1
00:00:00,000 --> 00:00:02,583
(upbeat music)

2
00:00:08,940 --> 00:00:10,860
- Hey everyone and thanks for joining us

3
00:00:10,860 --> 00:00:12,720
for Conversations at the Perimeter.

4
00:00:12,720 --> 00:00:15,090
I'm Colin, and as always
I'm here with Lauren.

5
00:00:15,090 --> 00:00:16,170
- Hi, everyone.

6
00:00:16,170 --> 00:00:17,490
- And on this episode we had

7
00:00:17,490 --> 00:00:20,070
the pleasure of chatting
with Pedro Vieira,

8
00:00:20,070 --> 00:00:22,470
who holds the Clay
Riddell Paul Dirac Chair

9
00:00:22,470 --> 00:00:24,810
in theoretical physics here at Perimeter.

10
00:00:24,810 --> 00:00:27,690
And Pedro is also an expert
in quantum field theory,

11
00:00:27,690 --> 00:00:30,690
which is something that
I am most definitely not.

12

00:00:30,690 --> 00:00:31,523
As you'll hear,

13
00:00:31,523 --> 00:00:33,990
both Lauren and I had some apprehensions

14
00:00:33,990 --> 00:00:36,450
about discussing such
a complicated subject,

15
00:00:36,450 --> 00:00:38,910
but Pedro immediately put us at ease.

16
00:00:38,910 --> 00:00:41,220
- I've actually worked with
Pedro a few times over the years

17
00:00:41,220 --> 00:00:43,170
to create courses for graduate students

18
00:00:43,170 --> 00:00:44,850
and I even took one of his courses back

19
00:00:44,850 --> 00:00:45,990
when I was a student.

20
00:00:45,990 --> 00:00:47,850
So I've seen him explain technical

21
00:00:47,850 --> 00:00:50,190
mathematical concepts many times,

22
00:00:50,190 --> 00:00:52,350
but in this conversation you'll experience

23
00:00:52,350 --> 00:00:54,120
something pretty different from that.

24

00:00:54,120 --> 00:00:56,520
Pedro takes some of those same concepts

25
00:00:56,520 --> 00:00:57,960
from these graduate courses,

26
00:00:57,960 --> 00:01:00,960
but he paints some amazing
non-technical mental pictures

27
00:01:00,960 --> 00:01:03,720
for us with no mathematical
background required.

28
00:01:03,720 --> 00:01:05,400
- Yeah, you'll hear Pedro describe

29
00:01:05,400 --> 00:01:07,680
some really esoteric ideas in physics

30
00:01:07,680 --> 00:01:11,111
like quantum field theory and
holography and black holes,

31
00:01:11,111 --> 00:01:13,890
but he describes them
in terms of sculptures

32
00:01:13,890 --> 00:01:16,315
and maps and bouncing red balls.

33
00:01:16,315 --> 00:01:18,120
And as he was describing

34
00:01:18,120 --> 00:01:20,160
how our universe could be a hologram,

35
00:01:20,160 --> 00:01:22,800
I could actually see a mental

picture forming in my brain

36
00:01:22,800 --> 00:01:24,840
where there hadn't been
a mental picture before.

37
00:01:24,840 --> 00:01:27,300
- Pedro also talks about
how he finds great joy

38
00:01:27,300 --> 00:01:28,770
in sharing science with others,

39
00:01:28,770 --> 00:01:31,680
both here at Perimeter
and in Brazil at the ICTP,

40
00:01:31,680 --> 00:01:35,190
South American Institute for
Fundamental Research or SAIFR,

41
00:01:35,190 --> 00:01:36,780
which he helped to launch.

42
00:01:36,780 --> 00:01:39,510
And he even gives a theoretical
physicist perspective on

43
00:01:39,510 --> 00:01:42,480
why you may or may not want
to keep your room messy.

44
00:01:42,480 --> 00:01:44,400
We talk about some complicated stuff here,

45
00:01:44,400 --> 00:01:46,020
but Pedro really makes it fun.

46
00:01:46,020 --> 00:01:48,903

So let's step inside the
perimeter with Pedro Vieira.

47
00:01:51,600 --> 00:01:53,850
Hi Pedro, thank you so
much for joining us today

48
00:01:53,850 --> 00:01:55,950
on Conversations at the Perimeter.

49
00:01:55,950 --> 00:01:56,783
- Thank you.

50
00:01:56,783 --> 00:01:57,616
Thank you for having me.

51
00:01:57,616 --> 00:01:58,470
It's fun to be here.

52
00:01:58,470 --> 00:01:59,880
- I wanna start by admitting

53
00:01:59,880 --> 00:02:02,730
I was a little bit nervous
to interview today,

54
00:02:02,730 --> 00:02:06,420
you today at first because
a lot of your work relies

55
00:02:06,420 --> 00:02:09,690
on quantum field theory and as a teacher

56
00:02:09,690 --> 00:02:12,060
of some subjects like that,

57
00:02:12,060 --> 00:02:14,700
I'm may be used to a
different pedagogical approach

58
00:02:14,700 --> 00:02:17,790
where one might first take
an undergraduate degree

59
00:02:17,790 --> 00:02:21,030
in physics study some classical mechanics,

60
00:02:21,030 --> 00:02:22,500
special relativity,

61
00:02:22,500 --> 00:02:24,840
take a graduate course
in quantum mechanics

62
00:02:24,840 --> 00:02:28,050
before even mentioning the
term quantum field theory.

63
00:02:28,050 --> 00:02:29,760
But of course, we're not gonna walk

64
00:02:29,760 --> 00:02:32,370
through all of those prerequisites today.

65
00:02:32,370 --> 00:02:34,230
So I thought, how are we gonna talk

66
00:02:34,230 --> 00:02:36,270
about Pedro's work with all of those

67
00:02:36,270 --> 00:02:37,500
things that usually come before?

68
00:02:37,500 --> 00:02:38,333
But you know,

69
00:02:38,333 --> 00:02:40,350

we had a conversation
with you and you were

70
00:02:40,350 --> 00:02:42,180
so great at explaining what you do.

71
00:02:42,180 --> 00:02:43,110
So now I'm not nervous,

72
00:02:43,110 --> 00:02:45,630
I'm just excited to hear
how you're gonna explain

73
00:02:45,630 --> 00:02:47,580
all of these complicated concepts.

74
00:02:47,580 --> 00:02:49,620
And so maybe we can
just start by asking you

75
00:02:49,620 --> 00:02:51,180
what is a quantum field

76
00:02:51,180 --> 00:02:53,610
and what is quantum field theory?

77
00:02:53,610 --> 00:02:55,230
- In physics, the two main theories

78
00:02:55,230 --> 00:02:57,210
that describe physics as you said,

79
00:02:57,210 --> 00:02:59,790
are quantum mechanics and the relativity.

80
00:02:59,790 --> 00:03:00,777
So those if you want,

81

00:03:00,777 --> 00:03:05,460
are the very basic
principles of all of physics.

82
00:03:05,460 --> 00:03:07,950
So relativity tells us about space

83
00:03:07,950 --> 00:03:11,490
and time and how things
behave in space and time.

84
00:03:11,490 --> 00:03:13,980
It even tells us what is space and time.

85
00:03:13,980 --> 00:03:16,590
I mean how space can
become time and how time

86
00:03:16,590 --> 00:03:19,200
can become space and how
do we measure distances,

87
00:03:19,200 --> 00:03:21,000
how do we measure times,

88
00:03:21,000 --> 00:03:23,820
and what are points in space and time?

89
00:03:23,820 --> 00:03:27,717
Where do things happen and when
do things happen and so on.

90
00:03:27,717 --> 00:03:30,930
And quantum mechanics is the
theory that describes particles

91
00:03:30,930 --> 00:03:34,680
that describes the most fundamental
objects of the universe,

92
00:03:34,680 --> 00:03:38,310
our microscopic particles
that move in this space-time.

93
00:03:38,310 --> 00:03:41,250
And what we understood is
that one way of understanding

94
00:03:41,250 --> 00:03:43,620
what are particles that
move in this space-time

95
00:03:43,620 --> 00:03:47,850
is by imagining there there
is this fluid like quantity,

96
00:03:47,850 --> 00:03:52,850
this field that permeates
all of space-time.

97
00:03:52,860 --> 00:03:55,050
So a field is just a way of assigning

98
00:03:55,050 --> 00:03:59,160
to each point of space
and time, some quantity.

99
00:03:59,160 --> 00:04:02,040
That quantity could be
the temperature in a room

100
00:04:02,040 --> 00:04:05,070
to each point in the room
there is a temperature.

101
00:04:05,070 --> 00:04:07,890
It can be the velocity of
water inside a swimming pool.

102

00:04:07,890 --> 00:04:09,510
To each point inside the swimming pool,

103
00:04:09,510 --> 00:04:11,580
there is a velocity of water there.

104
00:04:11,580 --> 00:04:14,130
It can be the magnetic
field in the universe.

105
00:04:14,130 --> 00:04:17,340
To each point around around
us there is a magnetic field,

106
00:04:17,340 --> 00:04:21,750
stronger close to the sun
and weaker farther away.

107
00:04:21,750 --> 00:04:22,710
And in particular,

108
00:04:22,710 --> 00:04:26,670
particles themselves are
excitations of fields.

109
00:04:26,670 --> 00:04:29,010
You can imagine that all

110
00:04:29,010 --> 00:04:31,740
our fundamental particles are understood,

111
00:04:31,740 --> 00:04:35,850
they're small waves of fields
that permeate the universe.

112
00:04:35,850 --> 00:04:38,760
And so field theory is the
language that puts together

113

00:04:38,760 --> 00:04:40,680
quantum mechanics and relativity.

114
00:04:40,680 --> 00:04:42,000
It's all about space-time.

115
00:04:42,000 --> 00:04:45,360
It's all about this
arena where things move.

116
00:04:45,360 --> 00:04:48,180
And it describes not only
the arena where things move,

117
00:04:48,180 --> 00:04:49,830
but the things that move themselves

118
00:04:49,830 --> 00:04:54,830
as excitations of some kind
of a field like object.

119
00:04:54,990 --> 00:04:58,470
We can picture it as like a
membrane that can be still.

120
00:04:58,470 --> 00:05:01,020
And then there are some small
ripples of this membrane,

121
00:05:01,020 --> 00:05:02,970
of this shape that move around.

122
00:05:02,970 --> 00:05:04,920
And these small ripples are particles

123
00:05:04,920 --> 00:05:07,380
that make us and the universe.

124
00:05:07,380 --> 00:05:09,990

- And what is quantum
about this description?

125
00:05:09,990 --> 00:05:13,200
- So quantum mechanics is
the theory of the world,

126
00:05:13,200 --> 00:05:14,880
of the world of particles.

127
00:05:14,880 --> 00:05:18,660
And the very basic feature
of nature and of quantum

128
00:05:18,660 --> 00:05:23,660
mechanics is the idea that
many things can happen at once.

129
00:05:26,310 --> 00:05:29,520
When a particle moves
from a point to another,

130
00:05:29,520 --> 00:05:31,740
what's actually happening
is that the particle

131
00:05:31,740 --> 00:05:35,013
is going through all possible
trajectories at once.

132
00:05:35,970 --> 00:05:37,620
And that's very surprising

133
00:05:37,620 --> 00:05:40,410
because that's not what we
see in our day to day, right?

134
00:05:40,410 --> 00:05:42,450
We throw a ball and the ball goes along

135
00:05:42,450 --> 00:05:46,140
some trajectory and I throw
the ball, you catch the ball,

136
00:05:46,140 --> 00:05:47,160
you throw the ball back to me,

137
00:05:47,160 --> 00:05:49,500
we don't see the ball
going in all direction.

138
00:05:49,500 --> 00:05:52,830
And the reason is just that
the most important trajectories

139
00:05:52,830 --> 00:05:55,320
dominate the physics,
they dominate the process,

140
00:05:55,320 --> 00:05:56,490
they are more important.

141
00:05:56,490 --> 00:05:58,770
And when you compute indeed,

142
00:05:58,770 --> 00:06:01,865
you realize that there
are some trajectories,

143
00:06:01,865 --> 00:06:02,698
some classical things that are happening

144
00:06:02,698 --> 00:06:04,920
that are much more important than others.

145
00:06:04,920 --> 00:06:06,510
But strictly speaking,

146

00:06:06,510 --> 00:06:09,060
and in particular when you
go to the microscopic world,

147
00:06:09,060 --> 00:06:10,560
all these things that can happen

148
00:06:10,560 --> 00:06:12,810
are happening at the same
time and they matter.

149
00:06:12,810 --> 00:06:14,550
And so when you have these fields

150
00:06:14,550 --> 00:06:17,460
that describe these particles,
these fields are not quiet,

151
00:06:17,460 --> 00:06:20,460
they are not just some boring
membrane that is still.

152
00:06:20,460 --> 00:06:21,840
And then there is a particle here

153
00:06:21,840 --> 00:06:24,300
that's moving and
following a straight line.

154
00:06:24,300 --> 00:06:26,850
These fields are vibrating
and these vibrations

155
00:06:26,850 --> 00:06:29,280
are what we call quantum
mechanical vibrations.

156
00:06:29,280 --> 00:06:30,750
Many things are happening at once

157
00:06:30,750 --> 00:06:33,510
and in fact everything is
happening at the same time.

158
00:06:33,510 --> 00:06:35,970
And these particles are all
interacting with each other,

159
00:06:35,970 --> 00:06:38,190
moving in all possible trajectories,

160
00:06:38,190 --> 00:06:39,810
throwing particles at each other.

161
00:06:39,810 --> 00:06:41,370
That's how particles interact.

162
00:06:41,370 --> 00:06:44,217
Particles deflect because
they throw stuff at each other

163
00:06:44,217 --> 00:06:46,770
and so they are coming into collision,

164
00:06:46,770 --> 00:06:48,990
but they throw stuff at
each other and they deviate

165
00:06:48,990 --> 00:06:50,850
and they deflect and they
interact with each other.

166
00:06:50,850 --> 00:06:52,230
And that's how nature works.

167
00:06:52,230 --> 00:06:54,180
This might start to look very complicated.

168

00:06:54,180 --> 00:06:56,850
How are we going to
describe things that happen?

169
00:06:56,850 --> 00:06:58,560
If I tell you that to
describe what happens,

170
00:06:58,560 --> 00:07:00,450
you have to describe
everything that can happen.

171
00:07:00,450 --> 00:07:02,610
- That sounds impossibly complicated.

172
00:07:02,610 --> 00:07:04,560
- It sounds complicated.

173
00:07:04,560 --> 00:07:07,440
And the way out is because as I said,

174
00:07:07,440 --> 00:07:10,020
there are things that
matter more than others.

175
00:07:10,020 --> 00:07:13,467
When you throw a particle in
the middle of empty space,

176
00:07:13,467 --> 00:07:16,200
the thing that matters most
is when the particle goes

177
00:07:16,200 --> 00:07:19,080
in a straight line from
point A to point B.

178
00:07:19,080 --> 00:07:20,880
Then there are other
things that can happen.

179
00:07:20,880 --> 00:07:24,210
The particle can emit some other particle

180
00:07:24,210 --> 00:07:26,550
that can be absorbed later and so on.

181
00:07:26,550 --> 00:07:28,740
But that, it's a little bit less likely

182
00:07:28,740 --> 00:07:30,450
and it can emit two or three particles

183
00:07:30,450 --> 00:07:32,250
and that's even less likely.

184
00:07:32,250 --> 00:07:36,270
And there is an notion in
physics of the coupling

185
00:07:36,270 --> 00:07:39,120
and the coupling is it's what quantifies,

186
00:07:39,120 --> 00:07:42,300
how much of these quantum
fluctuations are going on?

187
00:07:42,300 --> 00:07:44,100
Are you studying a system where the,

188
00:07:44,100 --> 00:07:46,170
where if you want the coupling is small,

189
00:07:46,170 --> 00:07:47,910
where this quantum effects are small

190
00:07:47,910 --> 00:07:51,990
and where things are not

as bubbly as they could be?

191
00:07:51,990 --> 00:07:54,420
Or are you studying something
where the coupling is big

192
00:07:54,420 --> 00:07:56,970
and really everything is
happening at the same time?

193
00:07:56,970 --> 00:07:58,590
And most things we study,

194
00:07:58,590 --> 00:08:02,370
the coupling is small and
not much is happening.

195
00:08:02,370 --> 00:08:05,610
And yet that describes
most of what we see.

196
00:08:05,610 --> 00:08:07,410
Take for example, light.

197
00:08:07,410 --> 00:08:10,290
Light for the most part
just goes straight.

198
00:08:10,290 --> 00:08:12,420
We turn on a flashlight
and what's happening

199
00:08:12,420 --> 00:08:14,820
is that a gazillion photons are going

200
00:08:14,820 --> 00:08:16,647
from the flashlight to the wall.

201
00:08:16,647 --> 00:08:17,480

- Is that the actual number?

202
00:08:17,480 --> 00:08:18,420
- Yeah.
- Give or take.

203
00:08:18,420 --> 00:08:19,865
- Maybe three or four.

204
00:08:19,865 --> 00:08:20,730
- Got it.

205
00:08:20,730 --> 00:08:22,200
- So three or four gazillion

206
00:08:22,200 --> 00:08:25,126
go from the flashlight to the wall.

207
00:08:25,126 --> 00:08:27,270
And what do they do as they travel?

208
00:08:27,270 --> 00:08:29,160
They go all together, right?

209
00:08:29,160 --> 00:08:34,160
Quiet, like very respectful
photons all by each other.

210
00:08:34,920 --> 00:08:36,210
And they just go and they go

211
00:08:36,210 --> 00:08:37,260
from the flashlight to the wall.

212
00:08:37,260 --> 00:08:38,640
They are not struggling,

213
00:08:38,640 --> 00:08:40,890

they are not fighting with
each other as they go.

214
00:08:40,890 --> 00:08:42,330
They're not like a bunch of hooligans.

215
00:08:42,330 --> 00:08:44,550
They're really going calmly

216
00:08:44,550 --> 00:08:46,200
from the flashlight to the wall.

217
00:08:46,200 --> 00:08:48,810
And so that's an example
where not much is going on.

218
00:08:48,810 --> 00:08:50,670
So it's true that to describe the photons,

219
00:08:50,670 --> 00:08:52,200
we don't describe just a straight line

220
00:08:52,200 --> 00:08:53,430
from the flashlight to the wall.

221
00:08:53,430 --> 00:08:54,750
We describe the other trajectories,

222
00:08:54,750 --> 00:08:57,090
but they really matter very little.

223
00:08:57,090 --> 00:09:00,600
And so that's an example of a
system that is weekly coupled.

224
00:09:00,600 --> 00:09:02,280
So the photons, they also interact.

225

00:09:02,280 --> 00:09:03,330
They interact with the air,

226
00:09:03,330 --> 00:09:05,640
they heat the light ones in the air.

227
00:09:05,640 --> 00:09:08,640
That's why we see the
light when the light,

228
00:09:08,640 --> 00:09:11,190
because it's from time to
time heating some particles

229
00:09:11,190 --> 00:09:13,380
in the air and being
deflected into our eyes.

230
00:09:13,380 --> 00:09:14,250
But for the most part,

231
00:09:14,250 --> 00:09:15,900
most of the light goes from the flashlight

232
00:09:15,900 --> 00:09:18,150
and we see just a spot
of light on the wall.

233
00:09:18,150 --> 00:09:21,030
And so when things don't interact much,

234
00:09:21,030 --> 00:09:24,660
this taking into account all
the possibility in practice

235
00:09:24,660 --> 00:09:27,920
means taking account a few
possibilities because not man,

236

00:09:27,920 --> 00:09:30,390
the craziest ones don't matter.

237
00:09:30,390 --> 00:09:33,570
We don't consider the
trajectory of a photon

238
00:09:33,570 --> 00:09:34,590
where the photon and instead

239
00:09:34,590 --> 00:09:36,480
of going photon are particles of light.

240
00:09:36,480 --> 00:09:37,650
When the particles of light go

241
00:09:37,650 --> 00:09:39,900
from the flashlight to the wall,

242
00:09:39,900 --> 00:09:42,090
if instead of going directly it first goes

243
00:09:42,090 --> 00:09:43,770
around the room and then it goes,

244
00:09:43,770 --> 00:09:46,500
that's going to be an
irrelevant contribution

245
00:09:46,500 --> 00:09:47,910
to what's going on.

246
00:09:47,910 --> 00:09:49,890
Now that's not always the case.

247
00:09:49,890 --> 00:09:54,683
So sometimes there are situations
in physics where really

248
00:09:55,590 --> 00:09:57,360
this craziness of quantum mechanics

249
00:09:57,360 --> 00:10:01,080
where everything is going on
at the same time matters a lot.

250
00:10:01,080 --> 00:10:03,360
And an example is what
happens inside the nucleus.

251
00:10:03,360 --> 00:10:04,530
Inside the nucleus.

252
00:10:04,530 --> 00:10:06,810
We also have particles like photons.

253
00:10:06,810 --> 00:10:08,250
What do I mean by like photons?

254
00:10:08,250 --> 00:10:09,990
It's particles that don't have mass

255
00:10:09,990 --> 00:10:11,130
that are very, very light.

256
00:10:11,130 --> 00:10:13,740
They are called gluons instead of photons.

257
00:10:13,740 --> 00:10:15,810
And the main difference between the gluons

258
00:10:15,810 --> 00:10:19,200
and the photons is that
the gluons, when they move,

259
00:10:19,200 --> 00:10:21,660
if I had a flashlight of

gluons and even if I would turn

260
00:10:21,660 --> 00:10:24,930
on my flashlight instead
of the gluons propagating

261
00:10:24,930 --> 00:10:26,040
from the flashlight to the wall,

262
00:10:26,040 --> 00:10:28,080
they would start fighting with each other.

263
00:10:28,080 --> 00:10:29,880
They would start of having these brawls

264
00:10:29,880 --> 00:10:33,270
and fighting and making
balls of energy of gluons.

265
00:10:33,270 --> 00:10:37,200
And they would end up being
stuck in this big, big fight,

266
00:10:37,200 --> 00:10:38,790
and this by this fight,

267
00:10:38,790 --> 00:10:40,680
I mean all these quantum effects going on.

268
00:10:40,680 --> 00:10:44,430
- I want that gluon flashlight,
that sounds fascinating.

269
00:10:44,430 --> 00:10:45,750
- That's what keeps us,

270
00:10:45,750 --> 00:10:49,560
that's what makes us
alive because the gluons,

271
00:10:49,560 --> 00:10:51,780
the name gluons comes from glue.

272
00:10:51,780 --> 00:10:56,070
And what they do is this crazy
fight of the gluons is what

273
00:10:56,070 --> 00:10:58,800
keeps the constituents
of the nucleus together.

274
00:10:58,800 --> 00:11:00,210
So you could imagine that you put many,

275
00:11:00,210 --> 00:11:02,853
many protons together at
the center of our atom,

276
00:11:03,840 --> 00:11:06,210
and the protons, they
have all positive charge.

277
00:11:06,210 --> 00:11:07,650
Why would they want to be together?

278
00:11:07,650 --> 00:11:08,610
They don't, right?

279
00:11:08,610 --> 00:11:09,750
They hate each other.

280
00:11:09,750 --> 00:11:12,210
Particles with positive
charge, they repel.

281
00:11:12,210 --> 00:11:13,677
So you put a bunch of protons together,

282
00:11:13,677 --> 00:11:15,600
the first thing they
want to do is each one,

283
00:11:15,600 --> 00:11:16,440
they want to go apart.

284
00:11:16,440 --> 00:11:20,460
And yet our nucleus is full
of a bunch of protons, right?

285
00:11:20,460 --> 00:11:21,510
So what is happening?

286
00:11:21,510 --> 00:11:22,343
Who is keeping them?

287
00:11:22,343 --> 00:11:23,340
They want to fly apart,

288
00:11:23,340 --> 00:11:26,460
but all these gluons are there
fighting with each other.

289
00:11:26,460 --> 00:11:27,960
And so the protons cannot get away

290
00:11:27,960 --> 00:11:29,550
because they're in the
middle of this fight.

291
00:11:29,550 --> 00:11:30,600
They're just looking, oh my God,

292
00:11:30,600 --> 00:11:32,040
let me stay here.

293
00:11:32,040 --> 00:11:34,080

'Cause there is all these
gluon fight around them.

294
00:11:34,080 --> 00:11:36,000
And by this fight I mean that the gluons

295
00:11:36,000 --> 00:11:37,380
are behaving all possible ways.

296
00:11:37,380 --> 00:11:38,310
Everything is happening.

297
00:11:38,310 --> 00:11:39,960
They are moving left,
they're moving right.

298
00:11:39,960 --> 00:11:42,090
They're moving up, down
all at the same time.

299
00:11:42,090 --> 00:11:43,260
And we really need to take

300
00:11:43,260 --> 00:11:45,180
all these quantum effects into account.

301
00:11:45,180 --> 00:11:47,670
- Another way to say this is
that they're strongly coupled.

302
00:11:47,670 --> 00:11:49,410
- And that's another way,
they're strongly coupled.

303
00:11:49,410 --> 00:11:51,730
So the probability of
the gluon going straight

304
00:11:52,573 --> 00:11:54,900

is as likely as the gluon
splitting into two gluons

305
00:11:54,900 --> 00:11:56,700
or turning right or turning left.

306
00:11:56,700 --> 00:11:58,260
And everything matters at the same time.

307
00:11:58,260 --> 00:12:01,200
And it's not true like with
the photons that you just

308
00:12:01,200 --> 00:12:03,400
consider something simple
like going straight

309
00:12:03,400 --> 00:12:04,800
and the rest doesn't matter.

310
00:12:04,800 --> 00:12:06,450
That's not true with gluons.

311
00:12:06,450 --> 00:12:08,700
And that means that when you stay,

312
00:12:08,700 --> 00:12:10,470
the world is described
by quantum field theory.

313
00:12:10,470 --> 00:12:11,700
That's totally true.

314
00:12:11,700 --> 00:12:13,350
But quantum field theory gets split

315
00:12:13,350 --> 00:12:15,180
into two quantum field theories.

316
00:12:15,180 --> 00:12:17,370
If you want, you can call it
the easy one and the hard one.

317
00:12:17,370 --> 00:12:19,328
- I'll go for the easy one, please.

318
00:12:19,328 --> 00:12:20,161
- Yeah.

319
00:12:20,161 --> 00:12:23,460
When the coupling is small,
you get the easy one.

320
00:12:23,460 --> 00:12:26,280
Somethings happen but not much.

321
00:12:26,280 --> 00:12:29,100
You can control what's
going on and you can compute

322
00:12:29,100 --> 00:12:31,920
what's going on and improve
slowly your computation.

323
00:12:31,920 --> 00:12:35,040
You can say the particles
of light go straight plus

324
00:12:35,040 --> 00:12:36,930
a small deviation plus a small deviation,

325
00:12:36,930 --> 00:12:37,800
plus a small deviation.

326
00:12:37,800 --> 00:12:40,320
And step by step you
improve your calculation.

327
00:12:40,320 --> 00:12:42,270
So in school you learn some, you learn,

328
00:12:42,270 --> 00:12:43,410
then you go to graduate school,

329
00:12:43,410 --> 00:12:45,690
you learn how to correct
it a little bit more

330
00:12:45,690 --> 00:12:47,130
and you keep improving.

331
00:12:47,130 --> 00:12:48,060
And this is fantastic.

332
00:12:48,060 --> 00:12:50,880
It works amazingly and
in many, many situations.

333
00:12:50,880 --> 00:12:52,530
It's what allows us to test physics

334
00:12:52,530 --> 00:12:54,564
with this crazy number of precisions

335
00:12:54,564 --> 00:12:55,950
where we have all this analogies

336
00:12:55,950 --> 00:12:57,369
that we measure instances

337
00:12:57,369 --> 00:12:59,592
in particle physics within the precision

338
00:12:59,592 --> 00:13:02,280
of an error and stuff like this.

339
00:13:02,280 --> 00:13:05,490
But sometimes when quantum
effects are strong,

340
00:13:05,490 --> 00:13:08,010
sometimes we have a qualitative
picture of what's going on.

341
00:13:08,010 --> 00:13:10,950
We kind of understand in
cartoonish terms what's going on.

342
00:13:10,950 --> 00:13:13,170
We understand the protons
they need to be stuck there

343
00:13:13,170 --> 00:13:15,090
because all these gluons are
fighting with each other.

344
00:13:15,090 --> 00:13:16,770
But this is a cartoonish picture, right?

345
00:13:16,770 --> 00:13:18,330
I'm speaking with my hands literally

346
00:13:18,330 --> 00:13:20,880
right in in saying this.

347
00:13:20,880 --> 00:13:22,560
Now if you want to ask me, okay,

348
00:13:22,560 --> 00:13:25,350
given that you know that gluons
interact in this crazy way

349
00:13:25,350 --> 00:13:30,210
and that they hold the protons
together, can you from that,

350
00:13:30,210 --> 00:13:32,100
and even they allow the proton to exist

351
00:13:32,100 --> 00:13:33,720
because the proton itself is made out

352
00:13:33,720 --> 00:13:35,940
of these quarks and quarks,

353
00:13:35,940 --> 00:13:38,067
they also like to get away from each other

354
00:13:38,067 --> 00:13:39,570
and it's the gluons that keep

355
00:13:39,570 --> 00:13:41,520
the constituents of the proton together.

356
00:13:41,520 --> 00:13:43,530
So given that gluons are so important

357
00:13:43,530 --> 00:13:46,200
in maintaining the stability of matter,

358
00:13:46,200 --> 00:13:48,547
can you from the dynamics of the gluons,

359
00:13:48,547 --> 00:13:50,790
tell me what's the mass of the proton?

360
00:13:50,790 --> 00:13:53,340
Tell me about this fundamental properties.

361
00:13:53,340 --> 00:13:54,870
And the answer for the most part,

362

00:13:54,870 --> 00:13:57,300
for these very tough questions
that involve controlling

363
00:13:57,300 --> 00:14:01,680
strong coupling is no, our
mathematics is not good enough.

364
00:14:01,680 --> 00:14:05,940
I cannot sit with a piece
of empty paper and start my

365
00:14:05,940 --> 00:14:08,940
computation, step one,
the gluon, da, da, da,

366
00:14:08,940 --> 00:14:10,200
compute, compute, compute.

367
00:14:10,200 --> 00:14:11,730
And at the end give you
the mass of the proton

368
00:14:11,730 --> 00:14:12,690
at the end of the page

369
00:14:12,690 --> 00:14:15,390
or at the end of 20 pages or 50 pages.

370
00:14:15,390 --> 00:14:16,223
That's not possible.

371
00:14:16,223 --> 00:14:18,450
We don't know how to
do these computations,

372
00:14:18,450 --> 00:14:21,480
and that means we need to
develop these new tools.

373
00:14:21,480 --> 00:14:25,080
So we need to understand quantum
fields when they are easy,

374
00:14:25,080 --> 00:14:26,970
but that we kind of understand

375
00:14:26,970 --> 00:14:29,000
it's just about computing more and more.

376
00:14:29,000 --> 00:14:32,143
So you suffer and you
get three decimal places

377
00:14:32,143 --> 00:14:33,513
and you suffer more and you get

378
00:14:33,513 --> 00:14:35,610
four decimal places and you suffer

379
00:14:35,610 --> 00:14:37,410
even more and you get five decimal places.

380
00:14:37,410 --> 00:14:40,890
And the more you suffer, the
more decimal places you get.

381
00:14:40,890 --> 00:14:42,540
And then you have the
hard quantum field theory

382
00:14:42,540 --> 00:14:43,890
that is not even about suffering.

383
00:14:43,890 --> 00:14:45,750
It's that you don't know where to start

384
00:14:45,750 --> 00:14:47,610

because everything matters.

385
00:14:47,610 --> 00:14:48,900
I need to compute everything.

386
00:14:48,900 --> 00:14:50,070
How do I compute everything?

387
00:14:50,070 --> 00:14:51,270
I dunno how to compute everything.

388
00:14:51,270 --> 00:14:52,650
And you need new tools.

389
00:14:52,650 --> 00:14:54,450
And some of these tools are, for example,

390
00:14:54,450 --> 00:14:57,367
using computers like
what you learn and do.

391
00:14:58,800 --> 00:15:01,770
And some other tools
could be trying to develop

392
00:15:01,770 --> 00:15:03,480
what could be the new ways of thinking

393
00:15:03,480 --> 00:15:07,980
about quantum fields
that allow me to develop

394
00:15:07,980 --> 00:15:11,010
some techniques for
studying what could happen

395
00:15:11,010 --> 00:15:12,360
in these crazy situations

396
00:15:12,360 --> 00:15:15,131
where quantum mechanics is so strong.

397
00:15:15,131 --> 00:15:16,170
And by the way,

398
00:15:16,170 --> 00:15:17,520
typically that also means

399
00:15:17,520 --> 00:15:19,980
that relativity effects are very important

400
00:15:19,980 --> 00:15:21,720
because when things are happening

401
00:15:21,720 --> 00:15:23,220
a lot at these very high energies

402
00:15:23,220 --> 00:15:24,300
and things are vibrating a lot,

403
00:15:24,300 --> 00:15:25,650
they're moving very fast.

404
00:15:25,650 --> 00:15:26,940
And when things are moving very fast

405
00:15:26,940 --> 00:15:28,380
is when relativity is important,

406
00:15:28,380 --> 00:15:30,750
when space and time get
entangled with each other.

407
00:15:30,750 --> 00:15:32,775
- So both quantum theory
and relativity are at play.

408
00:15:32,775 --> 00:15:35,460
- Both quantum theory and
relativity are at play.

409
00:15:35,460 --> 00:15:37,290
Everything is happening at the same time.

410
00:15:37,290 --> 00:15:40,290
We need new rules, we
need new ideas to think.

411
00:15:40,290 --> 00:15:42,360
And I would say that's one
of the key things we try

412
00:15:42,360 --> 00:15:43,920
to do at PI is understand

413
00:15:43,920 --> 00:15:45,720
what are these new ideas that we need?

414
00:15:45,720 --> 00:15:49,440
How do I describe quantum
nature when quantum effects are

415
00:15:49,440 --> 00:15:52,229
the dominant thing and when
everything is happening at once,

416
00:15:52,229 --> 00:15:55,533
do we just give up or what do we do?

417
00:15:56,940 --> 00:15:57,940
- So what do you do?

418
00:16:00,840 --> 00:16:05,250
What would you see as the eureka moment

419

00:16:05,250 --> 00:16:07,980
if you could suddenly
calculate these things,

420
00:16:07,980 --> 00:16:09,420
where would that take us?

421
00:16:09,420 --> 00:16:12,000
- So another way of saying it is

422
00:16:12,000 --> 00:16:15,240
when do we care about
these very strong effects?

423
00:16:15,240 --> 00:16:16,770
So I told you already one example

424
00:16:16,770 --> 00:16:20,280
which is to understand the matter,

425
00:16:20,280 --> 00:16:23,670
to understand the stability even of matter

426
00:16:23,670 --> 00:16:26,700
and what holds us together

427
00:16:26,700 --> 00:16:31,700
and what makes nucleus and
fundamental particles stable.

428
00:16:32,670 --> 00:16:36,240
So understanding matter
and particle physics

429
00:16:36,240 --> 00:16:38,490
is one of the ultimate goals,

430
00:16:38,490 --> 00:16:40,323
but maybe more conceptually,

431
00:16:42,626 --> 00:16:44,730
another very important
situation where we would need

432
00:16:44,730 --> 00:16:46,560
to tame this very quantum effects

433
00:16:46,560 --> 00:16:49,680
is when we try to understand how

434
00:16:49,680 --> 00:16:52,770
to merge quantum mechanics and relativity

435
00:16:52,770 --> 00:16:55,470
into what is called a
theory of quantum gravity.

436
00:16:55,470 --> 00:16:58,500
We understand very well the
rules of quantum mechanics

437
00:16:58,500 --> 00:17:01,230
when quantum mechanics is important.

438
00:17:01,230 --> 00:17:04,080
We understand very well
the rules of relativity

439
00:17:04,080 --> 00:17:07,770
and of Einstein's theory
of relativity of gravity.

440
00:17:07,770 --> 00:17:09,510
When we try to put both together,

441
00:17:09,510 --> 00:17:11,700
we don't know how how that works.

442
00:17:11,700 --> 00:17:13,440
We don't know what are
the rules of the game

443
00:17:13,440 --> 00:17:16,290
when I need to use at the
same time quantum mechanics.

444
00:17:16,290 --> 00:17:18,930
That's very important especially
when things are very small.

445
00:17:18,930 --> 00:17:20,280
And then when things are very small,

446
00:17:20,280 --> 00:17:22,137
everything that can happen will happen

447
00:17:22,137 --> 00:17:24,660
and you have to take all that into account

448
00:17:24,660 --> 00:17:27,150
and gravity that describes
how the space-time

449
00:17:27,150 --> 00:17:28,740
can itself be deformed

450
00:17:28,740 --> 00:17:32,970
and how because that is
actually what gravity is.

451
00:17:32,970 --> 00:17:34,590
Now, normally we don't care

452
00:17:34,590 --> 00:17:36,660
because normally when space-time

453

00:17:36,660 --> 00:17:39,990
is deformed is when you
have some kind of huge star

454
00:17:39,990 --> 00:17:43,650
that is bending the space-time
or a black hole or something.

455
00:17:43,650 --> 00:17:45,870
And typically when objects are huge,

456
00:17:45,870 --> 00:17:48,060
quantum effects are irrelevant.

457
00:17:48,060 --> 00:17:49,830
And when quantum mechanics is important is

458
00:17:49,830 --> 00:17:52,890
when we are studying electrons
or protons or photons,

459
00:17:52,890 --> 00:17:54,360
but then they are very light

460
00:17:54,360 --> 00:17:56,070
and they don't deform space-time.

461
00:17:56,070 --> 00:17:57,060
On the other hand,

462
00:17:57,060 --> 00:17:59,310
when you are close to
singularities of black holes

463
00:17:59,310 --> 00:18:00,660
or at the beginning of the universe

464
00:18:00,660 --> 00:18:02,940
where everything was squeezed

together in a big bang,

465
00:18:02,940 --> 00:18:05,430
then you cannot get away without
using both at the same time

466
00:18:05,430 --> 00:18:09,690
because things are both very
heavy but also very small.

467
00:18:09,690 --> 00:18:12,080
And that's a key thing
we want to understand

468
00:18:12,080 --> 00:18:14,190
what are the ultimate rules of the game?

469
00:18:14,190 --> 00:18:16,020
What describes really our universe

470
00:18:16,020 --> 00:18:18,780
and what's the ultimate theory of physics?

471
00:18:18,780 --> 00:18:21,630
And that ultimate theory needs
to deal with strong coupling.

472
00:18:21,630 --> 00:18:24,690
So understanding, developing
these mathematical tools

473
00:18:24,690 --> 00:18:27,630
is useful both for real world physics,

474
00:18:27,630 --> 00:18:30,720
for understanding how do protons behave,

475
00:18:30,720 --> 00:18:33,300
how do some materials behave?

476
00:18:33,300 --> 00:18:35,070
Because not all materials
are weakly coupled.

477
00:18:35,070 --> 00:18:37,830
Sometimes we have in regular materials

478
00:18:37,830 --> 00:18:39,660
what are called phase transitions.

479
00:18:39,660 --> 00:18:42,030
And these phase transitions are precisely,

480
00:18:42,030 --> 00:18:45,750
transitions are precisely
points in the material where

481
00:18:45,750 --> 00:18:47,310
everything is happening at the same time

482
00:18:47,310 --> 00:18:48,720
and at all possible scales.

483
00:18:48,720 --> 00:18:50,670
And everything is very important there.

484
00:18:50,670 --> 00:18:52,740
All these quantum effects
are very important.

485
00:18:52,740 --> 00:18:56,220
And so taming this strongly coupled effect

486
00:18:56,220 --> 00:18:59,040
are important both in
this real world situation

487

00:18:59,040 --> 00:19:02,340
but also they will be needed to understand

488
00:19:02,340 --> 00:19:04,260
what's the ultimate
theory of quantum gravity?

489
00:19:04,260 --> 00:19:06,600
What's the ultimate theory
that describes our universe?

490
00:19:06,600 --> 00:19:08,670
And that puts together
all the rules of physics

491
00:19:08,670 --> 00:19:11,321
that we know into a unified rule.

492
00:19:11,321 --> 00:19:13,110
- And we can't go to a black hole

493
00:19:13,110 --> 00:19:14,820
or the beginning of the universe.

494
00:19:14,820 --> 00:19:18,333
So it has to happen largely
on blackboards at first.

495
00:19:19,950 --> 00:19:22,530
- How could we do progress in such field

496
00:19:22,530 --> 00:19:24,870
where things are so abstract

497
00:19:24,870 --> 00:19:27,720
and where you are trying to even develop

498
00:19:27,720 --> 00:19:28,770
the rules of the game?

499
00:19:28,770 --> 00:19:30,540
So what do you use?

500
00:19:30,540 --> 00:19:33,510
So you use lots of thought
experiments, like you said,

501
00:19:33,510 --> 00:19:35,820
you cannot jump into a black hole,

502
00:19:35,820 --> 00:19:37,950
but you can do a thought experiment.

503
00:19:37,950 --> 00:19:39,150
Suppose I jump,

504
00:19:39,150 --> 00:19:44,130
I throw Alice into a black
hole and Bob stays outside

505
00:19:44,130 --> 00:19:46,380
and Bob sends a signal to Alice

506
00:19:46,380 --> 00:19:48,360
and as Alice is falling
into the black hole,

507
00:19:48,360 --> 00:19:50,610
she keeps sending the signal back to Bob

508
00:19:50,610 --> 00:19:54,120
at the rate of three photons
per second, et cetera.

509
00:19:54,120 --> 00:19:56,130
And you do these thought experiments

510

00:19:56,130 --> 00:19:56,970
and you start imagining

511
00:19:56,970 --> 00:19:59,057
what would happen if you do this kind,

512
00:19:59,057 --> 00:20:02,250
if you go to these extreme situations

513
00:20:02,250 --> 00:20:06,570
and often these thought
experiments allow you to deduce,

514
00:20:06,570 --> 00:20:10,740
to come up with new rules
for how physics work.

515
00:20:10,740 --> 00:20:15,120
So that's how Einstein
developed many of his ideas was

516
00:20:15,120 --> 00:20:18,000
by imagining he had these experiments

517
00:20:18,000 --> 00:20:19,800
where he would jump and if I'm falling

518
00:20:19,800 --> 00:20:22,530
and something is falling nearby me,

519
00:20:22,530 --> 00:20:23,910
how can I tell that I'm falling?

520
00:20:23,910 --> 00:20:26,430
I just, I look at this red ball

521
00:20:26,430 --> 00:20:27,570
that is just falling with me.

522
00:20:27,570 --> 00:20:29,610
How do I know that we are both
falling and we are not both

523
00:20:29,610 --> 00:20:31,470
just standing in space?

524
00:20:31,470 --> 00:20:32,370
And indeed you cannot,

525
00:20:32,370 --> 00:20:33,570
if all you see is the red ball

526
00:20:33,570 --> 00:20:35,880
that is close to you and
you are both falling,

527
00:20:35,880 --> 00:20:37,560
you'd see the red ball and you are falling

528
00:20:37,560 --> 00:20:39,150
or you are in the middle of empty space,

529
00:20:39,150 --> 00:20:40,230
it's the same thing.

530
00:20:40,230 --> 00:20:41,063
And so he said, oh,

531
00:20:41,063 --> 00:20:44,220
basically then gravity
should just be like falling,

532
00:20:44,220 --> 00:20:47,160
should just be like going
freely in empty space

533
00:20:47,160 --> 00:20:49,257

and then maybe gravity can be geometrize

534
00:20:49,257 --> 00:20:50,550
and maybe gravity is just

535
00:20:50,550 --> 00:20:52,140
the formation of space-time and so on.

536
00:20:52,140 --> 00:20:54,720
And eventually it led him
to the theory of relativity.

537
00:20:54,720 --> 00:20:56,610
So by thinking of the
thought experiments, right?

538
00:20:56,610 --> 00:20:57,600
So he was just thinking,

539
00:20:57,600 --> 00:21:00,570
I fall and I have this
red ball nearby and boom,

540
00:21:00,570 --> 00:21:01,623
gravity came about.

541
00:21:02,550 --> 00:21:05,010
So thought experiments
is one of the key thing.

542
00:21:05,010 --> 00:21:09,660
The other, like I said before
is computers, often we say,

543
00:21:09,660 --> 00:21:12,750
I have this crazy stuff,
everything goes on and it's,

544
00:21:12,750 --> 00:21:14,940

I put it in a computer and I ask, okay,

545
00:21:14,940 --> 00:21:16,800
I cannot compute all these things.

546
00:21:16,800 --> 00:21:18,600
I'll ask the computer to compute

547
00:21:18,600 --> 00:21:20,130
and the computer will crunch numbers.

548
00:21:20,130 --> 00:21:21,643
And a few days later tells me, okay,

549
00:21:21,643 --> 00:21:25,560
the result is 7.3 and then I have to go

550
00:21:25,560 --> 00:21:27,420
and develop totally different tools

551
00:21:27,420 --> 00:21:30,120
that could run some
computation in pen and paper

552
00:21:30,120 --> 00:21:32,009
and give me the 7.3.

553
00:21:32,009 --> 00:21:33,870
And now I have some hints from computers.

554
00:21:33,870 --> 00:21:37,860
So computers are like a way
of creating your own universe

555
00:21:37,860 --> 00:21:40,500
are like thought experiments,
but with numbers,

556

00:21:40,500 --> 00:21:42,000
I run my computer computation

557
00:21:42,000 --> 00:21:45,180
and I have this prediction
for what it could be.

558
00:21:45,180 --> 00:21:47,730
And recently in physics
there are other ideas

559
00:21:47,730 --> 00:21:50,035
that are now emerging as alternatives

560
00:21:50,035 --> 00:21:54,690
for studying these theories
at a very strong coupling.

561
00:21:54,690 --> 00:21:57,188
And we might at some point discuss some of

562
00:21:57,188 --> 00:22:00,195
these ideas that go by
the name of holography

563
00:22:00,195 --> 00:22:04,380
and ADSCFT and that are
new descriptions of physics

564
00:22:04,380 --> 00:22:05,790
that sometimes give you a totally

565
00:22:05,790 --> 00:22:07,140
different perspective on a problem.

566
00:22:07,140 --> 00:22:08,910
You're stuck on trying to
understand this problem

567

00:22:08,910 --> 00:22:10,800
and then a new idea comes that says,

568
00:22:10,800 --> 00:22:12,630
well actually this problem is equivalent

569
00:22:12,630 --> 00:22:14,970
to this other problem
that's totally different.

570
00:22:14,970 --> 00:22:17,550
And now suddenly you
are attacking a problem

571
00:22:17,550 --> 00:22:20,100
and you have two different
descriptions of the same thing.

572
00:22:20,100 --> 00:22:22,560
You have two different
approaches that you can use.

573
00:22:22,560 --> 00:22:26,940
And so that's another concept that we use,

574
00:22:26,940 --> 00:22:30,390
which is this concept of
dualities or correspondences,

575
00:22:30,390 --> 00:22:32,760
which are often in physics,
there are more than,

576
00:22:32,760 --> 00:22:35,250
there is more than one way
of describing the same thing,

577
00:22:35,250 --> 00:22:37,980
like a fluid in a swimming
pool like we said before.

578
00:22:37,980 --> 00:22:40,980
One way of describing is just
describe where is the water,

579
00:22:40,980 --> 00:22:43,770
how is it moving and at what velocity,

580
00:22:43,770 --> 00:22:44,760
what's the temperature?

581
00:22:44,760 --> 00:22:45,750
Is it too cold?

582
00:22:45,750 --> 00:22:48,177
Is there too much salt in it?

583
00:22:48,177 --> 00:22:50,370
And you describe the
properties of the water

584
00:22:50,370 --> 00:22:52,290
and the fluid that's
moving the swimming pool.

585
00:22:52,290 --> 00:22:54,420
Another description would be you go,

586
00:22:54,420 --> 00:22:55,650
you zoom in and you see oh,

587
00:22:55,650 --> 00:22:57,360
it's just a bunch of
atoms and you describe

588
00:22:57,360 --> 00:22:58,710
the position of all the atoms

589

00:22:58,710 --> 00:23:01,211
and where they are and what
they're trying to do, et cetera.

590
00:23:01,211 --> 00:23:02,970
And of course it's the same thing.

591
00:23:02,970 --> 00:23:04,770
- But that sounds much harder.

592
00:23:04,770 --> 00:23:06,660
- But the atom one sounds much harder

593
00:23:06,660 --> 00:23:07,830
in this particular case.

594
00:23:07,830 --> 00:23:08,850
It's true.

595
00:23:08,850 --> 00:23:10,470
In fact, what happens is that

596
00:23:10,470 --> 00:23:12,120
the atom one is much harder because

597
00:23:12,120 --> 00:23:14,100
there are many, many more atoms and so on.

598
00:23:14,100 --> 00:23:17,610
But it's also more fundamental
because it's the same atoms

599
00:23:17,610 --> 00:23:20,850
that describe the movement in
the swimming pool that will

600
00:23:20,850 --> 00:23:24,120
describe water vapor that
is totally different, right?

601
00:23:24,120 --> 00:23:25,260
So if you have water vapor,

602
00:23:25,260 --> 00:23:27,660
it's the same molecules of
water that describe water

603
00:23:27,660 --> 00:23:31,650
in the swimming pool and
that describe a tsunami.

604
00:23:31,650 --> 00:23:34,380
And so tsunami, the swimming
pool and water vapor,

605
00:23:34,380 --> 00:23:35,340
it's more or less the same thing.

606
00:23:35,340 --> 00:23:37,050
Ice is also the same thing, right?

607
00:23:37,050 --> 00:23:38,850
So it's the same molecules of water.

608
00:23:39,780 --> 00:23:41,940
And so what happens is that sometimes

609
00:23:41,940 --> 00:23:43,650
the rules at the microscopic level,

610
00:23:43,650 --> 00:23:46,710
the rules for this atoms
that will be the atoms

611
00:23:46,710 --> 00:23:50,235
of water are very, very simple
at the microscopic level.

612
00:23:50,235 --> 00:23:53,640
But then because you put so many of them

613
00:23:53,640 --> 00:23:55,560
and even with a very simple rule,

614
00:23:55,560 --> 00:23:58,290
complicated emergent phenomena appear,

615
00:23:58,290 --> 00:24:00,510
and you can get ice, you can get vapor,

616
00:24:00,510 --> 00:24:01,560
you can get liquids,

617
00:24:01,560 --> 00:24:03,440
you can get all these different things out

618
00:24:03,440 --> 00:24:05,340
of very simple rules,

619
00:24:05,340 --> 00:24:07,800
it's like in a game you can have a game

620
00:24:07,800 --> 00:24:09,630
with very simple rules like chess.

621
00:24:09,630 --> 00:24:11,580
And then you have these
beautiful games that people say,

622
00:24:11,580 --> 00:24:14,670
oh wow, this was a masterpiece,
how amazing and so on.

623
00:24:14,670 --> 00:24:16,500
And the rules of chess are the same.

624
00:24:16,500 --> 00:24:20,220
But then some games are amazing
and some games are boring.

625
00:24:20,220 --> 00:24:21,990
And similarly with water,

626
00:24:21,990 --> 00:24:24,030
some phases of water are very boring

627
00:24:24,030 --> 00:24:25,617
and the most exciting phases of water

628
00:24:25,617 --> 00:24:27,780
are in the transition between liquid

629
00:24:27,780 --> 00:24:30,780
and vapor and when it's
really transitioning

630
00:24:30,780 --> 00:24:33,150
and then it's where this quantum effects

631
00:24:33,150 --> 00:24:36,315
become more important and
where everything matters

632
00:24:36,315 --> 00:24:40,170
and that's where even
though the fundamental rules

633
00:24:40,170 --> 00:24:42,360
are the same, the emergent phenomena,

634
00:24:42,360 --> 00:24:46,450
the emergent effects can be much richer

635
00:24:47,377 --> 00:24:50,460

than the fundamental rules.

636
00:24:50,460 --> 00:24:53,550
Now, it's true that the
fundamental rules can be simple,

637
00:24:53,550 --> 00:24:57,180
but indeed predicting what's
happening at an emergent level,

638
00:24:57,180 --> 00:24:58,500
it's often very complicated.

639
00:24:58,500 --> 00:24:59,340
So in that sense,

640
00:24:59,340 --> 00:25:01,320
it's easier to use the
equations that describe

641
00:25:01,320 --> 00:25:02,850
the water in the swimming pool of course,

642
00:25:02,850 --> 00:25:05,430
than describing all the
atoms in the swimming pool.

643
00:25:05,430 --> 00:25:08,070
- You said that the hard
problems that you're working

644
00:25:08,070 --> 00:25:11,190
on in quantum field
theory require new tools.

645
00:25:11,190 --> 00:25:12,870
Can you tell us what
some of these tools are

646

00:25:12,870 --> 00:25:15,960
that you use to tackle these
very difficult problems?

647
00:25:15,960 --> 00:25:17,759
- Like we said in quantum mechanics,

648
00:25:17,759 --> 00:25:20,820
many things happen at once
and you cannot really say

649
00:25:20,820 --> 00:25:22,290
for sure what's going to happen

650
00:25:22,290 --> 00:25:23,940
because everything is happen at once.

651
00:25:23,940 --> 00:25:26,460
When I told you that particles
travel from a flashlight from

652
00:25:26,460 --> 00:25:29,430
a point to another, they
actually do many things at once.

653
00:25:29,430 --> 00:25:31,140
And in particular,

654
00:25:31,140 --> 00:25:33,270
even to say that particle
goes from A to B,

655
00:25:33,270 --> 00:25:35,790
you cannot know for sure
that it goes from A to B.

656
00:25:35,790 --> 00:25:37,680
You can only compute probabilities.

657

00:25:37,680 --> 00:25:40,410
And so physics is all about
computing probabilities.

658
00:25:40,410 --> 00:25:43,080
There is some probability
that it goes from A to B,

659
00:25:43,080 --> 00:25:44,430
but it can go from A to C,

660
00:25:44,430 --> 00:25:45,750
it can go from A to D,

661
00:25:45,750 --> 00:25:47,550
it can go from A to any other point.

662
00:25:48,390 --> 00:25:49,800
And so at the end of the day,

663
00:25:49,800 --> 00:25:53,580
what you are studying are
what are the probabilities

664
00:25:53,580 --> 00:25:56,280
of something to happen in physics,

665
00:25:56,280 --> 00:25:58,560
and sometimes to do these
computations in physics

666
00:25:58,560 --> 00:26:00,420
and to compute all this,

667
00:26:00,420 --> 00:26:02,640
what's the probability
for something to happen,

668
00:26:02,640 --> 00:26:04,680

you have to do these long computations,

669
00:26:04,680 --> 00:26:07,110
you have to develop these new tools.

670
00:26:07,110 --> 00:26:09,030
But you could flip it around and say,

671
00:26:09,030 --> 00:26:11,040
well, if it's a probability,

672
00:26:11,040 --> 00:26:13,260
it's a number between zero and one,

673
00:26:13,260 --> 00:26:14,310
you can ask,

674
00:26:14,310 --> 00:26:16,260
instead of doing the
computation, let me think,

675
00:26:16,260 --> 00:26:18,120
what could be the possible results?

676
00:26:18,120 --> 00:26:21,480
It must respect the rules
of causality and relativity.

677
00:26:21,480 --> 00:26:22,620
So if I'm very far away,

678
00:26:22,620 --> 00:26:25,260
I cannot influence what's
happening here right away.

679
00:26:25,260 --> 00:26:27,720
And you start thinking instead
of doing the computation,

680
00:26:27,720 --> 00:26:31,500
is there a way of trying
to constrain to fix,

681
00:26:31,500 --> 00:26:35,400
we call it to bootstrap what
could happen just by trying

682
00:26:35,400 --> 00:26:36,630
to impose very fundamental

683
00:26:36,630 --> 00:26:38,580
principles on the result directly.

684
00:26:38,580 --> 00:26:42,060
So instead of trying to describe
what is really going on,

685
00:26:42,060 --> 00:26:43,470
can we think of a question,

686
00:26:43,470 --> 00:26:46,380
a physics question like
what's the probability

687
00:26:46,380 --> 00:26:50,670
of a photon reaching my hand
coming from Lawrence's hand?

688
00:26:50,670 --> 00:26:53,460
And then instead of trying to
do this honest computation,

689
00:26:53,460 --> 00:26:55,890
let's try to fix the result to ask

690
00:26:55,890 --> 00:26:58,263
what are the possible
outcomes of this result?

691
00:26:59,100 --> 00:27:01,410
In any possible theory we might not

692
00:27:01,410 --> 00:27:02,490
even know the rules of the game.

693
00:27:02,490 --> 00:27:04,230
We might not even know
the fundamental theory

694
00:27:04,230 --> 00:27:06,660
that we could be studying quantum gravity.

695
00:27:06,660 --> 00:27:10,290
And this is a new perspective,
it's called the bootstrap.

696
00:27:10,290 --> 00:27:11,370
And it's the idea of trying

697
00:27:11,370 --> 00:27:14,250
to use very fundamental
physics principles,

698
00:27:14,250 --> 00:27:16,830
quantum mechanics, relativity,

699
00:27:16,830 --> 00:27:20,070
some very simple mathematical
principles as well,

700
00:27:20,070 --> 00:27:22,950
and trying to use these
fundamental physics principles

701
00:27:22,950 --> 00:27:25,230
that we believe are sacred to try

702
00:27:25,230 --> 00:27:27,900
to carve out the space of

703
00:27:27,900 --> 00:27:30,420
what is possible and what's impossible

704
00:27:30,420 --> 00:27:33,063
in a given experiment, in
a given physical quantity.

705
00:27:33,990 --> 00:27:36,750
So this is a very
different way of thinking.

706
00:27:36,750 --> 00:27:38,850
Instead of thinking I have one theory

707
00:27:38,850 --> 00:27:40,500
and one computation I have to do

708
00:27:40,500 --> 00:27:42,030
and I don't know how
to do the computation.

709
00:27:42,030 --> 00:27:43,500
And I try and I try and I try,

710
00:27:43,500 --> 00:27:44,333
I say, no, no, no,

711
00:27:44,333 --> 00:27:47,550
let me take a step back and
say there is some theory,

712
00:27:47,550 --> 00:27:48,840
there is some computation.

713
00:27:48,840 --> 00:27:50,160

I dunno what the computation is,

714
00:27:50,160 --> 00:27:52,290
but I know that the
result must be compatible

715
00:27:52,290 --> 00:27:54,390
with the fundamental
principles of physics.

716
00:27:54,390 --> 00:27:55,790
So what could the result be?

717
00:27:56,970 --> 00:27:58,740
And so this is a new approach.

718
00:27:58,740 --> 00:28:00,960
Now, typically what you'd
study in this approach

719
00:28:00,960 --> 00:28:03,600
is then you ask this
very general questions

720
00:28:03,600 --> 00:28:05,220
of what could be the outcomes

721
00:28:05,220 --> 00:28:07,800
of some probability of some experiment.

722
00:28:07,800 --> 00:28:10,470
And of course, just by thinking of

723
00:28:10,470 --> 00:28:12,660
what could be possible
and what is impossible,

724
00:28:12,660 --> 00:28:15,810
you cannot get the 7.3

that I mentioned before.

725
00:28:15,810 --> 00:28:17,820
You cannot get a sharp
number, but you can say,

726
00:28:17,820 --> 00:28:20,970
well, it could be between five and eight.

727
00:28:20,970 --> 00:28:23,490
And then you start inputting
more physical principles.

728
00:28:23,490 --> 00:28:24,360
You start saying, oh,

729
00:28:24,360 --> 00:28:25,680
and I also want to impose

730
00:28:25,680 --> 00:28:28,560
a little bit of Einstein's
theory of relativity and so on.

731
00:28:28,560 --> 00:28:32,130
And now you run the thought
experiment of what could happen

732
00:28:32,130 --> 00:28:35,130
and you get between 5.3 and 7.8

733
00:28:35,130 --> 00:28:36,840
and you start squeezing the result.

734
00:28:36,840 --> 00:28:39,360
You start squeezing the possible outcomes

735
00:28:39,360 --> 00:28:41,580
of what's possible and impossible.

736
00:28:41,580 --> 00:28:44,310
And the question we might ask is the space

737
00:28:44,310 --> 00:28:45,480
of what's possible and impossible

738
00:28:45,480 --> 00:28:46,800
that's not the one dimensional space

739
00:28:46,800 --> 00:28:48,120
because there's not one experiment,

740
00:28:48,120 --> 00:28:49,580
there are millions of
experiments we could do.

741
00:28:49,580 --> 00:28:51,660
So it's an infinite dimensional space.

742
00:28:51,660 --> 00:28:53,580
So you should think of
it as like a sculpture

743
00:28:53,580 --> 00:28:55,500
in infinite dimensions and the inside

744
00:28:55,500 --> 00:28:56,940
of the sculpture is what's possible.

745
00:28:56,940 --> 00:28:59,790
And the outside of the
sculpture is what's impossible,

746
00:28:59,790 --> 00:29:01,710
and how is this space,

747
00:29:01,710 --> 00:29:04,380
can we study this metaphysic space,

748
00:29:04,380 --> 00:29:06,540
this space of all
possible physics outcomes?

749
00:29:06,540 --> 00:29:07,860
Can we study it?

750
00:29:07,860 --> 00:29:10,320
Does it have nice features
like a nice sculpture?

751
00:29:10,320 --> 00:29:13,590
Does it have pointy edges, pointy corners?

752
00:29:13,590 --> 00:29:16,230
So that's something we
are trying to understand

753
00:29:16,230 --> 00:29:17,940
that many people are trying to understand

754
00:29:17,940 --> 00:29:20,670
is what is this possible space of theories

755
00:29:20,670 --> 00:29:23,250
and can it be that some of the theories

756
00:29:23,250 --> 00:29:25,740
that we struggle to solve
because they are so strongly

757
00:29:25,740 --> 00:29:28,320
couple and the quantum
effects are so strong,

758
00:29:28,320 --> 00:29:30,600
could it be that they
occupy special places

759
00:29:30,600 --> 00:29:32,400
in this space of theories?

760
00:29:32,400 --> 00:29:35,520
Could it be that there is special points

761
00:29:35,520 --> 00:29:38,310
in this landscape of what's
possible and impossible?

762
00:29:38,310 --> 00:29:42,561
And perhaps there are special
points and tips of some

763
00:29:42,561 --> 00:29:46,620
corners of this space of theories

764
00:29:46,620 --> 00:29:48,060
and perhaps there are some locations

765
00:29:48,060 --> 00:29:51,150
that are privileged
and that could indicate

766
00:29:51,150 --> 00:29:52,653
more exciting things going on.

767
00:29:52,653 --> 00:29:54,240
So that's one approach.

768
00:29:54,240 --> 00:29:56,640
- You said this is the bootstrap approach.

769
00:29:56,640 --> 00:29:57,960
- This is the bootstrap approach.

770
00:29:57,960 --> 00:30:02,960

- This seems like such a real
world nitty dirty bootstrap.

771
00:30:03,210 --> 00:30:05,460
Can you explain what it
means in this context?

772
00:30:05,460 --> 00:30:08,730
- Bootstrap alludes to
an impossible picture.

773
00:30:08,730 --> 00:30:11,280
It's the picture that
you hold your yourself

774
00:30:11,280 --> 00:30:14,310
from your bootstraps and you
push and then you are flying.

775
00:30:14,310 --> 00:30:17,880
You lift yourself out of
the air by pushing off your,

776
00:30:17,880 --> 00:30:20,010
by pulling off your bootstraps.

777
00:30:20,010 --> 00:30:22,650
And why is it related
to what I said before?

778
00:30:22,650 --> 00:30:26,640
Because I'm trying to get
the result of a computation

779
00:30:26,640 --> 00:30:29,610
without doing the computation,
that really looks impossible.

780
00:30:29,610 --> 00:30:32,220
I should not be able

to get away with that.

781
00:30:32,220 --> 00:30:33,530
- That's like yanking yourself

782
00:30:33,530 --> 00:30:34,693
into the air by your bootstraps.

783
00:30:34,693 --> 00:30:37,440
- It's like, I want to
know this result 5.3

784
00:30:37,440 --> 00:30:39,330
to 7.8 without doing the computation.

785
00:30:39,330 --> 00:30:40,163
How come?

786
00:30:40,163 --> 00:30:40,996
Why?

787
00:30:40,996 --> 00:30:42,120
How could I do it?

788
00:30:42,120 --> 00:30:43,290
And that looks counterintuitive.

789
00:30:43,290 --> 00:30:47,580
It looks strange, and that's
why we like this picture.

790
00:30:47,580 --> 00:30:50,580
Now it turns out that why
would this be possible?

791
00:30:50,580 --> 00:30:53,820
And it's possible because
physics is such a beautiful,

792
00:30:53,820 --> 00:30:57,180
but at the same time, rigid framework,

793
00:30:57,180 --> 00:30:59,250
it's amazing that things can work,

794
00:30:59,250 --> 00:31:01,740
because so many things need to
work at the same time, right?

795
00:31:01,740 --> 00:31:05,760
So you need with the same
rules of electromagnetism

796
00:31:05,760 --> 00:31:10,200
to explain radio waves and properties

797
00:31:10,200 --> 00:31:14,947
of matter and electronics
and spectrum of the sun,

798
00:31:15,870 --> 00:31:19,061
the same rules need to
describe so many things.

799
00:31:19,061 --> 00:31:21,390
And so everything is so
rigid that if you ask,

800
00:31:21,390 --> 00:31:24,570
could I change this
parameter a little bit here,

801
00:31:24,570 --> 00:31:26,640
I want to explain some physics experiment

802
00:31:26,640 --> 00:31:27,960
where in some material I got

803
00:31:27,960 --> 00:31:29,760
some blue line instead of some red lines,

804
00:31:29,760 --> 00:31:31,740
so I'll change this law of physics,

805
00:31:31,740 --> 00:31:33,620
but then everything else will fail, right?

806
00:31:33,620 --> 00:31:35,850
So you cannot just
change things at random.

807
00:31:35,850 --> 00:31:37,440
So everything's very, very rigid.

808
00:31:37,440 --> 00:31:40,500
So even without doing
computations sometimes

809
00:31:40,500 --> 00:31:42,161
because things are so constrained,

810
00:31:42,161 --> 00:31:45,210
just by thinking what could happen,

811
00:31:45,210 --> 00:31:47,640
you can indeed nail things down.

812
00:31:47,640 --> 00:31:49,620
And it brings us back to this power

813
00:31:49,620 --> 00:31:53,820
of thought experiments that
this is often built on thinking,

814
00:31:53,820 --> 00:31:57,630
suppose I want to study

this probability needs to be

815
00:31:57,630 --> 00:31:58,830
a number between zero and one.

816
00:31:58,830 --> 00:32:00,960
But if this number was 0.7,

817
00:32:00,960 --> 00:32:04,403
it might imply that the
outcome of another experiment,

818
00:32:04,403 --> 00:32:07,825
another thought experiment will be 1.3,

819
00:32:07,825 --> 00:32:10,050
but probabilities cannot be 1.3,

820
00:32:10,050 --> 00:32:11,460
they need to be smaller than one and then

821
00:32:11,460 --> 00:32:14,250
that's 0.7 needs to be excluded.

822
00:32:14,250 --> 00:32:15,940
Okay, so let me try 0.1,

823
00:32:15,940 --> 00:32:18,802
but 0.1 would then imply
that this other experiment

824
00:32:18,802 --> 00:32:21,750
would predict a signal arriving
there faster than light.

825
00:32:21,750 --> 00:32:23,850
Okay, so then 0.1 is also excluded.

826

00:32:23,850 --> 00:32:26,460
And by just thinking about
all these thought experiments,

827
00:32:26,460 --> 00:32:28,890
now we are starting to squeeze
the space of what's possible

828
00:32:28,890 --> 00:32:30,240
and impossible and we are getting

829
00:32:30,240 --> 00:32:31,500
to a smaller and smaller space.

830
00:32:31,500 --> 00:32:32,850
- It's like detective work,

831
00:32:32,850 --> 00:32:34,500
it's like eliminating the possibilities.

832
00:32:34,500 --> 00:32:35,757
- It's very much like detective work.

833
00:32:35,757 --> 00:32:37,200
- And I think this type of approach

834
00:32:37,200 --> 00:32:39,390
is usually referred to
as a bottom up approach,

835
00:32:39,390 --> 00:32:40,470
whereas some of the other ones

836
00:32:40,470 --> 00:32:42,090
are called a top down approach.

837
00:32:42,090 --> 00:32:44,550
In general, what are
the types of situations

838
00:32:44,550 --> 00:32:46,860
where you wanna use some
kind of bottom up approach

839
00:32:46,860 --> 00:32:48,930
versus a top down approach?

840
00:32:48,930 --> 00:32:49,763
- Exactly. Yeah.

841
00:32:49,763 --> 00:32:54,345
So there is two descriptions.

842
00:32:54,345 --> 00:32:56,790
I confess that I always mixed them up,

843
00:32:56,790 --> 00:32:59,490
so I will not try to use
bottom up and top down

844
00:32:59,490 --> 00:33:01,500
because I never know which one is which,

845
00:33:01,500 --> 00:33:03,448
but I know such thing exists.

846
00:33:03,448 --> 00:33:04,500
But basically=

847
00:33:04,500 --> 00:33:07,480
- Your boots are on the
bottom (indistinct).

848
00:33:08,850 --> 00:33:12,450
- I never know which one is
top up, top down, bottom up.

849

00:33:12,450 --> 00:33:16,683
Yeah, for me, I never understood
the logic between that,

850
00:33:18,540 --> 00:33:19,980
but indeed there is this picture

851
00:33:19,980 --> 00:33:23,700
that you can try to understand
the rules of the game,

852
00:33:23,700 --> 00:33:26,040
the rules of the world by either trying

853
00:33:26,040 --> 00:33:27,930
to get the very big picture

854
00:33:27,930 --> 00:33:31,290
of what could be the
possible and impossible,

855
00:33:31,290 --> 00:33:34,230
what can happen in the
most general situations.

856
00:33:34,230 --> 00:33:38,130
And the other way you could
make progress is saying no,

857
00:33:38,130 --> 00:33:40,890
let me pick one special example and learn

858
00:33:40,890 --> 00:33:43,650
that special example
in great, great detail.

859
00:33:43,650 --> 00:33:46,710
Those are two very extreme
ways of getting knowledge,

860
00:33:46,710 --> 00:33:48,330
totally big picture.

861
00:33:48,330 --> 00:33:51,450
I mean it'll be like say
what do we have in common?

862
00:33:51,450 --> 00:33:55,916
We all want things, we all
move from one place to another.

863
00:33:55,916 --> 00:33:58,770
We all have anxiety, et cetera.

864
00:33:58,770 --> 00:34:01,650
That's a very general way of
describing humanity, right?

865
00:34:01,650 --> 00:34:04,410
Or you can just follow one person

866
00:34:04,410 --> 00:34:08,340
and learn about all its
inner desires and so on.

867
00:34:08,340 --> 00:34:10,110
And even though it is just one person,

868
00:34:10,110 --> 00:34:12,076
if you really learn about everything

869
00:34:12,076 --> 00:34:14,400
that person feels or thinks,

870
00:34:14,400 --> 00:34:16,650
you really learn a great
deal about humanity.

871

00:34:16,650 --> 00:34:17,910
And so in physics it's the same thing.

872
00:34:17,910 --> 00:34:20,280
You can either get the full picture

873
00:34:20,280 --> 00:34:22,530
of what's happening in
all possible generality,

874
00:34:22,530 --> 00:34:24,570
but then you will not go as deep

875
00:34:24,570 --> 00:34:27,780
in any particular
direction, or you can say,

876
00:34:27,780 --> 00:34:31,320
let me focus on one example
and let me go really down on

877
00:34:31,320 --> 00:34:34,800
along that rabbit hole and
try to understand everything

878
00:34:34,800 --> 00:34:36,540
from all possible points of view

879
00:34:36,540 --> 00:34:38,010
about that particular problem

880
00:34:38,010 --> 00:34:39,750
or that particular theory.

881
00:34:39,750 --> 00:34:41,040
And in that way by,

882
00:34:41,040 --> 00:34:43,560
based on that particular example,

883
00:34:43,560 --> 00:34:45,660
try to then draw general lessons

884
00:34:45,660 --> 00:34:50,100
that could be valid in much
more general situations.

885
00:34:50,100 --> 00:34:53,730
- You said we can think of the
what it gives us as you know,

886
00:34:53,730 --> 00:34:57,180
an ice sculpture or some
complicated landscape with these

887
00:34:57,180 --> 00:34:59,400
peninsulas or islands or different things.

888
00:34:59,400 --> 00:35:02,400
So is the ultimate goal
to try to figure out

889
00:35:02,400 --> 00:35:04,830
where our reality, our world fits in?

890
00:35:04,830 --> 00:35:09,090
And this is just some point
in one of these landscapes?

891
00:35:09,090 --> 00:35:11,160
- Right, exactly.

892
00:35:11,160 --> 00:35:13,427
So we could imagine we have this map

893
00:35:13,427 --> 00:35:16,440
and there's this cross, you are here,

894
00:35:16,440 --> 00:35:17,790
and now there are two possibilities.

895
00:35:17,790 --> 00:35:20,310
Maybe we carve out this map

896
00:35:20,310 --> 00:35:22,350
of what's possible and
what's impossible, right?

897
00:35:22,350 --> 00:35:24,330
And maybe this map is like Canada

898
00:35:24,330 --> 00:35:27,600
and maybe we are at some
point in the middle of Canada.

899
00:35:27,600 --> 00:35:29,883
Well then it's hard to find us, right?

900
00:35:29,883 --> 00:35:31,770
Canada's very big.

901
00:35:31,770 --> 00:35:35,430
If you are in some random point
in the middle of of Canada,

902
00:35:35,430 --> 00:35:37,230
no one will ever find you.

903
00:35:37,230 --> 00:35:39,930
But if you are at the tip of the peninsula

904
00:35:39,930 --> 00:35:42,660
or in the middle of a very
small island or something,

905
00:35:42,660 --> 00:35:45,180

those are special points
you could look at.

906
00:35:45,180 --> 00:35:46,500
And it so happens,

907
00:35:46,500 --> 00:35:47,940
and sometimes we understand why,

908
00:35:47,940 --> 00:35:50,040
sometimes we don't understand why,

909
00:35:50,040 --> 00:35:52,200
that often the most
interesting theories are

910
00:35:52,200 --> 00:35:55,140
lying in these most interesting
spots, these corners,

911
00:35:55,140 --> 00:35:58,890
these tips, these places where
you cannot go any further.

912
00:35:58,890 --> 00:35:59,850
It's like at the boundary

913
00:35:59,850 --> 00:36:02,070
between what's possible
and what's impossible.

914
00:36:02,070 --> 00:36:04,393
Now why would people live at the boundary?

915
00:36:04,393 --> 00:36:06,450
That's where people live in Canada, right?

916
00:36:06,450 --> 00:36:09,390
They live at the boundary

between the US and Canada, right?

917
00:36:09,390 --> 00:36:10,223
Why?

918
00:36:10,223 --> 00:36:11,056
Because they were trying to go down

919
00:36:11,056 --> 00:36:12,840
because it was warmer
and then they stopped

920
00:36:12,840 --> 00:36:14,550
where they could not go anymore.

921
00:36:14,550 --> 00:36:16,110
So with physics it
could do the same thing.

922
00:36:16,110 --> 00:36:18,900
The theory could try
to go in some direction

923
00:36:18,900 --> 00:36:20,220
because it wants to maximize

924
00:36:20,220 --> 00:36:22,068
some physical principle and he wants to

925
00:36:22,068 --> 00:36:24,390
increase the entropy or something

926
00:36:24,390 --> 00:36:26,790
and it's trying to move and
then boom, cannot move anymore.

927
00:36:26,790 --> 00:36:28,380
So I got stuck here and then it's

928
00:36:28,380 --> 00:36:30,330
the boundary which not
possible and impossible.

929
00:36:30,330 --> 00:36:32,400
And so if if there's
some underlying principle

930
00:36:32,400 --> 00:36:34,800
that we might not know that is trying

931
00:36:34,800 --> 00:36:38,100
to push theories in some
particular direction,

932
00:36:38,100 --> 00:36:39,630
then it's natural that they stop

933
00:36:39,630 --> 00:36:41,280
where they cannot go any further.

934
00:36:41,280 --> 00:36:42,360
And that is the boundary

935
00:36:42,360 --> 00:36:44,040
between what's possible and impossible.

936
00:36:44,040 --> 00:36:47,310
And so that gives us hope
that if we could carve out

937
00:36:47,310 --> 00:36:49,620
this space of what's
possible and impossible,

938
00:36:49,620 --> 00:36:52,020
it's probably at the boundary
that the most interesting

939
00:36:52,020 --> 00:36:55,140
theories are if indeed such principles

940
00:36:55,140 --> 00:36:59,056
of wanting to go towards something.

941
00:36:59,056 --> 00:37:01,410
Like again, in countries we want

942
00:37:01,410 --> 00:37:02,940
to go towards the water or towards

943
00:37:02,940 --> 00:37:04,576
the warmer climate typically, right?

944
00:37:04,576 --> 00:37:06,210
And so there are these two principles

945
00:37:06,210 --> 00:37:09,960
that push you towards
water or warmer climate.

946
00:37:09,960 --> 00:37:11,490
If there is something similar in physics

947
00:37:11,490 --> 00:37:13,440
that pushes you towards, I dunno,

948
00:37:13,440 --> 00:37:15,212
some information theoretical principle

949
00:37:15,212 --> 00:37:17,550
or some anthropic principle or something

950
00:37:17,550 --> 00:37:20,400
that pushes you in some
particular direction,

951
00:37:20,400 --> 00:37:22,470
then you would expect interesting theories

952
00:37:22,470 --> 00:37:23,640
to lie at the boundary.

953
00:37:23,640 --> 00:37:25,830
So far that seems to
be what we are finding

954
00:37:25,830 --> 00:37:28,290
when we study this space of
the interesting theories.

955
00:37:28,290 --> 00:37:29,850
And then we try to put these crosses

956
00:37:29,850 --> 00:37:31,530
of we are here, we are here.

957
00:37:31,530 --> 00:37:32,850
Or interesting theories here.

958
00:37:32,850 --> 00:37:34,770
Another interesting theories there,

959
00:37:34,770 --> 00:37:36,060
these interesting theories

960
00:37:36,060 --> 00:37:38,070
and this crosses of where we are seem

961
00:37:38,070 --> 00:37:39,840
to indeed be very close to the boundary

962
00:37:39,840 --> 00:37:41,400
as far as we can tell.

963
00:37:41,400 --> 00:37:43,740
- One thing I really love
about these explanations

964
00:37:43,740 --> 00:37:44,850
that you give is you're helping

965
00:37:44,850 --> 00:37:48,240
to have us develop these really
nice pictures in our head.

966
00:37:48,240 --> 00:37:50,610
Just now you're telling
us about these landscapes

967
00:37:50,610 --> 00:37:52,680
and peninsulas and making connections

968
00:37:52,680 --> 00:37:54,510
to the Canadian border.

969
00:37:54,510 --> 00:37:57,420
And earlier you were telling
us about quantum field theory,

970
00:37:57,420 --> 00:37:58,988
you were talking about
membranes and bubbles,

971
00:37:58,988 --> 00:38:00,480
these kinds of things.

972
00:38:00,480 --> 00:38:02,340
Rather than just having to resort to math,

973
00:38:02,340 --> 00:38:04,050
we can develop these nice pictures.

974

00:38:04,050 --> 00:38:07,230
I also looked at some of
the titles of your papers

975
00:38:07,230 --> 00:38:08,850
and you had some other nice expressions,

976
00:38:08,850 --> 00:38:09,870
which I don't understand,

977
00:38:09,870 --> 00:38:12,270
but I can picture them
like spinning hexagons.

978
00:38:12,270 --> 00:38:15,960
There was a paper about
stampedes, non-zero bridges.

979
00:38:15,960 --> 00:38:18,330
So I'm just curious about
these kinds of pictures

980
00:38:18,330 --> 00:38:19,590
that you help us to create

981
00:38:19,590 --> 00:38:21,090
when you're making these explanations.

982
00:38:21,090 --> 00:38:23,640
Is this fundamental to
helping you to understand

983
00:38:23,640 --> 00:38:25,040
these concepts or is this something

984
00:38:25,040 --> 00:38:27,270
that you do to help communicate

985
00:38:27,270 --> 00:38:29,640

the work to the public at the end?

986
00:38:29,640 --> 00:38:30,930
- I think it's both.

987
00:38:30,930 --> 00:38:33,990
I think the style of physics that I do,

988
00:38:33,990 --> 00:38:35,290
I like to have a physical,

989
00:38:36,506 --> 00:38:38,850
to have some kind of
picture of what's going on.

990
00:38:38,850 --> 00:38:40,440
- In your head or are you actually

991
00:38:40,440 --> 00:38:42,540
sketching out pictures as well?

992
00:38:42,540 --> 00:38:45,480
- Both, this stampede
example, for example,

993
00:38:45,480 --> 00:38:49,980
is really literally processes
where particles are moving

994
00:38:49,980 --> 00:38:52,980
in a tight space and therefore
it's really like a stampede,

995
00:38:52,980 --> 00:38:54,480
they are moving and hitting each other

996
00:38:54,480 --> 00:38:57,207
and trying to pass from
one point to the other.

997
00:38:57,207 --> 00:38:59,430
And you could ask could

998
00:38:59,430 --> 00:39:02,430
those type of stampede-like behavior

999
00:39:02,430 --> 00:39:06,120
happen at the most
fundamental level of nature?

1000
00:39:06,120 --> 00:39:08,130
Could gluons sometimes try to move

1001
00:39:08,130 --> 00:39:09,810
from one point to the other and be hitting

1002
00:39:09,810 --> 00:39:11,760
another gluon and say, get away,

1003
00:39:11,760 --> 00:39:12,600
let me pass.

1004
00:39:12,600 --> 00:39:13,920
And pushing each other and trying

1005
00:39:13,920 --> 00:39:15,720
to move from point like a stampede.

1006
00:39:15,720 --> 00:39:20,250
And indeed we found some
limits where in some physics

1007
00:39:20,250 --> 00:39:22,800
situations where particles are trying

1008
00:39:22,800 --> 00:39:25,800
to move at a speed of light

from one point to another.

1009
00:39:25,800 --> 00:39:28,800
And because they are forced
to move at a speed of light,

1010
00:39:28,800 --> 00:39:30,240
if a bunch of particles are trying

1011
00:39:30,240 --> 00:39:31,830
to move at the same time
at a speed of light,

1012
00:39:31,830 --> 00:39:33,150
they will be on top of each other.

1013
00:39:33,150 --> 00:39:34,740
There's only one speed of light.

1014
00:39:34,740 --> 00:39:36,180
And then they will make the stampedes

1015
00:39:36,180 --> 00:39:38,610
and they will try to
interact with each other.

1016
00:39:38,610 --> 00:39:41,310
And that was cute because
then we started, we looked,

1017
00:39:41,310 --> 00:39:44,940
and there are some techniques
for studying this stampedes.

1018
00:39:44,940 --> 00:39:46,650
Actually people that study this stampedes,

1019
00:39:46,650 --> 00:39:48,960
they studied very different situations,

1020
00:39:48,960 --> 00:39:53,250
like boarding an airplane,
like who boards first,

1021
00:39:53,250 --> 00:39:54,870
and maybe not in Canada,

1022
00:39:54,870 --> 00:39:56,820
Canada probably people
have board in a steady way,

1023
00:39:56,820 --> 00:39:59,280
but if you're trying to board an airplane

1024
00:39:59,280 --> 00:40:01,407
and you hit each other and so on,

1025
00:40:01,407 --> 00:40:04,080
and or in traffic jams and so on

1026
00:40:04,080 --> 00:40:07,047
when the cars need to slow
down and accelerate and so on.

1027
00:40:07,047 --> 00:40:09,600
And so there are techniques
developed for counting

1028
00:40:09,600 --> 00:40:11,310
how many ways it's possible to board

1029
00:40:11,310 --> 00:40:13,560
an airplane or to move in traffic.

1030
00:40:13,560 --> 00:40:16,380
And those same type of counting
ways will be the same kind

1031
00:40:16,380 --> 00:40:18,930
of counting techniques that
we use to count how many ways

1032
00:40:18,930 --> 00:40:20,460
the gluons can move when they have to move

1033
00:40:20,460 --> 00:40:23,550
at the speed of light to
go from point A to point B.

1034
00:40:23,550 --> 00:40:24,690
- This is kind of going back

1035
00:40:24,690 --> 00:40:26,040
to earlier when you were telling us

1036
00:40:26,040 --> 00:40:28,020
about some of the tools that you make use

1037
00:40:28,020 --> 00:40:29,760
of in studying these
quantum field theories.

1038
00:40:29,760 --> 00:40:31,830
And I know another one
that you I think said,

1039
00:40:31,830 --> 00:40:34,140
but we didn't talk about
too much is holography,

1040
00:40:34,140 --> 00:40:36,480
which is making some of these connections

1041
00:40:36,480 --> 00:40:37,890
but in different dimensions.

1042

00:40:37,890 --> 00:40:39,390
And could you tell us a little bit more

1043
00:40:39,390 --> 00:40:41,610
about this tool of holography?

1044
00:40:41,610 --> 00:40:44,730
- So before mentioning
holography, let me mention again,

1045
00:40:44,730 --> 00:40:46,740
a little bit about this emergence.

1046
00:40:46,740 --> 00:40:50,310
So this emergence is the idea that,

1047
00:40:50,310 --> 00:40:53,610
so something that emerges
that was not there again,

1048
00:40:53,610 --> 00:40:55,980
like the a beautiful chess game.

1049
00:40:55,980 --> 00:40:57,900
The chess game by itself is not beautiful.

1050
00:40:57,900 --> 00:41:00,570
Just the horse moves like
an L and the pawn moves

1051
00:41:00,570 --> 00:41:03,900
by one step and then suddenly
beauty comes out of it, right?

1052
00:41:03,900 --> 00:41:05,040
When the game is amazing.

1053
00:41:05,040 --> 00:41:06,240
So beauty was not there.

1054
00:41:06,240 --> 00:41:09,270
And then it comes about, it's
the same thing with a fluid.

1055
00:41:09,270 --> 00:41:11,970
Like we said, a fluid
is just made of atoms.

1056
00:41:11,970 --> 00:41:14,790
So this notion of something being fluid

1057
00:41:14,790 --> 00:41:16,530
and smooth and so on, it's an illusion,

1058
00:41:16,530 --> 00:41:17,550
it's something emergent,

1059
00:41:17,550 --> 00:41:21,150
it emerges because we are not
looking very, very closely.

1060
00:41:21,150 --> 00:41:25,680
So we could say that a fluid
emerges when we zoom out.

1061
00:41:25,680 --> 00:41:29,070
When we look from far away,
then yes, a fluid exists,

1062
00:41:29,070 --> 00:41:33,420
A fluid makes sense, but when
we go in, oh, it was fake.

1063
00:41:33,420 --> 00:41:34,620
Same with temperature.

1064
00:41:34,620 --> 00:41:35,760
What is temperature?

1065
00:41:35,760 --> 00:41:36,810
Temperature is nothing.

1066
00:41:36,810 --> 00:41:38,610
There's no such thing as temperature.

1067
00:41:38,610 --> 00:41:41,010
What exists are particles moving around.

1068
00:41:41,010 --> 00:41:42,960
If particles move very, very, very fast,

1069
00:41:42,960 --> 00:41:45,900
you put your hand there and
the particles moving very fast

1070
00:41:45,900 --> 00:41:48,570
will hit the particles in your
hand and now the particles

1071
00:41:48,570 --> 00:41:51,510
in your hand are moving very
fast and your hand is warmer.

1072
00:41:51,510 --> 00:41:53,700
And that's what touching
a hot thing means.

1073
00:41:53,700 --> 00:41:56,010
You touch a very cold thing,

1074
00:41:56,010 --> 00:41:58,980
the particles in the cold
object are not moving.

1075
00:41:58,980 --> 00:42:00,660
So the ones in your hand, they are moving.

1076
00:42:00,660 --> 00:42:02,730
So you touch them and now
the ones in your hand,

1077
00:42:02,730 --> 00:42:05,520
they shake the ones in the
cold stuff and therefore they

1078
00:42:05,520 --> 00:42:08,610
lose energy because they
have to waste energy

1079
00:42:08,610 --> 00:42:10,350
to wake the other ones up,

1080
00:42:10,350 --> 00:42:12,450
and therefore, your hand cools down.

1081
00:42:12,450 --> 00:42:15,780
So what exists are particles
moving and particles dancing.

1082
00:42:15,780 --> 00:42:18,690
But what emerges is this
notion of temperature,

1083
00:42:18,690 --> 00:42:21,480
is this idea that there is
such thing as being hot,

1084
00:42:21,480 --> 00:42:22,590
being cold,

1085
00:42:22,590 --> 00:42:23,940
but again, that's emergent.

1086
00:42:23,940 --> 00:42:26,103
What's fundamental is particle moving.

1087
00:42:26,940 --> 00:42:30,300
Now in physics, it's not
a shock if I tell you no,

1088
00:42:30,300 --> 00:42:31,133
it's not really,

1089
00:42:31,133 --> 00:42:32,670
temperature is not really
something fundamental.

1090
00:42:32,670 --> 00:42:34,320
What's fundamental is particles, no,

1091
00:42:34,320 --> 00:42:35,850
fluid is not something fundamental.

1092
00:42:35,850 --> 00:42:37,560
What's fundamental is particles.

1093
00:42:37,560 --> 00:42:41,340
But a more recent idea that
is pushing this idea of

1094
00:42:41,340 --> 00:42:45,510
emergence to an extrema is
saying that perhaps even gravity,

1095
00:42:45,510 --> 00:42:48,040
even space-time is emergent,

1096
00:42:48,040 --> 00:42:50,160
perhaps even if you want reality.

1097
00:42:50,160 --> 00:42:52,500
Even us, we don't exist.

1098
00:42:52,500 --> 00:42:53,613

We are emergent.

1099
00:42:54,630 --> 00:42:56,820
And the idea is that we say in this room,

1100
00:42:56,820 --> 00:42:58,860
we are here in three dimensions, right?

1101
00:42:58,860 --> 00:43:01,620
We might be the image
of a hologram, right?

1102
00:43:01,620 --> 00:43:04,100
Right, like Princess Leia,
right, in "Star Wars", right?

1103
00:43:04,100 --> 00:43:07,140
So we might be a bunch of holograms here

1104
00:43:07,140 --> 00:43:08,190
and maybe we don't exist,

1105
00:43:08,190 --> 00:43:10,140
we are just projected holograms

1106
00:43:10,140 --> 00:43:12,030
into this three dimensional space.

1107
00:43:12,030 --> 00:43:14,910
But we are actually just being generated

1108
00:43:14,910 --> 00:43:19,080
by a 2D hologram at the
boundary of the universe, say,

1109
00:43:19,080 --> 00:43:21,690
now this seems like a crazy idea, right?

1110

00:43:21,690 --> 00:43:24,300
If I say we don't exist,
gravity doesn't exist,

1111
00:43:24,300 --> 00:43:26,430
space-time doesn't
exist, it's all emergent,

1112
00:43:26,430 --> 00:43:29,430
it's all an illusion, and
we are all a hologram.

1113
00:43:29,430 --> 00:43:30,480
So let me tell you a little bit,

1114
00:43:30,480 --> 00:43:33,630
where would such strange idea come about?

1115
00:43:33,630 --> 00:43:35,850
That there could be
something like a membrane,

1116
00:43:35,850 --> 00:43:38,698
a hologram that could
describe something inside.

1117
00:43:38,698 --> 00:43:41,070
Now the idea comes from the following,

1118
00:43:41,070 --> 00:43:43,110
by thinking about information.

1119
00:43:43,110 --> 00:43:46,170
So there is this
fundamental idea in physics,

1120
00:43:46,170 --> 00:43:51,060
which is that mass always
grows, there's always more mass.

1121
00:43:51,060 --> 00:43:53,400
In physics, we call it entropy.

1122
00:43:53,400 --> 00:43:56,580
So entropy is always increasing.

1123
00:43:56,580 --> 00:44:00,600
You break a glass, you get
pieces all over, right?

1124
00:44:00,600 --> 00:44:02,610
And the glass is not going
to reconstruct itself

1125
00:44:02,610 --> 00:44:04,050
into a beautiful glass, right?

1126
00:44:04,050 --> 00:44:05,460
So things always increase.

1127
00:44:05,460 --> 00:44:07,200
The entropy is always increasing.

1128
00:44:07,200 --> 00:44:10,110
So we dying is because our entropy

1129
00:44:10,110 --> 00:44:11,220
is growing, growing, growing, growing,

1130
00:44:11,220 --> 00:44:12,243
eventually we die.

1131
00:44:13,440 --> 00:44:15,000
When we clean up our room,

1132
00:44:15,000 --> 00:44:17,010
something that's very popular these days,

1133
00:44:17,010 --> 00:44:18,420
you have to clean up your room.

1134
00:44:18,420 --> 00:44:20,130
When you clean up,

1135
00:44:20,130 --> 00:44:21,360
when you clean up your room.

1136
00:44:21,360 --> 00:44:22,950
- You're a father, aren't you?

1137
00:44:22,950 --> 00:44:24,450
- When you clean up your room,

1138
00:44:25,470 --> 00:44:28,233
you are reducing the
entropy in the room, right?

1139
00:44:29,160 --> 00:44:32,070
But the entropy, I said,
always needs to increase.

1140
00:44:32,070 --> 00:44:34,980
So what's happening is
that to clean up the room

1141
00:44:34,980 --> 00:44:36,630
and to reduce the entropy of the room,

1142
00:44:36,630 --> 00:44:39,440
you are increasing your own inside entropy

1143
00:44:39,440 --> 00:44:41,856
and you are coming closer to being dead.

1144
00:44:41,856 --> 00:44:44,760
So-

1145
00:44:44,760 --> 00:44:46,620
- I've never thought of it that way.

1146
00:44:46,620 --> 00:44:49,167
- Yeah, so be careful.

1147
00:44:49,167 --> 00:44:50,717
You need to clean up your room.

1148
00:44:52,178 --> 00:44:54,270
So entropy always grows.

1149
00:44:54,270 --> 00:44:56,490
And so there is this notion of disorder,

1150
00:44:56,490 --> 00:45:01,490
and entropy also quantifies
the amount of information.

1151
00:45:01,950 --> 00:45:04,560
If you have an empty
room, it cannot be messy.

1152
00:45:04,560 --> 00:45:06,060
If you have a room full of books,

1153
00:45:06,060 --> 00:45:07,050
it can be very messy, right?

1154
00:45:07,050 --> 00:45:08,610
You can tear all the books apart,

1155
00:45:08,610 --> 00:45:10,770
throw pages around and so on.

1156
00:45:10,770 --> 00:45:11,910
So the more mess you have,

1157
00:45:11,910 --> 00:45:14,670
the more potential information you have.

1158
00:45:14,670 --> 00:45:17,880
Now, let's try to make a really, really,

1159
00:45:17,880 --> 00:45:20,220
really messy room by throwing more

1160
00:45:20,220 --> 00:45:21,930
and more stuff inside the room, right?

1161
00:45:21,930 --> 00:45:23,880
So we have this room and
we keep throwing books

1162
00:45:23,880 --> 00:45:26,160
like we said, we throw some ketchup,

1163
00:45:26,160 --> 00:45:27,900
we throw lots of stuff inside

1164
00:45:27,900 --> 00:45:30,540
the room to make it really, really messy.

1165
00:45:30,540 --> 00:45:31,800
So what happens?

1166
00:45:31,800 --> 00:45:34,590
Well, what happens that at some
point the room is so heavy,

1167
00:45:34,590 --> 00:45:38,193
so full, so big, so full of
stuff, it forms a black hole.

1168
00:45:39,060 --> 00:45:40,594

- So this is a thought experiment.

1169
00:45:40,594 --> 00:45:41,570
- This is an example.

1170
00:45:41,570 --> 00:45:43,290
- You haven't made a
room this messy before.

1171
00:45:43,290 --> 00:45:44,961
- Well, you should say,

1172
00:45:44,961 --> 00:45:47,397
but no, not that messy.

1173
00:45:47,397 --> 00:45:49,080
- Not with ketchup.

1174
00:45:49,080 --> 00:45:51,180
- No, no, the ketchup was missing.

1175
00:45:51,180 --> 00:45:54,180
And so you have this idea
that things can be messier

1176
00:45:54,180 --> 00:45:56,400
and messier and messier and messier

1177
00:45:56,400 --> 00:45:58,500
and eventually they form a black hole.

1178
00:45:58,500 --> 00:46:00,660
But if the mass is always increasing

1179
00:46:00,660 --> 00:46:01,980
and if you eventually form a black hole,

1180
00:46:01,980 --> 00:46:05,147

it means the black hole is
the messier object there is,

1181
00:46:05,147 --> 00:46:07,230
because it's the end
point of a messier room.

1182
00:46:07,230 --> 00:46:12,230
And so that means that the amount of mass,

1183
00:46:12,240 --> 00:46:16,280
the amount of information
is biggest in a ball.

1184
00:46:16,280 --> 00:46:18,660
If that ball is a black hole, as we said,

1185
00:46:18,660 --> 00:46:19,770
we put more and more stuff,

1186
00:46:19,770 --> 00:46:21,660
more and one information is there inside

1187
00:46:21,660 --> 00:46:23,240
and suddenly we have a black hole.

1188
00:46:23,240 --> 00:46:24,300
On the other hand,

1189
00:46:24,300 --> 00:46:27,660
a black hole because it's such
a simple, after all, object,

1190
00:46:27,660 --> 00:46:29,460
much simpler than a messy room.

1191
00:46:29,460 --> 00:46:32,190
It's just a black ball where light gets in

1192
00:46:32,190 --> 00:46:35,130
and cannot get out, there
are things we can compute,

1193
00:46:35,130 --> 00:46:38,910
we can study about black
holes and we can quantify

1194
00:46:38,910 --> 00:46:42,600
how much disorder, how
much of this mess there is.

1195
00:46:42,600 --> 00:46:46,425
When people compute with
people like Bekenstein

1196
00:46:46,425 --> 00:46:48,600
and Stephen Hawking and
many people studied,

1197
00:46:48,600 --> 00:46:51,701
asked what is the amount of
disorder inside a black hole,

1198
00:46:51,701 --> 00:46:54,360
they found a very surprising thing.

1199
00:46:54,360 --> 00:46:56,340
The bigger the black hole,
the bigger the disorder.

1200
00:46:56,340 --> 00:46:57,510
That's normal, right?

1201
00:46:57,510 --> 00:46:59,640
If a room is twice as as big,

1202
00:46:59,640 --> 00:47:02,220
the disorder can be twice as big inside,

1203
00:47:02,220 --> 00:47:05,010
but it was not proportional to
the volume of the black hole.

1204
00:47:05,010 --> 00:47:07,320
It was proportional to the
area of the black hole.

1205
00:47:07,320 --> 00:47:09,360
And that's very surprising, right?

1206
00:47:09,360 --> 00:47:11,820
If you see a huge building
and you see a building

1207
00:47:11,820 --> 00:47:14,130
that the volume is twice
as big, you say inside,

1208
00:47:14,130 --> 00:47:15,720
that can be twice as much mess.

1209
00:47:15,720 --> 00:47:17,160
You don't say the mess is proportional

1210
00:47:17,160 --> 00:47:18,780
to the area of the building.

1211
00:47:18,780 --> 00:47:20,790
When would you say that
the mess is proportional

1212
00:47:20,790 --> 00:47:21,930
to the area of the building?

1213
00:47:21,930 --> 00:47:24,000
If all the mess is in the wall,

1214
00:47:24,000 --> 00:47:27,360
that's the only scenario where
you would say if a building,

1215
00:47:27,360 --> 00:47:31,440
if a room doubles in
area, the mass doubles,

1216
00:47:31,440 --> 00:47:32,970
if someone tells you
that, then you say, oh,

1217
00:47:32,970 --> 00:47:34,890
inside that room you just have

1218
00:47:34,890 --> 00:47:37,350
a bunch of papers on the wall, right?

1219
00:47:37,350 --> 00:47:39,330
Like the serial killer
investigators, right?

1220
00:47:39,330 --> 00:47:44,330
With all these strings and
newspaper clips and so on,

1221
00:47:44,760 --> 00:47:45,840
everything is on the walls.

1222
00:47:45,840 --> 00:47:47,670
There's nothing in the middle, right?

1223
00:47:47,670 --> 00:47:51,690
Because then the wall surface
doubles and the mass doubles.

1224
00:47:51,690 --> 00:47:53,490
And so what we are saying is

1225
00:47:53,490 --> 00:47:57,240
that we were throwing
information in this room,

1226
00:47:57,240 --> 00:47:58,500
we form a black hole,

1227
00:47:58,500 --> 00:48:00,510
and now we can describe this black hole

1228
00:48:00,510 --> 00:48:03,450
and the amount of information
is only at the boundary.

1229
00:48:03,450 --> 00:48:04,770
It's only at the walls.

1230
00:48:04,770 --> 00:48:06,660
It's only at the end.

1231
00:48:06,660 --> 00:48:09,420
Well, but then if you take this seriously,

1232
00:48:09,420 --> 00:48:12,390
it means that you should be able,

1233
00:48:12,390 --> 00:48:14,610
if even in the most extreme situation

1234
00:48:14,610 --> 00:48:16,680
where you have the most
amount of information,

1235
00:48:16,680 --> 00:48:19,800
if it's possible to describe
it just by looking at the wall,

1236
00:48:19,800 --> 00:48:22,230

when you have less, you
should also be able to.

1237
00:48:22,230 --> 00:48:24,750
And so the ultimate conclusion
of this crazy thought

1238
00:48:24,750 --> 00:48:27,540
experiment is that you
should be able to describe

1239
00:48:27,540 --> 00:48:29,640
what's inside the universe by describing

1240
00:48:29,640 --> 00:48:31,800
the boundary of the universe.

1241
00:48:31,800 --> 00:48:34,037
Now, this could be a dinner chat, right?

1242
00:48:34,037 --> 00:48:35,670
I mean we are having some drinks

1243
00:48:35,670 --> 00:48:38,580
and we are having some fun,

1244
00:48:38,580 --> 00:48:41,280
and we come up with these crazy ideas.

1245
00:48:41,280 --> 00:48:43,473
But then in '97,

1246
00:48:43,473 --> 00:48:47,340
Maldacena said this is
not just a crazy idea.

1247
00:48:47,340 --> 00:48:49,680
Here is one theory of quantum gravity

1248
00:48:49,680 --> 00:48:52,740
that describes an example
of what could be a universe.

1249
00:48:52,740 --> 00:48:54,690
And here is an hologram at the boundary

1250
00:48:54,690 --> 00:48:57,330
of this universe and they
should be the same thing.

1251
00:48:57,330 --> 00:49:01,650
And this idea that you could
not only speculatively,

1252
00:49:01,650 --> 00:49:06,650
but really write equations
that says this reality is equal

1253
00:49:06,750 --> 00:49:09,600
to this description in
terms of an hologram

1254
00:49:09,600 --> 00:49:12,150
that is just at the
boundary of the universe

1255
00:49:12,150 --> 00:49:13,890
is what's called holography,

1256
00:49:13,890 --> 00:49:16,608
also goes by the name of ADSCFT,

1257
00:49:16,608 --> 00:49:18,570
or gauge gravity dualities.

1258
00:49:18,570 --> 00:49:21,330
These are all names for the same thing.

1259
00:49:21,330 --> 00:49:24,450
And it's a concrete
realization of what was before

1260
00:49:24,450 --> 00:49:26,610
a crazy idea that came mostly

1261
00:49:26,610 --> 00:49:29,160
from the thought experiments
with the black holes.

1262
00:49:29,160 --> 00:49:30,630
Because if the idea is that everything

1263
00:49:30,630 --> 00:49:32,310
can be described by the walls,

1264
00:49:32,310 --> 00:49:34,710
but we don't feel like we
are stuck to the wall, right?

1265
00:49:34,710 --> 00:49:36,000
We feel like we are here.

1266
00:49:36,000 --> 00:49:37,560
So what's the way out?

1267
00:49:37,560 --> 00:49:38,880
Everything is described by the wall,

1268
00:49:38,880 --> 00:49:39,900
but we feel like we are here.

1269
00:49:39,900 --> 00:49:43,110
Well, then maybe we are a
hologram projected from the wall

1270
00:49:43,110 --> 00:49:45,540

and maybe all the
information is on the wall.

1271
00:49:45,540 --> 00:49:46,860
And if you really look at the wall,

1272
00:49:46,860 --> 00:49:48,360
you see all the rules of the game,

1273
00:49:48,360 --> 00:49:50,130
the analog of the atoms in the water,

1274
00:49:50,130 --> 00:49:52,050
and you see in the wall,

1275
00:49:52,050 --> 00:49:54,690
the electrons in the chips
and the quantum computer

1276
00:49:54,690 --> 00:49:56,340
that is at the boundary of the universe.

1277
00:49:56,340 --> 00:49:57,690
And do, do, do, do, do, do.

1278
00:49:58,740 --> 00:50:01,650
But then from far away you
have this princess Leia's,

1279
00:50:01,650 --> 00:50:02,490
which are us,

1280
00:50:02,490 --> 00:50:07,490
and this hologram is being
projected in and we emerge.

1281
00:50:07,560 --> 00:50:10,830
And even the inside of the
wall, the universe, the space,

1282
00:50:10,830 --> 00:50:12,780
the gravity would emerge.

1283
00:50:12,780 --> 00:50:15,570
We would all be emergent concepts

1284
00:50:15,570 --> 00:50:19,110
that would be produced
by this quantum hologram.

1285
00:50:19,110 --> 00:50:21,600
This idea would've far
reaching implications

1286
00:50:21,600 --> 00:50:25,260
because it would tell you that gravity,

1287
00:50:25,260 --> 00:50:27,600
for example, would be emergent.

1288
00:50:27,600 --> 00:50:30,810
And at some point we said
it's very hard to put gravity

1289
00:50:30,810 --> 00:50:34,590
and quantum mechanics together
and what this idea would say,

1290
00:50:34,590 --> 00:50:35,940
yeah, throw away gravity.

1291
00:50:35,940 --> 00:50:37,620
Gravity doesn't exist.

1292
00:50:37,620 --> 00:50:39,060
Gravity is emergent.

1293

00:50:39,060 --> 00:50:40,530
All there exists is quantum mechanics

1294
00:50:40,530 --> 00:50:41,610
in this quantum computer.

1295
00:50:41,610 --> 00:50:42,840
That's the hologram.

1296
00:50:42,840 --> 00:50:44,760
And then gravity is fake news.

1297
00:50:44,760 --> 00:50:46,985
It's just you think there's gravity,

1298
00:50:46,985 --> 00:50:48,240
but it's like you have a hologram

1299
00:50:48,240 --> 00:50:51,330
of a colibri flying here
and it's not flying,

1300
00:50:51,330 --> 00:50:53,220
it's just a hologram.

1301
00:50:53,220 --> 00:50:54,960
That could be how the world works.

1302
00:50:54,960 --> 00:50:56,613
Maybe the world is holographic.

1303
00:50:57,630 --> 00:50:58,463
- Well, Pedro,

1304
00:50:58,463 --> 00:50:59,820
we'd like to share with you now a question

1305
00:50:59,820 --> 00:51:01,500

that was sent in by a student.

1306
00:51:01,500 --> 00:51:02,970
She'd like to ask you to say

1307
00:51:02,970 --> 00:51:05,283
a little bit more about ADSCFT.

1308
00:51:06,150 --> 00:51:08,160
- Hi, my name is Anna.

1309
00:51:08,160 --> 00:51:10,833
I'm currently a sci student
at Perimeter Institute,

1310
00:51:10,833 --> 00:51:12,753
and I have the following question.

1311
00:51:12,753 --> 00:51:16,050
Could you give the main gist

1312
00:51:16,050 --> 00:51:19,420
of the so-called ADSCFT correspondence

1313
00:51:20,280 --> 00:51:21,690
and explain why people

1314
00:51:21,690 --> 00:51:25,560
in your research community
are so interested in it,

1315
00:51:25,560 --> 00:51:28,560
even though we probably
live in a different type of

1316
00:51:28,560 --> 00:51:32,853
universe, not anti-De
Sitter, but De Sitter space.

1317
00:51:34,560 --> 00:51:37,920
- Let me go one step back
and say we have this thought

1318
00:51:37,920 --> 00:51:42,920
experiment of the messy room
that led us to this idea

1319
00:51:42,960 --> 00:51:47,960
that there should be some
hologram description of reality.

1320
00:51:48,780 --> 00:51:52,620
Someone tells you that it's
like one of those emails,

1321
00:51:52,620 --> 00:51:53,670
I have a theory about everything,

1322
00:51:53,670 --> 00:51:55,770
but okay fine.

1323
00:51:55,770 --> 00:51:57,060
- We do get a lot of those emails.

1324
00:51:57,060 --> 00:51:59,178
- We do get a lot of those.

1325
00:51:59,178 --> 00:52:00,011
Okay, what can I do?

1326
00:52:00,011 --> 00:52:01,680
You have to be a bit more specific,

1327
00:52:01,680 --> 00:52:03,480
and it's hard and I don't know.

1328
00:52:03,480 --> 00:52:05,340

And no one knows what's the hologram

1329
00:52:05,340 --> 00:52:07,500
that describes our universe.

1330
00:52:07,500 --> 00:52:10,680
Then we ask, is there a toy universe,

1331
00:52:10,680 --> 00:52:13,440
a toy theory that we can play with,

1332
00:52:13,440 --> 00:52:15,240
which would be an alternative universe,

1333
00:52:15,240 --> 00:52:18,930
A simpler one where you
would have, in that universe,

1334
00:52:18,930 --> 00:52:20,250
you would still have gravity,

1335
00:52:20,250 --> 00:52:22,418
you would still have particles,

1336
00:52:22,418 --> 00:52:23,427
but it would be a toy theory.

1337
00:52:23,427 --> 00:52:24,870
And in that toy theory,

1338
00:52:24,870 --> 00:52:27,540
you can make these ideas
precise and at least you have

1339
00:52:27,540 --> 00:52:29,790
a mental laboratory where you can exercise

1340
00:52:29,790 --> 00:52:31,153

and practice and test these ideas

1341
00:52:31,153 --> 00:52:34,470
and see if they make sense
and push them forward.

1342
00:52:34,470 --> 00:52:37,230
And it's related to this bottom
up and top down approach.

1343
00:52:37,230 --> 00:52:40,170
And I never know which one
that Lauren was referring to.

1344
00:52:40,170 --> 00:52:42,270
And that would be amazing.

1345
00:52:42,270 --> 00:52:44,700
And indeed we were able to make

1346
00:52:44,700 --> 00:52:47,520
these ideas precise in some toy examples.

1347
00:52:47,520 --> 00:52:48,870
And this question was referring

1348
00:52:48,870 --> 00:52:53,130
to that the examples we describe,

1349
00:52:53,130 --> 00:52:55,620
we manage to make this precise are toys.

1350
00:52:55,620 --> 00:52:56,787
They're not the real thing.

1351
00:52:56,787 --> 00:52:58,440
And so given that they are toys,

1352

00:52:58,440 --> 00:53:00,090
why do we like them so much, right?

1353
00:53:00,090 --> 00:53:01,590
Why don't we care about the real thing

1354
00:53:01,590 --> 00:53:03,022
and not about the toy?

1355
00:53:03,022 --> 00:53:05,670
And as usual, the answer is,

1356
00:53:05,670 --> 00:53:09,591
we start first trying to
understand these toys.

1357
00:53:09,591 --> 00:53:11,790
And now there are two possibilities.

1358
00:53:11,790 --> 00:53:13,410
Some people will try to make

1359
00:53:13,410 --> 00:53:15,360
this toys more and more realistic.

1360
00:53:15,360 --> 00:53:18,180
Try to say, I will try to add more

1361
00:53:18,180 --> 00:53:19,920
and more ingredients to make this

1362
00:53:19,920 --> 00:53:22,110
more closer and closer to the real world.

1363
00:53:22,110 --> 00:53:24,480
Some people will stay longer
with the toys and say, no,

1364

00:53:24,480 --> 00:53:26,850
I want to play with this toy a bit longer.

1365
00:53:26,850 --> 00:53:28,470
I want to go deeper and deeper

1366
00:53:28,470 --> 00:53:30,840
and try to extract more
lessons from this toy.

1367
00:53:30,840 --> 00:53:33,150
And it's a spectrum.

1368
00:53:33,150 --> 00:53:35,730
ADS is related to the name of this toy.

1369
00:53:35,730 --> 00:53:39,952
It turns out that it's better
to describe this holograms.

1370
00:53:39,952 --> 00:53:42,240
If there is a wall we have,

1371
00:53:42,240 --> 00:53:44,340
we need a wall to hang the hologram.

1372
00:53:44,340 --> 00:53:46,672
And if you have just a regular space-time,

1373
00:53:46,672 --> 00:53:48,840
imagine space-time that goes on forever.

1374
00:53:48,840 --> 00:53:50,160
Where's the wall?

1375
00:53:50,160 --> 00:53:51,090
There's no end.

1376

00:53:51,090 --> 00:53:52,500
You just go, go, go, go.

1377
00:53:52,500 --> 00:53:53,730
When you are waiting for a place

1378
00:53:53,730 --> 00:53:56,550
to hang the hologram
and you don't find one.

1379
00:53:56,550 --> 00:54:00,510
So it would be better if your
space-time was a very big box

1380
00:54:00,510 --> 00:54:02,970
because when your space-time
is a very big box,

1381
00:54:02,970 --> 00:54:04,410
you go to the boundary of the box

1382
00:54:04,410 --> 00:54:05,910
and put the hologram there.

1383
00:54:05,910 --> 00:54:09,150
And ADS, it's a space-time that's a box.

1384
00:54:09,150 --> 00:54:12,150
There is an end where you
can put this hologram.

1385
00:54:12,150 --> 00:54:13,950
Now I should say it's a fantastic box.

1386
00:54:13,950 --> 00:54:15,030
It's not a random box.

1387
00:54:15,030 --> 00:54:17,124
Let me tell you something special about,

1388
00:54:17,124 --> 00:54:20,190
let me give you an example.

1389
00:54:20,190 --> 00:54:22,230
Take a shoebox, right?

1390
00:54:22,230 --> 00:54:23,610
There is a midpoint.

1391
00:54:23,610 --> 00:54:25,410
There is a point which
is the middle, right?

1392
00:54:25,410 --> 00:54:27,630
And then there are the corners
and the walls and so on.

1393
00:54:27,630 --> 00:54:30,360
But there is a special point
which is the middle of the box.

1394
00:54:30,360 --> 00:54:33,270
This anti-De Sitter is a
box, but there's no middle.

1395
00:54:33,270 --> 00:54:34,410
All points are the same.

1396
00:54:34,410 --> 00:54:35,640
There's no special point.

1397
00:54:35,640 --> 00:54:37,110
It's a strange box.

1398
00:54:37,110 --> 00:54:38,400
Why do I call it a box?

1399

00:54:38,400 --> 00:54:39,870
What is special about the box?

1400
00:54:39,870 --> 00:54:43,081
Because I take this red ball
here and I throw the red ball

1401
00:54:43,081 --> 00:54:46,110
and I'm talking to you and I
get hit by the red ball again.

1402
00:54:46,110 --> 00:54:47,970
So I say this is a box.

1403
00:54:47,970 --> 00:54:50,730
I throw the ball and the ball comes back

1404
00:54:50,730 --> 00:54:53,190
and I'm here and I throw this
red ball and I get it back,

1405
00:54:53,190 --> 00:54:55,398
I throw it and I get it back.
I throw it and I get it back.

1406
00:54:55,398 --> 00:54:57,120
And doesn't matter which direction

1407
00:54:57,120 --> 00:54:58,620
I throw it and I get it back.

1408
00:54:58,620 --> 00:55:00,810
And doesn't matter where
I am in space-time,

1409
00:55:00,810 --> 00:55:02,940
When I throw the red ball, I get it back.

1410
00:55:02,940 --> 00:55:04,740

So in that sense, there is no center.

1411
00:55:04,740 --> 00:55:05,670
It's all the same,

1412
00:55:05,670 --> 00:55:07,380
whatever you are, you take a red ball,

1413
00:55:07,380 --> 00:55:08,340
you throw in the red ball,

1414
00:55:08,340 --> 00:55:10,200
you receive the red ball back.

1415
00:55:10,200 --> 00:55:11,850
So you feel like a box.

1416
00:55:11,850 --> 00:55:13,350
But if I feel like a box,

1417
00:55:13,350 --> 00:55:14,880
Colin feels like a box.

1418
00:55:14,880 --> 00:55:17,070
Everyone feels like being
at the center of the box.

1419
00:55:17,070 --> 00:55:19,200
It's very democratic box.

1420
00:55:19,200 --> 00:55:21,780
So it's the most perfect box there is.

1421
00:55:21,780 --> 00:55:23,010
It's called ADS.

1422
00:55:23,010 --> 00:55:24,480
It stands for anti-De Sitter,

1423
00:55:24,480 --> 00:55:28,800
which is the name of a geometer
that thought about this box.

1424
00:55:28,800 --> 00:55:31,410
And in this box, in this very big box,

1425
00:55:31,410 --> 00:55:33,150
we understand that what happens inside

1426
00:55:33,150 --> 00:55:34,290
the box can be described

1427
00:55:34,290 --> 00:55:36,570
by a hologram at the boundary of this box.

1428
00:55:36,570 --> 00:55:37,950
Now we don't live in a box,

1429
00:55:37,950 --> 00:55:39,780
at least we don't know
if we live in a box.

1430
00:55:39,780 --> 00:55:40,890
Maybe we do.

1431
00:55:40,890 --> 00:55:43,530
Maybe the boundary is
very, very far, far away.

1432
00:55:43,530 --> 00:55:46,590
But one thing you could
say is that whether we live

1433
00:55:46,590 --> 00:55:49,729
in the box or not should not
matter if the box is huge.

1434
00:55:49,729 --> 00:55:54,270
Should the rules of
physics here for us change?

1435
00:55:54,270 --> 00:55:57,030
If in the gazillion, gazillion,

1436
00:55:57,030 --> 00:55:59,580
gazillion parsecs there is a wall?

1437
00:55:59,580 --> 00:56:00,930
Probably not.

1438
00:56:00,930 --> 00:56:03,720
It's really, really super, super far away.

1439
00:56:03,720 --> 00:56:04,680
Who cares.

1440
00:56:04,680 --> 00:56:06,690
From that point of view, some people,

1441
00:56:06,690 --> 00:56:10,907
I would say that if you
can think of physics

1442
00:56:10,907 --> 00:56:14,040
with a fake box provided you say the box

1443
00:56:14,040 --> 00:56:15,330
is big enough and if with

1444
00:56:15,330 --> 00:56:18,090
that fake box you can
describe what's inside,

1445
00:56:18,090 --> 00:56:20,400
you can always pretend

the box is big enough

1446
00:56:20,400 --> 00:56:21,300
that it doesn't matter

1447
00:56:21,300 --> 00:56:23,430
that if we are inside the box or not.

1448
00:56:23,430 --> 00:56:25,350
So if you can learn something
about physics inside

1449
00:56:25,350 --> 00:56:29,070
the box from a big box,
that's good enough.

1450
00:56:29,070 --> 00:56:32,670
But I say this because I don't
know how to do holography

1451
00:56:32,670 --> 00:56:34,860
if I have no box, if I
knew I wouldn't say this,

1452
00:56:34,860 --> 00:56:36,660
I would just do holography
without the box.

1453
00:56:36,660 --> 00:56:39,540
If I knew how to realize
this crazy holographic

1454
00:56:39,540 --> 00:56:43,500
ideas directly in our universe,
which goes on forever,

1455
00:56:43,500 --> 00:56:45,020
I would prefer that.

1456

00:56:45,020 --> 00:56:46,200
And so some people are trying,

1457
00:56:46,200 --> 00:56:49,230
some even some people here
at Perimeter like Sabrina

1458
00:56:49,230 --> 00:56:51,150
and others are trying to study better

1459
00:56:51,150 --> 00:56:53,640
what happens at infinity in the universe.

1460
00:56:53,640 --> 00:56:56,580
And is it really impossible
to put an hologram there?

1461
00:56:56,580 --> 00:56:58,440
Do we really need a box?

1462
00:56:58,440 --> 00:57:00,480
It'll be very difficult.

1463
00:57:00,480 --> 00:57:02,736
So there are things to
understand and things

1464
00:57:02,736 --> 00:57:06,930
get even more subtle when
you think about cosmology.

1465
00:57:06,930 --> 00:57:09,180
When you think that the
universe is expanding

1466
00:57:09,180 --> 00:57:12,720
and it's growing and then
it's even harder to imagine,

1467

00:57:12,720 --> 00:57:14,940
where do you put the hologram?

1468
00:57:14,940 --> 00:57:16,230
- And we have one more question

1469
00:57:16,230 --> 00:57:18,150
that was sent in from another colleague

1470
00:57:18,150 --> 00:57:19,593
of ours here at Perimeter.

1471
00:57:20,460 --> 00:57:23,340
- I'm Dao from Perimeter Institute.

1472
00:57:23,340 --> 00:57:27,180
A question is that I have heard

1473
00:57:27,180 --> 00:57:29,550
that you said you have solved

1474
00:57:29,550 --> 00:57:32,370
a quantum field theory a few times.

1475
00:57:32,370 --> 00:57:34,590
I wonder what that exactly mean

1476
00:57:34,590 --> 00:57:38,880
and when will we actually
solve quantum field theory?

1477
00:57:38,880 --> 00:57:42,180
- So why do we say solving?

1478
00:57:42,180 --> 00:57:44,010
Solving means computing.

1479
00:57:44,010 --> 00:57:46,290

If I want to study a physical quantity,

1480
00:57:46,290 --> 00:57:47,970
we have to take our theory

1481
00:57:47,970 --> 00:57:50,670
and understand what are
the rules of the theory,

1482
00:57:50,670 --> 00:57:52,380
what's the outcome of the experiment

1483
00:57:52,380 --> 00:57:53,760
and how do I go from the rules

1484
00:57:53,760 --> 00:57:55,440
to the outcome of the experiment?

1485
00:57:55,440 --> 00:57:58,410
Sometimes we can bypass that
step by doing this bootstrap

1486
00:57:58,410 --> 00:58:01,800
kind of ideas and studying
what's possible and impossible.

1487
00:58:01,800 --> 00:58:05,880
But then we have toy
theories and real theories.

1488
00:58:05,880 --> 00:58:08,640
So again, it's like describing say

1489
00:58:08,640 --> 00:58:11,010
the trajectory of a tennis ball, right?

1490
00:58:11,010 --> 00:58:12,570
If I just say it's a parabola,

1491
00:58:12,570 --> 00:58:15,150
there's gravity and so on, it's easy.

1492
00:58:15,150 --> 00:58:18,480
If I say no, but there's
wind now it's a bit harder.

1493
00:58:18,480 --> 00:58:19,800
Pieces of the ball are falling

1494
00:58:19,800 --> 00:58:21,240
as it's going now it's harder.

1495
00:58:21,240 --> 00:58:23,520
So the more realistic
you make it harder it is.

1496
00:58:23,520 --> 00:58:25,770
And you can never really do a perfect job.

1497
00:58:25,770 --> 00:58:27,480
You do better and better and better,

1498
00:58:27,480 --> 00:58:30,510
but there's always more
effects to take into account.

1499
00:58:30,510 --> 00:58:32,700
So when are we going to solve

1500
00:58:32,700 --> 00:58:34,620
real world quantum field theory

1501
00:58:34,620 --> 00:58:39,450
and be able to wake up and
with a clean page of paper

1502
00:58:39,450 --> 00:58:41,820

and at the end of the page
compute a mass of the proton?

1503
00:58:41,820 --> 00:58:42,810
I don't know.

1504
00:58:42,810 --> 00:58:45,750
That would be amazing if I could compute

1505
00:58:45,750 --> 00:58:49,080
a mass of the proton even with
two digits in my lifetime,

1506
00:58:49,080 --> 00:58:50,760
I would be delighted.

1507
00:58:50,760 --> 00:58:52,230
We know the answer to this, right?

1508
00:58:52,230 --> 00:58:54,988
We can put it in computers
or we can measure it.

1509
00:58:54,988 --> 00:58:57,240
We can take a scale and and figure it out.

1510
00:58:57,240 --> 00:59:00,150
But computing it from first
principles we don't know.

1511
00:59:00,150 --> 00:59:02,280
Now on the other hand,

1512
00:59:02,280 --> 00:59:04,890
solving quantum field theory
means developing techniques,

1513
00:59:04,890 --> 00:59:07,320
new techniques that we can use

1514
00:59:07,320 --> 00:59:10,080
to do better and better
in quantum field theory.

1515
00:59:10,080 --> 00:59:12,960
And that requires solving
these toy theories

1516
00:59:12,960 --> 00:59:14,460
and understanding how to develop

1517
00:59:14,460 --> 00:59:16,563
these techniques in simplified examples.

1518
00:59:17,400 --> 00:59:20,700
In the same way that if
you want to solve chess,

1519
00:59:20,700 --> 00:59:22,020
you will solve checkers first.

1520
00:59:22,020 --> 00:59:22,920
It's easier, right?

1521
00:59:22,920 --> 00:59:25,860
You will develop computer
techniques for counting all

1522
00:59:25,860 --> 00:59:27,690
possible checkers or for developing

1523
00:59:27,690 --> 00:59:29,640
artificial intelligence,
for solving checkers.

1524
00:59:29,640 --> 00:59:31,950
And then you'll apply
to chess and then to go

1525
00:59:31,950 --> 00:59:35,883
and eventually to give
dating advices and so on.

1526
00:59:37,440 --> 00:59:39,390
So the more complicated it goes,

1527
00:59:39,390 --> 00:59:41,760
you will develop step by step, right?

1528
00:59:41,760 --> 00:59:44,100
And so similarly with physics,

1529
00:59:44,100 --> 00:59:48,000
what we want to do is be able
to tame these quantum effects

1530
00:59:48,000 --> 00:59:51,570
and in particular these
strong quantum effects

1531
00:59:51,570 --> 00:59:54,480
in the analog of checkers, in
the simplest possible case,

1532
00:59:54,480 --> 00:59:57,120
let's have at least one
example where we can do it.

1533
00:59:57,120 --> 00:59:59,400
And if we can really
nail one example down,

1534
00:59:59,400 --> 01:00:01,710
everyone will believe, okay,
now it's a question of time.

1535
01:00:01,710 --> 01:00:03,720

We have to work harder,
but we'll do the next,

1536
01:00:03,720 --> 01:00:06,463
we'll do chess and then
we'll do go, et cetera.

1537
01:00:06,463 --> 01:00:08,460
But we need the first example.

1538
01:00:08,460 --> 01:00:13,410
And it was the case in
other areas of physics

1539
01:00:13,410 --> 01:00:15,300
before like statistical mechanics,

1540
01:00:15,300 --> 01:00:19,140
we needed to solve one
statistical mechanics system.

1541
01:00:19,140 --> 01:00:22,410
And there was a beautiful
solution in '49 I believe,

1542
01:00:22,410 --> 01:00:24,570
of the so-called two
dimensionalizing model,

1543
01:00:24,570 --> 01:00:27,120
which is a particular
model in two dimensions

1544
01:00:27,120 --> 01:00:28,530
of statistical mechanics

1545
01:00:28,530 --> 01:00:30,750
of a particular two-dimensional material.

1546

01:00:30,750 --> 01:00:32,550
And it was the first example

1547
01:00:32,550 --> 01:00:35,070
that was possible to solve exactly.

1548
01:00:35,070 --> 01:00:36,510
And then it was like a Pandora box.

1549
01:00:36,510 --> 01:00:39,240
Once that one has solved many
others followed afterwards

1550
01:00:39,240 --> 01:00:41,370
and we learned many general lessons

1551
01:00:41,370 --> 01:00:43,650
about phase transitions
and properties of matter,

1552
01:00:43,650 --> 01:00:46,380
and so on, the energy
levels of the hydrogen atom

1553
01:00:46,380 --> 01:00:47,970
that we learn in school,

1554
01:00:47,970 --> 01:00:50,580
it was crucial to have
that one solution exactly.

1555
01:00:50,580 --> 01:00:53,220
And then we developed
techniques, sometimes exact,

1556
01:00:53,220 --> 01:00:55,470
sometimes approximate for
studying many other atoms.

1557

01:00:55,470 --> 01:00:57,510
And now we know chemistry.

1558
01:00:57,510 --> 01:01:00,220
And so it's often about

1559
01:01:01,920 --> 01:01:06,540
breaking this barrier of
solving a quantum field theory.

1560
01:01:06,540 --> 01:01:09,540
Solving a quantum field
theory is like solving a game.

1561
01:01:09,540 --> 01:01:13,290
And there are easier games
and more complicated games.

1562
01:01:13,290 --> 01:01:18,120
And even solving a game can
mean many things like chess

1563
01:01:18,120 --> 01:01:20,670
is solved when you have
seven pieces on the board.

1564
01:01:20,670 --> 01:01:21,870
If you have more than seven,

1565
01:01:21,870 --> 01:01:23,607
it's not completely solved yet.

1566
01:01:23,607 --> 01:01:25,800
So chest with seven pieces done,

1567
01:01:25,800 --> 01:01:28,230
chest with nine pieces not done yet.

1568
01:01:28,230 --> 01:01:30,315

Similarly, in some quantum field theories,

1569
01:01:30,315 --> 01:01:33,330
we managed to understand for example

1570
01:01:33,330 --> 01:01:35,370
the analog of the spectrum
of the hydrogen atom.

1571
01:01:35,370 --> 01:01:38,100
What are the energies
of that quantum theory?

1572
01:01:38,100 --> 01:01:40,460
What energies can the states have?

1573
01:01:40,460 --> 01:01:42,270
So that was something that we did

1574
01:01:42,270 --> 01:01:44,610
and that was probably greatly

1575
01:01:44,610 --> 01:01:45,930
why I am at Perimeter was

1576
01:01:45,930 --> 01:01:47,370
because we solved that problem.

1577
01:01:47,370 --> 01:01:48,480
That was a tough problem,

1578
01:01:48,480 --> 01:01:50,400
that was an open problem in the field.

1579
01:01:50,400 --> 01:01:52,680
How do we compute those energy levels?

1580
01:01:52,680 --> 01:01:53,820

But that's the zero.

1581
01:01:53,820 --> 01:01:54,990
The first thing we ask about

1582
01:01:54,990 --> 01:01:57,523
the nitrogen atom is what
are the energy levels?

1583
01:01:57,523 --> 01:01:59,070
Then we ask, okay,

1584
01:01:59,070 --> 01:02:00,540
now I take two hydrogen atoms

1585
01:02:00,540 --> 01:02:01,710
and I throw them against each other.

1586
01:02:01,710 --> 01:02:02,543
What happens?

1587
01:02:02,543 --> 01:02:04,920
Oh, that's much harder than
just studying the energy level.

1588
01:02:04,920 --> 01:02:06,000
And then once we do that,

1589
01:02:06,000 --> 01:02:09,360
we ask the next question and
that's like solving chess

1590
01:02:09,360 --> 01:02:12,690
step by step and in more and
more complicated situation.

1591
01:02:12,690 --> 01:02:14,340
- So it's like you start with a toy,

1592
01:02:14,340 --> 01:02:15,900
you solve that toy model,

1593
01:02:15,900 --> 01:02:17,880
you make a more complicated
toy, you solve that.

1594
01:02:17,880 --> 01:02:20,400
And maybe someday this
toy can be so complicated

1595
01:02:20,400 --> 01:02:23,310
that we can solve it and
then represent the universe.

1596
01:02:23,310 --> 01:02:25,503
- That's the hope, yeah.

1597
01:02:25,503 --> 01:02:30,000
It's also the hope that sometimes
physics tends to look more

1598
01:02:30,000 --> 01:02:33,060
and more like a toy in
the sense that it's often

1599
01:02:33,060 --> 01:02:35,190
the case that physics looks complicated.

1600
01:02:35,190 --> 01:02:38,220
And then we find this unifying principles,

1601
01:02:38,220 --> 01:02:41,070
this idea that there was a electricity

1602
01:02:41,070 --> 01:02:43,590
and magnetism and there was
some loss for electricity,

1603
01:02:43,590 --> 01:02:45,387
some loss for magnets,
but it was complicated.

1604
01:02:45,387 --> 01:02:47,250
And then we understood, oh no,

1605
01:02:47,250 --> 01:02:49,710
they can be combined and
actually things are simpler.

1606
01:02:49,710 --> 01:02:52,530
And it's not like we have the electricity

1607
01:02:52,530 --> 01:02:54,360
and the magnets and so no, no,

1608
01:02:54,360 --> 01:02:56,760
they really talk to each other
and there's a single thing,

1609
01:02:56,760 --> 01:03:00,630
and now it became closer to
the to than to the real world.

1610
01:03:00,630 --> 01:03:02,910
And so it's also the hope,

1611
01:03:02,910 --> 01:03:04,830
but that might be just a dream,

1612
01:03:04,830 --> 01:03:06,720
that the world can be closer to a toy

1613
01:03:06,720 --> 01:03:08,880
and that perhaps the fundamental rules

1614
01:03:08,880 --> 01:03:11,100

will link things together that right

1615
01:03:11,100 --> 01:03:13,740
now look very complicated and disparate.

1616
01:03:13,740 --> 01:03:16,440
And that doesn't seem to be a connection

1617
01:03:16,440 --> 01:03:18,030
between the expansion of the universe

1618
01:03:18,030 --> 01:03:20,790
and the mass of the
electron or whatever, right?

1619
01:03:20,790 --> 01:03:22,710
There are many things in
physics that look totally

1620
01:03:22,710 --> 01:03:24,840
independent and different from each other

1621
01:03:24,840 --> 01:03:26,610
that maybe once we will understand really

1622
01:03:26,610 --> 01:03:27,660
what are the rules of the game,

1623
01:03:27,660 --> 01:03:30,300
maybe they'll be connected,
maybe things will be simpler.

1624
01:03:30,300 --> 01:03:33,150
It might be that the
goal is not create a toy

1625
01:03:33,150 --> 01:03:34,770
and make it more and more complicated,

1626
01:03:34,770 --> 01:03:37,110
but understand what are
the underlying rules

1627
01:03:37,110 --> 01:03:40,677
and perhaps the fundamental
rules will be that (indistinct).

1628
01:03:42,090 --> 01:03:43,410
- When we started this conversation,

1629
01:03:43,410 --> 01:03:45,510
Lauren admitted that she
was a little intimidated

1630
01:03:45,510 --> 01:03:46,920
because of all the terminology,

1631
01:03:46,920 --> 01:03:48,360
you know, quantum field theory.

1632
01:03:48,360 --> 01:03:51,090
And I can emphasize that
I was 10 times more,

1633
01:03:51,090 --> 01:03:51,923
a hundred times more

1634
01:03:51,923 --> 01:03:53,850
'cause I haven't studied
physics in university.

1635
01:03:53,850 --> 01:03:56,310
Lauren's a quantum scientist
and she was intimidated.

1636
01:03:56,310 --> 01:03:58,950
But I wanna say that just to
reiterate that your ability

1637
01:03:58,950 --> 01:04:03,060
to draw pictures verbally and
then I create them in my head.

1638
01:04:03,060 --> 01:04:04,410
I don't know what your sculpture looks

1639
01:04:04,410 --> 01:04:06,390
like of what's possible versus impossible.

1640
01:04:06,390 --> 01:04:09,150
Mine is a very cool quartz
crystalline structure.

1641
01:04:09,150 --> 01:04:14,130
But the idea that you can convey
these ideas in a clear way,

1642
01:04:14,130 --> 01:04:16,230
I think it relates to
your teaching as well.

1643
01:04:16,230 --> 01:04:17,880
You've done a lot of teaching and outreach

1644
01:04:17,880 --> 01:04:19,350
and I know that I think you two have

1645
01:04:19,350 --> 01:04:20,790
worked together before on teaching.

1646
01:04:20,790 --> 01:04:22,350
Can you talk about what,

1647
01:04:22,350 --> 01:04:25,110
how you approach teaching these subjects

1648

01:04:25,110 --> 01:04:27,750
to younger people and you even do outreach

1649
01:04:27,750 --> 01:04:29,910
to non-scientists like myself.

1650
01:04:29,910 --> 01:04:31,650
- I like teaching very much.

1651
01:04:31,650 --> 01:04:35,910
It's one of the most exciting
things about what we do.

1652
01:04:35,910 --> 01:04:38,940
I mean especially the teaching that I do,

1653
01:04:38,940 --> 01:04:41,824
which is a huge privilege,
is that we get to teach,

1654
01:04:41,824 --> 01:04:46,020
first of all amazing students
that are really super excited

1655
01:04:46,020 --> 01:04:50,820
about being here and no one
is studying some particular

1656
01:04:50,820 --> 01:04:52,140
physics subject because you have

1657
01:04:52,140 --> 01:04:53,970
to get some grades or some credits.

1658
01:04:53,970 --> 01:04:55,260
No, people are really excited

1659
01:04:55,260 --> 01:04:56,896
and they want to learn physics

1660
01:04:56,896 --> 01:04:58,620
because they really are passionate

1661
01:04:58,620 --> 01:05:02,370
about understanding how
nature works the way it works.

1662
01:05:02,370 --> 01:05:03,270
Often to teach,

1663
01:05:03,270 --> 01:05:04,770
you have to really understand things

1664
01:05:04,770 --> 01:05:07,620
in a very deep way if
you want to simplify it.

1665
01:05:07,620 --> 01:05:12,240
It's easier often to protect
yourself in the math.

1666
01:05:12,240 --> 01:05:13,800
Writing equations is easy.

1667
01:05:13,800 --> 01:05:15,390
Solving equations is easy.

1668
01:05:15,390 --> 01:05:16,223
- Says you.

1669
01:05:16,223 --> 01:05:17,130
- No, no.

1670
01:05:17,130 --> 01:05:18,780
- But I'm an non-scientist.

1671
01:05:18,780 --> 01:05:21,068

But I see where you're coming from.

1672
01:05:21,068 --> 01:05:24,450
- But it's something mechanical,
it's something you learn,

1673
01:05:24,450 --> 01:05:26,520
you have to learn how to do it.

1674
01:05:26,520 --> 01:05:29,354
- Or you learn to ask a computer to do it.

1675
01:05:29,354 --> 01:05:30,625
- Ask the computer to do it.

1676
01:05:30,625 --> 01:05:31,590
- You have to know how to ask the computer

1677
01:05:31,590 --> 01:05:33,960
or know what to ask the computer as well.

1678
01:05:33,960 --> 01:05:36,093
- It's a language, you learn it, right?

1679
01:05:37,346 --> 01:05:40,462
But teaching forces you

1680
01:05:40,462 --> 01:05:44,670
to have a clean picture
of the fundamentals,

1681
01:05:44,670 --> 01:05:47,970
to not to be lost in the technicalities

1682
01:05:47,970 --> 01:05:50,760
and details that sometimes don't matter,

1683
01:05:50,760 --> 01:05:53,550

but really focus on what is really

1684
01:05:53,550 --> 01:05:54,960
the problem we want to solve.

1685
01:05:54,960 --> 01:05:58,085
What's really simple, what's really hard,

1686
01:05:58,085 --> 01:06:00,750
and I think that's very
important for a physicist

1687
01:06:00,750 --> 01:06:04,680
to keep some mental sanity is to teach,

1688
01:06:04,680 --> 01:06:06,120
teaching too much is not good

1689
01:06:06,120 --> 01:06:07,680
and you don't have time to do research.

1690
01:06:07,680 --> 01:06:09,510
But teaching a good deal I think is very,

1691
01:06:09,510 --> 01:06:11,340
very powerful and useful.

1692
01:06:11,340 --> 01:06:14,670
In particular when you are
teaching some of these subjects

1693
01:06:14,670 --> 01:06:17,772
that are not yet in textbooks

1694
01:06:17,772 --> 01:06:19,297
or that are a little bit more advanced,

1695
01:06:19,297 --> 01:06:23,700

you are really often
going into the unknown,

1696
01:06:23,700 --> 01:06:26,100
going into the world of
what is not yet known.

1697
01:06:26,100 --> 01:06:28,380
And as you try to understand things

1698
01:06:28,380 --> 01:06:31,380
and try to bring them to the students,

1699
01:06:31,380 --> 01:06:33,090
you are trying to cleaning it up,

1700
01:06:33,090 --> 01:06:36,510
purifying it, and really polishing it.

1701
01:06:36,510 --> 01:06:37,770
And it's really something precious

1702
01:06:37,770 --> 01:06:41,820
that you are allowing
yourself to tell someone.

1703
01:06:41,820 --> 01:06:44,460
And when you explain
the way you understood

1704
01:06:44,460 --> 01:06:47,920
some high energy
collision of two particles

1705
01:06:49,076 --> 01:06:52,200
and why when these two
particles hit each other,

1706
01:06:52,200 --> 01:06:54,180

things can fly in all possible directions

1707
01:06:54,180 --> 01:06:56,160
with all equal probability
and you understood

1708
01:06:56,160 --> 01:06:57,590
why was it all equal probability

1709
01:06:57,590 --> 01:07:00,296
in that particular case and
you managed to simplify.

1710
01:07:00,296 --> 01:07:02,250
It's really a magical moment

1711
01:07:02,250 --> 01:07:05,490
when you manage to get that across.

1712
01:07:05,490 --> 01:07:07,980
So yeah, it's something transcendental

1713
01:07:07,980 --> 01:07:10,050
that you go into this
platonic world of ideas,

1714
01:07:10,050 --> 01:07:12,840
you drag them down and then
you give them as a gift.

1715
01:07:12,840 --> 01:07:14,430
- Earlier in this
conversation you mentioned

1716
01:07:14,430 --> 01:07:15,930
how some people in Canada,

1717
01:07:15,930 --> 01:07:18,450
they amass along the border

so they can be far south

1718
01:07:18,450 --> 01:07:20,400
for the warm weather, but
you spend about, what,

1719
01:07:20,400 --> 01:07:22,200
half your year in Brazil

1720
01:07:22,200 --> 01:07:25,590
at the South American Institute
for Fundamental Research.

1721
01:07:25,590 --> 01:07:27,450
Can you tell us how that came to be

1722
01:07:27,450 --> 01:07:30,180
and what drew you there?

1723
01:07:30,180 --> 01:07:31,013
- Yeah, that's true.

1724
01:07:31,013 --> 01:07:33,900
So I spend a few months every year there.

1725
01:07:33,900 --> 01:07:35,700
So I go back and forth.

1726
01:07:35,700 --> 01:07:37,290
So it's convenient.

1727
01:07:37,290 --> 01:07:39,153
It's the same time zone more or less.

1728
01:07:40,477 --> 01:07:43,530
So I go with a cloud of
students typically moving up

1729

01:07:43,530 --> 01:07:46,083
and down in this strong coupled system.

1730
01:07:47,610 --> 01:07:49,200
So indeed I first got to know

1731
01:07:49,200 --> 01:07:52,470
this institute in South America,

1732
01:07:52,470 --> 01:07:55,170
the goal of this institute that SAIFR

1733
01:07:55,170 --> 01:07:57,750
that ICTP SAIFR that you mentioned

1734
01:07:57,750 --> 01:08:00,690
is to serve as a hub
for all of South America

1735
01:08:00,690 --> 01:08:03,810
for theoretical physics in South America.

1736
01:08:03,810 --> 01:08:06,750
And so what happens in
practice at this institute

1737
01:08:06,750 --> 01:08:09,180
is that you have schools and workshops

1738
01:08:09,180 --> 01:08:10,980
and conferences running all the time

1739
01:08:10,980 --> 01:08:13,410
with students from all
over South America going

1740
01:08:13,410 --> 01:08:17,550
there for a week or two
interacting with excited students

1741
01:08:17,550 --> 01:08:20,190
that are really passionate
about a particular topic

1742
01:08:20,190 --> 01:08:22,560
and say strongly correlated electrons

1743
01:08:22,560 --> 01:08:24,030
and then going back to their

1744
01:08:24,030 --> 01:08:26,250
home institutions in Chile, Argentina,

1745
01:08:26,250 --> 01:08:27,960
Bolivia, et cetera.

1746
01:08:27,960 --> 01:08:29,700
And then a few months later coming back

1747
01:08:29,700 --> 01:08:31,800
to another event that happens there.

1748
01:08:31,800 --> 01:08:34,920
And at some point a
community starts to emerge.

1749
01:08:34,920 --> 01:08:37,110
You start to know people
from the various places,

1750
01:08:37,110 --> 01:08:39,090
people that were previously
totally isolated,

1751
01:08:39,090 --> 01:08:42,150
now they get to meet each other at SAIFR.

1752

01:08:42,150 --> 01:08:45,296
Top scientists from all over
the world get to go to SAIFR.

1753
01:08:45,296 --> 01:08:48,000
And at the same time you have access

1754
01:08:48,000 --> 01:08:53,000
to this huge pool of 400
million people in South America,

1755
01:08:53,520 --> 01:08:56,190
the best of the best
that start to go there

1756
01:08:56,190 --> 01:08:58,110
and they have an opportunity to be exposed

1757
01:08:58,110 --> 01:08:59,310
to all these top people and then

1758
01:08:59,310 --> 01:09:01,410
eventually come here and join us

1759
01:09:01,410 --> 01:09:03,510
at the Perimeter Masters International,

1760
01:09:03,510 --> 01:09:05,220
or come here for PhD,

1761
01:09:05,220 --> 01:09:07,890
or become future postdocs, et cetera.

1762
01:09:07,890 --> 01:09:09,780
So it really serves as a hub not only

1763
01:09:09,780 --> 01:09:12,540
to connect everyone in South America,

1764
01:09:12,540 --> 01:09:16,290
but to connect South America
to the world more broadly.

1765
01:09:16,290 --> 01:09:18,273
It's a relatively recent institute,

1766
01:09:18,273 --> 01:09:22,080
it's like 15 years, at
the level of what it does,

1767
01:09:22,080 --> 01:09:24,960
which is organizing this
schools and workshops,

1768
01:09:24,960 --> 01:09:28,620
it's already one of the leading
institutes in the world.

1769
01:09:28,620 --> 01:09:32,910
I'm Portuguese, which the
language is the same as in Brazil,

1770
01:09:32,910 --> 01:09:35,430
more or less the same type of culture.

1771
01:09:35,430 --> 01:09:38,160
But everything is
multiplied by 10 in Brazil,

1772
01:09:38,160 --> 01:09:39,030
people are happy,

1773
01:09:39,030 --> 01:09:41,490
they are 10 times as happy as in Portugal

1774
01:09:41,490 --> 01:09:44,020
and people are sad, they
are 10 times as more

1775
01:09:45,640 --> 01:09:48,090
depressed as if they were in Portugal.

1776
01:09:48,090 --> 01:09:51,000
So everything in Portugal
happens, whatever.

1777
01:09:51,000 --> 01:09:53,130
I take that I know how
it works in Portugal,

1778
01:09:53,130 --> 01:09:55,650
I multiply by 10 and I get a good feel

1779
01:09:55,650 --> 01:09:57,090
of what would happen in Brazil.

1780
01:09:57,090 --> 01:09:59,640
So I have a good intuition
about the culture.

1781
01:09:59,640 --> 01:10:01,410
I thought this project,

1782
01:10:01,410 --> 01:10:06,300
trying to create this institute
and grow it was exciting.

1783
01:10:06,300 --> 01:10:09,180
I spoke with some people at PI

1784
01:10:09,180 --> 01:10:12,330
that encouraged me to try to do it.

1785
01:10:12,330 --> 01:10:15,810
We leveraged many of the
things that we knew at PI

1786
01:10:15,810 --> 01:10:19,980
to create things that
are sometimes similar,

1787
01:10:19,980 --> 01:10:21,300
sometimes different because you have

1788
01:10:21,300 --> 01:10:24,930
to adapt their different
way of doing things.

1789
01:10:24,930 --> 01:10:25,920
But for example,

1790
01:10:25,920 --> 01:10:29,070
we translated all of the
outreach material of PI

1791
01:10:29,070 --> 01:10:32,130
to Portuguese and now to Spanish as well.

1792
01:10:32,130 --> 01:10:33,270
People from outreach,

1793
01:10:33,270 --> 01:10:37,200
Greg and friends, went over
to Brazil several times

1794
01:10:37,200 --> 01:10:42,090
to give workshops for high
school teachers and students.

1795
01:10:42,090 --> 01:10:45,690
I gave several lectures on
relativity and quantum mechanics

1796
01:10:45,690 --> 01:10:48,030
on Saturday mornings for high school kids

1797
01:10:48,030 --> 01:10:50,760
that wake up at 4:00
AM to take these trains

1798
01:10:50,760 --> 01:10:55,760
to go to attend this lectures
and understand how space

1799
01:10:56,550 --> 01:10:58,740
and time can morph into each other.

1800
01:10:58,740 --> 01:11:00,540
And so it's lots of fun.

1801
01:11:00,540 --> 01:11:04,680
I think the impact is
huge and can be huge.

1802
01:11:04,680 --> 01:11:08,640
It's obviously super
useful for these students

1803
01:11:08,640 --> 01:11:10,110
that otherwise would not have

1804
01:11:10,110 --> 01:11:12,630
a contact with some researchers

1805
01:11:12,630 --> 01:11:15,420
that are really doing research
in these exciting topics.

1806
01:11:15,420 --> 01:11:19,350
But it's also fantastic
for us that we have access

1807
01:11:19,350 --> 01:11:21,690
to this amazing pool of talent.

1808
01:11:21,690 --> 01:11:23,010
When we'll finish this podcast,

1809
01:11:23,010 --> 01:11:24,810
I'm going to chat with
Alessandro that came

1810
01:11:24,810 --> 01:11:26,250
from this program and we are going

1811
01:11:26,250 --> 01:11:28,050
to try to play a little bit more

1812
01:11:28,050 --> 01:11:32,070
with this time models
that I told you about.

1813
01:11:32,070 --> 01:11:35,580
- We did have one more
question that's less technical.

1814
01:11:35,580 --> 01:11:37,260
It's from a young person here in Waterloo,

1815
01:11:37,260 --> 01:11:39,420
so maybe we can play that one for you.

1816
01:11:39,420 --> 01:11:41,400
- My name's Alice and I'm in grade two.

1817
01:11:41,400 --> 01:11:45,840
What would you consider to
be a good day at your job?

1818
01:11:45,840 --> 01:11:46,860
- That's a very good question.

1819
01:11:46,860 --> 01:11:50,070

So what would I consider to be a good day?

1820
01:11:50,070 --> 01:11:52,380
As you said at some point a lot

1821
01:11:52,380 --> 01:11:56,190
of the work we do in
practice is detective work.

1822
01:11:56,190 --> 01:11:58,500
You are trying to think of many,

1823
01:11:58,500 --> 01:12:01,800
many thought experiments
and try to see could it be

1824
01:12:01,800 --> 01:12:05,820
that this experiment result

1825
01:12:05,820 --> 01:12:08,487
has anything to say about
this other experiment result.

1826
01:12:08,487 --> 01:12:11,460
And you keep trying and 99%

1827
01:12:11,460 --> 01:12:14,460
of the time you are trying out things,

1828
01:12:14,460 --> 01:12:16,740
converting the thought
experiments into equations,

1829
01:12:16,740 --> 01:12:20,100
trying to solve the equations,
simplifying equations,

1830
01:12:20,100 --> 01:12:21,570
not solving the equations you want,

1831
01:12:21,570 --> 01:12:22,950
but solving simpler equations

1832
01:12:22,950 --> 01:12:23,880
so that later you can solve

1833
01:12:23,880 --> 01:12:25,770
the equations you want to solve.

1834
01:12:25,770 --> 01:12:29,040
And then some days you crack one of them,

1835
01:12:29,040 --> 01:12:31,320
some days it works, you find,

1836
01:12:31,320 --> 01:12:32,970
oh this is the right question.

1837
01:12:32,970 --> 01:12:34,353
So those are amazing days.

1838
01:12:35,280 --> 01:12:37,230
And even better typically
is when you do it

1839
01:12:37,230 --> 01:12:39,180
in the blackboard with someone else.

1840
01:12:39,180 --> 01:12:41,550
When sometimes you are,

1841
01:12:41,550 --> 01:12:42,660
you are in a blackboard,

1842
01:12:42,660 --> 01:12:45,393
then you are thinking we need to,

1843
01:12:46,230 --> 01:12:48,930
I dunno, understand the movement

1844
01:12:48,930 --> 01:12:50,490
of these gluons when
they're trying to move

1845
01:12:50,490 --> 01:12:54,090
at a speed of light and then
someone points out well,

1846
01:12:54,090 --> 01:12:55,620
but if they are moving all together,

1847
01:12:55,620 --> 01:12:58,230
they cannot pass by each
other, then someone says,

1848
01:12:58,230 --> 01:13:00,390
oh maybe that's about counting how things

1849
01:13:00,390 --> 01:13:02,880
go when they cannot pass by each other.

1850
01:13:02,880 --> 01:13:04,749
Could this be related

1851
01:13:04,749 --> 01:13:06,300
to this counting problems of stampedes,

1852
01:13:06,300 --> 01:13:09,480
and I think truth has this
attractor force to it.

1853
01:13:09,480 --> 01:13:10,710
It's like a basin,

1854
01:13:10,710 --> 01:13:13,200

like water swirling around,

1855
01:13:13,200 --> 01:13:14,400
so sometimes you feel lost,

1856
01:13:14,400 --> 01:13:16,234
but when you are close to
something that makes sense,

1857
01:13:16,234 --> 01:13:18,270
close to something that is,

1858
01:13:18,270 --> 01:13:19,680
oh that's the right thing,

1859
01:13:19,680 --> 01:13:21,750
it pushes you towards it.

1860
01:13:21,750 --> 01:13:23,850
And so there are these moments

1861
01:13:23,850 --> 01:13:25,971
where you are on the blackboard,

1862
01:13:25,971 --> 01:13:26,804
and you have this feeling that you

1863
01:13:26,804 --> 01:13:30,270
are being pushed towards
truth and that's amazing.

1864
01:13:30,270 --> 01:13:31,513
That's an amazing feeling.

1865
01:13:31,513 --> 01:13:33,270
You just go with the flow and it's like

1866
01:13:33,270 --> 01:13:35,190

a dance and each of you are changing ideas

1867
01:13:35,190 --> 01:13:37,710
but you feel like, oh
we are going somewhere.

1868
01:13:37,710 --> 01:13:41,760
And that feeling of letting
you flow and you don't,

1869
01:13:41,760 --> 01:13:44,910
you just let go and you will
eventually get to something

1870
01:13:44,910 --> 01:13:48,030
awesome because you feel
like you are moving closer

1871
01:13:48,030 --> 01:13:50,520
to something deep is fantastic,

1872
01:13:50,520 --> 01:13:51,750
but often you are just lost,

1873
01:13:51,750 --> 01:13:53,880
you are scattered, you
are moving left, right,

1874
01:13:53,880 --> 01:13:56,040
left right and then
suddenly there's this click

1875
01:13:56,040 --> 01:13:59,310
and you feel like you
found one of these streams

1876
01:13:59,310 --> 01:14:01,893
that will swirl to something true.

1877

01:14:02,790 --> 01:14:03,630
- Amazing.

1878
01:14:03,630 --> 01:14:05,250
Well this has been so much fun, Pedro.

1879
01:14:05,250 --> 01:14:07,804
Thank you so much for sharing your time.

1880
01:14:07,804 --> 01:14:09,930
I think we're gonna be leaving
with a lot of new lessons

1881
01:14:09,930 --> 01:14:12,150
to ponder and I think we're
all gonna remember not to let

1882
01:14:12,150 --> 01:14:15,150
our rooms get too messy 'cause
we might create a black hole.

1883
01:14:16,800 --> 01:14:19,743
- But if you clean them,
you are closer to dying.

1884
01:14:23,222 --> 01:14:26,007
- So we'll just keep
the room sort of tidy.

1885
01:14:26,007 --> 01:14:27,447
- Yeah, that's good.

1886
01:14:27,447 --> 01:14:30,480
(upbeat music)

1887
01:14:30,480 --> 01:14:31,380
- Thanks for listening

1888
01:14:31,380 --> 01:14:33,240

to Conversations at the Perimeter.

1889
01:14:33,240 --> 01:14:34,200
If you like what you hear,

1890
01:14:34,200 --> 01:14:36,090
please help us spread the word,

1891
01:14:36,090 --> 01:14:37,620
rate, review and subscribe

1892
01:14:37,620 --> 01:14:38,940
to Conversations at Perimeter

1893
01:14:38,940 --> 01:14:40,980
wherever you get your podcasts.

1894
01:14:40,980 --> 01:14:43,200
Every review helps us out a lot

1895
01:14:43,200 --> 01:14:45,930
and it helps more science
enthusiasts find us.

1896
01:14:45,930 --> 01:14:47,830
Thanks for being part of the equation.