

1072
00:45:23,600 --> 00:45:25,610
is his sense of humor.

1073
00:45:25,610 --> 00:45:26,697
He liked to tease people,

1074
00:45:26,697 --> 00:45:29,720
and this happened often between him and me

1075
00:45:29,720 --> 00:45:31,540
and the staff around kind of

1076
00:45:31,540 --> 00:45:33,780
where we'd play tricks on each other

1077
00:45:33,780 --> 00:45:36,470
and throw things to each
other at different place.

1078
00:45:36,470 --> 00:45:40,720
He would have a good laugh,
and I was not very shy.

1079
00:45:40,720 --> 00:45:44,130
And this, I don't know why is that,

1080
00:45:44,130 --> 00:45:48,240
but many people who arrived
next to Stephen totally freeze,

1081
00:45:48,240 --> 00:45:51,000
and he was very, very disabled.

1082
00:45:51,000 --> 00:45:53,210
And his voice was distorted

1083
00:45:53,210 --> 00:45:56,083
when you started to talk with him.

1084
00:45:56,083 --> 00:45:59,260
When I started my PhD after
that, he had a computer.

1085
00:45:59,260 --> 00:46:00,540
So people would kind of,

1086
00:46:00,540 --> 00:46:02,930
often if I would be helping Stephen,

1087
00:46:02,930 --> 00:46:05,280
they would ask question
to me instead of Stephen

1088
00:46:05,280 --> 00:46:08,010
because they don't know
what kind of reaction.

1089
00:46:08,010 --> 00:46:12,540
Maybe I can thank my mother,
who was very hands on

1090
00:46:14,063 --> 00:46:16,670
and not be shy and always
telling us, the kids,

1091
00:46:16,670 --> 00:46:18,430
to help whenever help was needed.

1092
00:46:18,430 --> 00:46:19,790
So I would help Stephen,

1093

00:46:19,790 --> 00:46:21,877
and sometimes I would say to Stephen,

1094
00:46:21,877 --> 00:46:23,760
"I just don't know what to do now,"

1095
00:46:23,760 --> 00:46:26,910
kind of trying to help him when
things were not going right.

1096
00:46:26,910 --> 00:46:30,540
Stephen's sense of humor
comes out in different ways

1097
00:46:30,540 --> 00:46:33,150
that quite often people don't notice.

1098
00:46:33,150 --> 00:46:35,940
And once you notice it, he likes to joke.

1099
00:46:35,940 --> 00:46:37,350
He likes to tease people.

1100
00:46:37,350 --> 00:46:39,693
He likes to kind of have fun.

1101
00:46:40,670 --> 00:46:44,310
That's one part that I
really was impressed of him,

1102
00:46:44,310 --> 00:46:46,580
of somebody who's incredibly disabled.

1103
00:46:46,580 --> 00:46:50,030
I've rarely seen people as disabled

1104
00:46:50,030 --> 00:46:52,830
in my life who can still function

1105
00:46:52,830 --> 00:46:55,110
and do extraordinary things

1106
00:46:55,110 --> 00:46:59,890
of being a worldwide scientist, traveler,

1107
00:46:59,890 --> 00:47:02,847
nearly a rock star in many ways

1108
00:47:02,847 --> 00:47:06,020
but at the same time being
incredibly, incredibly disabled.

1109
00:47:06,020 --> 00:47:08,550
This is something that really impacted me,

1110
00:47:08,550 --> 00:47:12,780
saying, if you really
want to do something,

1111
00:47:12,780 --> 00:47:14,760
then things are possible.

1112
00:47:14,760 --> 00:47:18,280
Like don't let yourself
kind of pity yourself

1113
00:47:18,280 --> 00:47:22,700
and stumble on through
things because of hurdles.

1114
00:47:22,700 --> 00:47:24,770
- That actually leads
into my next question.

1115
00:47:24,770 --> 00:47:27,990
One of the reasons we're so
delighted to have you here today

1116
00:47:27,990 --> 00:47:30,600
is that a doctor told you some years ago

1117
00:47:30,600 --> 00:47:33,210
there was no guarantee that
you would be anywhere today.

1118
00:47:33,210 --> 00:47:37,450
So you had a prognosis of cancer
that came out of the blue.

1119
00:47:37,450 --> 00:47:39,880
Can you tell us what
that was like for you?

1120
00:47:39,880 --> 00:47:41,190
- Yes, 5 1/2 years ago,

1121
00:47:41,190 --> 00:47:45,780
I was diagnosed with lung
cancer, stage three also.

1122
00:47:45,780 --> 00:47:49,490
People who know about
this know that prognostics

1123
00:47:49,490 --> 00:47:50,970
were not that great at the time.

1124
00:47:50,970 --> 00:47:54,580
So I was told that I had about 20% chance

1125
00:47:54,580 --> 00:47:56,790
of surviving five years.

1126
00:47:56,790 --> 00:47:59,500
Except for the lung
cancer, perfectly healthy.

1127
00:47:59,500 --> 00:48:00,850
I like to do outdoor stuff.

1128
00:48:00,850 --> 00:48:02,300
I like to go on bicycle.

1129
00:48:02,300 --> 00:48:05,310
In fact, while I was being diagnosed,

1130
00:48:05,310 --> 00:48:07,330
I went on my bike to a little cottage

1131
00:48:07,330 --> 00:48:10,310
that we have on the way to
Owen Sound very far from me,

1132
00:48:10,310 --> 00:48:12,930
not very far from here,
about 125 kilometers.

1133
00:48:12,930 --> 00:48:13,763
I could do this,

1134
00:48:13,763 --> 00:48:18,763
so didn't feel really that
that impacted me that much.

1135
00:48:18,980 --> 00:48:22,500
But the doctors told me
the chances are very slim

1136
00:48:22,500 --> 00:48:23,880
to go through.

1137
00:48:23,880 --> 00:48:26,930
And that only made me change a little bit

1138
00:48:26,930 --> 00:48:29,290

my view of the future.

1139
00:48:29,290 --> 00:48:31,090
It turns out that I had been director

1140
00:48:31,090 --> 00:48:32,730
of the Institute for Quantum Computing

1141
00:48:32,730 --> 00:48:34,650
for pretty much 15 years.

1142
00:48:34,650 --> 00:48:37,950
I had told the institute
that I was not going to ask

1143
00:48:37,950 --> 00:48:39,560
for another mandate.

1144
00:48:39,560 --> 00:48:41,930
So I could just kind of quickly wrap up.

1145
00:48:41,930 --> 00:48:45,760
And I thanked my colleague
and partner Kevin Resch,

1146
00:48:45,760 --> 00:48:50,350
who have taken over at the
institute at that time.

1147
00:48:50,350 --> 00:48:53,630
And then I had to go to
chemo, surgery, radiation,

1148
00:48:53,630 --> 00:48:56,900
and all that stuff, and more chemo.

1149
00:48:56,900 --> 00:49:00,430
So many things seems to
have kind of picked up,

1150
00:49:00,430 --> 00:49:02,970
and things went okay.

1151
00:49:02,970 --> 00:49:07,240
I had a recurrence about three years ago,

1152
00:49:07,240 --> 00:49:11,160
but it turns out that the
particular cancer that I have is,

1153
00:49:11,160 --> 00:49:14,370
one particular piece
of my DNA has changed,

1154
00:49:14,370 --> 00:49:16,300
and there's targeted therapies.

1155
00:49:16,300 --> 00:49:20,130
It's a mutation of the
DNA, which is known,

1156
00:49:20,130 --> 00:49:22,290
and there's a drug that kind of came

1157
00:49:22,290 --> 00:49:24,650
to the market five or six years ago.

1158
00:49:24,650 --> 00:49:29,020
And that particular drug kind
of stops the cancer to go in,

1159
00:49:29,020 --> 00:49:30,650
and it's been incredibly good.

1160
00:49:30,650 --> 00:49:33,870
So, thank you for medical researchers,

1161

00:49:33,870 --> 00:49:36,370
people who design drugs.

1162
00:49:36,370 --> 00:49:40,180
And thank you for the
company who makes this drug

1163
00:49:41,170 --> 00:49:42,440
that I'm still alive today.

1164
00:49:42,440 --> 00:49:45,480
And here I am, and things look good.

1165
00:49:45,480 --> 00:49:47,530
- You mentioned last time we spoke

1166
00:49:47,530 --> 00:49:49,200
that there's actually a note on your file

1167
00:49:49,200 --> 00:49:51,567
at the regional cancer center saying,

1168
00:49:51,567 --> 00:49:53,210
"Note, this guy's a physicist,

1169
00:49:53,210 --> 00:49:55,290
and he'll ask a lot of questions."

1170
00:49:55,290 --> 00:49:57,900
Can you tell, were you asking questions

1171
00:49:57,900 --> 00:50:01,190
about the machinery they were
using for their diagnostics?

1172
00:50:01,190 --> 00:50:04,480
- Yeah, in fact, when I had treatment,

1173

00:50:04,480 --> 00:50:06,520
there was a kind of three piece of it.

1174
00:50:06,520 --> 00:50:10,170
Surgery, that's kind of biology stuff.

1175
00:50:10,170 --> 00:50:11,810
And with this,

1176
00:50:11,810 --> 00:50:15,020
I don't feel that much
attraction to that kind of stuff.

1177
00:50:15,020 --> 00:50:17,120
Then there's chemotherapy, chemistry,

1178
00:50:17,120 --> 00:50:19,940
all these stinking stuff
and kind of liquid things

1179
00:50:19,940 --> 00:50:22,800
that again, I'm not too keen on this.

1180
00:50:22,800 --> 00:50:24,530
I tried to understand a
little bit how it works,

1181
00:50:24,530 --> 00:50:26,630
but it's not natural to me.

1182
00:50:26,630 --> 00:50:29,080
Radiotherapy, that's radiation,

1183
00:50:29,080 --> 00:50:30,700
That's electromagnetism.

1184
00:50:30,700 --> 00:50:32,350
Ah, this, I can read about this.

1185
00:50:32,350 --> 00:50:35,780
I can try to understand
kind of how it works.

1186
00:50:35,780 --> 00:50:38,660
So I started my treatment
of radiotherapy here

1187
00:50:38,660 --> 00:50:40,870
at the hospital in Waterloo.

1188
00:50:40,870 --> 00:50:44,010
And I started to ask
questions about the machine,

1189
00:50:44,010 --> 00:50:47,030
and I was really curious to
see kind of how it works.

1190
00:50:47,030 --> 00:50:48,007
So I started to say,

1191
00:50:48,007 --> 00:50:51,310
"Well, what is the
frequency of the radiation

1192
00:50:51,310 --> 00:50:54,817
that we have?" and the staff
who were going kind of,

1193
00:50:54,817 --> 00:50:56,410
"Oh, I'm not really sure.

1194
00:50:56,410 --> 00:50:57,280
We'll kind of ask."

1195
00:50:57,280 --> 00:50:58,940
And they would come back and tell me this.

1196
00:50:58,940 --> 00:51:01,500
So some of the question I would ask,

1197
00:51:01,500 --> 00:51:03,440
they would come back and know the answer,

1198
00:51:03,440 --> 00:51:07,070
kind of how long does that
thing process work and all this,

1199
00:51:07,070 --> 00:51:08,940
how do you calibrate the machines?

1200
00:51:08,940 --> 00:51:10,207
One day I came in, I said,

1201
00:51:10,207 --> 00:51:13,100
"Well, do you have the instruction
manual for the machine?

1202
00:51:13,100 --> 00:51:16,473
I'd like to double check a few things."

1203
00:51:16,473 --> 00:51:18,350
(all laugh)

1204
00:51:18,350 --> 00:51:19,940
So they burst laughing.

1205
00:51:19,940 --> 00:51:22,880
And he said, "We have a medical physicist

1206
00:51:23,880 --> 00:51:25,840
on staff at the hospital.

1207
00:51:25,840 --> 00:51:28,830
Maybe we can set up an
appointment with him."

1208
00:51:28,830 --> 00:51:31,180
So his name is Ernest Jose.

1209
00:51:31,180 --> 00:51:34,760
And so the next time I
came after my appointment,

1210
00:51:34,760 --> 00:51:37,097
he was there waiting, and he said,

1211
00:51:37,097 --> 00:51:39,630
"Apparently you're a curious man."

1212
00:51:39,630 --> 00:51:40,570
And then he told me this.

1213
00:51:40,570 --> 00:51:42,660
He said, "Apparently in your
file, there's a note saying,

1214
00:51:42,660 --> 00:51:46,180
'This guy is a physicist and
asks a lot of questions.'"

1215
00:51:46,180 --> 00:51:47,013
- Amazing.

1216
00:51:47,013 --> 00:51:49,190
Did they ever give you
that operations manual

1217
00:51:49,190 --> 00:51:50,300
for the machine?

1218
00:51:50,300 --> 00:51:52,880
- I didn't get it through the hospital.

1219

00:51:52,880 --> 00:51:54,580
I got it through the internet somewhere.

1220
00:51:54,580 --> 00:51:56,580
I kind of figured it out.

1221
00:51:56,580 --> 00:51:58,800
And then interestingly,

1222
00:51:58,800 --> 00:52:03,780
the medical physicist was
giving course on oncology

1223
00:52:03,780 --> 00:52:07,720
and therapies at the university,
which I didn't know about.

1224
00:52:07,720 --> 00:52:10,740
I asked him if I could get in this course,

1225
00:52:10,740 --> 00:52:14,870
just be a listener, to which he laughed,

1226
00:52:14,870 --> 00:52:17,590
and he says, "If you
want to, that's fine."

1227
00:52:17,590 --> 00:52:19,550
So I joined the course,

1228
00:52:19,550 --> 00:52:23,320
and I spent the rest of the
term kind of at the back

1229
00:52:23,320 --> 00:52:26,500
of the lecture room and asking
question from time to time,

1230
00:52:26,500 --> 00:52:30,100

trying not to intimidate the
students who are at the front.

1231
00:52:30,100 --> 00:52:31,600
But quite often, they had questions

1232
00:52:31,600 --> 00:52:35,080
about what do patients feel
when certain things happen

1233
00:52:35,080 --> 00:52:37,170
and kind of questions
that patients would have.

1234
00:52:37,170 --> 00:52:39,300
And so there, I could
help them a little bit.

1235
00:52:39,300 --> 00:52:41,540
So now I know about radiation theory,

1236
00:52:41,540 --> 00:52:43,770
and I'm thinking that maybe there are ways

1237
00:52:43,770 --> 00:52:45,230
that quantum technologies

1238
00:52:45,230 --> 00:52:48,100
could help them kind of controlling,

1239
00:52:48,100 --> 00:52:49,023
after all of this,

1240
00:52:49,023 --> 00:52:52,560
kind of comes down to
controlling radiation.

1241
00:52:52,560 --> 00:52:55,140
In the NMR quantum computing that I do,

1242
00:52:55,140 --> 00:52:57,460
we do control the
radiation in certain ways

1243
00:52:57,460 --> 00:52:59,390
to reach certain goals.

1244
00:52:59,390 --> 00:53:02,240
So I think some of these
techniques can be applied there.

1245
00:53:03,190 --> 00:53:04,850
- So you've sort of become interested

1246
00:53:04,850 --> 00:53:06,180
in new fields a few times, right?

1247
00:53:06,180 --> 00:53:08,440
You started out working
in quantum cosmology,

1248
00:53:08,440 --> 00:53:10,560
and then you became interested
in quantum computing.

1249
00:53:10,560 --> 00:53:12,270
And now you've acquired some knowledge

1250
00:53:12,270 --> 00:53:13,960
about medical physics.

1251
00:53:13,960 --> 00:53:15,440
But I think it must be very difficult

1252
00:53:15,440 --> 00:53:17,670
when you try to start learning
about a whole new field.

1253
00:53:17,670 --> 00:53:19,800
There's so much vocabulary

1254
00:53:19,800 --> 00:53:22,840
and maybe assumptions that
people take for granted.

1255
00:53:22,840 --> 00:53:24,300
Was it difficult to move

1256
00:53:24,300 --> 00:53:26,563
into those new fields a couple of time?

1257
00:53:27,560 --> 00:53:29,340
- Yes, there's definitely some hurdles,

1258
00:53:29,340 --> 00:53:32,620
but I would say this
is the price I'm paying

1259
00:53:32,620 --> 00:53:33,863
for being curious.

1260
00:53:34,830 --> 00:53:36,940
It's a wonderful thing to be curious

1261
00:53:36,940 --> 00:53:39,380
because it tells you
that you're never bored.

1262
00:53:39,380 --> 00:53:42,990
There's always some neat
things that you can learn about

1263
00:53:42,990 --> 00:53:46,406
or kind of, I like to
understand how things work,

1264

00:53:46,406 --> 00:53:49,060
let it be quantum computing, qubits,

1265
00:53:49,060 --> 00:53:50,670
or quantum cosmology.

1266
00:53:50,670 --> 00:53:53,480
Or I have a Volkswagen van 1979,

1267
00:53:53,480 --> 00:53:57,030
and it doesn't always work perfectly

1268
00:53:57,030 --> 00:54:00,670
so that there are piece I
need to understand there.

1269
00:54:00,670 --> 00:54:01,840
And while you do this,

1270
00:54:01,840 --> 00:54:05,110
indeed, there's lingo
that people are using.

1271
00:54:05,110 --> 00:54:07,690
And that's probably most of the challenge,

1272
00:54:07,690 --> 00:54:11,960
is to understand exactly what
is the lingo that people do.

1273
00:54:11,960 --> 00:54:14,610
And all different fields have
different kind of assumption

1274
00:54:14,610 --> 00:54:19,610
that people absorb without
saying very explicitly.

1275
00:54:19,890 --> 00:54:23,310

And these are the hard
parts to kind of get over.

1276
00:54:23,310 --> 00:54:26,680
But once you know that
these are two hurdles,

1277
00:54:26,680 --> 00:54:29,200
then you can pick the
brains of other people.

1278
00:54:29,200 --> 00:54:34,200
So knowing this and not be
shy about asking questions

1279
00:54:34,750 --> 00:54:36,860
is something which is critical.

1280
00:54:36,860 --> 00:54:39,720
I try to get my students not be shy.

1281
00:54:39,720 --> 00:54:42,560
Personally, I'm a person who's shy

1282
00:54:42,560 --> 00:54:45,370
in kind of lecture room and all of this.

1283
00:54:45,370 --> 00:54:47,690
But now that I know enough things,

1284
00:54:47,690 --> 00:54:51,010
then that gives me less
shyness to be able to do this.

1285
00:54:51,010 --> 00:54:54,070
And if my question is a little too naive,

1286
00:54:54,070 --> 00:54:56,360
then I'll say, "Okay, I'm

just new in that field.

1287
00:54:56,360 --> 00:54:57,230
So what?"

1288
00:54:57,230 --> 00:54:59,380
And maybe being a little bit older,

1289
00:54:59,380 --> 00:55:02,090
I've become less shy of being seen.

1290
00:55:02,090 --> 00:55:04,370
So quite often, I see students worry

1291
00:55:04,370 --> 00:55:08,280
about looking like fool
of asking naive question.

1292
00:55:08,280 --> 00:55:10,000
But what I have learned

1293
00:55:10,000 --> 00:55:12,850
is that sometimes the naive
questions are the hardest one

1294
00:55:13,740 --> 00:55:16,920
to answer like the basic
assumptions in fields

1295
00:55:16,920 --> 00:55:19,210
of why do we do this this way?

1296
00:55:19,210 --> 00:55:21,170
It's kind of much harder to answer

1297
00:55:21,170 --> 00:55:24,620
than a really specific technical tricks

1298

00:55:24,620 --> 00:55:27,210
that people are using to
get a solution of something.

1299
00:55:27,210 --> 00:55:30,600
So asking things about the assumption is,

1300
00:55:30,600 --> 00:55:32,070
I think, very important

1301
00:55:32,070 --> 00:55:33,960
because once you know the assumption,

1302
00:55:33,960 --> 00:55:35,950
and then you learn a
bit of the mathematics,

1303
00:55:35,950 --> 00:55:38,920
then it's straightforward
to kind of move on.

1304
00:55:38,920 --> 00:55:41,430
- You've mentioned in this
conversation several times

1305
00:55:41,430 --> 00:55:43,390
the power of curiosity.

1306
00:55:43,390 --> 00:55:46,330
I remember you gave a TEDx
talk about 10 years ago,

1307
00:55:46,330 --> 00:55:49,090
and the very first word
of it was curiosity.

1308
00:55:49,090 --> 00:55:51,950
That was a standalone sentence, curiosity.

1309

00:55:51,950 --> 00:55:52,970
Is that something

1310
00:55:52,970 --> 00:55:55,160
that's you've had
innately your whole life?

1311
00:55:55,160 --> 00:55:56,090
Have you always been that way,

1312
00:55:56,090 --> 00:55:58,383
or is that something
you've developed over time?

1313
00:55:59,500 --> 00:56:00,860
- That's a really good question.

1314
00:56:00,860 --> 00:56:04,000
I think there's an innate
part that everybody has.

1315
00:56:04,000 --> 00:56:08,030
I think it comes down
to Darwin's principle.

1316
00:56:08,030 --> 00:56:12,490
Humans who are really curious
can harness this curiosity

1317
00:56:12,490 --> 00:56:15,110
to turn their life into something better.

1318
00:56:15,110 --> 00:56:19,070
And I think that's the story
of developing technologies.

1319
00:56:19,070 --> 00:56:21,100
So you start with curiosity,

1320

00:56:21,100 --> 00:56:23,350
and suddenly people like me will face this

1321
00:56:23,350 --> 00:56:25,750
kind of trying to understand
the world around us

1322
00:56:25,750 --> 00:56:28,400
and try to ask question
about how does it work

1323
00:56:28,400 --> 00:56:30,510
and kind of why do we see what we see

1324
00:56:30,510 --> 00:56:33,300
and trying to build what we call theories.

1325
00:56:33,300 --> 00:56:35,860
Theories at first step

1326
00:56:35,860 --> 00:56:38,440
try to put together a bunch

1327
00:56:38,440 --> 00:56:40,660
of data of observations

1328
00:56:40,660 --> 00:56:43,540
and kind of link them in a consistent way.

1329
00:56:43,540 --> 00:56:46,130
But a second step of
the theory is something

1330
00:56:46,130 --> 00:56:48,470
that allows us to make prediction

1331
00:56:48,470 --> 00:56:50,920
of what's going to happen in the future.

1332
00:56:50,920 --> 00:56:53,820
And then that's one way
that in a scientific matter

1333
00:56:53,820 --> 00:56:57,480
that we prove that our theories are good,

1334
00:56:57,480 --> 00:56:59,820
is that they have a predictive power,

1335
00:56:59,820 --> 00:57:02,380
and they agree with the future experiments

1336
00:57:02,380 --> 00:57:03,330
that we're gonna do.

1337
00:57:03,330 --> 00:57:06,810
But also once you know
how to predict things,

1338
00:57:06,810 --> 00:57:10,090
you can learn how to control
these physical phenomena

1339
00:57:10,090 --> 00:57:11,700
that we have around.

1340
00:57:11,700 --> 00:57:14,130
And once you can control
these physical phenomena,

1341
00:57:14,130 --> 00:57:17,020
you can make them do
things that helps you,

1342
00:57:17,020 --> 00:57:19,170
that helps you to survive.

1343

00:57:19,170 --> 00:57:20,830
And that's what we call technologies.

1344
00:57:20,830 --> 00:57:24,083
And I think the cycle
of going from curiosity,

1345
00:57:24,930 --> 00:57:27,790
making theories, controlling,

1346
00:57:27,790 --> 00:57:30,810
and then kind of developing
these technologies

1347
00:57:30,810 --> 00:57:32,560
have come again and again.

1348
00:57:32,560 --> 00:57:34,190
And once you develop new technologies,

1349
00:57:34,190 --> 00:57:39,190
interestingly, you can push
your curiosity steps ahead

1350
00:57:39,360 --> 00:57:41,150
or further down or further up,

1351
00:57:41,150 --> 00:57:43,010
depending on the scale
that you're looking at

1352
00:57:43,010 --> 00:57:45,920
in trying to understand
more physical phenomena

1353
00:57:45,920 --> 00:57:48,560
and take that cycle going
again and again and again.

1354

00:57:48,560 --> 00:57:53,010
And so I think curiosity is
something that everybody has.

1355
00:57:53,010 --> 00:57:55,970
People use them in different
degree, I would say,

1356
00:57:55,970 --> 00:57:58,200
but I think everybody's curious,

1357
00:57:58,200 --> 00:57:59,610
and that's what makes us drive

1358
00:57:59,610 --> 00:58:03,070
and kind of ask interesting question.

1359
00:58:03,070 --> 00:58:04,940
- Ray, I could talk to you all day,

1360
00:58:04,940 --> 00:58:07,390
and there have been times when
we have chatted for hours,

1361
00:58:07,390 --> 00:58:08,870
but we won't keep you any longer.

1362
00:58:08,870 --> 00:58:10,920
Can you just share with
us what your outlook is

1363
00:58:10,920 --> 00:58:14,640
for the future and your
research and your curiosity?

1364
00:58:14,640 --> 00:58:17,295
- Well, I think you want to
talk for a few more hours.

1365

00:58:17,295 --> 00:58:19,000
(Ray and Colin laugh)

1366
00:58:19,000 --> 00:58:20,910
I'm curious about different things.

1367
00:58:20,910 --> 00:58:25,090
Now I have the luxury
of not being director

1368
00:58:25,090 --> 00:58:26,420
of any institute.

1369
00:58:26,420 --> 00:58:28,970
So I have plenty of time to do things

1370
00:58:28,970 --> 00:58:31,670
which, when I was director, I had to focus

1371
00:58:31,670 --> 00:58:35,050
on developing this Institute
for Quantum Computing,

1372
00:58:35,050 --> 00:58:37,230
but now a lot of time to read things.

1373
00:58:37,230 --> 00:58:38,930
And I get lost from day to day

1374
00:58:38,930 --> 00:58:41,240
on kind of reading too many things,

1375
00:58:41,240 --> 00:58:42,957
but definitely on the scientific part,

1376
00:58:42,957 --> 00:58:44,420
I want to better understand how

1377

00:58:44,420 --> 00:58:46,890
to control these quantum systems.

1378
00:58:46,890 --> 00:58:48,930
Also having been a
director of an institute,

1379
00:58:48,930 --> 00:58:52,830
I want to understand how
do we really go from ideas

1380
00:58:52,830 --> 00:58:56,220
and this curiosity to
really develop technology,

1381
00:58:56,220 --> 00:58:59,000
and how do we do this in a
Canadian context, for example.

1382
00:58:59,000 --> 00:59:01,710
What are the piece that we're
doing very well in Canada,

1383
00:59:01,710 --> 00:59:03,270
and what are the piece which are missing?

1384
00:59:03,270 --> 00:59:04,700
That's another part.

1385
00:59:04,700 --> 00:59:07,800
And if we go to kind of
larger and larger scales,

1386
00:59:07,800 --> 00:59:10,410
one day, I'll come back
to quantum cosmology

1387
00:59:10,410 --> 00:59:13,220
and trying to understand
how the universe works.

1388
00:59:13,220 --> 00:59:15,720
And between the small world

1389
00:59:15,720 --> 00:59:17,660
and the large scale of the universe,

1390
00:59:17,660 --> 00:59:20,130
there's plenty of things
to push my curiosity

1391
00:59:20,130 --> 00:59:21,470
in different direction.

1392
00:59:21,470 --> 00:59:22,303
- Wonderful.

1393
00:59:22,303 --> 00:59:24,177
Well, thank you so much for
spending the time with us today.

1394
00:59:24,177 --> 00:59:26,393
- You're welcome. Great pleasure.

1395
00:59:27,734 --> 00:59:29,780
(soft electronic music)

1396
00:59:29,780 --> 00:59:31,540
- Thanks so much for listening.

1397
00:59:31,540 --> 00:59:33,640
Perimeter Institute is a not-for-profit

1398
00:59:33,640 --> 00:59:35,140
charitable organization

1399
00:59:35,140 --> 00:59:37,570
that shares cutting-edge

ideas with the world

1400
00:59:37,570 --> 00:59:39,210
thanks to the ongoing support

1401
00:59:39,210 --> 00:59:41,360
of the governments of Ontario and Canada

1402
00:59:41,360 --> 00:59:43,480
and thanks to donors like you.

1403
00:59:43,480 --> 00:59:45,380
Thanks for being part of the equation.