1
00:00:00,173 --> 00:00:02,237
(bright music)

2
00:00:08,940 --> 00:00:11,550
- Welcome back to
Conversations at the Perimeter.

3
00:00:11,550 --> 00:00:13,980
I'm Colin and I'm here with
Lauren, and we are thrilled

4
00:00:13,980 --> 00:00:17,390
to share our conversation
with Francois David.

5
00:00:17,390 --> 00:00:19,340
Francois is a mathematical physicist,

6
00:00:19,340 --> 00:00:22,100
which means he tackles really
hard problems of physics,

7
00:00:22,100 --> 00:00:26,100
like quantum gravity, using
a mathematical toolkit,

8
00:00:26,100 --> 00:00:28,170
and I have to admit that's a toolkit

9
00:00:28,170 --> 00:00:30,410
that I didn't have a lot of
experience with growing up.

10
00:00:30,410 --> 00:00:33,560
So I was a little apprehensive
going into this conversation,

11
00:00:33,560 --> 00:00:36,970
but thankfully, Francois

is a very gifted teacher.

12
00:00:36,970 --> 00:00:38,840
- Francois was actually one of my teachers

13
00:00:38,840 --> 00:00:41,530
when I first came to
Perimeter as a grad student

14
00:00:41,530 --> 00:00:44,920
in the Perimeter Scholars
International master's program,

15
00:00:44,920 --> 00:00:46,800
and he's been coming to
teach in this program

16
00:00:46,800 --> 00:00:49,270
from France for many, many years

17
00:00:49,270 --> 00:00:52,500
and he has an amazing
reputation among the students.

18
00:00:52,500 --> 00:00:55,180
I'm now actually an instructor
in that program myself,

19
00:00:55,180 --> 00:00:57,390
and so I've been able to
interact with Francois,

20
00:00:57,390 --> 00:01:00,444
both as one of my teachers
and now as a colleague.

21
00:01:00,444 --> 00:01:02,690
- So what's it like
for you to put Francois

22
00:01:02,690 --> 00:01:04,970
in the hot seat now, where
you ask all the hard questions

23
00:01:04,970 --> 00:01:06,460
and he has to answer them?

24
00:01:06,460 --> 00:01:08,410
- Honestly, it was a
really different experience

25
00:01:08,410 --> 00:01:10,040
because, back when I was a student,

26
00:01:10,040 --> 00:01:12,410
I was usually too
nervous to put my hand up

27
00:01:12,410 --> 00:01:13,850
in class and ask questions.

28
00:01:13,850 --> 00:01:16,170
He even mentions during this conversation

29
00:01:16,170 --> 00:01:18,420
that he remembers I always
had a lot of questions,

30
00:01:18,420 --> 00:01:20,810
but I know that I would
usually stay after class

31
00:01:20,810 --> 00:01:23,500
to ask those around just a
smaller group of students,

32
00:01:23,500 --> 00:01:25,150
and so this was really different,

33
00:01:25,150 --> 00:01:28,480
that I got to ask questions
and share the conversation

34
00:01:28,480 --> 00:01:30,620
with so many others.
- And for me,

35
00:01:30,620 --> 00:01:32,300
that apprehension I had off the bat,

36
00:01:32,300 --> 00:01:34,740
it melted away so quickly when I realized

37
00:01:34,740 --> 00:01:36,220
just how much he loves physics

38
00:01:36,220 --> 00:01:38,680
and how infectious his love is for it.

39
00:01:38,680 --> 00:01:41,480
I'm excited for other
people to get that sense

40
00:01:41,480 --> 00:01:44,450
of the joy of physics
and math from Francois,

41
00:01:44,450 --> 00:01:46,843
so let's step inside the Perimeter.

42
00:01:50,860 --> 00:01:52,200
- Thank you so much, Francois,

43
00:01:52,200 --> 00:01:54,380
for joining us for a conversation today,

44
00:01:54,380 --> 00:01:55,610

and it's great to have you here

45
00:01:55,610 --> 00:01:58,180
at PI all the way from France.

46
00:01:58,180 --> 00:02:00,200
Would you mind telling us a little bit

47
00:02:00,200 --> 00:02:03,300
about what you do as a
mathematical physicist

48
00:02:03,300 --> 00:02:05,650
and what it means to work in that field?

49
00:02:05,650 --> 00:02:08,240
- Well, first, thank you
very much for this invitation

50
00:02:08,240 --> 00:02:10,010
to this kind of interview.

51
00:02:10,010 --> 00:02:13,760
That's my first experience
in this, almost my first.

52
00:02:13,760 --> 00:02:17,000
Okay, about my experience
as a mathematical physicist,

53
00:02:17,000 --> 00:02:19,990
but I must say that I don't really know

54
00:02:19,990 --> 00:02:21,960
exactly what is mathematical physics,

55
00:02:21,960 --> 00:02:24,640
because it depends a bit on the country,

56
00:02:24,640 --> 00:02:26,170
on the culture, or the person.

57
00:02:26,170 --> 00:02:28,530
So I am partly a theoretical physicist

58
00:02:28,530 --> 00:02:32,550
and partly a mathematical
physicist or both.

59
00:02:32,550 --> 00:02:36,730
And mathematical physics
is a field of research.

60
00:02:36,730 --> 00:02:39,090
There is no real border, but interface

61
00:02:39,090 --> 00:02:42,080
between mathematics and
theoretical physics.

62
00:02:42,080 --> 00:02:47,080
Mathematical physicists
are more involved in using

63
00:02:47,130 --> 00:02:51,550
recent and sophisticated
mathematical techniques and ideas

64
00:02:51,550 --> 00:02:53,160
because mathematics are way much

65
00:02:53,160 --> 00:02:55,410
than just techniques of calculations.

66
00:02:55,410 --> 00:02:57,270
They are concept, ideas.

67

00:02:57,270 --> 00:02:59,430
So mathematical physicists
are more interested

68
00:02:59,430 --> 00:03:02,900
in the structure of physical theory

69
00:03:02,900 --> 00:03:05,960
and understanding how that works,

70
00:03:05,960 --> 00:03:08,180
what one can tell out of the mathematics

71
00:03:08,180 --> 00:03:10,460
that governs the physical theory,

72
00:03:10,460 --> 00:03:14,060
and understand, often on simple models,

73
00:03:14,060 --> 00:03:16,900
not always, but they take a simple model,

74
00:03:16,900 --> 00:03:21,900
not often directly related to
some real physical systems.

75
00:03:22,150 --> 00:03:25,370
It may be, but they're often idealized

76
00:03:25,370 --> 00:03:26,410
in order to keep track

77
00:03:26,410 --> 00:03:29,430
just of the important
physical feature they want

78
00:03:29,430 --> 00:03:34,010
to understand and working
out, as deeply as possible,

79
00:03:34,010 --> 00:03:37,940
the math and the theory
and see what comes out.

80
00:03:37,940 --> 00:03:42,350
Are those theoretical models
consistent, for instance?

81
00:03:42,350 --> 00:03:43,760
That's very important.

82
00:03:43,760 --> 00:03:48,317
Can we compute exactly and
prove properties of this model,

83
00:03:48,317 --> 00:03:52,010
or are we just able to use

84
00:03:52,010 --> 00:03:53,840
what are called phenomenological model?

85
00:03:53,840 --> 00:03:56,860
So one makes assumptions,

86
00:03:56,860 --> 00:04:00,620
some approximation, and then one relies

87
00:04:00,620 --> 00:04:04,133
on calculation and also
physical intuition,

88
00:04:05,100 --> 00:04:07,610
and often it works, but
sometimes it doesn't work.

89
00:04:07,610 --> 00:04:09,347
You really have to work hard

90
00:04:10,460 --> 00:04:13,150
and do hard math and some deep,

91
00:04:13,150 --> 00:04:15,950
and sometimes unexpected results come out.

92
00:04:15,950 --> 00:04:18,590
So that's mathematical physics.

93
00:04:18,590 --> 00:04:20,970
- Francois, you used the
word consistent there

94
00:04:20,970 --> 00:04:22,440
to describe the research.

95
00:04:22,440 --> 00:04:25,230
Does consistent mean that an idea is true,

96
00:04:25,230 --> 00:04:27,830
or that it's true enough for now,

97
00:04:27,830 --> 00:04:31,270
and is inconsistency an enemy of science?

98
00:04:31,270 --> 00:04:35,760
- In my mind, consistency is
a mathematical consistency.

99
00:04:35,760 --> 00:04:37,450
It's related to another concept,

100
00:04:37,450 --> 00:04:39,600
very important for some
physicists, not all of them,

101
00:04:39,600 --> 00:04:42,490
but it's a mathematical

beauty of a theory.

102
00:04:42,490 --> 00:04:45,900
So it's something which was
very important for Paul Dirac,

103
00:04:45,900 --> 00:04:49,770
one of the creator and
inventor of quantum mechanics,

104
00:04:49,770 --> 00:04:52,720
who considered that a
theory had to be true

105
00:04:52,720 --> 00:04:54,600
if it was beautiful.

106
00:04:54,600 --> 00:04:59,230
This led him, for instance, to
discover the Dirac equation,

107
00:04:59,230 --> 00:05:02,460
though often, beauty is associated

108
00:05:02,460 --> 00:05:06,100
to mathematical consistency
in the mind of mathematician

109
00:05:06,100 --> 00:05:09,630
and in the mind of many
theoretical physicists.

110
00:05:09,630 --> 00:05:13,670
There is something which is
more than just mere beauty

111
00:05:13,670 --> 00:05:16,870
because some very simple
object can be very beautiful.

112
00:05:16,870 --> 00:05:21,090
Consistency means that,
often in theoretical physics,

113
00:05:21,090 --> 00:05:23,610
one needs to start with some assumption.

114
00:05:23,610 --> 00:05:25,963
There is space, there is time.

115
00:05:26,832 --> 00:05:29,740
For instance, one important assumption is

116
00:05:29,740 --> 00:05:32,580
there is no difference between
the future and the past,

117
00:05:32,580 --> 00:05:34,073
which seems a bit,

118
00:05:35,220 --> 00:05:37,560
of course, contradictory
with our daily experience,

119
00:05:37,560 --> 00:05:39,480
but that's the deep principle

120
00:05:39,480 --> 00:05:41,490
of, nowadays, theoretical physics.

121
00:05:41,490 --> 00:05:45,070
So one makes assumption, let's
say what physical problem

122
00:05:45,070 --> 00:05:47,240
or physical system is described

123
00:05:47,240 --> 00:05:49,560

by one makes some assumption.

124
00:05:49,560 --> 00:05:51,055
One assume the rules, for instance,

125
00:05:51,055 --> 00:05:54,770
the rules of classical mechanics
or the rules of the law,

126
00:05:54,770 --> 00:05:57,770
other than the rules of the
law of quantum mechanics,

127
00:05:57,770 --> 00:06:01,530
the law of hydrodynamics,
the law of classical physics,

128
00:06:01,530 --> 00:06:04,150
Newton Law, et cetera, and one see,

129
00:06:04,150 --> 00:06:06,250
whether building out of that,

130
00:06:06,250 --> 00:06:09,580
one doesn't run up into some
mathematical inconsistency.

131
00:06:09,580 --> 00:06:11,650
Sometimes it's easy to see

132
00:06:11,650 --> 00:06:14,320
that there should be some inconsistency

133
00:06:15,160 --> 00:06:18,210
in some direction, so don't
look in this direction.

134
00:06:18,210 --> 00:06:22,440
Look in the problems where

inconsistency doesn't appear.

135
00:06:22,440 --> 00:06:27,270
And sometimes the inconsistency
appears in a surprising way.

136
00:06:27,270 --> 00:06:30,563
And of course, if you run into
a mathematical inconsistency,

137
00:06:31,560 --> 00:06:34,180
it means that you are to think more.

138
00:06:34,180 --> 00:06:38,240
Either one of our assumptions was wrong,

139
00:06:38,240 --> 00:06:40,840
or it might be a paradox,

140
00:06:40,840 --> 00:06:43,573
but not a real inconsistency
if you work out enough.

141
00:06:44,540 --> 00:06:48,300
Science and knowledge
progress by making errors.

142
00:06:48,300 --> 00:06:52,030
If everything was clearly
understandable and consistent

143
00:06:52,030 --> 00:06:56,179
from the very beginning,
it wouldn't be interesting.

144
00:06:56,179 --> 00:06:57,510
- And could I also say maybe

145
00:06:57,510 --> 00:07:01,930

that, if in physics we often
tend to start with assumptions

146
00:07:01,930 --> 00:07:04,380
and, as you said, sometimes
those assumptions might lead

147
00:07:04,380 --> 00:07:06,900
to inconsistencies and sometimes not,

148
00:07:06,900 --> 00:07:09,410
would a goal of mathematical physics be

149
00:07:09,410 --> 00:07:12,210
to provide more structure
to those assumptions

150
00:07:12,210 --> 00:07:16,010
so that there may be, at some
point, no longer assumptions?

151
00:07:16,010 --> 00:07:17,290
- Yeah, this happens, too.

152
00:07:17,290 --> 00:07:22,080
Sometimes you start, from assumptions,

153
00:07:22,080 --> 00:07:26,020
you work or after some
other researchers come out

154
00:07:26,020 --> 00:07:29,610
from different field or different ideas,

155
00:07:29,610 --> 00:07:31,990
or even some mathematicians come out also,

156
00:07:31,990 --> 00:07:36,880
and when discovered that those

assumption were were correct,

157
00:07:36,880 --> 00:07:40,040
it was not coming from some naturalness

158
00:07:40,040 --> 00:07:43,610
or intuition that things
should be that way.

159
00:07:43,610 --> 00:07:46,050
It comes out that they had to be this way.

160
00:07:46,050 --> 00:07:48,060
And that's a difference
between often, one start

161
00:07:48,060 --> 00:07:51,620
by, oh, things should
work this way or that way.

162
00:07:51,620 --> 00:07:55,460
And then you may have different theory,

163
00:07:55,460 --> 00:07:57,920
which start from different point of view.

164
00:07:57,920 --> 00:07:59,760
After working often very hard

165
00:07:59,760 --> 00:08:02,310
by a team of very different
people, one comes out of that

166
00:08:02,310 --> 00:08:05,720
that, in fact, oh, things
had to be that way,

167
00:08:05,720 --> 00:08:09,240
this way, and not that way, or sometimes,

168
00:08:09,240 --> 00:08:13,230
oh, things had to be this way
and your two approach were

169
00:08:13,230 --> 00:08:17,010
seemingly contradictory, but consistent.

170
00:08:17,010 --> 00:08:19,580
One time, this happens in the early days

171
00:08:19,580 --> 00:08:23,140
of quantum mechanics, very
often, where people were starting

172
00:08:23,140 --> 00:08:26,200
from some kind of wild assumptions.

173
00:08:26,200 --> 00:08:27,850
- I often hear mathematicians talk

174
00:08:27,850 --> 00:08:30,230
about the sense of beauty in mathematics,

175
00:08:30,230 --> 00:08:32,360
and that's a beauty that, personally,

176
00:08:32,360 --> 00:08:34,280
I haven't been able to experience

177
00:08:34,280 --> 00:08:37,320
because I grew up a
little bit afraid of math.

178
00:08:37,320 --> 00:08:39,800
Can you describe the sense of beauty

179
00:08:39,800 --> 00:08:40,887

that you see in mathematics?

180
00:08:40,887 --> 00:08:42,660
- I'm not a mathematician,

181
00:08:42,660 --> 00:08:44,430
so I won't speak as a mathematician,

182
00:08:44,430 --> 00:08:46,690
although I know some mathematics.

183
00:08:46,690 --> 00:08:50,170
I was educated in mathematics
since the French high school,

184
00:08:50,170 --> 00:08:53,680
and the university system is more focused

185
00:08:53,680 --> 00:08:56,070
on mathematics than in other countries.

186
00:08:56,070 --> 00:08:58,180
Also, I married a mathematician

187
00:08:58,180 --> 00:09:01,320
and two of my daughters
are mathematicians.

188
00:09:01,320 --> 00:09:04,110
My impression is that
mathematicians see beauty

189
00:09:04,110 --> 00:09:07,330
in simplicity of structure,
but consistencies of structure,

190
00:09:07,330 --> 00:09:10,560
objects can be mathematical,
theories can be complicated,

191
00:09:10,560 --> 00:09:13,240
but there is some underlying structure

192
00:09:13,240 --> 00:09:17,470
which enables you to come out to theorems

193
00:09:17,470 --> 00:09:20,170
by abstract reasoning, not just heavy

194
00:09:20,170 --> 00:09:21,003
and technical calculation.

195
00:09:21,003 --> 00:09:23,570
Although they are also very important,

196
00:09:23,570 --> 00:09:26,940
they also both in theoretical physics,

197
00:09:26,940 --> 00:09:30,070
science in general, or in mathematics,

198
00:09:30,070 --> 00:09:33,740
you see simplicity after
a lot of hard work.

199
00:09:33,740 --> 00:09:36,450
It's a bit like digging
an archeological dig.

200
00:09:36,450 --> 00:09:37,640
You find some beautiful archaeology,

201
00:09:37,640 --> 00:09:41,710
but you had to work, work,
and once you find something,

202
00:09:41,710 --> 00:09:44,280

you say, "Oh, but I should
have looked in this direction,"

203
00:09:44,280 --> 00:09:46,130
come to the results very easily,

204
00:09:46,130 --> 00:09:49,440
but of course, you just know
because you worked hard.

205
00:09:49,440 --> 00:09:51,160
So that's my feeling

206
00:09:51,160 --> 00:09:54,780
of what a mathematician feel about beauty.

207
00:09:54,780 --> 00:09:57,220
So one of my daughter is a mathematician.

208
00:09:57,220 --> 00:10:00,060
She's doing algebra, geometry,
a number of theories,

209
00:10:00,060 --> 00:10:03,637
and she said, "I prefer math
to physics because in math,

210
00:10:03,637 --> 00:10:08,637
"we are dealing with objects
we have created ourselves

211
00:10:08,707 --> 00:10:11,287
"and so we know it's
consistent, while in physics,

212
00:10:11,287 --> 00:10:15,160
"there is some external world
and we start from that."

213

00:10:15,160 --> 00:10:18,680
We want to understand the
universe, we want to understand

214
00:10:18,680 --> 00:10:21,750
how a cell works

215
00:10:21,750 --> 00:10:24,020
or how the solar system works

216
00:10:24,020 --> 00:10:27,430
or why there are chemical reactions,

217
00:10:27,430 --> 00:10:30,090
and that's something which is given to us

218
00:10:30,090 --> 00:10:32,123
or which is there for us to understand.

219
00:10:33,290 --> 00:10:37,970
That's probably one reason
why I prefer to be a physicist

220
00:10:37,970 --> 00:10:39,110
than a pure mathematician.

221
00:10:39,110 --> 00:10:43,670
So probably my brain prefers
to be a mathematician.

222
00:10:43,670 --> 00:10:45,280
That's why I'm a mathematical physicist,

223
00:10:45,280 --> 00:10:49,290
but my curiosity or my intuition prefers

224
00:10:49,290 --> 00:10:52,630
to have surprises coming
from where we live.

225
00:10:52,630 --> 00:10:54,370
Especially here, you have

226
00:10:54,370 --> 00:10:56,890
a group of very good people working

227
00:10:56,890 --> 00:10:58,680
with the foundations of physics

228
00:10:58,680 --> 00:11:01,140
and the foundation of
some philosopher, too.

229
00:11:01,140 --> 00:11:03,790
They will be able to tell
more, but it's unclear

230
00:11:03,790 --> 00:11:06,390
whether the mathematics
are part of the real world

231
00:11:06,390 --> 00:11:08,340
or something completely outside.

232
00:11:08,340 --> 00:11:10,030
That's a view of many mathematicians,

233
00:11:10,030 --> 00:11:13,570
that mathematics exists by themself.

234
00:11:13,570 --> 00:11:17,910
This is more considered,
mathematics as a tool.

235
00:11:17,910 --> 00:11:20,780
There is a debate that goes
back to the great philosophers

236
00:11:20,780 --> 00:11:23,920
about what are mathematics and physics,

237
00:11:23,920 --> 00:11:25,260
since they are intertwined

238
00:11:25,260 --> 00:11:27,600
since they were created or discovered.

239
00:11:27,600 --> 00:11:29,730
- From what you say, I mean,

240
00:11:29,730 --> 00:11:31,690
you're giving us a nice description

241
00:11:31,690 --> 00:11:35,110
that mathematics involves
some beautiful structures

242
00:11:35,110 --> 00:11:38,460
that we can create, and
physics is about describing

243
00:11:38,460 --> 00:11:41,240
these really interesting
phenomena in our world,

244
00:11:41,240 --> 00:11:43,770
so maybe mathematical physics is working

245
00:11:43,770 --> 00:11:44,790
from both of those ends

246
00:11:44,790 --> 00:11:47,203
to give some structure to the universe,

247
00:11:48,720 --> 00:11:50,640
and oh, maybe that's not correct, but-

248
00:11:50,640 --> 00:11:53,620
- No, I think that's a good view,

249
00:11:53,620 --> 00:11:55,410
but I'm not an historian of science,

250
00:11:55,410 --> 00:11:58,310
but many of the mathematical
object were created

251
00:11:58,310 --> 00:11:59,870
from the real worlds

252
00:11:59,870 --> 00:12:02,440
and then evolved on their
own, and some structure

253
00:12:02,440 --> 00:12:06,260
of the real worlds have been
discovered through mathematics.

254
00:12:06,260 --> 00:12:07,130
- And is that why we need

255
00:12:07,130 --> 00:12:09,280
mathematical physics, so that we make sure

256
00:12:09,280 --> 00:12:11,643
that those two ends are
talking to each other?

257
00:12:13,100 --> 00:12:14,460
- The interface has been there.

258
00:12:14,460 --> 00:12:16,213
It has been important,

259

00:12:17,230 --> 00:12:19,590
depending on the historical
period in science

260
00:12:19,590 --> 00:12:22,710
and also on the countries,
but the interface has to be.

261
00:12:22,710 --> 00:12:26,100
Otherwise, there won't be good
physics without mathematics,

262
00:12:26,100 --> 00:12:28,780
of course, because I think Galileo stated,

263
00:12:28,780 --> 00:12:30,020
one of the first to state,

264
00:12:30,020 --> 00:12:32,930
that mathematics is a language, physics.

265
00:12:32,930 --> 00:12:36,180
Also, a lot of mathematicians
now, not all of them,

266
00:12:36,180 --> 00:12:39,900
but of course, it depends,
get inspiration from physics,

267
00:12:39,900 --> 00:12:44,580
and the ideas which,
somehow, a bit clumsy ideas,

268
00:12:44,580 --> 00:12:49,580
created by theoretical
physicists, common mathematics,

269
00:12:49,730 --> 00:12:53,250
challenge things, and
then come back to physics

270
00:12:53,250 --> 00:12:57,670
as a neat tool and with new
ideas provided mathematicians.

271
00:12:57,670 --> 00:13:00,460
There are many examples
that one can think,

272
00:13:00,460 --> 00:13:02,053
but a few in the last decades.

273
00:13:03,040 --> 00:13:06,240
- So mathematics, you said,
is a tool that we can use

274
00:13:06,240 --> 00:13:09,180
to make progress in big
problems in physics.

275
00:13:09,180 --> 00:13:11,370
So what are some of the
big problems in physics

276
00:13:11,370 --> 00:13:14,523
that you are trying to tackle
using mathematical techniques?

277
00:13:15,490 --> 00:13:18,060
- I've been very much interested.

278
00:13:18,060 --> 00:13:20,703
In fact, I realized all along, my career,

279
00:13:21,990 --> 00:13:25,070
not only this question,
but about random geometry,

280
00:13:25,070 --> 00:13:28,100

let's say starting from
geometrical objects,

281
00:13:28,100 --> 00:13:30,420
and see what's the role of randomness,

282
00:13:30,420 --> 00:13:34,220
and one of my interests in that
comes from quantum gravity,

283
00:13:34,220 --> 00:13:37,510
so quantum physics and gravitation.

284
00:13:37,510 --> 00:13:41,380
Theory of gravitation has
been born with Kaplan, Newton,

285
00:13:41,380 --> 00:13:44,820
all the great mind in the 19th century.

286
00:13:44,820 --> 00:13:46,820
Then Einstein discovered

287
00:13:46,820 --> 00:13:49,560
that, in order to make
habitation compatible

288
00:13:49,560 --> 00:13:53,910
with the theory of
relativity that he discovered

289
00:13:53,910 --> 00:13:57,120
in order to understand the behavior

290
00:13:57,120 --> 00:14:00,150
between light and matter, no habitation,

291
00:14:00,150 --> 00:14:03,330
he discovered that, in

fact, spacetime orders

292
00:14:03,330 --> 00:14:05,980
that you shouldn't consider space and time

293
00:14:05,980 --> 00:14:08,070
as two separate notion or entities,

294
00:14:08,070 --> 00:14:12,040
but they have to be taken
as a part of spacetime.

295
00:14:12,040 --> 00:14:14,130
Einstein discovered that,
in order to formulate

296
00:14:14,130 --> 00:14:16,740
the consistency of gravity,
the spacetime itself

297
00:14:16,740 --> 00:14:19,460
as a internal structure, it has a metric

298
00:14:19,460 --> 00:14:21,980
and it can be a geometrical object.

299
00:14:21,980 --> 00:14:24,320
In fact, it is a curved object.

300
00:14:24,320 --> 00:14:26,810
All of spacetime, so both space is curved.

301
00:14:26,810 --> 00:14:29,603
Usually, you often form this fact.

302
00:14:30,450 --> 00:14:32,470
You said that you have flat
space, you put the body in it,

303
00:14:32,470 --> 00:14:35,210
like the sun, and it curves the space.

304
00:14:35,210 --> 00:14:36,930
And then therefore, it's like a ball,

305
00:14:36,930 --> 00:14:40,210
and you can have a marbles way

306
00:14:40,210 --> 00:14:45,210
to explain empirically why the
planets orbit around the sun.

307
00:14:45,330 --> 00:14:48,140
The theory of general
relativity of Einstein says

308
00:14:48,140 --> 00:14:50,840
that, also, time is curved,
and that's something

309
00:14:50,840 --> 00:14:54,140
which is more difficult, too,

310
00:14:54,140 --> 00:14:58,293
that it's space and time which
are curved, not only space.

311
00:14:59,150 --> 00:15:01,220
Productivity tells us that, in fact,

312
00:15:01,220 --> 00:15:04,990
time is associated to space,
so times has to be considered

313
00:15:04,990 --> 00:15:09,160
as a separate time at
different points in space.

314
00:15:09,160 --> 00:15:12,110
When you start to
compare what's happening,

315
00:15:12,110 --> 00:15:15,260
when you go to a different
place, you let run time

316
00:15:15,260 --> 00:15:17,810
and then you come back at the same place,

317
00:15:17,810 --> 00:15:21,530
you discover that space
behaved in a different way

318
00:15:21,530 --> 00:15:24,440
that you could have expected
if time was something uniform,

319
00:15:24,440 --> 00:15:26,550
like in Newton theory of time,

320
00:15:26,550 --> 00:15:28,790
especially when there is
a gravitational field.

321
00:15:28,790 --> 00:15:32,350
If you have a black hole and you are far

322
00:15:32,350 --> 00:15:36,350
from the black hole, or if
you go close to the black hole

323
00:15:36,350 --> 00:15:39,290
and come back or close to
the sun and then come back,

324
00:15:39,290 --> 00:15:44,120
then time has very differently

approach a black hole.

325
00:15:44,120 --> 00:15:47,520
You come back, then the
clocks are desynchronized.

326
00:15:47,520 --> 00:15:49,690
There was a very nice example of that

327
00:15:49,690 --> 00:15:51,880
in a movie, this "Interstellar."

328
00:15:51,880 --> 00:15:56,520
This is checked in laboratories,
not going near black holes,

329
00:15:56,520 --> 00:15:58,770
but just having two atomic clocks.

330
00:15:58,770 --> 00:16:02,640
As you raise one of the
atomic clocks by a few meters,

331
00:16:02,640 --> 00:16:05,750
drop it back on the table
where it started from,

332
00:16:05,750 --> 00:16:07,110
and you can see such effects,

333
00:16:07,110 --> 00:16:08,777
tiny effects, but they are measurable

334
00:16:08,777 --> 00:16:10,510
and I agree with the theory.

335
00:16:10,510 --> 00:16:14,350
Now come quantum mechanics,
great discovery of last century.

336
00:16:14,350 --> 00:16:17,280
Einstein also played a
role, but less central,

337
00:16:17,280 --> 00:16:19,140
compared to relativity.

338
00:16:19,140 --> 00:16:21,383
And in quantum mechanics,

339
00:16:22,400 --> 00:16:24,370
some very special kind of randomness,

340
00:16:24,370 --> 00:16:26,653
rather than randomness, one choose it.

341
00:16:27,719 --> 00:16:30,510
The role of chance is very important.

342
00:16:30,510 --> 00:16:32,350
There is some indeterminacy.

343
00:16:32,350 --> 00:16:35,590
You are never sure of what the results

344
00:16:35,590 --> 00:16:38,000
of a measurement will
be, but this randomness,

345
00:16:38,000 --> 00:16:41,350
in some senses, uncertainty is governed

346
00:16:41,350 --> 00:16:44,310
by mathematical role which
are very, very precise,

347
00:16:44,310 --> 00:16:47,770

so it's not randomness
just because we don't know

348
00:16:47,770 --> 00:16:49,330
exactly what's going on.

349
00:16:49,330 --> 00:16:51,688
When you are interested in,

350
00:16:51,688 --> 00:16:54,420
for instance, the theory
of quantization of gravity,

351
00:16:54,420 --> 00:16:58,750
one of the great problems
nowadays of present physics,

352
00:16:58,750 --> 00:17:00,620
you have to treat spacetime

353
00:17:00,620 --> 00:17:05,090
as a curved object, a curved spacetime,

354
00:17:05,090 --> 00:17:07,920
but with some randomness coming

355
00:17:07,920 --> 00:17:11,080
from the quantum nature of the universe.

356
00:17:11,080 --> 00:17:13,940
And we know that, for consistency,

357
00:17:13,940 --> 00:17:17,010
this idea of consistency,
the beauty of the theory,

358
00:17:17,010 --> 00:17:20,584
the geometry of spacetime,
the curvature of spacetime,

359
00:17:20,584 --> 00:17:23,200
has to be treated as a random object,

360
00:17:23,200 --> 00:17:25,640
but an object with randomness agreeing

361
00:17:25,640 --> 00:17:28,750
with the law of quantum
mechanics, if, indeed,

362
00:17:28,750 --> 00:17:31,850
gravitation is consistent
with quantum mechanics,

363
00:17:31,850 --> 00:17:34,870
and we don't really know
if they are consistent.

364
00:17:34,870 --> 00:17:37,160
We hope that it's
consistent, we are trying

365
00:17:37,160 --> 00:17:39,870
to make a consistent
theory of quantum gravity,

366
00:17:39,870 --> 00:17:44,640
but maybe we'll come up
into an inconsistency,

367
00:17:44,640 --> 00:17:46,410
which means that we will have to build

368
00:17:46,410 --> 00:17:48,630
a new theory of nature, which will be

369
00:17:48,630 --> 00:17:51,470
post-quantum and post-gravitational.

370
00:17:51,470 --> 00:17:54,210
- So quantum gravity,
it's essentially the quest

371
00:17:54,210 --> 00:17:56,330
to reconcile two theories,

372
00:17:56,330 --> 00:17:59,050
quantum mechanics and general relativity,

373
00:17:59,050 --> 00:18:02,543
and to come up with a
bridge between the two?

374
00:18:03,620 --> 00:18:07,490
- We need to have a
consistent physical theory,

375
00:18:07,490 --> 00:18:08,500
which leads us

376
00:18:08,500 --> 00:18:11,020
to a complete understanding
of quantum mechanics

377
00:18:11,020 --> 00:18:14,260
and a complete understanding of gravity.

378
00:18:14,260 --> 00:18:16,170
We have to build such a theory.

379
00:18:16,170 --> 00:18:19,050
Some physicists think
that it's not necessary,

380
00:18:19,050 --> 00:18:21,160
that we can still live
with those two theories,

381
00:18:21,160 --> 00:18:23,310
but the vast majority thinks

382
00:18:23,310 --> 00:18:26,490
that, for just this reason
of consistency and beauty,

383
00:18:26,490 --> 00:18:28,360
in the sense of logical consistency,

384
00:18:28,360 --> 00:18:30,000
there has to be such a theory.

385
00:18:30,000 --> 00:18:31,710
It depends with whom you talk, though.

386
00:18:31,710 --> 00:18:35,020
There are several direction of research,

387
00:18:35,020 --> 00:18:37,020
and it's a very active subject,

388
00:18:37,020 --> 00:18:39,170
in part, well represented

389
00:18:39,170 --> 00:18:41,064
here in the Perimeter, of course,

390
00:18:41,064 --> 00:18:44,690
and there are many different ideas.

391
00:18:44,690 --> 00:18:46,930
Some are mathematically well-developed,

392
00:18:46,930 --> 00:18:50,270
some are less and more rely on intuition

393
00:18:50,270 --> 00:18:52,617
or some toy model.

394
00:18:52,617 --> 00:18:55,100
The two main ones are string theory,

395
00:18:55,100 --> 00:18:56,870
and the other one is based

396
00:18:56,870 --> 00:18:59,610
on still treating the
geometry of spacetime,

397
00:18:59,610 --> 00:19:02,960
how four-dimensional
spacetime as some basic data

398
00:19:02,960 --> 00:19:07,070
and quantizing it according to
the law of quantum mechanics,

399
00:19:07,070 --> 00:19:10,090
while string theory is
wider and more speculative.

400
00:19:10,090 --> 00:19:12,070
- A lot of your contributions are

401
00:19:12,070 --> 00:19:15,190
specifically to two-dimensional
quantum gravity,

402
00:19:15,190 --> 00:19:17,090
and we had a really good question sent in

403
00:19:17,090 --> 00:19:18,770
from Tebra in Bangladesh-
- Ah, okay, yes.

404
00:19:18,770 --> 00:19:21,373
- So maybe we can listen to his question.

405
00:19:22,810 --> 00:19:24,800
- Hi, Francois, this is Tebra.

406
00:19:24,800 --> 00:19:28,400
I'm a theoretical physicist
based in Bangladesh.

407
00:19:28,400 --> 00:19:31,330
Of course, you and I know each other,

408
00:19:31,330 --> 00:19:34,740
so this is for other
people, other listeners.

409
00:19:34,740 --> 00:19:36,660
Anyway, I have a question for you.

410
00:19:36,660 --> 00:19:38,170
Recently, there have been some buzz

411
00:19:38,170 --> 00:19:41,550
in the physics circle

412
00:19:41,550 --> 00:19:44,820
about your work in two-dimensional gravity

413
00:19:44,820 --> 00:19:48,340
and how that has helped breakthroughs

414
00:19:49,550 --> 00:19:51,910
in recent years, so I was just wondering

415
00:19:51,910 --> 00:19:54,770
if you could explain in general terms

416
00:19:54,770 --> 00:19:57,900
what your contribution was

417
00:19:57,900 --> 00:20:00,080
to the field of two-dimensional gravity

418
00:20:00,080 --> 00:20:03,310
and how that contributed
to recent breakthroughs

419
00:20:03,310 --> 00:20:04,930
in two-dimensional gravity.

420
00:20:04,930 --> 00:20:07,763
Thank you for listening and
thank you for your answer.

421
00:20:10,090 --> 00:20:11,510
- Thank you, Tebra.

422
00:20:11,510 --> 00:20:13,180
I've been specifically interested

423
00:20:13,180 --> 00:20:17,370
and worked and got some
interesting results in a subfield

424
00:20:17,370 --> 00:20:19,670
of quantum gravity called
two-dimensional gravity.

425
00:20:19,670 --> 00:20:22,210
It's both a toy model and
a very interesting model

426
00:20:22,210 --> 00:20:23,830
for some physical application.

427

00:20:23,830 --> 00:20:25,970
It's a model which is
very much simplified,

428
00:20:25,970 --> 00:20:30,970
a core model where you can
study one aspect of the physics.

429
00:20:31,420 --> 00:20:34,090
- But the idea would be that,
by working with this toy,

430
00:20:34,090 --> 00:20:37,240
we can still gain some insights
that will still help us

431
00:20:37,240 --> 00:20:39,180
to understand the more complicated system?

432
00:20:39,180 --> 00:20:42,260
- Yes, and so an example of a toy model,

433
00:20:42,260 --> 00:20:43,680
which is a very useful example

434
00:20:43,680 --> 00:20:48,450
for studying quantum gravity
is to consider that spacetime,

435
00:20:48,450 --> 00:20:52,680
instead of having three
dimension one time,

436
00:20:52,680 --> 00:20:55,160
or as in string theory,

437
00:20:55,160 --> 00:20:58,990
nine or 10 dimensions of space
and one dimension of time,

438
00:20:58,990 --> 00:21:02,910
or maybe nine dimension of space
and two direction of times,

439
00:21:02,910 --> 00:21:05,560
would consider a very simplifying model

440
00:21:05,560 --> 00:21:07,000
of spacetime, where you have

441
00:21:07,000 --> 00:21:10,600
one direction of space,
so space is just a line,

442
00:21:10,600 --> 00:21:12,660
and one direction of time,

443
00:21:12,660 --> 00:21:15,440
so spacetime is just a sheet of paper.

444
00:21:15,440 --> 00:21:17,900
So it's a very simple model,

445
00:21:17,900 --> 00:21:21,750
and you lose many aspects
of habitation theory.

446
00:21:21,750 --> 00:21:22,830
In particular, you lose

447
00:21:22,830 --> 00:21:25,520
a very important aspect of your operation.

448
00:21:25,520 --> 00:21:28,690
You lose the law of attraction,

449
00:21:28,690 --> 00:21:30,880
Newton's Law, for some technical reason.

450
00:21:30,880 --> 00:21:34,740
So you have no habitation
anymore, but you have geometry

451
00:21:34,740 --> 00:21:37,430
because a sheet of paper can be curved.

452
00:21:37,430 --> 00:21:40,010
If it's a rubber sheet, it has curvature,

453
00:21:40,010 --> 00:21:42,670
so you keep one of the basic point,

454
00:21:42,670 --> 00:21:44,060
that spacetime is curved.

455
00:21:44,060 --> 00:21:45,790
So you can quantize it

456
00:21:45,790 --> 00:21:48,130
and you can study the quantum effects.

457
00:21:48,130 --> 00:21:51,180
In particular, that's the simple case

458
00:21:51,180 --> 00:21:55,087
where you can build a consistent
quantum model of gravity,

459
00:21:55,087 --> 00:21:59,010
and you can build a
theory on simple axioms

460
00:21:59,010 --> 00:22:02,500
and compute things and go to
the end of your calculation

461

00:22:02,500 --> 00:22:05,980
and get insights about what
quantum gravity could be,

462
00:22:05,980 --> 00:22:09,460
or some aspects of quantum
gravity could be or could not be.

463
00:22:09,460 --> 00:22:12,110
So working with a two-dimensional model

464
00:22:12,110 --> 00:22:14,560
or either one-plus-one-dimensional model,

465
00:22:14,560 --> 00:22:17,800
spacetime, rather than
two four-dimensional,

466
00:22:17,800 --> 00:22:20,597
three-plus-one-dimensional
spacetime is very important

467
00:22:20,597 --> 00:22:21,880
and is very interesting.

468
00:22:21,880 --> 00:22:25,400
And I've been working,
I think, since the 80s,

469
00:22:25,400 --> 00:22:28,010
by some period on those models.

470
00:22:28,010 --> 00:22:31,320
My contribution in this idea,

471
00:22:31,320 --> 00:22:32,650
I've been twofold.

472
00:22:32,650 --> 00:22:35,470

I've been one of the first
to implement the idea

473
00:22:35,470 --> 00:22:38,070
that, instead of taking
a continual spacetime,

474
00:22:38,070 --> 00:22:42,560
you can approximate it
by a discrete object.

475
00:22:42,560 --> 00:22:45,460
Typically, you can see that
you can build a surface

476
00:22:45,460 --> 00:22:49,760
out of taking triangles, flat
triangles, but gluing them,

477
00:22:49,760 --> 00:22:51,600
and if you glue them in a proper way,

478
00:22:51,600 --> 00:22:53,070
you can build polyhedra.

479
00:22:53,070 --> 00:22:55,240
So you can build curved surfaces

480
00:22:55,240 --> 00:23:00,240
or curved spacetime
out of discrete objects

481
00:23:00,560 --> 00:23:04,900
and realize the quantum
nest of a quantum spacetime

482
00:23:04,900 --> 00:23:07,070
by looking at the common matrix

483

00:23:07,070 --> 00:23:09,630
of this construction you can make

484
00:23:09,630 --> 00:23:11,870
by building what's called triangulation.

485
00:23:11,870 --> 00:23:13,930
If you glue a triangle,

486
00:23:13,930 --> 00:23:16,780
you build a triangulation of a surface

487
00:23:16,780 --> 00:23:20,280
or you build a discretized
surface or a discrete surface,

488
00:23:20,280 --> 00:23:23,200
and treating this object
at quantum means look

489
00:23:23,200 --> 00:23:25,120
at the status, see that's a surface.

490
00:23:25,120 --> 00:23:27,810
That's a typical, average size,

491
00:23:27,810 --> 00:23:31,270
average shape, average
curvature, or such an object,

492
00:23:31,270 --> 00:23:34,500
and it seems they're
naive and simple ideas,

493
00:23:34,500 --> 00:23:38,170
but it was motivated by the
fact that this procedures is

494
00:23:38,170 --> 00:23:42,700

now to work already in quantum
physics without gravitation.

495
00:23:42,700 --> 00:23:45,314
When this idea was
introduced, it was in the 80s.

496
00:23:45,314 --> 00:23:48,180
Theoretical physicists had introduced

497
00:23:48,180 --> 00:23:50,840
what they called lattice gauge theory,

498
00:23:50,840 --> 00:23:53,200
discretized theory of the strong
interaction, for instance,

499
00:23:53,200 --> 00:23:57,513
but on a discrete spacetime
by extension and energy,

500
00:23:58,440 --> 00:24:00,280
we put high in it.

501
00:24:00,280 --> 00:24:02,830
Other theoreticians and
some mathematician, too,

502
00:24:02,830 --> 00:24:05,210
started to look at can
you make this idea working

503
00:24:05,210 --> 00:24:09,510
for very simple, one-plus-one
theory of quantum spacetime?

504
00:24:09,510 --> 00:24:12,970
And it turns out that you
can work and make calculation

505
00:24:12,970 --> 00:24:16,320
in these toy models using
mathematical theory,

506
00:24:16,320 --> 00:24:18,420
which came out from something
completely different,

507
00:24:18,420 --> 00:24:21,560
which is called the
theory of random matrices,

508
00:24:21,560 --> 00:24:24,700
which comes from the
study of quantum systems,

509
00:24:24,700 --> 00:24:27,430
which are very complicated dynamics.

510
00:24:27,430 --> 00:24:31,490
So not toy models, but very,
very complicated models,

511
00:24:31,490 --> 00:24:34,050
and looking for whether they still exhibit

512
00:24:34,050 --> 00:24:37,360
some universal feature, which are there

513
00:24:37,360 --> 00:24:40,830
because the system are
very, very complicated

514
00:24:40,830 --> 00:24:43,310
instead of being very, very simple.

515
00:24:43,310 --> 00:24:45,150
- The idea of a toy model,

516
00:24:45,150 --> 00:24:48,500
is it akin to building a toy car

517
00:24:48,500 --> 00:24:51,960
with just a wooden rectangle
and four round wheels,

518
00:24:51,960 --> 00:24:54,890
making sure it rolls, and then eventually,

519
00:24:54,890 --> 00:24:56,810
gradually adding more and more features

520
00:24:56,810 --> 00:24:58,310
until you've got a sports car?

521
00:24:59,220 --> 00:25:01,093
- If we didn't have the
toy model to think about,

522
00:25:01,093 --> 00:25:03,090
it would have been very difficult

523
00:25:03,090 --> 00:25:05,180
to find in the very complicated system.

524
00:25:05,180 --> 00:25:08,140
So that's one aspect of the
toy model, but then I could say

525
00:25:08,140 --> 00:25:11,263
that there are other kind of toy models,

526
00:25:12,370 --> 00:25:15,620
which is exemplified by this
idea of random matrices.

527
00:25:15,620 --> 00:25:16,650

Want to explain, but think

528
00:25:16,650 --> 00:25:20,000
about the matrices are
just a table of numbers,

529
00:25:20,000 --> 00:25:23,914
like an Excel spreadsheet,
where you can add them.

530
00:25:23,914 --> 00:25:26,850
You know that you can add the
cells up in a spreadsheet,

531
00:25:26,850 --> 00:25:28,570
but you can also multiply them.

532
00:25:28,570 --> 00:25:31,820
More complicated, but the
mathematician and physicist know

533
00:25:31,820 --> 00:25:32,830
very well what it means.

534
00:25:32,830 --> 00:25:37,120
And so order comes out of complexity,

535
00:25:37,120 --> 00:25:39,950
or to mention a word

536
00:25:39,950 --> 00:25:43,650
of a famous physicist, E. W. Anderson,

537
00:25:43,650 --> 00:25:46,370
the sum is more than the parts.

538
00:25:46,370 --> 00:25:49,960
It appears, for deep mathematical reasons,

539
00:25:49,960 --> 00:25:53,080
then if you take a very
complicated object made

540
00:25:53,080 --> 00:25:57,340
out of simple objects, instead
of it becoming just a mess,

541
00:25:57,340 --> 00:26:00,990
it becomes something which
exhibit very simple feature.

542
00:26:00,990 --> 00:26:05,170
Some universal behavior
comes out of complexity,

543
00:26:05,170 --> 00:26:08,250
and the property of the
sum of the subject is

544
00:26:08,250 --> 00:26:11,880
not just emerging from the
properties of the small parts.

545
00:26:11,880 --> 00:26:14,380
It's come out from the rule.

546
00:26:14,380 --> 00:26:16,990
This is also an idea which is important,

547
00:26:16,990 --> 00:26:18,630
for instance, in quantum gravity.

548
00:26:18,630 --> 00:26:20,490
Many suspect that, in fact,

549
00:26:20,490 --> 00:26:24,160
the fact that we have a
smooth, neat spacetime

550
00:26:24,160 --> 00:26:27,420
with a bit of curvature, explain gravity.

551
00:26:27,420 --> 00:26:31,630
It may come out from
something at quantum scales

552
00:26:32,490 --> 00:26:35,140
and below at some post-quantum scales,

553
00:26:35,140 --> 00:26:38,023
which is completely
different and maybe random,

554
00:26:39,240 --> 00:26:41,460
both the idea of taking toy models

555
00:26:41,460 --> 00:26:45,040
to understand the real systems
and taking complicated system

556
00:26:45,040 --> 00:26:48,290
to understand what's going
on for large systems.

557
00:26:48,290 --> 00:26:49,880
There are two trends in common,

558
00:26:49,880 --> 00:26:52,360
not in completely not incompatible ideas,

559
00:26:52,360 --> 00:26:55,200
which are very important in
modern and theoretical physics,

560
00:26:55,200 --> 00:26:56,940
because then you can make toy models

561
00:26:56,940 --> 00:27:00,340
of very complex system and study them.

562
00:27:00,340 --> 00:27:02,030
That's the idea of those fundamentals,

563
00:27:02,030 --> 00:27:05,057
but they are simple, complex models.

564
00:27:05,057 --> 00:27:07,900
- And I wanna go back to a word
you said a little while ago,

565
00:27:07,900 --> 00:27:09,440
which is this word universal.

566
00:27:09,440 --> 00:27:10,830
You said sometimes in these systems,

567
00:27:10,830 --> 00:27:13,490
you can end up finding something
that's actually universal,

568
00:27:13,490 --> 00:27:16,110
so can you tell us what that means?

569
00:27:16,110 --> 00:27:19,690
- Universality means that,
out of very different systems,

570
00:27:19,690 --> 00:27:22,490
exhibits the same behavior,

571
00:27:22,490 --> 00:27:25,900
although, in some sense,
this behavior is universal.

572
00:27:25,900 --> 00:27:28,680

This concept, which is now one
of the very important concept

573
00:27:28,680 --> 00:27:30,010
in theoretical physics,

574
00:27:30,010 --> 00:27:33,190
come out, not from high-energy
physics, not from gravity.

575
00:27:33,190 --> 00:27:35,950
It comes out from condensed matter.

576
00:27:35,950 --> 00:27:40,510
It led to the discovery or
the creation of a theory

577
00:27:40,510 --> 00:27:43,510
which is called the theory
of homogenization group,

578
00:27:43,510 --> 00:27:45,170
but forget about the group.

579
00:27:45,170 --> 00:27:47,230
You have some different physical system,

580
00:27:47,230 --> 00:27:50,910
completely different,
which in fact, exhibit,

581
00:27:50,910 --> 00:27:54,400
in some regime, exactly the same behavior.

582
00:27:54,400 --> 00:27:57,920
If you study the behavior
of ice and water,

583
00:27:57,920 --> 00:28:02,600

water can be a liquid, can be
solid, and it can be a gas.

584
00:28:02,600 --> 00:28:05,780
Usually, it's one or the other,

585
00:28:05,780 --> 00:28:07,520
but there is a very special point

586
00:28:07,520 --> 00:28:11,940
when you have water at a
very specific temperature

587
00:28:11,940 --> 00:28:14,100
and a very specific pressure.

588
00:28:14,100 --> 00:28:16,630
You reach what is called a critical point,

589
00:28:16,630 --> 00:28:20,670
where water is neither a
liquid or a gas, it's both.

590
00:28:20,670 --> 00:28:23,570
At this point, there are huge fluctuations

591
00:28:23,570 --> 00:28:25,223
of pressure and density.

592
00:28:26,260 --> 00:28:29,640
These behaviors occurs for water,

593
00:28:29,640 --> 00:28:32,340
but it occurs also for other gases.

594
00:28:32,340 --> 00:28:34,070
In fact, it's better studied

595

00:28:34,070 --> 00:28:36,870
in other gases or other liquids.

596
00:28:36,870 --> 00:28:39,730
Usually, you have this function.

597
00:28:39,730 --> 00:28:41,710
You heat water, and at
some point, it boils.

598
00:28:41,710 --> 00:28:44,180
It's very simple, suddenly,
vapor starts to happen,

599
00:28:44,180 --> 00:28:45,880
so it's called the first-order transition,

600
00:28:45,880 --> 00:28:48,910
but if you increase the
pressure, there is a point

601
00:28:48,910 --> 00:28:50,930
where the transition
becomes smaller and smaller.

602
00:28:50,930 --> 00:28:53,090
At some point, it disappear.

603
00:28:53,090 --> 00:28:56,250
It turns out that you
have system of magnet.

604
00:28:56,250 --> 00:28:57,200
I don't know if, in high school,

605
00:28:57,200 --> 00:29:00,790
you might have done the
experiment that you take a magnet.

606

00:29:00,790 --> 00:29:03,930
So the magnet has some magnetic property.

607
00:29:03,930 --> 00:29:06,210
And if you heat a magnet,

608
00:29:06,210 --> 00:29:09,670
you put it under a Bunsen flame,

609
00:29:09,670 --> 00:29:13,350
at some point, the magnet
stops being a magnet.

610
00:29:13,350 --> 00:29:15,730
It's just a dull piece of metal.

611
00:29:15,730 --> 00:29:17,800
So there is a critical temperature

612
00:29:17,800 --> 00:29:21,310
where a magnet stops being
a magnet, and it turns out

613
00:29:21,310 --> 00:29:24,870
that the property of
this magnet are the same

614
00:29:24,870 --> 00:29:28,040
or very similar to the property of water.

615
00:29:28,040 --> 00:29:29,630
That's very strange.

616
00:29:29,630 --> 00:29:32,540
This has not been
understood for many years,

617
00:29:32,540 --> 00:29:34,090
and in the beginning of the 70s

618
00:29:35,207 --> 00:29:37,740
and the 60s and end of the 70s,

619
00:29:37,740 --> 00:29:41,360
physicists working in
condensed matter understood

620
00:29:41,360 --> 00:29:44,520
why this occurs, but they understood,

621
00:29:44,520 --> 00:29:48,690
thanks to one of the great
high-energy physicists

622
00:29:48,690 --> 00:29:52,050
of that time, Ken Wilson,
who started being interested

623
00:29:52,050 --> 00:29:54,410
in what's called critical phenomena.

624
00:29:54,410 --> 00:29:56,210
He built out of high ideas,

625
00:29:56,210 --> 00:29:58,310
which came from high-energy physics,

626
00:29:58,310 --> 00:30:01,360
the concept of
randomization transformation

627
00:30:01,360 --> 00:30:04,100
and what's called now randomization group.

628
00:30:04,100 --> 00:30:07,620
The idea is that, if
you start from a system,

629
00:30:07,620 --> 00:30:10,670
for instance, which is
described at microscopic scales

630
00:30:10,670 --> 00:30:12,840
by a collection of atoms,

631
00:30:12,840 --> 00:30:14,750
atoms can behave as small magnets,

632
00:30:14,750 --> 00:30:16,230
very little magnets, in fact.

633
00:30:16,230 --> 00:30:17,890
That's the origin of magnetism.

634
00:30:17,890 --> 00:30:20,590
You have atoms, you have
electrons turning around,

635
00:30:20,590 --> 00:30:23,320
and the electrons have a magnetic moment.

636
00:30:23,320 --> 00:30:25,890
In the addition, they
create magnetic moments

637
00:30:25,890 --> 00:30:29,060
because they go around the
nuclei of the atom, et cetera.

638
00:30:29,060 --> 00:30:31,510
Okay, anyway, so that's
the origin of magnetism,

639
00:30:31,510 --> 00:30:34,450
but if you start from the magnet described

640

00:30:34,450 --> 00:30:37,860
just by its microscopic
structure at the atomic scale

641
00:30:37,860 --> 00:30:39,550
and you start to look

642
00:30:39,550 --> 00:30:41,880
at what are the properties of this magnet,

643
00:30:41,880 --> 00:30:45,500
if you go at larger and larger scales,

644
00:30:45,500 --> 00:30:48,790
so changing the scales
or making some averaging,

645
00:30:48,790 --> 00:30:50,570
the magnetic property of a magnet,

646
00:30:50,570 --> 00:30:52,627
instead of looking at
whatever magnet you see

647
00:30:52,627 --> 00:30:56,290
at the property, at the scale of an atom,

648
00:30:56,290 --> 00:30:59,770
you see a cube, 10-by-10-by-10 atoms,

649
00:30:59,770 --> 00:31:01,970
and you see what are the
properties of this magnet.

650
00:31:01,970 --> 00:31:04,330
- Like zooming out on a picture?

651
00:31:04,330 --> 00:31:06,210
- No, it's exactly like zooming out,

652
00:31:06,210 --> 00:31:08,250
but zooming out being defined

653
00:31:08,250 --> 00:31:10,040
in a proper mathematical way.
- (laughs) Right.

654
00:31:10,040 --> 00:31:11,650
- And if you do that,

655
00:31:11,650 --> 00:31:14,360
it was discovered by Ken
Wilson and explained,

656
00:31:14,360 --> 00:31:16,920
and the other physicist
working in that field,

657
00:31:16,920 --> 00:31:20,940
that this posed view sometimes
converges in substance.

658
00:31:20,940 --> 00:31:23,080
You zoom out, you zoom out, you zoom out,

659
00:31:23,080 --> 00:31:26,800
and when you have zoomed,
you find something

660
00:31:26,800 --> 00:31:31,510
which is the same kind of object,
wherever you were looking,

661
00:31:31,510 --> 00:31:34,960
at a magnet or at a fluid,

662
00:31:34,960 --> 00:31:37,697
where you could say,

"Okay, this tiny region

663
00:31:37,697 --> 00:31:40,600
"of space can be either
a liquid or a gas."

664
00:31:40,600 --> 00:31:43,050
So if you want, you would take
the molecule of your water,

665
00:31:43,050 --> 00:31:45,390
and either they are very closely packed

666
00:31:45,390 --> 00:31:47,864
and they are connected by hydrogen bonds

667
00:31:47,864 --> 00:31:50,920
or there, they can wander
around so they form a liquid.

668
00:31:50,920 --> 00:31:52,240
So it's exactly the same thing.

669
00:31:52,240 --> 00:31:53,950
You take very different system,

670
00:31:53,950 --> 00:31:55,410
sometimes complicated objects,

671
00:31:55,410 --> 00:31:57,630
so the dynamics can be complicated,

672
00:31:57,630 --> 00:31:58,969
can be simple in your toy model.

673
00:31:58,969 --> 00:32:00,800
It can be complicated in your model.

674

00:32:00,800 --> 00:32:02,770
You zoom out, you zoom out, you zoom out,

675
00:32:02,770 --> 00:32:05,460
and if you go zoom out enough,

676
00:32:05,460 --> 00:32:08,940
sometimes you find the same object.

677
00:32:08,940 --> 00:32:10,770
So in this sense,

678
00:32:10,770 --> 00:32:13,860
simplicity or beauty is emerging

679
00:32:13,860 --> 00:32:18,020
by zooming out what's going
on in the complicated system.

680
00:32:18,020 --> 00:32:20,810
So this is the idea of universality,

681
00:32:20,810 --> 00:32:23,690
which is very important in physics.

682
00:32:23,690 --> 00:32:26,830
When you normalize, you average

683
00:32:26,830 --> 00:32:28,470
and see what has a property.

684
00:32:28,470 --> 00:32:31,740
This creates some kind of
norm, and renormalization means

685
00:32:31,740 --> 00:32:35,210
that you normal the scales
and you change the scale.

686
00:32:35,210 --> 00:32:38,270
You renormalize, and you
change against the scale.

687
00:32:38,270 --> 00:32:40,780
You will renormalize,
et cetera, et cetera.

688
00:32:40,780 --> 00:32:42,900
So you have this idea of toy models

689
00:32:42,900 --> 00:32:44,670
and this idea of normalization,

690
00:32:44,670 --> 00:32:46,560
so that the simple phenomenon come

691
00:32:46,560 --> 00:32:49,140
out of very complicated object,

692
00:32:49,140 --> 00:32:51,270
and irrespective of the detail

693
00:32:51,270 --> 00:32:54,050
of what's going on the small scales.

694
00:32:54,050 --> 00:32:56,500
- And it seems, Francois,
like some of these tools,

695
00:32:56,500 --> 00:32:59,740
like renormalization group
or random matrix theory,

696
00:32:59,740 --> 00:33:02,900
they've allowed you to study
quite different problems.

697

00:33:02,900 --> 00:33:04,770
You've talked just now about some problems

698
00:33:04,770 --> 00:33:06,030
in condensed matter.

699
00:33:06,030 --> 00:33:08,040
You were telling us about quantum gravity.

700
00:33:08,040 --> 00:33:10,610
Would you mind maybe telling us the story

701
00:33:10,610 --> 00:33:13,420
of your career and maybe
the different problems

702
00:33:13,420 --> 00:33:15,670
that you've looked at along the way?

703
00:33:15,670 --> 00:33:19,160
- Yes, in fact, I
realize that this concept

704
00:33:19,160 --> 00:33:22,290
of universality and
normalization group has been

705
00:33:22,290 --> 00:33:25,480
one of the guiding line of my research.

706
00:33:25,480 --> 00:33:28,440
Those tools were created
when I was in high school,

707
00:33:28,440 --> 00:33:30,090
so I learned them when I started.

708
00:33:30,090 --> 00:33:31,560
I was a graduate student,

709
00:33:31,560 --> 00:33:35,473
and I've been trying to
improve them and apply them.

710
00:33:36,400 --> 00:33:39,550
So I started in high-energy
physics and theory,

711
00:33:39,550 --> 00:33:41,400
and then I started being interested

712
00:33:41,400 --> 00:33:44,970
in whether I could apply those
idea to condensed matter.

713
00:33:44,970 --> 00:33:47,200
And then when I was a post-doc

714
00:33:48,390 --> 00:33:51,030
in Princeton, I came in contact

715
00:33:51,030 --> 00:33:53,210
with a researcher working
in quantum gravity,

716
00:33:53,210 --> 00:33:55,310
this idea of discretizing spacetime,

717
00:33:55,310 --> 00:33:58,270
and so I applied it to quantum gravity.

718
00:33:58,270 --> 00:34:01,630
So I started to study this idea
to work in quantum gravity,

719
00:34:01,630 --> 00:34:04,210
so I studied mission model,
a bit of higher dimension,

720
00:34:04,210 --> 00:34:07,340
but this doesn't work so well,
and then I came in contact

721
00:34:07,340 --> 00:34:09,630
with another field of theoretical physics,

722
00:34:09,630 --> 00:34:13,550
which is biophysics, in fact,
and one very specific subject,

723
00:34:13,550 --> 00:34:16,810
which is the study of membranes

724
00:34:16,810 --> 00:34:19,630
who have two-dimensional
themes in three dimensions,

725
00:34:19,630 --> 00:34:23,020
because when I was in touch
with young physicists,

726
00:34:23,020 --> 00:34:25,570
visiting (indistinct),
and one got a position

727
00:34:25,570 --> 00:34:27,350
and they were working in that field.

728
00:34:27,350 --> 00:34:30,350
And this idea of universality
is very important

729
00:34:30,350 --> 00:34:32,290
because, by discussing, we
discovered that, in fact,

730
00:34:32,290 --> 00:34:35,450

some models of quantum
gravity in two dimension

731
00:34:35,450 --> 00:34:38,120
and some models of
membranes were very similar.

732
00:34:38,120 --> 00:34:40,950
They had some difference,
in particular as a whole

733
00:34:40,950 --> 00:34:44,410
of bending in two-dimensional gravity.

734
00:34:44,410 --> 00:34:45,990
Bending is not important.

735
00:34:45,990 --> 00:34:49,010
Well, it's very important
in a physical membrane.

736
00:34:49,010 --> 00:34:52,260
So I've been working in this concept,

737
00:34:52,260 --> 00:34:56,610
studying the physics of
what's called fluid membranes

738
00:34:56,610 --> 00:34:58,293
and then crystalline membranes.

739
00:34:59,200 --> 00:35:02,660
This was a very exciting field
and it's still important,

740
00:35:02,660 --> 00:35:06,060
but then a few years later,
there was some great progress

741

00:35:06,060 --> 00:35:09,100
in the theory of quantum
gravity and in string theory,

742
00:35:09,100 --> 00:35:12,220
made by a group of theoreticians,
especially Russian ones,

743
00:35:12,220 --> 00:35:15,450
this Russian school with Migdal, Polyakov,

744
00:35:15,450 --> 00:35:19,040
and we made progress in the
two-dimensional quantum gravity,

745
00:35:19,040 --> 00:35:20,630
so I came back to that field.

746
00:35:20,630 --> 00:35:22,780
And I was there, more interested

747
00:35:22,780 --> 00:35:26,880
in not discretizing spacetime,
but taking continuum theory

748
00:35:26,880 --> 00:35:29,490
of two-dimensional gravity,
a theory which was,

749
00:35:29,490 --> 00:35:31,540
well, created and invented

750
00:35:31,540 --> 00:35:34,255
by Polyakov, which is
called Liouville theory.

751
00:35:34,255 --> 00:35:37,870
Liouville is a famous French mathematician

752

00:35:37,870 --> 00:35:40,240
from the 20th century.

753
00:35:40,240 --> 00:35:43,050
He was mostly a number theorist,

754
00:35:43,050 --> 00:35:46,640
but some of his equation were
important in quantum gravity.

755
00:35:46,640 --> 00:35:49,200
So our model was neutral gravity,

756
00:35:49,200 --> 00:35:50,670
which is connected to string theory.

757
00:35:50,670 --> 00:35:52,450
It was developed by this Russian school,

758
00:35:52,450 --> 00:35:54,583
and that tends to be known
as the Liouville theory,

759
00:35:54,583 --> 00:35:58,676
but there are other theories
up to Newton's quantum gravity,

760
00:35:58,676 --> 00:36:00,310
like Kiev's Titan Boom
model and some other one,

761
00:36:00,310 --> 00:36:01,900
but one is the Liouville theory,

762
00:36:01,900 --> 00:36:03,890
and so I've been working on that.

763
00:36:03,890 --> 00:36:05,430
After that, I came back

764
00:36:05,430 --> 00:36:08,240
to quantum metric theory

765
00:36:08,240 --> 00:36:12,370
for several years and
was interested in that,

766
00:36:12,370 --> 00:36:15,540
in particular for quantum cows,

767
00:36:15,540 --> 00:36:19,380
because quantum metric
theory has application

768
00:36:19,380 --> 00:36:23,760
to quantum cows, and then I
came back to quantum gravity.

769
00:36:23,760 --> 00:36:25,010
- The first time we spoke,

770
00:36:25,010 --> 00:36:28,580
you used the term journey
to describe your career,

771
00:36:28,580 --> 00:36:30,610
and you said that
theoretical physics requires

772
00:36:30,610 --> 00:36:32,750
all sorts of different minds,

773
00:36:32,750 --> 00:36:34,260
so what kind of mind do you bring

774
00:36:34,260 --> 00:36:36,810
to the journey of theoretical physics?

775
00:36:36,810 --> 00:36:38,720
- I would say there are
different kind of minds

776
00:36:38,720 --> 00:36:40,030
in theoretical physics.

777
00:36:40,030 --> 00:36:42,420
I'm not completely sure which mind I am.

778
00:36:42,420 --> 00:36:46,040
Some likes to wander around.

779
00:36:46,040 --> 00:36:49,230
I'm still a bit stubborn, so
I come back to old problems.

780
00:36:49,230 --> 00:36:51,870
When I'm stuck, sometimes
I look elsewhere,

781
00:36:51,870 --> 00:36:53,370
but I always come back.

782
00:36:53,370 --> 00:36:54,590
I have some problem in my mind

783
00:36:54,590 --> 00:36:56,410
that I have them since 20 years.

784
00:36:56,410 --> 00:36:59,240
I'm just waiting for
the good idea, if any,

785
00:36:59,240 --> 00:37:01,530
or if someone had a good idea to solve it,

786
00:37:01,530 --> 00:37:03,370

they are still there.

787
00:37:03,370 --> 00:37:05,720
- Some of these problems
that you've described

788
00:37:05,720 --> 00:37:07,570
to us are incredibly challenging.

789
00:37:07,570 --> 00:37:08,780
Some of them are so difficult

790
00:37:08,780 --> 00:37:10,590
that they may not see a solution

791
00:37:10,590 --> 00:37:13,620
in our lifetimes, possibly ever.

792
00:37:13,620 --> 00:37:16,530
Francois, given the hugeness
of these challenges,

793
00:37:16,530 --> 00:37:18,010
what keeps you going?

794
00:37:18,010 --> 00:37:20,270
- Well, I think that's curiosity.

795
00:37:20,270 --> 00:37:22,750
As long as I've not understood something,

796
00:37:22,750 --> 00:37:24,060
I like to think about it.

797
00:37:24,060 --> 00:37:25,870
I feel disappointed.

798
00:37:25,870 --> 00:37:30,180

I feel the failure of not
having made progress in a field.

799
00:37:30,180 --> 00:37:33,170
If someone else made the
progress, that's fine.

800
00:37:33,170 --> 00:37:34,997
I said, "Okay, I was not smart enough.

801
00:37:34,997 --> 00:37:36,247
"I didn't have the idea."

802
00:37:37,367 --> 00:37:39,170
There is change in research.

803
00:37:39,170 --> 00:37:42,830
Sometimes you just have a
good idea at a good time

804
00:37:42,830 --> 00:37:46,800
and sometimes you had it too early,

805
00:37:46,800 --> 00:37:49,133
and you couldn't make out something of it.

806
00:37:50,500 --> 00:37:52,480
- So Francois, we also
got a question for you

807
00:37:52,480 --> 00:37:54,500
that was sent in from one of the students

808
00:37:54,500 --> 00:37:56,010
that you're currently teaching

809
00:37:56,010 --> 00:37:57,840
within your quantum field theory course

810
00:37:57,840 --> 00:38:00,820
within the Perimeter Scholars
International program.

811
00:38:00,820 --> 00:38:03,053
Let's play the question from Anna Kanur.

812
00:38:04,240 --> 00:38:07,170
- You teach a course on
quantum field theory,

813
00:38:07,170 --> 00:38:10,713
and one of the topics is ghosts.

814
00:38:11,570 --> 00:38:13,110
Without writing down any integrals,

815
00:38:13,110 --> 00:38:16,340
how would you explain
what these ghosts are?

816
00:38:16,340 --> 00:38:18,570
- Well, the denomination
ghost has been given

817
00:38:18,570 --> 00:38:22,590
by the physicists who
created this concept.

818
00:38:22,590 --> 00:38:24,640
It was a Russian, Faddeev and Popov,

819
00:38:24,640 --> 00:38:26,580
but I'm not completely sure anyway.

820
00:38:26,580 --> 00:38:30,870
Physics likes to find nice names
when they have new objects.

821
00:38:30,870 --> 00:38:33,030
Sometimes the names are well-suited.

822
00:38:33,030 --> 00:38:35,260
Sometimes they are silly, but okay.

823
00:38:35,260 --> 00:38:39,050
So ghosts, in fact, are
articles in a quantum theory

824
00:38:39,050 --> 00:38:42,603
with probability to be there is negative.

825
00:38:42,603 --> 00:38:45,037
If you think about probability,

826
00:38:45,037 --> 00:38:47,420
it's a very important tool of mathematics.

827
00:38:47,420 --> 00:38:49,330
And the probability of an event,

828
00:38:49,330 --> 00:38:51,970
if you have some uncertainty
on something happening,

829
00:38:51,970 --> 00:38:54,090
for example, if you play coins

830
00:38:54,090 --> 00:38:55,520
and it has a probability 1/2

831
00:38:55,520 --> 00:38:57,320
to be heads and 1/2 to be tails.

832
00:38:57,320 --> 00:38:59,940
Okay, if the probability
of some events is one,

833
00:38:59,940 --> 00:39:02,540
it means that it's certain, you are sure.

834
00:39:02,540 --> 00:39:05,020
If it's zero, it means
that it never happens.

835
00:39:05,020 --> 00:39:06,640
So the probability are numbers which are

836
00:39:06,640 --> 00:39:10,760
in between zero and one, or 0% and 100%.

837
00:39:10,760 --> 00:39:13,053
You cannot have a probability of two.

838
00:39:14,530 --> 00:39:16,800
The sum of the probability
of all realization

839
00:39:16,800 --> 00:39:20,100
of an event has to be one,
'cause something happens.

840
00:39:20,100 --> 00:39:22,470
Whatever it is, you're
sure it's going to happen.

841
00:39:22,470 --> 00:39:25,860
If you have a head and
tails, 1/2 plus 1/2 is one.

842
00:39:25,860 --> 00:39:28,840
In quantum theory, whether
it's change and uncertainty,

843
00:39:28,840 --> 00:39:31,890
you can calculate probabilities

of something to be measured,

844
00:39:31,890 --> 00:39:35,490
and so some of the probabilities
of all possible outcomes

845
00:39:35,490 --> 00:39:39,620
of the experiments or
measurements has to be one.

846
00:39:39,620 --> 00:39:41,550
In the inconsistent quantum theory,

847
00:39:41,550 --> 00:39:44,750
the sum of probability is
one, it's called unitality,

848
00:39:44,750 --> 00:39:47,240
but it turns out that,
in some quantum theory,

849
00:39:47,240 --> 00:39:51,010
you get probability two
and probability minus one,

850
00:39:51,010 --> 00:39:53,170
but it's not a physical theory

851
00:39:53,170 --> 00:39:56,130
because you have a
probability, for instance,

852
00:39:56,130 --> 00:39:59,760
to get a particle created,
which is minus one.

853
00:39:59,760 --> 00:40:02,923
When you have a theory
which such particles,

854
00:40:02,923 --> 00:40:04,560
they are called ghosts.

855
00:40:04,560 --> 00:40:07,370
Sometimes when you make a theory

856
00:40:07,370 --> 00:40:09,510
and you get probability which are negative

857
00:40:09,510 --> 00:40:13,240
or greater than one, that's an
example of an inconsistency.

858
00:40:13,240 --> 00:40:15,270
- I was gonna say, it
sounds like something

859
00:40:15,270 --> 00:40:17,470
that must bother mathematicians.

860
00:40:17,470 --> 00:40:19,917
- It bothers mathematicians
and it bothers physicists, too,

861
00:40:19,917 --> 00:40:21,710
(Lauren laughs)
of course,

862
00:40:21,710 --> 00:40:23,120
because there are many theory

863
00:40:23,120 --> 00:40:25,000
of quantum gravity which have ghosts.

864
00:40:25,000 --> 00:40:28,620
The first theories of strong
interaction are the ghosts.

865

00:40:28,620 --> 00:40:32,583
Most of the ghost's
particles, when you see them,

866
00:40:34,070 --> 00:40:36,760
it means there's a theory,
you can put it aside

867
00:40:36,760 --> 00:40:38,200
and start with a better theory.

868
00:40:38,200 --> 00:40:40,530
In the lecture that I gave, it's a theory

869
00:40:40,530 --> 00:40:44,290
where you try to quantize the
theory of strong interactions.

870
00:40:44,290 --> 00:40:49,230
In this theory, well, you run
into technical difficulties,

871
00:40:49,230 --> 00:40:52,930
and one way to deal with this difficulty

872
00:40:52,930 --> 00:40:57,040
and to solve the problem is to
introduce a fiducial particle

873
00:40:57,040 --> 00:40:59,860
in the theory, which
precisely has this property

874
00:40:59,860 --> 00:41:02,880
of having negative
probability to be observed

875
00:41:02,880 --> 00:41:06,370
or larger than one
probability to be observed.

876
00:41:06,370 --> 00:41:08,430
The fact that you have
to consider those parts

877
00:41:08,430 --> 00:41:10,190
of those kind of ghostly particle

878
00:41:10,190 --> 00:41:14,230
when you make calculation
comes out from the math.

879
00:41:14,230 --> 00:41:16,490
So they have to be there,

880
00:41:16,490 --> 00:41:19,260
but when you work out more on the theory,

881
00:41:19,260 --> 00:41:21,930
you see that you can never observe them.

882
00:41:21,930 --> 00:41:24,540
They are virtual particles that are there

883
00:41:24,540 --> 00:41:26,370
in the quantum vacuum of the theory,

884
00:41:26,370 --> 00:41:29,863
or when you make calculation,
you have two particles.

885
00:41:29,863 --> 00:41:32,130
You sew them on together in accelerator,

886
00:41:32,130 --> 00:41:33,670
you have a quantum theory

887
00:41:33,670 --> 00:41:36,450

that this type of what's
going on when they interact,

888
00:41:36,450 --> 00:41:39,410
and you have a lot of
virtual quantum process.

889
00:41:39,410 --> 00:41:40,650
And then there is an outcome,

890
00:41:40,650 --> 00:41:43,410
some other particles,
two, three, four, many,

891
00:41:43,410 --> 00:41:45,680
because you can create
particles, come out.

892
00:41:45,680 --> 00:41:47,670
When you do the calculation, you see

893
00:41:47,670 --> 00:41:51,880
that you never see any of
those ghostly particles.

894
00:41:51,880 --> 00:41:55,730
So those ghostly particles
are there in your calculation.

895
00:41:55,730 --> 00:41:58,080
So in some sense, if
you are mathematician,

896
00:41:58,080 --> 00:42:00,030
you see if it's in the calculation,

897
00:42:00,030 --> 00:42:04,144
it's something that exists,
but you can never observe it.

898
00:42:04,144 --> 00:42:06,564
So in some sense, it's a
feature of the calculation.

899
00:42:06,564 --> 00:42:10,930
In some sense, they are like
imaginary numbers in algebra.

900
00:42:10,930 --> 00:42:12,410
I never thought about this analogy,

901
00:42:12,410 --> 00:42:14,290
but I think it's a good analogy.

902
00:42:14,290 --> 00:42:18,780
Imaginary numbers are numbers
a bit like real numbers,

903
00:42:18,780 --> 00:42:21,790
but the most important
imaginary number is called i

904
00:42:21,790 --> 00:42:24,230
for imaginary, and i is a number

905
00:42:24,230 --> 00:42:26,393
so that its square is minus one.

906
00:42:27,580 --> 00:42:30,270
So in some sense, you can
say it's not a real number,

907
00:42:30,270 --> 00:42:32,940
but now when you are in high school,

908
00:42:32,940 --> 00:42:34,730
you learn about imaginary numbers

909

00:42:34,730 --> 00:42:36,130
because they are everywhere

910
00:42:36,130 --> 00:42:38,270
when you do calculation
in math and in physics.

911
00:42:38,270 --> 00:42:41,400
And in fact, imaginary
numbers were invented by,

912
00:42:41,400 --> 00:42:44,980
I think, Italian mathematician
in the 15th century

913
00:42:44,980 --> 00:42:49,010
to solve a quadratic
equation, algebraic equation

914
00:42:49,010 --> 00:42:51,480
that mathematician were
solving since the Greek

915
00:42:51,480 --> 00:42:53,750
and the Egyptians and
maybe the Babylonians.

916
00:42:53,750 --> 00:42:56,240
Okay, and in order to find the solution

917
00:42:56,240 --> 00:42:59,070
of equation involving real numbers,

918
00:42:59,070 --> 00:43:02,000
they discovered that it was not
quadratic equation, in fact,

919
00:43:02,000 --> 00:43:03,430
but it was question of degree theory.

920
00:43:03,430 --> 00:43:05,760
Anyway, so algebraic equation,

921
00:43:05,760 --> 00:43:08,860
they discover that it was very convenient

922
00:43:08,860 --> 00:43:13,310
to introduce this number
where the square is minus one

923
00:43:13,310 --> 00:43:15,520
and consider it as a real number.

924
00:43:15,520 --> 00:43:18,140
Just make calculation
and consider it at par

925
00:43:18,140 --> 00:43:20,910
with a number we're used to at that time.

926
00:43:20,910 --> 00:43:24,500
And so now you discuss
with a mathematician

927
00:43:24,500 --> 00:43:28,980
or with a physicist, or
even with the engineering.

928
00:43:28,980 --> 00:43:31,310
Those are useful when you
study electric currents.

929
00:43:31,310 --> 00:43:33,497
Well, they said, "Okay,
well, i is a number,

930
00:43:33,497 --> 00:43:37,610
"as one or minus one."

931
00:43:37,610 --> 00:43:40,130
They treat it as just an ordinary number,

932
00:43:40,130 --> 00:43:43,050
although if you measure something,

933
00:43:43,050 --> 00:43:45,110
if you measure lengths,

934
00:43:45,110 --> 00:43:46,920
you measure an electric current,

935
00:43:46,920 --> 00:43:49,720
you are never going to find object

936
00:43:49,720 --> 00:43:54,020
where the length is minus
i one meter or one inch.

937
00:43:54,020 --> 00:43:57,120
So ghost particles are similar,

938
00:43:57,120 --> 00:43:59,400
particles that you never observe,

939
00:43:59,400 --> 00:44:01,980
so in some sense, they do not exist,

940
00:44:01,980 --> 00:44:04,610
but if you introduce them and treat them

941
00:44:04,610 --> 00:44:07,993
in your calculations,
they'll obey the same rule.

942
00:44:07,993 --> 00:44:12,993
For instance, i is maybe
considered as a ghostly number,

943
00:44:14,070 --> 00:44:16,400
The first ghostly number ever-
- (laughs) Okay.

944
00:44:16,400 --> 00:44:17,670
- To be considered.

945
00:44:17,670 --> 00:44:21,196
One shouldn't be too
much afraid about ghosts.

946
00:44:21,196 --> 00:44:23,870
- (laughs) Good, and Francois,

947
00:44:23,870 --> 00:44:26,050
you've been teaching here at Perimeter

948
00:44:26,050 --> 00:44:28,120
for more than 10 years, teaching students

949
00:44:28,120 --> 00:44:30,360
about ghosts and quantum field theory,

950
00:44:30,360 --> 00:44:31,530
and actually, I wanted to share

951
00:44:31,530 --> 00:44:34,770
that you taught me many years
ago when I was a student

952
00:44:34,770 --> 00:44:36,057
in this program.
- Yes, I still remember you.

953
00:44:36,057 --> 00:44:37,617
(Francois laughs)
- (laughs) You remember.

954
00:44:37,617 --> 00:44:39,380
- Which means that you ask question.

955
00:44:39,380 --> 00:44:41,959
- I ask, oh, good, well, I'm
still asking questions now.

956
00:44:41,959 --> 00:44:44,660
(laughs) I wanted to tell
you I still remember,

957
00:44:44,660 --> 00:44:46,790
there was one day after
one of your lectures

958
00:44:46,790 --> 00:44:49,820
where a group of my
classmates and I were talking,

959
00:44:49,820 --> 00:44:52,347
and one student came over and he said,

960
00:44:52,347 --> 00:44:55,820
"That lecture by Francois
today was just perfect."

961
00:44:55,820 --> 00:44:57,897
He said, "There's no way
that anyone could have been

962
00:44:57,897 --> 00:44:59,747
"in the room and not understand

963
00:44:59,747 --> 00:45:01,490
"everything that he wrote down,"

964
00:45:01,490 --> 00:45:02,920
and I never heard him say that again

965
00:45:02,920 --> 00:45:06,730
about any other lectures,
(laughs) so yours was

966
00:45:06,730 --> 00:45:08,933
definitely one of the best.
- Okay, great, thank you.

967
00:45:08,933 --> 00:45:11,650
- And we have one more
question about your teaching,

968
00:45:11,650 --> 00:45:13,400
in fact, from another student

969
00:45:13,400 --> 00:45:16,410
from a few years ago that you taught.

970
00:45:16,410 --> 00:45:21,300
- Hey Francois, this is
Farthi from PSI, 2019 Class.

971
00:45:21,300 --> 00:45:23,300
I was wondering, actually,

972
00:45:23,300 --> 00:45:26,280
when did you realize
that you loved teaching?

973
00:45:26,280 --> 00:45:28,880
Would you mind telling
more about your journey

974
00:45:28,880 --> 00:45:31,083
into becoming a teacher?

975
00:45:32,400 --> 00:45:35,950
- Good question, in fact,
I realized I love teaching

976
00:45:35,950 --> 00:45:37,370
when I started teaching.

977
00:45:37,370 --> 00:45:40,630
I don't know if it's a
chance or an unfortunate fact

978
00:45:40,630 --> 00:45:44,130
to get researcher
position in France at CNRS

979
00:45:44,130 --> 00:45:46,560
when I was a young scientist.

980
00:45:46,560 --> 00:45:49,930
From start, I didn't
have any teaching duty.

981
00:45:49,930 --> 00:45:52,510
It's good to teach, but I had all my time

982
00:45:52,510 --> 00:45:55,070
for doing my research, and I know

983
00:45:55,070 --> 00:45:58,080
that most young scientists nowadays

984
00:45:58,080 --> 00:46:00,650
in France and everywhere,
they have to teach.

985
00:46:00,650 --> 00:46:04,260
As long as they have to teach
a reasonable amount of time,

986
00:46:04,260 --> 00:46:06,530
that's okay, but often, it's too much.

987
00:46:06,530 --> 00:46:09,600
So I had this great chance
and I think this helped me.

988
00:46:09,600 --> 00:46:13,190
So I was not especially
looking for doing teaching,

989
00:46:13,190 --> 00:46:16,310
but I was offered first in France,

990
00:46:16,310 --> 00:46:20,630
whether I was already
older, to give some lecture

991
00:46:20,630 --> 00:46:24,270
at a level of master or graduate school.

992
00:46:24,270 --> 00:46:26,890
I realized that I liked it.

993
00:46:26,890 --> 00:46:28,270
So I had the chance, in fact,

994
00:46:28,270 --> 00:46:32,540
to teach first in France in
Ecole Normale with a group,

995
00:46:32,540 --> 00:46:35,010
it was for about more than 15 years,

996
00:46:35,010 --> 00:46:37,610
some course in application
of quantum theory

997
00:46:37,610 --> 00:46:39,470
to structural mechanics.

998

00:46:39,470 --> 00:46:40,930
This has been a very good experience

999
00:46:40,930 --> 00:46:42,240
because the students were

1000
00:46:42,240 --> 00:46:45,020
some of the best student in France.

1001
00:46:45,020 --> 00:46:47,077
Then I was offered this change.

1002
00:46:47,077 --> 00:46:50,590
One of the greatest
experience in my career

1003
00:46:50,590 --> 00:46:55,493
to teach at PSI, which was really great.

1004
00:46:59,107 --> 00:47:01,710
Well, first I discovered

1005
00:47:01,710 --> 00:47:06,030
a new research institute,
Perimeter Institute,

1006
00:47:06,030 --> 00:47:08,760
which was still in the phase one building.

1007
00:47:08,760 --> 00:47:13,750
I discovered entire different
worlds of students coming

1008
00:47:13,750 --> 00:47:16,350
from many, many different countries

1009
00:47:16,350 --> 00:47:18,360
with different backgrounds.

1010
00:47:18,360 --> 00:47:20,230
This was different from
teaching in France,

1011
00:47:20,230 --> 00:47:22,460
where I had very, very good students,

1012
00:47:22,460 --> 00:47:27,020
but somehow, more from the
same mouth, very good mouth,

1013
00:47:27,020 --> 00:47:30,620
but the mouth of French physics
educational system in Paris.

1014
00:47:30,620 --> 00:47:33,360
So this was complimentary.

1015
00:47:33,360 --> 00:47:34,740
It was an international problem,

1016
00:47:34,740 --> 00:47:38,630
where, in France, we
mostly had French students.

1017
00:47:38,630 --> 00:47:40,830
Well, now this has
changed in the last year.

1018
00:47:41,885 --> 00:47:44,060
It's really European, but here,

1019
00:47:44,060 --> 00:47:46,110
it was the first time I had student

1020
00:47:46,110 --> 00:47:50,510
from Africa, South Africa, Far East,

1021

00:47:50,510 --> 00:47:51,770
and this mixture and seeing

1022
00:47:51,770 --> 00:47:54,230
how the students were
interacting together,

1023
00:47:54,230 --> 00:47:57,840
how the Perimeter was accommodating them,

1024
00:47:57,840 --> 00:48:00,850
taking care of them, also having

1025
00:48:00,850 --> 00:48:03,610
a decent proportion

1026
00:48:04,879 --> 00:48:06,680
of women compared to men.

1027
00:48:06,680 --> 00:48:08,540
Great things about this program.

1028
00:48:08,540 --> 00:48:10,963
This was a discovery for me.

1029
00:48:12,170 --> 00:48:14,080
- Francois, I'd actually
like to read something

1030
00:48:14,080 --> 00:48:16,751
that you wrote a couple of years ago.

1031
00:48:16,751 --> 00:48:19,260
It's from a book that Perimeter
Institute put together

1032
00:48:19,260 --> 00:48:21,130
to celebrate the 10th anniversary

1033
00:48:21,130 --> 00:48:24,160
of the Perimeter Scholars
International program,

1034
00:48:24,160 --> 00:48:27,040
the PSI program, which
you've been involved with

1035
00:48:27,040 --> 00:48:29,150
since practically the beginning.

1036
00:48:29,150 --> 00:48:31,837
You wrote, "Every year was memorable,

1037
00:48:31,837 --> 00:48:34,437
"with a special remembrance
for the adventures

1038
00:48:34,437 --> 00:48:38,400
"and heroic first years
in the old post office."

1039
00:48:38,400 --> 00:48:39,770
The old post office, by the way,

1040
00:48:39,770 --> 00:48:41,210
was Perimeter's first building,

1041
00:48:41,210 --> 00:48:43,920
just a few blocks from where we are now.

1042
00:48:43,920 --> 00:48:45,987
You wrote, "The old post office building,

1043
00:48:45,987 --> 00:48:48,707
"with its sofas and the billiard table

1044
00:48:48,707 --> 00:48:50,407

"and the big coffee machine,

1045
00:48:50,407 --> 00:48:53,607
"an evening spent preparing
the next day's tutorials.

1046
00:48:53,607 --> 00:48:55,367
"Long life to the PSI program

1047
00:48:55,367 --> 00:48:58,630
"and to all the students
who have benefited from it."

1048
00:48:58,630 --> 00:49:00,630
Now I just thought that
was a beautiful sentiment

1049
00:49:00,630 --> 00:49:03,260
in the book, and now there
are a lot of students

1050
00:49:03,260 --> 00:49:06,650
after 10 years who have
benefited from that PSI program.

1051
00:49:06,650 --> 00:49:09,490
What keeps you coming back
year after year to teach,

1052
00:49:09,490 --> 00:49:12,100
and what do you get out of it nowadays?

1053
00:49:12,100 --> 00:49:15,650
- Well, I come because
I'm very happy to come.

1054
00:49:15,650 --> 00:49:17,263
I think it's a chance for me.

1055

00:49:18,250 --> 00:49:21,650
I hope the students still enjoy it,

1056
00:49:21,650 --> 00:49:25,130
but I consider it as both a privilege

1057
00:49:25,130 --> 00:49:27,340
and this bring me happiness teaching

1058
00:49:27,340 --> 00:49:30,570
in front, enjoying the students.

1059
00:49:30,570 --> 00:49:33,060
Very interesting group,
all the interacting

1060
00:49:33,060 --> 00:49:35,390
with the other lecturer and teacher.

1061
00:49:35,390 --> 00:49:38,820
Well, last year and this
year had been much disrupted

1062
00:49:38,820 --> 00:49:43,320
by pandemics, and also, seeing this,

1063
00:49:43,320 --> 00:49:45,970
that's an opportunity for
me to visit the Perimeter

1064
00:49:45,970 --> 00:49:49,100
as a scientific research institute,

1065
00:49:49,100 --> 00:49:51,910
which is a great, new, vibrant place

1066
00:49:51,910 --> 00:49:54,020
for doing theoretical physics.

1067
00:49:54,020 --> 00:49:56,840
- Great, well, we're really
glad to have you here

1068
00:49:56,840 --> 00:50:00,720
and part of the teaching here
and the research community.

1069
00:50:00,720 --> 00:50:03,140
Thank you so much for sharing your time

1070
00:50:03,140 --> 00:50:04,751
with us today.
- Thanks.

1071
00:50:04,751 --> 00:50:07,334
(bright music)

1072
00:50:08,450 --> 00:50:10,200
- Thanks so much for listening.

1073
00:50:10,200 --> 00:50:12,310
Perimeter Institute is a not-for-profit,

1074
00:50:12,310 --> 00:50:15,410
charitable organization that
shares cutting-edge ideas

1075
00:50:15,410 --> 00:50:17,890
with the world, thanks
to the ongoing support

1076
00:50:17,890 --> 00:50:20,030
of the governments of Ontario and Canada

1077
00:50:20,030 --> 00:50:22,140
and thanks to donors like you.

1078

00:50:22,140 --> 00:50:24,040
Thanks for being part of the equation.