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

2
00:00:08,930 --> 00:00:11,500
- Welcome, everyone, to
"Conversations at the Perimeter."

3
00:00:11,500 --> 00:00:15,170
Lauren and I are thrilled
that our guest is Katie Mack,

4
00:00:15,170 --> 00:00:16,880
who is known as AstroKatie

5
00:00:16,880 --> 00:00:19,540
to her hundreds of thousands
of followers on Twitter.

6
00:00:19,540 --> 00:00:22,200
- Katie is a professor of
physics and, of course,

7
00:00:22,200 --> 00:00:24,000
a well-known science communicator,

8
00:00:24,000 --> 00:00:25,740
and in June, she's going to join us

9
00:00:25,740 --> 00:00:28,540
here at the Perimeter Institute
for Theoretical Physics

10
00:00:28,540 --> 00:00:32,480
as the Hawking Chair in Cosmology
and Science Communication.

11
00:00:32,480 --> 00:00:33,540
- As you'll hear, it's pretty amazing

12
00:00:33,540 --> 00:00:35,230
that she holds the Hawking Chair

13
00:00:35,230 --> 00:00:37,800
because her whole exploration
into science started

14
00:00:37,800 --> 00:00:39,120
in childhood when she picked up

15
00:00:39,120 --> 00:00:41,300
Stephen Hawking's "Brief History of Time."

16
00:00:41,300 --> 00:00:43,633
- Yeah, and she had some
pretty interesting interactions

17
00:00:43,633 --> 00:00:46,180
with him throughout her
career as she tells us.

18
00:00:46,180 --> 00:00:47,637
- And she also tells us about her book,

19
00:00:47,637 --> 00:00:50,360
"The End of Everything:
Astrophysically Speaking,"

20
00:00:50,360 --> 00:00:52,290
which, I have to say, this conversation is

21
00:00:52,290 --> 00:00:54,280
the most enjoyable talk I've ever had

22
00:00:54,280 --> 00:00:55,940
about the end of the universe.

23
00:00:55,940 --> 00:00:56,773

- I agree.

24
00:00:56,773 --> 00:00:58,633
Let's step inside the Perimeter.

25
00:01:02,410 --> 00:01:04,080
- Katie Mack, thank you for joining us.

26
00:01:04,080 --> 00:01:05,770
- Thank you for having me.

27
00:01:05,770 --> 00:01:07,030
- It's great to have you here.

28
00:01:07,030 --> 00:01:09,480
Tell us why you're here now

29
00:01:09,480 --> 00:01:11,470
and why you're going
to be here again soon.

30
00:01:11,470 --> 00:01:14,330
- Right now, I'm officially
a visiting fellow,

31
00:01:14,330 --> 00:01:17,480
but I'm coming to join
the Perimeter Institute

32
00:01:17,480 --> 00:01:19,046
on a full-time basis starting in June.

33
00:01:19,046 --> 00:01:20,050
- Yay!

34
00:01:20,050 --> 00:01:21,128
We're very happy about that.

35

00:01:21,128 --> 00:01:21,961
- Thank you.

36
00:01:21,961 --> 00:01:23,911
Yes, I'm very excited about it as well.

37
00:01:25,000 --> 00:01:26,470
I've been having a bunch
of meetings with people

38
00:01:26,470 --> 00:01:29,280
and sort of sorting out
details of the role,

39
00:01:29,280 --> 00:01:31,360
but yeah, it's going to be great.

40
00:01:31,360 --> 00:01:33,410
- And what is this full-time
role going to look like

41
00:01:33,410 --> 00:01:34,380
here at Perimeter?

42
00:01:34,380 --> 00:01:36,090
- It's called the Hawking Chair

43
00:01:36,090 --> 00:01:38,290
in Cosmology and Science Communication,

44
00:01:38,290 --> 00:01:41,320
and it's a position that
is going to be joint

45
00:01:41,320 --> 00:01:45,370
between cosmology research,
carrying on my research program,

46
00:01:45,370 --> 00:01:48,740

and doing public engagement
work and communication

47
00:01:48,740 --> 00:01:51,520
and working with the amazing outreach team

48
00:01:51,520 --> 00:01:54,623
here at Perimeter to bring
physics to the public.

49
00:01:55,510 --> 00:01:57,550
- We're sitting here in
the Stephen Hawking Centre

50
00:01:57,550 --> 00:01:58,510
at Perimeter Institute.

51
00:01:58,510 --> 00:02:00,040
You're going to be the Hawking Chair.

52
00:02:00,040 --> 00:02:03,210
What's it like to have a position
that's named after someone

53
00:02:03,210 --> 00:02:05,870
that you've not only sort of looked up to,

54
00:02:05,870 --> 00:02:07,840
I almost said idolized, but
also you've worked with?

55
00:02:07,840 --> 00:02:10,120
Can you tell us about
what it means for you

56
00:02:10,120 --> 00:02:11,503
to have this title?

57
00:02:13,060 --> 00:02:15,600

- Stephen Hawking was the
first person I ever knew of

58
00:02:15,600 --> 00:02:17,990
who was called a cosmologist.

59
00:02:17,990 --> 00:02:20,410
When I was a little kid, I
read "A Brief History of Time,"

60
00:02:20,410 --> 00:02:23,100
and I was just amazed at all these ideas

61
00:02:23,100 --> 00:02:24,810
about the Big Bang and black holes

62
00:02:24,810 --> 00:02:26,750
and space-time and all of that,

63
00:02:26,750 --> 00:02:30,030
and so I looked at Stephen Hawking

64
00:02:30,030 --> 00:02:32,080
and his job was called cosmologist,

65
00:02:32,080 --> 00:02:33,607
so I was like, "Okay, I'm
going to be a cosmologist.

66
00:02:33,607 --> 00:02:34,621
"That's what I want to do."

67
00:02:34,621 --> 00:02:35,503
- What age was this where you decided-

68
00:02:35,503 --> 00:02:38,317
- I think I was probably 10. (laughs)

69

00:02:38,317 --> 00:02:39,150
I was pretty young.

70
00:02:39,150 --> 00:02:40,070
- And here you are, a cosmologist.

71
00:02:40,070 --> 00:02:41,300
- And I am a cosmologist,

72
00:02:41,300 --> 00:02:43,730
and I've encountered Stephen Hawking

73
00:02:43,730 --> 00:02:45,623
a couple of times in my career.

74
00:02:46,510 --> 00:02:48,670
The first time I met him,
I was like 14 years old.

75
00:02:48,670 --> 00:02:50,320
He gave a talk at Caltech

76
00:02:50,320 --> 00:02:52,550
before I was even an undergrad there,

77
00:02:52,550 --> 00:02:54,780
'cause I lived in Southern California,

78
00:02:54,780 --> 00:02:57,670
and so I went and watched his talk,

79
00:02:57,670 --> 00:03:00,540
and afterward did a little fangirl moment,

80
00:03:00,540 --> 00:03:02,940
said hi to him and said I
was an admirer of his work,

81

00:03:02,940 --> 00:03:03,773
and he said, "Thank you very much,"

82
00:03:03,773 --> 00:03:05,600
which was very exciting for me.

83
00:03:05,600 --> 00:03:07,760
But then when I was in grad school,

84
00:03:07,760 --> 00:03:10,790
I spent at year at
Cambridge University working

85
00:03:10,790 --> 00:03:13,652
with people doing a
research kind of thing,

86
00:03:13,652 --> 00:03:15,570
and I ended giving a talk there

87
00:03:15,570 --> 00:03:19,247
where Stephen Hawking came
to my talk, and that was-

88
00:03:19,247 --> 00:03:20,080
- No pressure, no pressure.

89
00:03:20,080 --> 00:03:22,400
- Yeah, that was one of the most harrowing

90
00:03:22,400 --> 00:03:25,890
academic experiences I've had. (laughs)

91
00:03:25,890 --> 00:03:27,650
It's one thing to give a talk

92
00:03:27,650 --> 00:03:30,630
in front of your sort of childhood idol

93
00:03:30,630 --> 00:03:33,410
about a topic that he sort of pioneered.

94
00:03:33,410 --> 00:03:34,940
I was talking about
primordial black holes,

95
00:03:34,940 --> 00:03:37,410
which is something he
worked on very extensively,

96
00:03:37,410 --> 00:03:41,393
but it's another when
he's heckling. (laughs)

97
00:03:43,610 --> 00:03:46,320
So what happened was I
went to give this talk,

98
00:03:46,320 --> 00:03:47,790
I was setting up for the talk,

99
00:03:47,790 --> 00:03:50,470
and all of these eminent professors

100
00:03:50,470 --> 00:03:52,263
were already sitting down,

101
00:03:53,209 --> 00:03:55,940
and I was nervous 'cause I
thought he could show up,

102
00:03:55,940 --> 00:03:58,100
but he hadn't yet, and I was like, "Okay."

103
00:03:58,100 --> 00:04:00,831
And then hear this like beep, beep, beep

104

00:04:00,831 --> 00:04:01,727
as his wheelchair is coming in,

105
00:04:01,727 --> 00:04:05,860
and so he's set up in
the front of the room,

106
00:04:05,860 --> 00:04:08,300
so I'm like, "Okay, I
have to do this thing,"

107
00:04:08,300 --> 00:04:12,080
and so I get started with the
talk and I introduce myself,

108
00:04:12,080 --> 00:04:13,210
I put up my title slide,

109
00:04:13,210 --> 00:04:15,470
I say I'm going to talk
about primordial black holes,

110
00:04:15,470 --> 00:04:18,340
and I hear "thank you,"
and I look at Hawking.

111
00:04:18,340 --> 00:04:20,940
I'm like, "Okay," and I kind of laugh.

112
00:04:20,940 --> 00:04:23,590
- You heard it in that iconic
voice that everyone knows.

113
00:04:23,590 --> 00:04:28,590
- Yeah, and I kind of
think maybe it's a joke

114
00:04:28,690 --> 00:04:30,450
because I'm talking about
primordial black holes

115
00:04:30,450 --> 00:04:31,910
and he worked on those.

116
00:04:31,910 --> 00:04:34,410
I don't know, but
everybody kind of chuckled,

117
00:04:34,410 --> 00:04:36,770
and then I moved on, and
then I continue the talk,

118
00:04:36,770 --> 00:04:40,567
and at some point, I hear
"no," and I'm like, "What?"

119
00:04:41,550 --> 00:04:45,000
And I look at him, and
he's just eating his lunch.

120
00:04:45,000 --> 00:04:46,777
The carer who's there feeding him

121
00:04:46,777 --> 00:04:48,600
was just kind of looking blankly at me.

122
00:04:48,600 --> 00:04:51,640
Nobody is giving me any kind
of clue what's going on here,

123
00:04:51,640 --> 00:04:54,770
and I can't ask him to repeat himself

124
00:04:54,770 --> 00:04:57,090
because at that point he
was using this machine

125
00:04:57,090 --> 00:04:59,113
that took like two minutes per word.

126
00:05:00,359 --> 00:05:02,090
- He was just using a cheek muscle to-

127
00:05:02,090 --> 00:05:05,350
- Yeah, this little thing
that looks at the cheek.

128
00:05:05,350 --> 00:05:08,070
He'd sort of wink to choose words.

129
00:05:08,070 --> 00:05:11,060
And so I just kind of
paused and then carried on,

130
00:05:11,060 --> 00:05:13,540
and then throughout the
talk, at various times,

131
00:05:13,540 --> 00:05:16,480
I'd hear something like
"yes" or "I don't know"

132
00:05:16,480 --> 00:05:20,313
or "I don't think so" and
I had to just keep going,

133
00:05:21,290 --> 00:05:24,130
and every time I would
sort of respectfully pause

134
00:05:24,130 --> 00:05:26,185
and then move on.

135
00:05:26,185 --> 00:05:28,450
- But you did hear Stephen
Hawking say "I don't know"

136
00:05:28,450 --> 00:05:29,380

in a talk you were giving.

137
00:05:29,380 --> 00:05:30,560
That's got to be something.
- That is true.

138
00:05:30,560 --> 00:05:32,097
Yeah, yeah.

139
00:05:32,097 --> 00:05:34,180
It was a number of
different little phrases.

140
00:05:34,180 --> 00:05:36,780
But then eventually the talk finishes,

141
00:05:36,780 --> 00:05:38,410
he goes off somewhere else.

142
00:05:38,410 --> 00:05:40,820
He didn't answer or ask any questions,

143
00:05:40,820 --> 00:05:43,287
and then I asked the organizer,

144
00:05:43,287 --> 00:05:45,037
"What was going on with Stephen Hawking?

145
00:05:45,037 --> 00:05:46,220
"What was he doing?"

146
00:05:46,220 --> 00:05:49,627
And he was like, "Oh, the little sensor

147
00:05:49,627 --> 00:05:50,937
"that senses his cheek movement,

148
00:05:50,937 --> 00:05:54,310

"it malfunctions when
he's eating." (laughs)

149
00:05:54,310 --> 00:05:56,380
So because he was chewing,

150
00:05:56,380 --> 00:06:00,010
it was just going through the
quick-select menu of phrases:

151
00:06:00,010 --> 00:06:02,390
yes, no, maybe, I don't
know, I don't think so,

152
00:06:02,390 --> 00:06:04,730
just the things that are easy to get to,

153
00:06:04,730 --> 00:06:06,440
and you can't turn it off

154
00:06:06,440 --> 00:06:08,430
because then he wouldn't
have any way of speaking,

155
00:06:08,430 --> 00:06:12,280
so he just has these
outbursts, and nobody told me.

156
00:06:12,280 --> 00:06:13,890
I had no idea that was going to happen.

157
00:06:13,890 --> 00:06:16,990
I don't know if it was like
a hazing thing. (laughs)

158
00:06:16,990 --> 00:06:18,140
I was just a grad student.

159
00:06:18,140 --> 00:06:19,460

I didn't know what was going on.

160
00:06:19,460 --> 00:06:22,990
- Do you know what he
eventually thought of the talk?

161
00:06:22,990 --> 00:06:24,180
- I don't know what he
thought of the talk.

162
00:06:24,180 --> 00:06:26,590
I did talk to him once
more about my research

163
00:06:26,590 --> 00:06:31,590
at a dinner thing, and he
didn't really say much.

164
00:06:31,780 --> 00:06:35,610
He was very careful with his words.

165
00:06:35,610 --> 00:06:37,120
He didn't go off on tangents.

166
00:06:37,120 --> 00:06:39,350
He didn't say things unless he
had a really good reason to,

167
00:06:39,350 --> 00:06:41,880
so we didn't end up having
a real conversation,

168
00:06:41,880 --> 00:06:44,810
although I was in the same research group

169
00:06:44,810 --> 00:06:45,850
sort of broadly as him,

170
00:06:45,850 --> 00:06:48,680

so I was around the stuff he was doing.

171
00:06:48,680 --> 00:06:50,140
I wasn't working directly with him,

172
00:06:50,140 --> 00:06:53,370
but it was neat to be able to meet

173
00:06:53,370 --> 00:06:56,108
and interact with your
sort of childhood hero.

174
00:06:56,108 --> 00:06:57,239
- And be heckled by him.

175
00:06:57,239 --> 00:06:58,519
- And be heckled by him.

176
00:06:58,519 --> 00:07:00,708
I mean, it made a great story,

177
00:07:00,708 --> 00:07:04,170
being able to survive
that and just carry on.

178
00:07:04,170 --> 00:07:05,980
- Just go back a little bit.

179
00:07:05,980 --> 00:07:07,740
Stephen Hawking was a cosmologist.

180
00:07:07,740 --> 00:07:08,810
You saw him when you were young.

181
00:07:08,810 --> 00:07:10,490
You said, "I want to be a cosmologist."

182
00:07:10,490 --> 00:07:11,960

What's a cosmologist?

183
00:07:11,960 --> 00:07:13,380
- So a cosmologist is somebody

184
00:07:13,380 --> 00:07:16,410
who studies the universe
sort of as a whole

185
00:07:16,410 --> 00:07:19,560
or the fundamental
physics of the universe.

186
00:07:19,560 --> 00:07:22,300
So I often explain it as the universe

187
00:07:22,300 --> 00:07:24,570
from the largest to the smallest scales

188
00:07:24,570 --> 00:07:25,520
from beginning to end,

189
00:07:25,520 --> 00:07:28,000
anything to do with the bigger picture

190
00:07:28,000 --> 00:07:29,450
of how the universe works.

191
00:07:29,450 --> 00:07:32,120
So cosmologists study
things like the Big Bang

192
00:07:32,120 --> 00:07:33,730
or the future of the universe.

193
00:07:33,730 --> 00:07:35,970
They study what the universe is made of,

194

00:07:35,970 --> 00:07:37,940
how it works physically,

195
00:07:37,940 --> 00:07:40,580
what the laws are that govern the cosmos,

196
00:07:40,580 --> 00:07:42,646
and so I've worked in
various areas around there.

197
00:07:42,646 --> 00:07:43,920
I've worked in the early universe

198
00:07:43,920 --> 00:07:46,720
and what happened at the Big
Bang, that kind of question.

199
00:07:46,720 --> 00:07:47,840
I work on dark matter,

200
00:07:47,840 --> 00:07:49,890
which is one of the most
important components

201
00:07:49,890 --> 00:07:52,270
of the universe, but we
don't know what it is,

202
00:07:52,270 --> 00:07:55,097
and I've also thought a lot
about the end of the universe

203
00:07:55,097 --> 00:07:58,010
and just various aspects
of, how does it work,

204
00:07:58,010 --> 00:07:59,430
what's really going on?

205

00:07:59,430 --> 00:08:01,923
- So nothing much then, just everything,

206
00:08:01,923 --> 00:08:03,100
just the whole universe.

207
00:08:03,100 --> 00:08:06,030
- Yeah, I was going to say,
just hearing your description,

208
00:08:06,030 --> 00:08:07,854
it seems just like such a broad field.

209
00:08:07,854 --> 00:08:09,070
I mean, you can study the past,

210
00:08:09,070 --> 00:08:11,450
the present, the future,
the big and the small.

211
00:08:11,450 --> 00:08:13,230
At any point in your career,

212
00:08:13,230 --> 00:08:15,853
how do you choose where
to focus your attention?

213
00:08:17,330 --> 00:08:19,030
- I've been very fortunate in my career

214
00:08:19,030 --> 00:08:21,020
that I've had a lot of freedom to study

215
00:08:21,020 --> 00:08:22,460
what I'm interested in

216
00:08:22,460 --> 00:08:25,340
and to just kind of follow my curiosity.

217
00:08:25,340 --> 00:08:26,780
I've had research fellowships

218
00:08:26,780 --> 00:08:28,590
where I'm not tied to
a particular project,

219
00:08:28,590 --> 00:08:30,947
but I get to present here's
what I want to work on,

220
00:08:30,947 --> 00:08:32,230
and then I work on that thing.

221
00:08:32,230 --> 00:08:35,290
So I've just kind of looked at,

222
00:08:35,290 --> 00:08:36,920
what's the interesting question,

223
00:08:36,920 --> 00:08:39,680
where can I be really creative about this,

224
00:08:39,680 --> 00:08:42,920
so things like talking to the theorists

225
00:08:42,920 --> 00:08:46,540
about what the new sort
of physical model is

226
00:08:46,540 --> 00:08:47,490
they're thinking about,

227
00:08:47,490 --> 00:08:49,540
what's the big theory that
everybody's excited about,

228
00:08:49,540 --> 00:08:52,800

and then talking to the observers
about the new telescopes

229
00:08:52,800 --> 00:08:53,633
that they're going to build like,

230
00:08:53,633 --> 00:08:55,350
what is this new radio
telescope going to see

231
00:08:55,350 --> 00:08:57,390
about the first galaxies in the universe,

232
00:08:57,390 --> 00:09:00,630
and then trying to find ways
to bring those together,

233
00:09:00,630 --> 00:09:01,780
trying to find out,

234
00:09:01,780 --> 00:09:04,230
what can those telescopes
tell us about those theories,

235
00:09:04,230 --> 00:09:06,340
and what kinds of experiments do we need

236
00:09:06,340 --> 00:09:07,330
to test those theories,

237
00:09:07,330 --> 00:09:09,930
and that kind of intermediate stage

238
00:09:09,930 --> 00:09:13,680
where you get to learn about
every aspect of these questions

239
00:09:13,680 --> 00:09:17,200
and try and find new creative

ways to bring them together.

240
00:09:17,200 --> 00:09:19,230
So that's kind of the
area I like to work in,

241
00:09:19,230 --> 00:09:20,530
but in terms of topic,

242
00:09:20,530 --> 00:09:23,090
it's anything from black
holes to early galaxies

243
00:09:23,090 --> 00:09:27,540
to cosmic strings to dark matter
to microscopic black holes

244
00:09:27,540 --> 00:09:29,230
that might have started
in the early universe,

245
00:09:29,230 --> 00:09:30,540
all kinds of stuff like that

246
00:09:30,540 --> 00:09:33,350
because there's some
interesting creative way

247
00:09:33,350 --> 00:09:35,060
I can approach the question.

248
00:09:35,060 --> 00:09:38,530
- What's the interesting problem
you're grappling with now,

249
00:09:38,530 --> 00:09:40,160
and what's your creative approach to it?

250
00:09:40,160 --> 00:09:42,490

- I'm particularly
interested in dark matter.

251
00:09:42,490 --> 00:09:45,130
So we know that most of
the matter in the universe,

252
00:09:45,130 --> 00:09:46,400
most of the stuff that has mass

253
00:09:46,400 --> 00:09:48,040
in the universe is totally invisible.

254
00:09:48,040 --> 00:09:50,530
We can't see it with ordinary light.

255
00:09:50,530 --> 00:09:54,530
It doesn't seem to reflect or
emit light or absorb light,

256
00:09:54,530 --> 00:09:56,260
so it's hard to look at directly,

257
00:09:56,260 --> 00:09:57,360
but we can see that it's there

258
00:09:57,360 --> 00:09:59,930
based on how it affects
things that are lit up

259
00:09:59,930 --> 00:10:01,630
in the universe, stars and galaxies.

260
00:10:01,630 --> 00:10:02,870
- Is dark matter everywhere?

261
00:10:02,870 --> 00:10:05,357
- Yes, yes, so there probably
is dark matter in this room.

262
00:10:05,357 --> 00:10:07,186
- It's not just far away in space.

263
00:10:07,186 --> 00:10:09,020
It's permeating.
- No, no.

264
00:10:09,020 --> 00:10:12,590
About a third of a proton
mass per cubic centimeter

265
00:10:12,590 --> 00:10:14,717
is roughly how much dark
matter is around here,

266
00:10:14,717 --> 00:10:16,230
and it's passing right through us.

267
00:10:16,230 --> 00:10:19,050
That's most likely sort of
where we're at with dark matter.

268
00:10:19,050 --> 00:10:20,177
There's a lot of uncertainties in this-

269
00:10:20,177 --> 00:10:22,121
- And this makes up most of the universe.

270
00:10:22,121 --> 00:10:23,079
- Most of the matter in the universe.

271
00:10:23,079 --> 00:10:23,912
- Okay, right.

272
00:10:23,912 --> 00:10:25,240
- When I get to most of the universe,

273

00:10:25,240 --> 00:10:26,073
we have to talk about dark energy.

274
00:10:26,073 --> 00:10:27,430
It's a totally different thing,

275
00:10:27,430 --> 00:10:29,350
but most of the matter, yes.

276
00:10:29,350 --> 00:10:31,450
But yeah, so we're pretty
sure dark matter is there.

277
00:10:31,450 --> 00:10:35,270
It seems to be important to
the functioning of matter

278
00:10:35,270 --> 00:10:37,330
in the universe, to
the growth of galaxies,

279
00:10:37,330 --> 00:10:40,270
to the formation of structure
on the largest scales,

280
00:10:40,270 --> 00:10:43,350
but we don't know what
it is, and there's a hope

281
00:10:43,350 --> 00:10:46,780
that maybe if dark matter particles,

282
00:10:46,780 --> 00:10:48,910
if they really are
particles, probably they are,

283
00:10:48,910 --> 00:10:51,950
if dark matter particles
collide in just the right way,

284
00:10:51,950 --> 00:10:54,130
they might annihilate with each other

285
00:10:54,130 --> 00:10:58,320
and create regular particles
like things like positrons

286
00:10:58,320 --> 00:11:01,920
and electrons or quark pairs
or something like that.

287
00:11:01,920 --> 00:11:03,340
And if that's the case,

288
00:11:03,340 --> 00:11:07,660
then regions of really dense
dark matter should glow

289
00:11:07,660 --> 00:11:10,080
with high-energy particles that we can see

290
00:11:10,080 --> 00:11:12,370
just to some tiny degree.

291
00:11:12,370 --> 00:11:14,830
A lot of people have
followed that possibility

292
00:11:14,830 --> 00:11:17,720
and looked for evidence of
dark matter annihilating

293
00:11:17,720 --> 00:11:20,940
in the center of the galaxy
or in small galaxies nearby

294
00:11:20,940 --> 00:11:22,860
or various places like that.

295
00:11:22,860 --> 00:11:25,150
One thing that I've been
interested in recently is,

296
00:11:25,150 --> 00:11:27,420
what if that does happen?

297
00:11:27,420 --> 00:11:28,620
How would it have affected

298
00:11:28,620 --> 00:11:30,360
the first galaxies in the universe?

299
00:11:30,360 --> 00:11:31,820
So these clumps of dark matter

300
00:11:31,820 --> 00:11:33,640
where the first gas got together

301
00:11:33,640 --> 00:11:35,280
and formed stars and galaxies,

302
00:11:35,280 --> 00:11:37,040
how would those structures be affected

303
00:11:37,040 --> 00:11:40,010
by a little bit of energy
coming out of the centers

304
00:11:40,010 --> 00:11:41,880
of these dark matter clumps?

305
00:11:41,880 --> 00:11:44,980
And then furthermore, if that
is happening, how does that,

306
00:11:44,980 --> 00:11:47,260
or if that did happen in the past,

307
00:11:47,260 --> 00:11:50,300
how does it change what we
can see with radio telescopes

308
00:11:50,300 --> 00:11:52,060
and with infrared telescopes,

309
00:11:52,060 --> 00:11:54,640
things that can look at
those first galaxies,

310
00:11:54,640 --> 00:11:56,660
so things like the James
Webb Space Telescope,

311
00:11:56,660 --> 00:11:58,650
which hopefully will be launched

312
00:11:58,650 --> 00:12:02,240
by the time this podcast
comes out. (laughs)

313
00:12:02,240 --> 00:12:05,910
Hopefully it's up there
doing great science.

314
00:12:05,910 --> 00:12:07,160
Now I'm getting nervous about it.

315
00:12:07,160 --> 00:12:11,740
Anyway, that telescope
and other space telescopes

316
00:12:11,740 --> 00:12:14,340
designed to look for
the very first galaxies,

317
00:12:14,340 --> 00:12:15,800

they might see something different

318
00:12:15,800 --> 00:12:18,070
if dark matter is annihilating
in those first galaxies

319
00:12:18,070 --> 00:12:18,970
or if it's not.

320
00:12:18,970 --> 00:12:20,980
- When our telescopes look
out really, really far,

321
00:12:20,980 --> 00:12:23,410
they're looking at
things the way they were.

322
00:12:23,410 --> 00:12:25,780
Was dark matter around
at the very beginning?

323
00:12:25,780 --> 00:12:26,830
Has it been around forever?

324
00:12:26,830 --> 00:12:28,670
- Yeah, as far as we can tell,

325
00:12:28,670 --> 00:12:31,880
dark matter was part of
the sort of primordial soup

326
00:12:31,880 --> 00:12:33,470
of the very, very early universe,

327
00:12:33,470 --> 00:12:37,010
and it was crucial to building up

328
00:12:37,010 --> 00:12:39,840
the first matter

structures in the universe,

329
00:12:39,840 --> 00:12:41,860
the first galaxies, the first stars.

330
00:12:41,860 --> 00:12:44,140
It helped bring all that gas together

331
00:12:44,140 --> 00:12:47,850
and allow it to form those
first stars and galaxies,

332
00:12:47,850 --> 00:12:50,520
and we have some idea of
kind of how that worked.

333
00:12:50,520 --> 00:12:53,170
We have a reasonably good idea of the fact

334
00:12:53,170 --> 00:12:54,950
that if dark matter were not there,

335
00:12:54,950 --> 00:12:57,630
then the gas that makes up
our own galaxy, the Milky Way,

336
00:12:57,630 --> 00:13:00,000
would not have been able
to come together enough

337
00:13:00,000 --> 00:13:02,420
to form the Milky Way as we see it today.

338
00:13:02,420 --> 00:13:04,010
So it's been a factor

339
00:13:04,010 --> 00:13:07,120
in the evolution of structure
since the beginning.

340
00:13:07,120 --> 00:13:10,670
Whether or not it's been
injecting high-energy particles

341
00:13:10,670 --> 00:13:15,380
and photons and energy into
these clumps, we don't know,

342
00:13:15,380 --> 00:13:18,060
and so that's what I'm
trying to figure out,

343
00:13:18,060 --> 00:13:20,980
trying to model what that would look like,

344
00:13:20,980 --> 00:13:23,520
how it would affect those
first stars and galaxies,

345
00:13:23,520 --> 00:13:24,980
what you would see with space telescopes,

346
00:13:24,980 --> 00:13:26,810
what you would see with radio telescopes

347
00:13:26,810 --> 00:13:29,570
that can sort of probe
the neutral hydrogen

348
00:13:29,570 --> 00:13:31,410
that formed the first stars and galaxies

349
00:13:31,410 --> 00:13:33,720
at very, very early
times, and it is great.

350
00:13:33,720 --> 00:13:35,700
As you say, these telescopes

are time machines.

351
00:13:35,700 --> 00:13:37,630
You can look at the past.

352
00:13:37,630 --> 00:13:40,630
You can see directly things that happened

353
00:13:40,630 --> 00:13:42,840
in the first billion
years of the universe.

354
00:13:42,840 --> 00:13:44,370
We're at 13.8 billion years now.

355
00:13:44,370 --> 00:13:48,630
We can see galaxies that were
before half-a-billion years,

356
00:13:48,630 --> 00:13:50,370
just very, very early in the universe,

357
00:13:50,370 --> 00:13:52,320
and of course, we can
see the background light

358
00:13:52,320 --> 00:13:55,270
from the Big Bang itself, the
cosmic microwave background,

359
00:13:55,270 --> 00:13:58,070
and we get clues about dark
matter from all of that,

360
00:13:58,070 --> 00:14:00,220
and hopefully we'll get some clues

361
00:14:00,220 --> 00:14:02,720
as to whether or not it

does this annihilation thing

362
00:14:02,720 --> 00:14:04,070
when we start to be able to look

363
00:14:04,070 --> 00:14:06,760
at those first galaxies more directly.

364
00:14:06,760 --> 00:14:09,390
- I'm curious what
specifically you're looking for

365
00:14:09,390 --> 00:14:10,300
with those telescopes.

366
00:14:10,300 --> 00:14:12,820
What is that evidence that
helps you be more sure

367
00:14:12,820 --> 00:14:14,140
that dark matter played a role

368
00:14:14,140 --> 00:14:16,110
at different stages of the universe?

369
00:14:16,110 --> 00:14:19,000
- So in terms of how it affects,

370
00:14:19,000 --> 00:14:21,550
just played a role gravitationally,

371
00:14:21,550 --> 00:14:24,780
how it brought matter together,
the way you learn that is

372
00:14:24,780 --> 00:14:27,970
from modeling the gravitational
growth of structure.

373
00:14:27,970 --> 00:14:29,730
So you do computer models

374
00:14:29,730 --> 00:14:33,340
to simulate matter coming
together, and you see what happens

375
00:14:33,340 --> 00:14:35,720
if that matter coming
together has pressure

376
00:14:35,720 --> 00:14:38,410
and acts like gas where it
can kind of puff up again,

377
00:14:38,410 --> 00:14:40,550
or if it's dark matter
where it just has gravity

378
00:14:40,550 --> 00:14:41,530
and doesn't have pressure.

379
00:14:41,530 --> 00:14:43,700
It doesn't puff up when you...

380
00:14:43,700 --> 00:14:47,130
If you let dark matter
sort of fall toward itself,

381
00:14:47,130 --> 00:14:48,040
it's not going to bounce off

382
00:14:48,040 --> 00:14:51,780
and it's not going to kind
of heat up the way that gas,

383
00:14:51,780 --> 00:14:54,110
if it falls together,
it kind of gets puffy.

384
00:14:54,110 --> 00:14:56,230
So you have different dynamics

385
00:14:56,230 --> 00:14:59,490
around how things grow through gravity

386
00:14:59,490 --> 00:15:00,917
if it's dark matter or
if it's regular matter,

387
00:15:00,917 --> 00:15:04,200
and so computer modeling is
a big part of figuring out

388
00:15:04,200 --> 00:15:05,950
how dark matter affected

389
00:15:05,950 --> 00:15:09,760
the gravitational sort of
development of these structures.

390
00:15:09,760 --> 00:15:12,650
In terms of how we'll know
if it's annihilating or not,

391
00:15:12,650 --> 00:15:15,250
that's a different question,
and that's also something

392
00:15:15,250 --> 00:15:17,530
where you have to do
computer modeling to see

393
00:15:17,530 --> 00:15:20,850
where that energy goes within
that dark matter structure,

394
00:15:20,850 --> 00:15:23,190

where it goes when it goes into the gas,

395
00:15:23,190 --> 00:15:26,200
and how that changes
the physics of that gas

396
00:15:26,200 --> 00:15:27,580
and how it changes.

397
00:15:27,580 --> 00:15:30,010
Maybe what it does is
it blows out all the gas

398
00:15:30,010 --> 00:15:32,190
in the smallest little
clumps of dark matter,

399
00:15:32,190 --> 00:15:33,830
and so you can only form galaxies

400
00:15:33,830 --> 00:15:34,888
in larger clumps of dark matter,

401
00:15:34,888 --> 00:15:35,721
and that would be something

402
00:15:35,721 --> 00:15:37,420
you would be able to tell the difference

403
00:15:37,420 --> 00:15:41,000
in a sort of large survey with telescopes.

404
00:15:41,000 --> 00:15:42,190
- You've mentioned that you look

405
00:15:42,190 --> 00:15:44,970
into the beginnings of the universe,

406

00:15:44,970 --> 00:15:47,210
and the ends of the universe
hasn't happened yet.

407
00:15:47,210 --> 00:15:49,990
Is looking at one imperative
for understanding the other?

408
00:15:49,990 --> 00:15:54,990
- I think that what we
really want is a big picture

409
00:15:55,620 --> 00:15:58,520
of the whole evolution of the universe

410
00:15:58,520 --> 00:15:59,957
and the structure of the universe,

411
00:15:59,957 --> 00:16:03,140
and so the beginning is
part of that question.

412
00:16:03,140 --> 00:16:04,880
How did the universe begin?

413
00:16:04,880 --> 00:16:05,967
- How did it begin?

414
00:16:05,967 --> 00:16:06,800
Tell us now, hurry.

415
00:16:06,800 --> 00:16:11,250
- (laughs) Well, we're kind
of still working on that.

416
00:16:11,250 --> 00:16:12,810
But yeah, the beginning of the universe

417
00:16:12,810 --> 00:16:13,643

is one part of the question,

418
00:16:13,643 --> 00:16:15,340
and the end of the
universe is another part,

419
00:16:15,340 --> 00:16:18,970
and if you have a theory for
the beginning of the universe,

420
00:16:18,970 --> 00:16:22,440
it generally has an implication
for the end as well,

421
00:16:22,440 --> 00:16:24,320
and if you have a theory for the end,

422
00:16:24,320 --> 00:16:25,660
maybe it'll lead to a new beginning.

423
00:16:25,660 --> 00:16:26,510
There are some theories

424
00:16:26,510 --> 00:16:28,960
that have a sort of cycling universe.

425
00:16:28,960 --> 00:16:31,620
So they are kind of parts
of the same question

426
00:16:31,620 --> 00:16:33,090
because they're both asking

427
00:16:33,090 --> 00:16:35,460
about this kind of
big-picture question of,

428
00:16:35,460 --> 00:16:37,190
what is the nature of the universe?

429
00:16:37,190 --> 00:16:40,620
Is it embedded in some larger multiverse,

430
00:16:40,620 --> 00:16:42,540
or is there some part of the universe

431
00:16:42,540 --> 00:16:45,480
that's so far away from us
it's not observable to us

432
00:16:45,480 --> 00:16:48,070
and how does that affect the
evolution of the universe,

433
00:16:48,070 --> 00:16:50,800
and if you really
understand the beginning,

434
00:16:50,800 --> 00:16:54,260
you know if that beginning
is the result of the end

435
00:16:54,260 --> 00:16:55,750
of a previous universe, for example,

436
00:16:55,750 --> 00:16:58,380
so there are ways that
these things are connected.

437
00:16:58,380 --> 00:17:02,610
But also we learn a lot about
what the universe is made of

438
00:17:02,610 --> 00:17:04,210
by looking at the
beginning of the universe,

439
00:17:04,210 --> 00:17:06,310

by looking at things like the
cosmic microwave background,

440
00:17:06,310 --> 00:17:09,660
which is the light from
the Big Bang itself really,

441
00:17:09,660 --> 00:17:11,750
but it's also something
that we can study carefully

442
00:17:11,750 --> 00:17:13,710
to learn about the
components of the universe

443
00:17:13,710 --> 00:17:16,520
because it encodes a lot of
really important information,

444
00:17:16,520 --> 00:17:18,500
but if we know what the
universe is made of completely,

445
00:17:18,500 --> 00:17:21,750
then that also helps us to
extrapolate into the future

446
00:17:21,750 --> 00:17:24,400
of how those things will evolve in time.

447
00:17:24,400 --> 00:17:27,840
So for example, dark energy
is some mysterious stuff

448
00:17:27,840 --> 00:17:31,140
that's making the universe
expand faster all the time,

449
00:17:31,140 --> 00:17:33,490
and we don't know what dark energy is,

450
00:17:33,490 --> 00:17:36,667
but if we can understand
the early universe

451
00:17:36,667 --> 00:17:38,347
and what was present in the early universe

452
00:17:38,347 --> 00:17:40,670
and how all the pieces fit together then

453
00:17:40,670 --> 00:17:42,620
and how it's evolved over time,

454
00:17:42,620 --> 00:17:44,240
then we can extrapolate into the future

455
00:17:44,240 --> 00:17:46,420
what dark energy will do and how it may

456
00:17:46,420 --> 00:17:48,610
or may not destroy the
universe in the future.

457
00:17:48,610 --> 00:17:50,990
- And what pieces are
needed, do you think,

458
00:17:50,990 --> 00:17:53,940
to help understand what
dark energy really is?

459
00:17:53,940 --> 00:17:57,600
- Well, dark energy is tough
because, as far as we can tell,

460
00:17:57,600 --> 00:17:59,980
all it does is make the
universe expand faster.

461
00:17:59,980 --> 00:18:01,490
It doesn't seem to interact

462
00:18:01,490 --> 00:18:03,090
with anything else in any other way.

463
00:18:03,090 --> 00:18:06,060
It stretches space, and that's it.

464
00:18:06,060 --> 00:18:09,400
So all you can really
study with dark energy,

465
00:18:09,400 --> 00:18:13,020
as we understand it, is
you can study the evolution

466
00:18:13,020 --> 00:18:15,610
of the expansion of the universe,

467
00:18:15,610 --> 00:18:18,880
how it's changed over time and
the expansion rate and so on,

468
00:18:18,880 --> 00:18:20,710
and you can study the evolution,

469
00:18:20,710 --> 00:18:22,700
the sort of growth of
structure in the universe,

470
00:18:22,700 --> 00:18:24,780
so how galaxy clusters come together,

471
00:18:24,780 --> 00:18:28,070
and you can do that by looking
at the past and seeing,

472
00:18:28,070 --> 00:18:31,720
watching kind of that growth
happen, and that's kind of it.

473
00:18:31,720 --> 00:18:33,450
There are some theories about dark energy

474
00:18:33,450 --> 00:18:36,910
that involve things that could
interact with experiments,

475
00:18:36,910 --> 00:18:40,830
and so people are really
hoping to find some connection

476
00:18:40,830 --> 00:18:42,610
with an experiment with dark energy,

477
00:18:42,610 --> 00:18:46,230
but it might just be a sort
of aspect of the universe

478
00:18:46,230 --> 00:18:48,276
that there's sort of some number

479
00:18:48,276 --> 00:18:51,630
that designates how this expansion works

480
00:18:51,630 --> 00:18:53,243
and it's just part of how,

481
00:18:53,243 --> 00:18:56,550
it's just written into
the equations of gravity.

482
00:18:56,550 --> 00:18:58,094
That's called a cosmological constant.

483

00:18:58,094 --> 00:19:00,100
It's just an aspect of the universe

484
00:19:00,100 --> 00:19:01,510
that's got this sort
of stretchiness in it,

485
00:19:01,510 --> 00:19:05,206
and it's also a challenge to
understand, why that number?

486
00:19:05,206 --> 00:19:06,610
Why does that term exist?

487
00:19:06,610 --> 00:19:07,670
We don't know.

488
00:19:07,670 --> 00:19:10,040
- So from hearing what you're
describing about your work,

489
00:19:10,040 --> 00:19:12,350
it just seems like you're
almost trying to put together

490
00:19:12,350 --> 00:19:13,730
a lot of pieces of the puzzle

491
00:19:13,730 --> 00:19:16,700
to talk about how we can
go from the beginning

492
00:19:16,700 --> 00:19:18,710
to the end and everything in between.

493
00:19:18,710 --> 00:19:19,880
From your perspective,

494
00:19:19,880 --> 00:19:23,810

what are the most interesting
chapters of that story?

495
00:19:23,810 --> 00:19:26,160
- On the timeline, the
beginning and the end are,

496
00:19:26,160 --> 00:19:27,710
of course, the exciting bits,

497
00:19:27,710 --> 00:19:29,530
but in terms of what
we're trying to learn,

498
00:19:29,530 --> 00:19:32,210
I think the big mysteries,
dark matter, dark energy,

499
00:19:32,210 --> 00:19:34,370
are the huge questions.

500
00:19:34,370 --> 00:19:37,010
The Big Bang, there are a
bunch of questions around that.

501
00:19:37,010 --> 00:19:40,150
There's this idea of cosmic inflation,

502
00:19:40,150 --> 00:19:43,200
that at some point very, very
early on in the universe,

503
00:19:43,200 --> 00:19:44,990
after whatever the beginning was,

504
00:19:44,990 --> 00:19:47,360
a tiny fraction of a second after that,

505
00:19:47,360 --> 00:19:49,510

there was a rapid expansion,

506
00:19:49,510 --> 00:19:52,860
and it sort of stretched out
space to an extreme degree,

507
00:19:52,860 --> 00:19:55,430
and then that rapid expansion calmed down

508
00:19:55,430 --> 00:19:56,750
to the normal expansion,

509
00:19:56,750 --> 00:19:59,390
and then sort of the kind of hot Big Bang

510
00:19:59,390 --> 00:20:02,300
that we talk about, the sort
of hot glowing plasma phase

511
00:20:02,300 --> 00:20:03,133
of the universe started,

512
00:20:03,133 --> 00:20:05,750
and then we got stars
and galaxies and so on.

513
00:20:05,750 --> 00:20:07,960
We don't know if cosmic
inflation happened or not.

514
00:20:07,960 --> 00:20:10,220
There's good reasons to
believe it probably did,

515
00:20:10,220 --> 00:20:12,350
but there are also
theories that are out there

516
00:20:12,350 --> 00:20:14,520

that involve not cosmic inflation,

517
00:20:14,520 --> 00:20:16,890
so something else that sort
of set up the conditions

518
00:20:16,890 --> 00:20:18,200
for that hot Big Bang.

519
00:20:18,200 --> 00:20:19,640
We don't know where to
go with that right now,

520
00:20:19,640 --> 00:20:22,540
and it's difficult to study.

521
00:20:22,540 --> 00:20:26,087
It's difficult to get strong
evidence either way and-

522
00:20:26,087 --> 00:20:27,880
- Will newer telescopes help with that?

523
00:20:27,880 --> 00:20:30,020
Are we still getting
further and further back?

524
00:20:30,020 --> 00:20:34,580
- Well, new ways to observe
the cosmic microwave background

525
00:20:34,580 --> 00:20:35,680
can help with that.

526
00:20:35,680 --> 00:20:37,730
What we're looking for there is,

527
00:20:37,730 --> 00:20:40,680
by looking at the details of the light

528
00:20:40,680 --> 00:20:42,370
from the cosmic microwave background,

529
00:20:42,370 --> 00:20:44,460
this first light in the universe,

530
00:20:44,460 --> 00:20:47,700
we might be able to see
signs of gravitational waves

531
00:20:47,700 --> 00:20:48,960
in the very, very early universe.

532
00:20:48,960 --> 00:20:52,320
So this is sort of waves
of space-time stretching.

533
00:20:52,320 --> 00:20:55,390
If we can see evidence of those,

534
00:20:55,390 --> 00:20:56,660
then that can give us a clue that,

535
00:20:56,660 --> 00:20:58,370
yes, inflation really did happen.

536
00:20:58,370 --> 00:21:01,140
And back in 2014, we
thought we did see that

537
00:21:01,140 --> 00:21:03,010
with an experiment called BICEP2.

538
00:21:03,010 --> 00:21:05,410
Turned out we were fooled by cosmic dust,

539
00:21:05,410 --> 00:21:06,980

so we didn't see that,

540
00:21:06,980 --> 00:21:09,650
and there are experiments going on now,

541
00:21:09,650 --> 00:21:11,850
observations with new telescopes,

542
00:21:11,850 --> 00:21:14,840
hoping to actually see a signature,

543
00:21:14,840 --> 00:21:16,300
and that would give us a big hint.

544
00:21:16,300 --> 00:21:17,710
Then there are other
sort of indirect things

545
00:21:17,710 --> 00:21:19,450
that might tell us
something about inflation,

546
00:21:19,450 --> 00:21:22,900
but it's hard because it's a process

547
00:21:22,900 --> 00:21:26,110
that doesn't leave a lot
of clues necessarily.

548
00:21:26,110 --> 00:21:27,190
There are a number of things

549
00:21:27,190 --> 00:21:29,930
that are very consistent with
inflation having happened,

550
00:21:29,930 --> 00:21:33,490
but those observations are also consistent

551
00:21:33,490 --> 00:21:36,160
with a few other theories that
involve different evolutions

552
00:21:36,160 --> 00:21:37,220
in the very early universe

553
00:21:37,220 --> 00:21:39,240
that led to this hot Big Bang phase.

554
00:21:39,240 --> 00:21:41,090
- You wrote a book a year or two ago

555
00:21:41,090 --> 00:21:43,942
with the very uplifting title,
"The End of Everything."

556
00:21:43,942 --> 00:21:44,775
- "The End of Everything."
- That was about

557
00:21:44,775 --> 00:21:46,085
the end of everything.

558
00:21:46,085 --> 00:21:48,060
- "The End of Everything:
Astrophysically Speaking."

559
00:21:48,060 --> 00:21:48,893
- Astrophysically speaking.

560
00:21:48,893 --> 00:21:49,726
Thanks for clarifying,

561
00:21:49,726 --> 00:21:51,774
'cause it would've been even
more terrifying had you not.

562

00:21:51,774 --> 00:21:52,760
(Katie and Lauren laugh)

563
00:21:52,760 --> 00:21:55,483
Why did you write a book
about the end of everything,

564
00:21:55,483 --> 00:21:57,440
and can you tell us,
what are some of the ways

565
00:21:57,440 --> 00:21:59,520
that everything might end astrophysically?

566
00:21:59,520 --> 00:22:02,150
- Right, right, so I
think the reason I wrote

567
00:22:02,150 --> 00:22:04,050
about the end of the universe

568
00:22:04,050 --> 00:22:05,680
as opposed to, say, the beginning,

569
00:22:05,680 --> 00:22:07,123
well, for one thing, there
are already lots of books

570
00:22:07,123 --> 00:22:08,150
about the beginning of the universe,

571
00:22:08,150 --> 00:22:10,210
and I didn't think that I
needed to write another book

572
00:22:10,210 --> 00:22:11,330
about the beginning of the universe,

573
00:22:11,330 --> 00:22:15,140

but also, in my various
studies in cosmology,

574
00:22:15,140 --> 00:22:18,010
I've frequently come
across papers or talks

575
00:22:18,010 --> 00:22:20,070
that are about different
ways the universe might end,

576
00:22:20,070 --> 00:22:22,650
and I'm always just
fascinated by that question,

577
00:22:22,650 --> 00:22:25,010
and I notice that when
I give public talks,

578
00:22:25,010 --> 00:22:26,440
the audience gets really excited

579
00:22:26,440 --> 00:22:27,780
about the question of the end,

580
00:22:27,780 --> 00:22:29,600
and I realized that
it's just not out there

581
00:22:29,600 --> 00:22:31,860
in the public consciousness enough,

582
00:22:31,860 --> 00:22:33,220
how do we think the
universe is going to end,

583
00:22:33,220 --> 00:22:34,500
what are the possibilities,

584

00:22:34,500 --> 00:22:37,940
and it seemed like a fun
opportunity to dig down on those

585
00:22:37,940 --> 00:22:40,050
and present what we really know

586
00:22:40,050 --> 00:22:41,940
about the future of the universe now,

587
00:22:41,940 --> 00:22:43,520
what are the different possibilities,

588
00:22:43,520 --> 00:22:45,760
how are we distinguishing between them,

589
00:22:45,760 --> 00:22:46,830
and what's all the physics

590
00:22:46,830 --> 00:22:48,920
that sort of comes into all that?

591
00:22:48,920 --> 00:22:51,470
It was really fun because
I was able to bring in

592
00:22:51,470 --> 00:22:53,660
all of my favorite cosmology fun facts

593
00:22:53,660 --> 00:22:55,870
and little bits of interesting physics

594
00:22:55,870 --> 00:22:57,990
along the way while also talking

595
00:22:57,990 --> 00:23:00,470
about this sort of big, scary destruction,

596

00:23:00,470 --> 00:23:02,240
and so (laughs) I probably shouldn't laugh

597
00:23:02,240 --> 00:23:04,796
at the destruction of the
universe, but it's hard-

598
00:23:04,796 --> 00:23:06,324
- It's going to happen
way down the road, right?

599
00:23:06,324 --> 00:23:09,160
- Yeah, it's not an immediate fear,

600
00:23:09,160 --> 00:23:11,530
and yet it's so overwhelmingly huge

601
00:23:11,530 --> 00:23:12,960
that you kind of have to laugh,

602
00:23:12,960 --> 00:23:15,830
because what else are you going to do?

603
00:23:15,830 --> 00:23:17,820
The whole universe is
going to be destroyed.

604
00:23:17,820 --> 00:23:19,022
Okay.

605
00:23:19,022 --> 00:23:21,760
- And if I'm right, one of your scenarios,

606
00:23:21,760 --> 00:23:23,000
not your scenarios.

607
00:23:23,000 --> 00:23:24,910
You're not the orchestrator
of the end of the universe,

608
00:23:24,910 --> 00:23:27,070
but a chronicler of it.

609
00:23:27,070 --> 00:23:29,120
It could happen right now, right?

610
00:23:29,120 --> 00:23:30,640
- Technically, yeah, yeah.

611
00:23:30,640 --> 00:23:33,420
So technically, one of the
scenarios called vacuum decay

612
00:23:33,420 --> 00:23:35,060
is something that would be triggered

613
00:23:35,060 --> 00:23:38,360
by a quantum event that is unpredictable

614
00:23:38,360 --> 00:23:40,280
and you wouldn't know that it happened.

615
00:23:40,280 --> 00:23:43,990
In principle, that could
happen anytime, anywhere.

616
00:23:43,990 --> 00:23:47,220
In practice, based on what
we think we understand,

617
00:23:47,220 --> 00:23:50,890
the timeline for that
actually to occur is like

618
00:23:50,890 --> 00:23:54,092
10 to the power of 100 years
from now, something like that.

619
00:23:54,092 --> 00:23:55,820
Well, we don't know 'cause
it's a hard calculation

620
00:23:55,820 --> 00:23:58,280
and there's still a lot
we're trying to figure out.

621
00:23:58,280 --> 00:23:59,740
I mean, we don't even know if the theory

622
00:23:59,740 --> 00:24:02,510
that suggests the possibility
of vacuum decay is valid.

623
00:24:02,510 --> 00:24:04,300
It's the standard model
of particle physics,

624
00:24:04,300 --> 00:24:06,310
which is this theory of particle physics

625
00:24:06,310 --> 00:24:08,450
that we've validated with experiment

626
00:24:08,450 --> 00:24:09,710
but we know has some holes in it,

627
00:24:09,710 --> 00:24:12,970
and there's things that
aren't explained by it.

628
00:24:12,970 --> 00:24:14,670
Maybe vacuum decay will happen.

629
00:24:14,670 --> 00:24:17,120
Maybe it'll happen in five
minutes, probably not.

630
00:24:17,957 --> 00:24:20,963
- I assume you have to tell
a lot of people probably not.

631
00:24:22,420 --> 00:24:23,253
- I do.

632
00:24:23,253 --> 00:24:24,310
Every time I talk about vacuum decay,

633
00:24:24,310 --> 00:24:25,797
I have to be really,
really careful to say,

634
00:24:25,797 --> 00:24:27,160
"Please do not worry about this,"

635
00:24:27,160 --> 00:24:29,120
because people do worry about this

636
00:24:29,120 --> 00:24:30,560
'cause some people get very anxious

637
00:24:30,560 --> 00:24:32,240
about the idea of the
universe suddenly ending,

638
00:24:32,240 --> 00:24:34,480
which, on some level, I can understand,

639
00:24:34,480 --> 00:24:37,740
but you wouldn't even
notice it if it happened

640
00:24:37,740 --> 00:24:40,005
because it would happen so quickly.

641
00:24:40,005 --> 00:24:41,176

- And it happens to everybody at once.

642
00:24:41,176 --> 00:24:43,360
- And it happens to everyone at once,

643
00:24:43,360 --> 00:24:46,160
or like in a sort of bubble of doom

644
00:24:46,160 --> 00:24:48,560
that expands at the speed of light,

645
00:24:48,560 --> 00:24:49,810
and so it doesn't matter.

646
00:24:50,693 --> 00:24:51,526
- Bubble of doom expanding

647
00:24:51,526 --> 00:24:52,359
at the speed of light?
- Yeah, what is that?

648
00:24:52,359 --> 00:24:54,500
What is a bubble of doom?

649
00:24:54,500 --> 00:24:56,800
- When the quantum event
occurs in one spot,

650
00:24:56,800 --> 00:24:58,610
it creates a bubble of a new kind of space

651
00:24:58,610 --> 00:24:59,630
called a true vacuum,

652
00:24:59,630 --> 00:25:02,500
and that bubble expands at
about the speed of light,

653

00:25:02,500 --> 00:25:04,520
and therefore you can't see it coming

654
00:25:04,520 --> 00:25:06,870
and it just destroys everything
immediately when it hits it.

655
00:25:06,870 --> 00:25:08,760
But anyway, the point is-

656
00:25:08,760 --> 00:25:09,593
- Don't worry.

657
00:25:09,593 --> 00:25:10,690
- The point is don't worry

658
00:25:10,690 --> 00:25:12,720
because there's nothing
you can do about it,

659
00:25:12,720 --> 00:25:13,770
you wouldn't see it coming,

660
00:25:13,770 --> 00:25:15,820
nothing would be left,
you wouldn't notice it,

661
00:25:15,820 --> 00:25:19,050
and it's all, as I said,
based on these ideas

662
00:25:19,050 --> 00:25:21,350
about the standard model
of particle physics

663
00:25:21,350 --> 00:25:24,240
where we know that there are
missing pieces to that theory,

664

00:25:24,240 --> 00:25:26,630
and so we don't know which pieces may

665
00:25:26,630 --> 00:25:28,090
or may not come into play

666
00:25:28,090 --> 00:25:30,110
in real possibility of vacuum decay,

667
00:25:30,110 --> 00:25:31,580
and there are much more immediate things

668
00:25:31,580 --> 00:25:34,060
that we should worry
about that are not a tiny,

669
00:25:34,060 --> 00:25:36,100
infinitesimally small chance of happening

670
00:25:36,100 --> 00:25:38,410
in like 100 billion years, right?

671
00:25:38,410 --> 00:25:39,680
So don't worry about vacuum decay.

672
00:25:39,680 --> 00:25:41,410
- Is there a more likely scenario

673
00:25:41,410 --> 00:25:43,443
that people billions of years
from now should worry about?

674
00:25:43,443 --> 00:25:45,630
- I think the most likely scenario,

675
00:25:45,630 --> 00:25:47,750
as far as what we know
about the universe now,

676
00:25:47,750 --> 00:25:49,430
is something called the heat death,

677
00:25:49,430 --> 00:25:52,670
which is where the universe
basically kind of fizzles out.

678
00:25:52,670 --> 00:25:55,210
So we know the universe
is currently expanding.

679
00:25:55,210 --> 00:25:57,170
We know it's accelerating
in its expansion,

680
00:25:57,170 --> 00:25:58,450
and what's happening is really

681
00:25:58,450 --> 00:26:01,100
that galaxies are getting
farther apart from each other.

682
00:26:01,100 --> 00:26:02,910
Everything's getting
more and more isolated,

683
00:26:02,910 --> 00:26:07,310
and so if we follow that,
extrapolate that into the future,

684
00:26:07,310 --> 00:26:08,970
in 100 billion years,

685
00:26:08,970 --> 00:26:11,270
every galaxy will be kind of on its own,

686
00:26:11,270 --> 00:26:12,660
unable to see other galaxies.

687
00:26:12,660 --> 00:26:13,493
In 100 billion years,

688
00:26:13,493 --> 00:26:15,360
if you put the Hubble Space Telescope up,

689
00:26:15,360 --> 00:26:16,700
it won't see anything.

690
00:26:16,700 --> 00:26:18,590
It'll just be darkness out there.

691
00:26:18,590 --> 00:26:19,423
You might see a few
lights in the Milky Way.

692
00:26:19,423 --> 00:26:20,256
- Because everything's expanding away

693
00:26:20,256 --> 00:26:22,360
from everything else all the time?

694
00:26:22,360 --> 00:26:23,800
- The Milky Way Galaxy, by that time,

695
00:26:23,800 --> 00:26:25,840
will have merged with
the Andromeda Galaxy,

696
00:26:25,840 --> 00:26:28,420
so there will be some
stars still in our galaxy.

697
00:26:28,420 --> 00:26:30,390
Most of them will have died by then,

698
00:26:30,390 --> 00:26:33,320
but some will be around, and that's it.

699
00:26:33,320 --> 00:26:34,420
All the other galaxies will be

700
00:26:34,420 --> 00:26:36,150
so far away from us moving so quickly

701
00:26:36,150 --> 00:26:37,948
we won't be able to see
their light anymore.

702
00:26:37,948 --> 00:26:41,080
- And this is even if we have
a major technological advance.

703
00:26:41,080 --> 00:26:41,913
- Oh yeah, yeah.

704
00:26:41,913 --> 00:26:43,663
No, this is a fundamental
limit of the universe that,

705
00:26:43,663 --> 00:26:44,820
in a 100 billion years,

706
00:26:44,820 --> 00:26:47,220
we will not be able to see other galaxies.

707
00:26:47,220 --> 00:26:50,160
- Is it like how now
we can only see so far

708
00:26:50,160 --> 00:26:52,580
until we can't see any further?

709
00:26:52,580 --> 00:26:54,080
The observable universe ends,

710

00:26:54,080 --> 00:26:55,820
and then whatever is past that.

711
00:26:55,820 --> 00:26:57,860
Do we have any idea what's...

712
00:26:57,860 --> 00:26:58,780
No?
- No, no.

713
00:26:58,780 --> 00:27:01,680
I mean, we're pretty sure
the universe continues

714
00:27:01,680 --> 00:27:02,880
more or less as it is

715
00:27:02,880 --> 00:27:05,070
past the edge of the observable universe,

716
00:27:05,070 --> 00:27:06,610
but we don't know.

717
00:27:06,610 --> 00:27:08,540
We have no direct information

718
00:27:08,540 --> 00:27:10,540
about anything beyond
the observable universe.

719
00:27:10,540 --> 00:27:13,020
So anyway, in the future,
like in 100 billion years,

720
00:27:13,020 --> 00:27:16,000
astronomers, physicists,
will have no evidence

721
00:27:16,000 --> 00:27:17,770

that other galaxies exist.

722
00:27:17,770 --> 00:27:19,110
They'll have no evidence of the Big Bang

723
00:27:19,110 --> 00:27:21,377
because they won't have
any direct data about that.

724
00:27:21,377 --> 00:27:22,900
- That's under the assumption

725
00:27:22,900 --> 00:27:26,150
that there will be people
around to make observations.

726
00:27:26,150 --> 00:27:28,530
Will our galaxy have
smashed into Andromeda

727
00:27:28,530 --> 00:27:31,491
in a catastrophic way or in a...

728
00:27:31,491 --> 00:27:34,382
- It depends on what you
mean by catastrophic.

729
00:27:34,382 --> 00:27:35,241
- You have a different definition-

730
00:27:35,241 --> 00:27:37,290
- Yeah, yeah.

731
00:27:37,290 --> 00:27:40,470
Most of the stars will
survive when that happens.

732
00:27:40,470 --> 00:27:41,690
Even in a galaxy collision,

733
00:27:41,690 --> 00:27:43,650
stars don't hit each other generally.

734
00:27:43,650 --> 00:27:44,910
There's a lot of empty space.

735
00:27:44,910 --> 00:27:47,230
There will be new bursts
of star formation,

736
00:27:47,230 --> 00:27:49,720
not a whole lot in that
collision, but some,

737
00:27:49,720 --> 00:27:52,050
so a few things might
get fried by supernovae.

738
00:27:52,050 --> 00:27:53,500
Supermassive black holes in the centers

739
00:27:53,500 --> 00:27:54,830
of the galaxies will merge,

740
00:27:54,830 --> 00:27:56,570
and that could create jets of radiation

741
00:27:56,570 --> 00:27:58,880
that might be hazardous,
but basically it'll be fine.

742
00:27:58,880 --> 00:28:01,840
- That should be the subtitle
of your book: "It'll Be Fine."

743
00:28:01,840 --> 00:28:03,390
- It'll be fine, yeah, yeah.

744
00:28:03,390 --> 00:28:06,060
But of course the Earth
will be long dead because-

745
00:28:06,060 --> 00:28:06,893
- That's the spirit.

746
00:28:06,893 --> 00:28:09,510
- Yeah, because the Sun only has

747
00:28:09,510 --> 00:28:12,990
about 5 billion years
more of burning hydrogen,

748
00:28:12,990 --> 00:28:16,770
and even before that, in only
about a billion years or so,

749
00:28:16,770 --> 00:28:19,160
it'll get so hot or so bright,

750
00:28:19,160 --> 00:28:20,480
and it'll expand a little bit

751
00:28:20,480 --> 00:28:22,390
and it'll boil off the
oceans of the Earth,

752
00:28:22,390 --> 00:28:24,050
and the Earth will become uninhabitable,

753
00:28:24,050 --> 00:28:25,400
so maybe we'll live somewhere else.

754
00:28:25,400 --> 00:28:28,000
I don't know, but the Earth will not...

755
00:28:28,000 --> 00:28:29,330

Humans will not be on Earth.

756
00:28:29,330 --> 00:28:31,700
- Is there anything that can happen

757
00:28:31,700 --> 00:28:33,100
after the end of the universe?

758
00:28:33,100 --> 00:28:35,140
Like in this vacuum decay situation,

759
00:28:35,140 --> 00:28:36,840
there's this new vacuum.

760
00:28:36,840 --> 00:28:38,340
Can anything come out of that?

761
00:28:40,240 --> 00:28:43,260
- Unfortunately, based
on what we understand

762
00:28:43,260 --> 00:28:44,680
of the new vacuum...

763
00:28:45,947 --> 00:28:47,780
I'm sorry. (laughs)

764
00:28:47,780 --> 00:28:48,730
- I love that you're laughing

765
00:28:48,730 --> 00:28:51,443
as you tell us all this
bad news about our future.

766
00:28:52,950 --> 00:28:56,580
- So once you're inside the
new vacuum, the true vacuum,

767

00:28:56,580 --> 00:28:59,410
so first of all, your atoms dissociate

768
00:28:59,410 --> 00:29:01,480
because you have new
laws of physics in there

769
00:29:01,480 --> 00:29:04,840
and you don't have
electromagnetism anymore.

770
00:29:04,840 --> 00:29:07,670
That's bad, but also
it turns out, (laughs)

771
00:29:07,670 --> 00:29:10,530
turns out there was a
calculation in 1980 suggesting

772
00:29:10,530 --> 00:29:13,960
that the new vacuum is
gravitationally unstable.

773
00:29:13,960 --> 00:29:15,760
Once you're inside and
you've been dissociated,

774
00:29:15,760 --> 00:29:17,780
you also collapse into a black hole.

775
00:29:17,780 --> 00:29:19,560
So, sorry. (laughs)

776
00:29:19,560 --> 00:29:20,393
- That's the way I've always wanted to go.

777
00:29:20,393 --> 00:29:23,840
- There's an amazing paper
by Coleman and De Luccia

778
00:29:23,840 --> 00:29:26,920
from 1980 that goes through this process

779
00:29:26,920 --> 00:29:30,080
and that explains that this
collapse will probably happen,

780
00:29:30,080 --> 00:29:32,580
and they have this wonderful paragraph

781
00:29:32,580 --> 00:29:37,580
about how you might have had
hope that after the new vacuum,

782
00:29:38,670 --> 00:29:39,980
there'd be a new concept of nature,

783
00:29:39,980 --> 00:29:42,050
and not only is life as
we know it impossible,

784
00:29:42,050 --> 00:29:43,960
so is chemistry as we know it impossible,

785
00:29:43,960 --> 00:29:46,150
but had some stoic comfort from the fact

786
00:29:46,150 --> 00:29:48,180
that perhaps in the course of time,

787
00:29:48,180 --> 00:29:51,130
the new vacuum would sustain,
if not life as we know it,

788
00:29:51,130 --> 00:29:54,090
at least some structures
capable of knowing joy,

789

00:29:54,090 --> 00:29:55,397
and then they say,

790
00:29:55,397 --> 00:29:57,350
"This possibility has
now been eliminated."

791
00:29:57,350 --> 00:29:59,903
- Great.
- (laughs) It's like, oh man.

792
00:30:01,550 --> 00:30:03,120
- I'm curious.

793
00:30:03,120 --> 00:30:04,270
You've looked at the universe

794
00:30:04,270 --> 00:30:07,220
in its entire lifetime
so far and then some.

795
00:30:07,220 --> 00:30:09,950
Where do we sit now in
the age of the universe?

796
00:30:09,950 --> 00:30:11,030
- Well, so if we're assuming

797
00:30:11,030 --> 00:30:13,450
that the heat death is where we're headed,

798
00:30:13,450 --> 00:30:17,460
where after you stop being
able to see other galaxies,

799
00:30:17,460 --> 00:30:18,960
then the universe continues to expand

800
00:30:18,960 --> 00:30:20,950

and stars burn out in our galaxy

801
00:30:20,950 --> 00:30:23,137
and matter decays and you
end up with black holes

802
00:30:23,137 --> 00:30:25,290
and the black holes evaporate
and then you're just

803
00:30:25,290 --> 00:30:28,410
sort of like this cold,
dark, empty universe,

804
00:30:28,410 --> 00:30:30,900
if that's where we're headed,
then on the time scale,

805
00:30:30,900 --> 00:30:32,520
we're at the very beginning because the-

806
00:30:32,520 --> 00:30:33,570
- Still.

807
00:30:33,570 --> 00:30:35,860
- Yeah, because the
amount of time it takes

808
00:30:35,860 --> 00:30:39,130
to get to that end stage is
like you putting exponents

809
00:30:39,130 --> 00:30:41,230
on exponents on exponents.

810
00:30:41,230 --> 00:30:43,550
There are not good words
for the number of years

811

00:30:43,550 --> 00:30:44,383
that you'd have to write down for that.

812
00:30:44,383 --> 00:30:48,520
- So we're roughly at 14
billion since the beginning now,

813
00:30:48,520 --> 00:30:51,070
and that's dwarfed by the time ahead?

814
00:30:51,070 --> 00:30:53,040
- Yeah, yeah, I mean, it's 100 billion

815
00:30:53,040 --> 00:30:55,610
before we just stop being
able to see other galaxies,

816
00:30:55,610 --> 00:30:57,590
and then trillions and
trillions and trillions

817
00:30:57,590 --> 00:31:01,340
and trillions onward before
black holes evaporate,

818
00:31:01,340 --> 00:31:02,830
and then onward and onward

819
00:31:02,830 --> 00:31:05,820
before you get to what
you would call the end,

820
00:31:05,820 --> 00:31:07,120
the true heat death.

821
00:31:07,120 --> 00:31:10,380
But if you judge by how much has happened,

822
00:31:10,380 --> 00:31:11,940

we're almost at the end.

823
00:31:11,940 --> 00:31:14,900
So you can calculate how
many stars have formed

824
00:31:14,900 --> 00:31:18,200
in the universe, the rate of
star formation in the universe,

825
00:31:18,200 --> 00:31:19,117
and it depends on a lot of things,

826
00:31:19,117 --> 00:31:20,680
and one of the things it depends on is

827
00:31:20,680 --> 00:31:23,050
how often galaxies are
colliding with each other

828
00:31:23,050 --> 00:31:25,370
and coming in to mix their gas

829
00:31:25,370 --> 00:31:27,240
and form new stars that way, right?

830
00:31:27,240 --> 00:31:29,210
And so as the universe is expanding,

831
00:31:29,210 --> 00:31:31,240
galaxy collisions are happening less often

832
00:31:31,240 --> 00:31:33,520
and starbursts are happening less often,

833
00:31:33,520 --> 00:31:36,100
and so we can look back and we can say,

834

00:31:36,100 --> 00:31:39,300
somewhere 6 or 7 or 8
or 9 billion years ago,

835
00:31:39,300 --> 00:31:41,027
there was way more star formation

836
00:31:41,027 --> 00:31:44,130
and it's been declining since then, right?

837
00:31:44,130 --> 00:31:45,670
And you can work out that,

838
00:31:45,670 --> 00:31:48,230
of all the stars that
ever formed in the past

839
00:31:48,230 --> 00:31:51,610
or that ever will form in the
future based on our evolution,

840
00:31:51,610 --> 00:31:54,723
about 90% have already happened,

841
00:31:55,790 --> 00:31:57,710
from now until the end of time.

842
00:31:57,710 --> 00:31:59,400
- Does the universe just get kind of

843
00:31:59,400 --> 00:32:00,570
more boring and spread out?

844
00:32:00,570 --> 00:32:02,210
Oh, great.
- Yeah, and just the last five

845
00:32:02,210 --> 00:32:04,350
or 10% of stars are going to form,

846
00:32:04,350 --> 00:32:06,570
but all the others have already been born

847
00:32:06,570 --> 00:32:08,120
and are either burning or died.

848
00:32:08,120 --> 00:32:10,060
So in that sense, we're almost at the end.

849
00:32:10,060 --> 00:32:11,751
So I don't know, it depends
on whether you want to-

850
00:32:11,751 --> 00:32:13,050
- You still seem so optimistic.

851
00:32:13,050 --> 00:32:14,660
- Yeah, it depends on
whether you want to think

852
00:32:14,660 --> 00:32:17,360
about how much time you have
or how much is going to happen.

853
00:32:17,360 --> 00:32:20,110
- But these are time scales
that boggle anyone's-

854
00:32:20,110 --> 00:32:20,943
- Yeah.

855
00:32:20,943 --> 00:32:21,776
- What's the term?

856
00:32:21,776 --> 00:32:22,609
Vertigo.

857

00:32:22,609 --> 00:32:24,157
- Cosmic vertigo?

858
00:32:24,157 --> 00:32:25,710
- Cosmic vertigo?
- Yeah.

859
00:32:25,710 --> 00:32:28,533
- When your mind reels at the scales

860
00:32:28,533 --> 00:32:31,200
and the time scale and the size.

861
00:32:32,700 --> 00:32:33,870
- I don't know, maybe some people can,

862
00:32:33,870 --> 00:32:35,460
but I can't really hold those numbers

863
00:32:35,460 --> 00:32:37,020
in my head in any meaningful way.

864
00:32:37,020 --> 00:32:40,220
This is why you use scientific
notation for everything,

865
00:32:40,220 --> 00:32:44,450
10 to the 11 years,
those kinds of numbers,

866
00:32:44,450 --> 00:32:46,987
because you have to try and think sort of

867
00:32:46,987 --> 00:32:50,850
and factor in powers of
10, or you just get...

868
00:32:50,850 --> 00:32:52,550
It's meaningless.

869
00:32:52,550 --> 00:32:55,430
Conceptually, I know that a billion is

870
00:32:55,430 --> 00:32:57,540
a thousand times as much as a million,

871
00:32:57,540 --> 00:33:00,180
but in my head, it's like it's
about twice as much, right?

872
00:33:00,180 --> 00:33:01,710
No, it's not.

873
00:33:01,710 --> 00:33:03,580
- Billionaires are much
richer than millionaires.

874
00:33:03,580 --> 00:33:05,840
- Yeah, to an absurd degree,

875
00:33:05,840 --> 00:33:09,540
but my own sort of conception is like,

876
00:33:09,540 --> 00:33:11,030
oh, it says million and
then there's a billion,

877
00:33:11,030 --> 00:33:13,273
and it's like it's
about twice, but no, no.

878
00:33:14,348 --> 00:33:15,780
- I'm glad to hear you do that too.

879
00:33:15,780 --> 00:33:19,490
- Yeah, so I still have to
remind myself that these are,

880
00:33:19,490 --> 00:33:21,070
when you're thinking and trying to think

881
00:33:21,070 --> 00:33:22,960
in a logarithmic scale,

882
00:33:22,960 --> 00:33:25,280
you're not really conceptualizing it.

883
00:33:25,280 --> 00:33:27,130
You just have to kind of trust the numbers

884
00:33:27,130 --> 00:33:29,510
and try and sort of fake the intuition.

885
00:33:29,510 --> 00:33:31,000
Again, maybe some people

886
00:33:31,000 --> 00:33:33,380
can hold those numbers in
their head, but I really can't.

887
00:33:33,380 --> 00:33:35,900
- And talking about
these different scenarios

888
00:33:35,900 --> 00:33:37,430
where the universe might end,

889
00:33:37,430 --> 00:33:40,200
would you be able to put any odds on

890
00:33:40,200 --> 00:33:41,560
what percentage you would say

891
00:33:41,560 --> 00:33:43,900
it's going to be this heat
death versus something else?

892
00:33:43,900 --> 00:33:46,920
- I'd put pretty good
odds on the heat death,

893
00:33:46,920 --> 00:33:49,060
I'd say, I don't know, maybe like 80%

894
00:33:49,060 --> 00:33:50,540
or something like that.

895
00:33:50,540 --> 00:33:51,610
There are other possibilities.

896
00:33:51,610 --> 00:33:53,880
So we don't know what dark energy is,

897
00:33:53,880 --> 00:33:55,540
and the idea of the heat death depends on

898
00:33:55,540 --> 00:33:58,150
dark energy being a cosmological constant

899
00:33:58,150 --> 00:34:00,350
where it's just a
property of the universe,

900
00:34:00,350 --> 00:34:02,230
it has this stretchiness built in,

901
00:34:02,230 --> 00:34:05,860
it's just that's a thing
that the universe does.

902
00:34:05,860 --> 00:34:07,820
Dark energy could be
something that's dynamic,

903

00:34:07,820 --> 00:34:08,880
that changes with time,

904
00:34:08,880 --> 00:34:11,460
that's a sort of field in the universe

905
00:34:11,460 --> 00:34:14,680
that has a behavior,
and if that's the case,

906
00:34:14,680 --> 00:34:16,920
then it could do anything, right?

907
00:34:16,920 --> 00:34:18,560
It could get more powerful over time,

908
00:34:18,560 --> 00:34:21,040
and that would lead to
something called a Big Rip,

909
00:34:21,040 --> 00:34:23,760
where not only are galaxies
isolated from each other,

910
00:34:23,760 --> 00:34:25,230
they're also torn apart from the inside,

911
00:34:25,230 --> 00:34:29,180
and then stars are destroyed
and atoms and nuclei

912
00:34:29,180 --> 00:34:30,654
and you just tear apart
the whole universe.

913
00:34:30,654 --> 00:34:31,700
- So violent.

914
00:34:31,700 --> 00:34:35,600

- Yeah, yeah, and that
one's unlikely for some...

915
00:34:35,600 --> 00:34:38,710
There's theoretical reasons
to not favor that idea,

916
00:34:38,710 --> 00:34:41,290
but the data can't rule it out just yet.

917
00:34:41,290 --> 00:34:42,910
And then there's the Big Crunch,

918
00:34:42,910 --> 00:34:44,490
which is something that they used to think

919
00:34:44,490 --> 00:34:47,000
in the 60s was most likely where,

920
00:34:47,000 --> 00:34:49,430
in the Big Crunch, the
expansion of the universe stops

921
00:34:49,430 --> 00:34:51,920
and reverses and everything
kind of comes back together.

922
00:34:51,920 --> 00:34:53,060
We don't think that's likely now

923
00:34:53,060 --> 00:34:54,350
'cause the expansion is accelerating,

924
00:34:54,350 --> 00:34:56,270
but if dark energy is
something that can change

925
00:34:56,270 --> 00:34:59,270
and turn around, it could

collapse the universe again.

926
00:34:59,270 --> 00:35:00,870
Because we don't know what dark energy is,

927
00:35:00,870 --> 00:35:03,430
we don't know which of those
possibilities might happen,

928
00:35:03,430 --> 00:35:05,660
and then there's cyclic models,

929
00:35:05,660 --> 00:35:08,640
models where the universe
ends one way or another

930
00:35:08,640 --> 00:35:11,050
and then starts again, and we don't know

931
00:35:11,050 --> 00:35:12,330
if those might have happened,

932
00:35:12,330 --> 00:35:14,430
and there are some reasons to believe

933
00:35:14,430 --> 00:35:17,250
that there are sort of
advantages to those models

934
00:35:17,250 --> 00:35:20,150
versus an inflationary early universe

935
00:35:20,150 --> 00:35:21,590
'cause you can set up
the initial conditions

936
00:35:21,590 --> 00:35:23,020
of the universe differently

937
00:35:23,020 --> 00:35:24,930
if you have a previous cycle to draw from.

938
00:35:24,930 --> 00:35:28,810
So the cyclic models could
give you something else,

939
00:35:28,810 --> 00:35:31,020
and those could end with
something like a heat death

940
00:35:31,020 --> 00:35:33,230
or something like a Big Crunch,

941
00:35:33,230 --> 00:35:36,250
depending on what's governing that cycle.

942
00:35:36,250 --> 00:35:37,220
There are other possibilities,

943
00:35:37,220 --> 00:35:39,160
but if I had to bet on it

944
00:35:39,160 --> 00:35:40,910
and if I thought that it would ever,

945
00:35:40,910 --> 00:35:43,170
I'd actually ever see
the result of that wager,

946
00:35:43,170 --> 00:35:46,250
then I would probably
put it on the heat death.

947
00:35:46,250 --> 00:35:50,160
- A lot of people may know
you not so well as Katie Mack

948

00:35:50,160 --> 00:35:52,780
and even better as AstroKatie.

949
00:35:52,780 --> 00:35:56,177
How and when did AstroKatie
become a thing on Twitter,

950
00:35:56,177 --> 00:35:57,930
and how did it...

951
00:35:57,930 --> 00:35:59,557
I don't know how many
followers you have, but-

952
00:35:59,557 --> 00:36:01,630
- A lot.
- It's astronomical numbers.

953
00:36:01,630 --> 00:36:03,850
- Yeah, I think it's around
400,000 or something now.

954
00:36:03,850 --> 00:36:04,683
I don't know.

955
00:36:04,683 --> 00:36:05,630
- And that's just when we record,

956
00:36:05,630 --> 00:36:07,050
not when we're airing this.

957
00:36:07,050 --> 00:36:07,883
- That's true.

958
00:36:07,883 --> 00:36:08,716
Yeah, who knows?

959
00:36:09,570 --> 00:36:11,669
Maybe they'll all wander off.

960
00:36:11,669 --> 00:36:12,760
- Oh, I meant it would grow, not-

961
00:36:12,760 --> 00:36:15,470
- Yeah, I know, I know,
but you never know.

962
00:36:15,470 --> 00:36:16,890
You always wonder.

963
00:36:16,890 --> 00:36:18,136
Like dark energy, you don't
know which way it'll go.

964
00:36:18,136 --> 00:36:19,255
- Yeah, might turn around.

965
00:36:19,255 --> 00:36:20,430
- Yeah.

966
00:36:20,430 --> 00:36:23,470
Yeah, so I started on Twitter
when I was in grad school,

967
00:36:23,470 --> 00:36:26,010
and I just chose the name AstroKatie

968
00:36:26,010 --> 00:36:27,910
just as like something...

969
00:36:27,910 --> 00:36:31,830
I wanted to throw in astronomy in my name.

970
00:36:31,830 --> 00:36:34,610
I don't know, it just seemed
like a reasonable choice.

971

00:36:34,610 --> 00:36:37,560
I started it just as
a way of kind of like,

972
00:36:37,560 --> 00:36:40,090
Twitter was new, I wanted to
see what people were doing,

973
00:36:40,090 --> 00:36:41,750
and then when I was a postdoc,

974
00:36:41,750 --> 00:36:44,860
I saw one of my colleagues
was using Twitter

975
00:36:44,860 --> 00:36:47,590
to talk about physics,
to talk about astronomy,

976
00:36:47,590 --> 00:36:49,123
and I thought that was

977
00:36:49,123 --> 00:36:50,537
a really interesting way to do things,

978
00:36:50,537 --> 00:36:53,270
and he would do things like he
would live tweet a conference

979
00:36:53,270 --> 00:36:55,940
and a little like one
tweet per talk or something

980
00:36:55,940 --> 00:36:57,030
about what was going on in a conference,

981
00:36:57,030 --> 00:36:58,600
and I thought that was a cool idea,

982

00:36:58,600 --> 00:37:00,990
and at some point I was visiting...

983
00:37:00,990 --> 00:37:02,910
He was based at Oxford.

984
00:37:02,910 --> 00:37:03,743
His name is Phil Marshall.

985
00:37:03,743 --> 00:37:04,800
He was based at Oxford at the time,

986
00:37:04,800 --> 00:37:08,050
and I was at Oxford to
attend a conference,

987
00:37:08,050 --> 00:37:09,270
and he was also at Oxford,

988
00:37:09,270 --> 00:37:10,560
but he couldn't make it to the meeting.

989
00:37:10,560 --> 00:37:12,080
He was like, "Oh, can you
live tweet this for me?"

990
00:37:12,080 --> 00:37:12,913
I'm like, "Okay."

991
00:37:12,913 --> 00:37:14,840
So I live tweet the talks,

992
00:37:14,840 --> 00:37:17,880
and he got a bunch of his followers to,

993
00:37:17,880 --> 00:37:20,090
he retweeted my stuff to
a bunch of his followers,

994
00:37:20,090 --> 00:37:21,150
so it started there.

995
00:37:21,150 --> 00:37:23,200
So it started really just talking

996
00:37:23,200 --> 00:37:27,840
to other physicists and astronomers
and a few non-scientists

997
00:37:27,840 --> 00:37:30,790
who just enjoy following
physicists and astronomers,

998
00:37:30,790 --> 00:37:33,010
and then it just kind of snowballed.

999
00:37:33,010 --> 00:37:34,850
I would tweet more and get more followers

1000
00:37:34,850 --> 00:37:37,810
through retweets and
stuff and it compounds,

1001
00:37:37,810 --> 00:37:39,373
and there were a few times
when I would tweet something

1002
00:37:39,373 --> 00:37:40,570
that would go kind of viral

1003
00:37:40,570 --> 00:37:43,150
and then that would give me a
huge chunk of new followers.

1004
00:37:43,150 --> 00:37:45,330
- Can you think of the
first time you had like a,

1005
00:37:45,330 --> 00:37:48,270
where @AstroKatie had like a viral...

1006
00:37:48,270 --> 00:37:52,130
- The biggest one was when I was tweeting

1007
00:37:52,130 --> 00:37:56,740
about climate change, and
somebody who doesn't believe

1008
00:37:56,740 --> 00:37:59,217
in climate change replied
to my tweet saying,

1009
00:37:59,217 --> 00:38:00,287
"Oh, this is a big scam.

1010
00:38:00,287 --> 00:38:01,277
"It's a hoax.

1011
00:38:01,277 --> 00:38:02,713
"You should go learn some science."

1012
00:38:02,713 --> 00:38:04,972
- (laughs) Oops.

1013
00:38:04,972 --> 00:38:09,117
- (laughs) And I said,
"Well, I don't know, man.

1014
00:38:09,117 --> 00:38:11,047
"I already went and got
a PhD in astrophysics.

1015
00:38:11,047 --> 00:38:13,397
"I feel like more than
that would be overkill."

1016

00:38:14,700 --> 00:38:17,560
I was just amusing myself
by replying to this guy.

1017
00:38:17,560 --> 00:38:19,140
I didn't think anybody would see it.

1018
00:38:19,140 --> 00:38:20,460
I wasn't trying to make a big thing.

1019
00:38:20,460 --> 00:38:22,730
I wasn't quote tweeting him or whatever.

1020
00:38:22,730 --> 00:38:25,410
It was just a nothing
reply, but people saw it

1021
00:38:25,410 --> 00:38:28,680
and started sharing it
and started retweeting it

1022
00:38:28,680 --> 00:38:31,373
and talking about it like,
oh, this is a smackdown.

1023
00:38:32,860 --> 00:38:33,780
I just wanted...

1024
00:38:34,834 --> 00:38:35,688
- Just wanted to answer a guy-

1025
00:38:35,688 --> 00:38:38,790
- Yeah, I was just kind of
making a little joke to myself.

1026
00:38:38,790 --> 00:38:40,800
Anyway, and it just got super viral,

1027
00:38:40,800 --> 00:38:44,950

and I went from 40,000 followers
to 80,000 in like a week,

1028
00:38:44,950 --> 00:38:47,700
and then a bunch of minor
internet celebrities

1029
00:38:47,700 --> 00:38:48,890
started following me,

1030
00:38:48,890 --> 00:38:53,890
and then J.K. Rowling tweeted
a screenshot of it on her feed

1031
00:38:54,060 --> 00:38:55,760
and that got a bunch of followers.

1032
00:38:56,780 --> 00:38:58,763
It just kind of became this thing.

1033
00:38:59,740 --> 00:39:01,370
- It seems like you've
rolled with it though,

1034
00:39:01,370 --> 00:39:04,120
because it's an outlet
for you to share science.

1035
00:39:04,120 --> 00:39:06,443
- Yeah, it's been great.

1036
00:39:08,110 --> 00:39:09,330
I really like Twitter

1037
00:39:09,330 --> 00:39:12,470
because I don't talk just about science.

1038
00:39:12,470 --> 00:39:14,140
I talk a lot about science on Twitter,

1039
00:39:14,140 --> 00:39:16,770
but I also talk about
what's going on in the world

1040
00:39:16,770 --> 00:39:19,100
and I make jokes about random things

1041
00:39:19,100 --> 00:39:22,150
and share funny images or whatever,

1042
00:39:22,150 --> 00:39:25,910
but it's a way for me to
both talk about science

1043
00:39:25,910 --> 00:39:28,060
and get immediate feedback on that,

1044
00:39:28,060 --> 00:39:30,070
like have conversations, answer questions.

1045
00:39:30,070 --> 00:39:32,040
That's really valuable
as a science communicator

1046
00:39:32,040 --> 00:39:34,070
to see what people are interested in,

1047
00:39:34,070 --> 00:39:35,560
see what people are confused about,

1048
00:39:35,560 --> 00:39:39,050
see how different metaphors
work and stuff like that.

1049
00:39:39,050 --> 00:39:42,280
But then also I can present
myself as a scientist

1050
00:39:42,280 --> 00:39:44,370
who is not a science robot,

1051
00:39:44,370 --> 00:39:45,700
and I think that's really valuable

1052
00:39:45,700 --> 00:39:47,980
as a science communicator to show that,

1053
00:39:47,980 --> 00:39:50,810
just 'cause I'm a physicist,

1054
00:39:50,810 --> 00:39:53,410
doesn't mean that I only
ever think about physics

1055
00:39:53,410 --> 00:39:55,710
and I have nothing else
going on in my life,

1056
00:39:55,710 --> 00:39:59,380
because the sort of media
perception of scientists is

1057
00:39:59,380 --> 00:40:02,330
these incredibly cloistered,
single-minded people

1058
00:40:02,330 --> 00:40:04,150
who don't know how to
interact with humans,

1059
00:40:04,150 --> 00:40:06,040
and I think that's a harmful stereotype

1060
00:40:06,040 --> 00:40:09,280
for a number of reasons, and
I think that it's helpful

1061
00:40:09,280 --> 00:40:12,500
for a lot of things for
scientists to be more visible,

1062
00:40:12,500 --> 00:40:14,533
be more obviously human.

1063
00:40:16,060 --> 00:40:18,647
It's a very important,
I think, role to play,

1064
00:40:18,647 --> 00:40:20,270
and so Twitter allows me to do that.

1065
00:40:20,270 --> 00:40:21,860
It allows me to give people an insight

1066
00:40:21,860 --> 00:40:24,620
into what's going on in my
life, what I care about,

1067
00:40:24,620 --> 00:40:27,030
and it gives me a platform for advocating

1068
00:40:27,030 --> 00:40:29,323
for things I think are important as well.

1069
00:40:29,323 --> 00:40:30,860
When I tweet about politics or whatever,

1070
00:40:30,860 --> 00:40:32,960
part of that's because people listen to me

1071
00:40:32,960 --> 00:40:35,620
and I want to get ideas out
there that I care about,

1072
00:40:35,620 --> 00:40:37,770

and I don't think that's a contradiction.

1073
00:40:37,770 --> 00:40:40,670
I think it's sort of
intentional oversharing

1074
00:40:40,670 --> 00:40:43,750
in terms of I want people
to see me as a human

1075
00:40:43,750 --> 00:40:45,020
with lots of different facets,

1076
00:40:45,020 --> 00:40:47,680
not just representing physics.

1077
00:40:47,680 --> 00:40:49,780
- One of the previous times
you and I hung out was

1078
00:40:49,780 --> 00:40:52,800
at Space Camp in Huntsville, Alabama,

1079
00:40:52,800 --> 00:40:55,470
and that was at a conference
full of science communicators

1080
00:40:55,470 --> 00:40:57,090
who are doing it through social media,

1081
00:40:57,090 --> 00:41:00,630
through YouTube, really creative ways.

1082
00:41:00,630 --> 00:41:03,430
When you started to
get momentum on Twitter

1083
00:41:03,430 --> 00:41:06,660
and got connected to all these

other science communicators,

1084
00:41:06,660 --> 00:41:09,180
was that sort of the impetus
for, oh, I want to do this,

1085
00:41:09,180 --> 00:41:10,013
or had you always thought,

1086
00:41:10,013 --> 00:41:13,100
"I want to communicate this science."

1087
00:41:13,100 --> 00:41:16,290
- The way I got started
into communicating science

1088
00:41:16,290 --> 00:41:19,720
in general is just that I get
really excited about things

1089
00:41:19,720 --> 00:41:21,910
and I want to share that excitement,

1090
00:41:21,910 --> 00:41:24,820
and I think it's just an
abundance of enthusiasm

1091
00:41:24,820 --> 00:41:28,020
that causes me to want to
tell everybody about like,

1092
00:41:28,020 --> 00:41:29,680
oh, this amazing thing I learned about

1093
00:41:29,680 --> 00:41:31,460
how orbits work or whatever,

1094
00:41:31,460 --> 00:41:33,270
and also I've done a lot of writing,

1095
00:41:33,270 --> 00:41:36,320
so I've always been somebody
who's done a ton of writing.

1096
00:41:36,320 --> 00:41:38,320
When I was little, I used to write stories

1097
00:41:38,320 --> 00:41:40,230
and letters and poems and stuff like that,

1098
00:41:40,230 --> 00:41:44,120
and then I got into science
writing as a freelancer

1099
00:41:44,120 --> 00:41:45,710
through grad school and postdoc,

1100
00:41:45,710 --> 00:41:48,930
years writing articles
for newspapers, magazines,

1101
00:41:48,930 --> 00:41:52,820
and so I just love
communicating about the universe

1102
00:41:52,820 --> 00:41:55,550
and sort of sharing what's exciting to me,

1103
00:41:55,550 --> 00:41:57,630
what's really fascinating.

1104
00:41:57,630 --> 00:42:00,530
Helping people to have
those insightful moments,

1105
00:42:00,530 --> 00:42:02,680
that's just hugely fun for me,

1106
00:42:02,680 --> 00:42:05,740
and so I think Twitter is part of that.

1107
00:42:05,740 --> 00:42:09,300
Twitter helped me a lot in
developing my understanding

1108
00:42:09,300 --> 00:42:11,960
of how to explain things
in a simple way 'cause-

1109
00:42:11,960 --> 00:42:13,510
- In a very small space.

1110
00:42:13,510 --> 00:42:15,333
- Yeah, and I have a question about that

1111
00:42:15,333 --> 00:42:17,580
because I've heard a
lot of researchers say,

1112
00:42:17,580 --> 00:42:20,710
and I really agree, that
giving a long presentation is

1113
00:42:20,710 --> 00:42:22,990
a lot easier than giving a
short presentation because,

1114
00:42:22,990 --> 00:42:24,810
and I find that really challenging

1115
00:42:24,810 --> 00:42:27,460
when I have to give a 15-minute
presentation on my work.

1116
00:42:27,460 --> 00:42:29,480
You have to take out all these details

1117
00:42:29,480 --> 00:42:31,760
that are maybe not necessary
to the fundamental point,

1118
00:42:31,760 --> 00:42:34,170
but figuring out what those
are is really not easy,

1119
00:42:34,170 --> 00:42:35,980
and so I think writing a tweet

1120
00:42:35,980 --> 00:42:38,570
where you're really limited
in how much you can share

1121
00:42:38,570 --> 00:42:39,950
is kind of the ultimate challenge.

1122
00:42:39,950 --> 00:42:42,680
So how do you face that
and how do you decide

1123
00:42:42,680 --> 00:42:43,920
what details to share,

1124
00:42:43,920 --> 00:42:45,620
what details the public needs to know,

1125
00:42:45,620 --> 00:42:46,620
whether it's about science

1126
00:42:46,620 --> 00:42:49,170
or some of these political
issues, whatever it is.

1127
00:42:49,170 --> 00:42:50,650
- Well, I mean, it got a lot easier

1128

00:42:50,650 --> 00:42:54,190
when they went from 120 to
240 characters, (laughs)

1129
00:42:54,190 --> 00:42:55,640
so that's one thing.

1130
00:42:55,640 --> 00:42:58,000
It's also possible now on
Twitter to do long threads,

1131
00:42:58,000 --> 00:43:00,330
and so that also takes
away some of the pressure,

1132
00:43:00,330 --> 00:43:03,200
but mostly it's about trying to...

1133
00:43:03,200 --> 00:43:04,033
It's hard.

1134
00:43:04,033 --> 00:43:06,550
I don't think there's
a quick, easy method,

1135
00:43:06,550 --> 00:43:09,250
but you have to think about the wording,

1136
00:43:09,250 --> 00:43:10,880
so it helps to be really good

1137
00:43:10,880 --> 00:43:12,770
with sort of a mental thesaurus

1138
00:43:12,770 --> 00:43:15,350
to be able to choose really compact words

1139
00:43:15,350 --> 00:43:17,210
to express the same idea,

1140
00:43:17,210 --> 00:43:21,530
but then also you want
to give a mental picture.

1141
00:43:21,530 --> 00:43:24,160
Maybe that's through an
analogy or maybe it's

1142
00:43:24,160 --> 00:43:27,460
through helping someone
to visualize something.

1143
00:43:27,460 --> 00:43:30,900
You want to give someone
something to connect to personally

1144
00:43:30,900 --> 00:43:32,830
one way or another, and how to do that,

1145
00:43:32,830 --> 00:43:34,250
it just depends on what
you're talking about,

1146
00:43:34,250 --> 00:43:37,003
but yeah, it's super hard,
and even longer-form stuff.

1147
00:43:38,060 --> 00:43:40,210
I used to write for Cosmos Magazine,

1148
00:43:40,210 --> 00:43:43,710
which is a magazine in
Australia, a science magazine

1149
00:43:43,710 --> 00:43:46,040
kind of like Discover
in the US or something,

1150

00:43:46,040 --> 00:43:47,350
and I had a column with them,

1151
00:43:47,350 --> 00:43:49,610
and it was like 700 or 800 words

1152
00:43:49,610 --> 00:43:51,860
and I'd write every couple of months,

1153
00:43:51,860 --> 00:43:53,130
and I could write about whatever I wanted.

1154
00:43:53,130 --> 00:43:54,970
At one point, I decided I wanted to write

1155
00:43:54,970 --> 00:43:58,010
about Noether's theorem,
which is this idea

1156
00:43:58,010 --> 00:44:01,180
that there's a connection
between conserved quantities

1157
00:44:01,180 --> 00:44:02,230
and symmetries of nature,

1158
00:44:02,230 --> 00:44:05,100
and explaining what those two things mean

1159
00:44:05,100 --> 00:44:07,920
is incredibly difficult,

1160
00:44:07,920 --> 00:44:09,890
and I won't try and go through it now

1161
00:44:09,890 --> 00:44:11,950
because it's actually really hard,

1162

00:44:11,950 --> 00:44:13,950
but this is an idea that's
really, really fundamental

1163
00:44:13,950 --> 00:44:15,860
in physics like the idea
of symmetries in general,

1164
00:44:15,860 --> 00:44:18,690
the idea of if you change
something about an equation,

1165
00:44:18,690 --> 00:44:20,870
what is it that changes
about the physics or doesn't

1166
00:44:20,870 --> 00:44:22,100
and how is that important,

1167
00:44:22,100 --> 00:44:24,380
and does the experiment work the same

1168
00:44:24,380 --> 00:44:26,590
forward or backward in time?

1169
00:44:26,590 --> 00:44:27,900
Is there rotational symmetry?

1170
00:44:27,900 --> 00:44:30,570
All these kinds of things
are just super fundamental

1171
00:44:30,570 --> 00:44:32,770
to how physics works, and
so I wanted to explain that.

1172
00:44:32,770 --> 00:44:37,320
It took me like two months
to get that into 700 words

1173
00:44:37,320 --> 00:44:39,030
in a way that was understandable

1174
00:44:39,030 --> 00:44:41,120
by somebody who has no physics background.

1175
00:44:41,120 --> 00:44:42,230
Some of those concepts are super,

1176
00:44:42,230 --> 00:44:44,420
super hard to explain simply,

1177
00:44:44,420 --> 00:44:47,210
and it's just a matter of practicing,

1178
00:44:47,210 --> 00:44:49,350
and sometimes you do need extra words.

1179
00:44:49,350 --> 00:44:52,250
I couldn't compress Noether's
theorem into a tweet

1180
00:44:53,190 --> 00:44:56,880
in any way that would be
giving meaningful information,

1181
00:44:56,880 --> 00:44:59,460
but it's a really fun
challenge I really enjoy.

1182
00:44:59,460 --> 00:45:02,010
It's like putting together a puzzle.

1183
00:45:02,010 --> 00:45:05,860
I enjoy that challenge
of trying to find a way

1184
00:45:05,860 --> 00:45:09,490

to explain something that
gets the idea across simply

1185
00:45:09,490 --> 00:45:12,270
and accessibly without being wrong,

1186
00:45:12,270 --> 00:45:16,710
'cause it's very easy to give
a bad answer that's short,

1187
00:45:16,710 --> 00:45:17,690
and people do that.

1188
00:45:17,690 --> 00:45:19,780
A lot of times, science
communicators will do that.

1189
00:45:19,780 --> 00:45:22,660
They'll use a metaphor that's
not a perfect metaphor,

1190
00:45:22,660 --> 00:45:23,550
but they won't make it clear

1191
00:45:23,550 --> 00:45:24,640
that it's not a perfect metaphor,

1192
00:45:24,640 --> 00:45:25,780
and then people get confused

1193
00:45:25,780 --> 00:45:28,610
and it's a whole problem trying to give

1194
00:45:28,610 --> 00:45:31,060
the right amount of
detail and make it clear

1195
00:45:32,427 --> 00:45:35,060
what you're brushing under the

carpet and what you're not.

1196
00:45:35,060 --> 00:45:36,840
It's just hard, but it's something that,

1197
00:45:36,840 --> 00:45:38,030
if you have a ton of practice

1198
00:45:38,030 --> 00:45:41,470
'cause you're on Twitter every
day, you get better at it.

1199
00:45:41,470 --> 00:45:42,970
- Science communication and outreach

1200
00:45:42,970 --> 00:45:45,570
is going to be part of what
you're doing here at Perimeter.

1201
00:45:45,570 --> 00:45:49,610
Can you tell us why you
wanted to take on this role?

1202
00:45:49,610 --> 00:45:51,290
- I've been very fortunate

1203
00:45:51,290 --> 00:45:54,930
in my career to have
opportunities to do both research

1204
00:45:54,930 --> 00:45:57,510
and public engagement in various ways.

1205
00:45:57,510 --> 00:45:59,160
As a postdoc, it was a little bit harder

1206
00:45:59,160 --> 00:46:02,070
'cause I was really just being
evaluated on my research,

1207
00:46:02,070 --> 00:46:05,040
and the outreach was sort of
my nights-and-weekends job,

1208
00:46:05,040 --> 00:46:07,060
but when I started at NC State,

1209
00:46:07,060 --> 00:46:10,160
where I'm currently a professor
in the physics department,

1210
00:46:10,160 --> 00:46:12,560
that job was explicitly written

1211
00:46:12,560 --> 00:46:15,820
as a job for a public scientist,

1212
00:46:15,820 --> 00:46:17,570
somebody who does science

1213
00:46:17,570 --> 00:46:20,380
and also interfaces with the
public one way or another,

1214
00:46:20,380 --> 00:46:23,600
and there's a whole group of
us, the public science cluster,

1215
00:46:23,600 --> 00:46:26,020
people who are connecting with
the public in different ways

1216
00:46:26,020 --> 00:46:27,380
through either their research

1217
00:46:27,380 --> 00:46:29,760
or disseminating their work in some way.

1218
00:46:29,760 --> 00:46:32,930
Going into that job, I was
explicitly given the freedom

1219
00:46:32,930 --> 00:46:37,221
to do public engagement as
part of my tenure package

1220
00:46:37,221 --> 00:46:38,150
and all of that.

1221
00:46:38,150 --> 00:46:41,550
It wasn't going to be a detriment
to my advancement in the job,

1222
00:46:41,550 --> 00:46:42,940
and they gave me some extra time

1223
00:46:42,940 --> 00:46:45,150
by reducing the teaching that I was doing.

1224
00:46:45,150 --> 00:46:46,948
That's been hugely helpful.

1225
00:46:46,948 --> 00:46:48,850
That allowed me to write
a book before tenure,

1226
00:46:48,850 --> 00:46:51,880
which is something that most
people do not attempt to do

1227
00:46:51,880 --> 00:46:54,000
if they're in the physical sciences.

1228
00:46:54,000 --> 00:46:57,410
When I started talking with
Perimeter about this job here,

1229
00:46:57,410 --> 00:47:00,670
I already knew how that
balance could work well.

1230
00:47:00,670 --> 00:47:04,740
I really wanted to find a way
to continue these two things

1231
00:47:04,740 --> 00:47:06,900
that I'm really passionate
about: doing my research,

1232
00:47:06,900 --> 00:47:09,160
trying to actually
contribute to discoveries

1233
00:47:09,160 --> 00:47:11,520
and the development of the field,

1234
00:47:11,520 --> 00:47:14,960
and also sharing everything with the world

1235
00:47:14,960 --> 00:47:16,440
and sharing my enthusiasm

1236
00:47:16,440 --> 00:47:18,870
and helping people to understand physics.

1237
00:47:18,870 --> 00:47:22,030
And so, fortunately, we were
able to put together a role

1238
00:47:22,030 --> 00:47:24,230
for me here that really
does both of those things

1239
00:47:24,230 --> 00:47:26,360
where I get to have the
same research support

1240
00:47:26,360 --> 00:47:28,270
as any other researcher here,

1241
00:47:28,270 --> 00:47:30,930
and also explicitly use part of my time

1242
00:47:30,930 --> 00:47:33,730
to connect with the public,
connect with the media,

1243
00:47:33,730 --> 00:47:36,670
to be a sort of public
face of the research side

1244
00:47:36,670 --> 00:47:40,460
of the institution, and
that's super exciting to me.

1245
00:47:40,460 --> 00:47:43,460
I love the idea of both
working with the amazing people

1246
00:47:43,460 --> 00:47:44,300
in both of those groups,

1247
00:47:44,300 --> 00:47:47,050
both cosmology and the
public engagement side,

1248
00:47:47,050 --> 00:47:50,470
and also representing
Perimeter Science to the media

1249
00:47:50,470 --> 00:47:53,530
or the public or whatever
when it's possible to do that.

1250
00:47:53,530 --> 00:47:55,238

I'm thrilled about it.

1251
00:47:55,238 --> 00:47:56,071
- So are we.
- I think it's going to be

1252
00:47:56,071 --> 00:47:57,029
an amazing job.

1253
00:47:57,029 --> 00:47:57,940
Thank you.

1254
00:47:57,940 --> 00:47:58,920
- We're thrilled as well.

1255
00:47:58,920 --> 00:48:00,860
We do have some questions
that were submitted

1256
00:48:00,860 --> 00:48:02,634
by people other than us.

1257
00:48:02,634 --> 00:48:04,060
You want to take the first one?
- Yeah, we have some.

1258
00:48:04,060 --> 00:48:05,710
Sure, yeah, there are
some graduate students

1259
00:48:05,710 --> 00:48:07,880
here at Perimeter that
sent in some questions.

1260
00:48:07,880 --> 00:48:10,580
So the first one is a
written question sent in

1261
00:48:10,580 --> 00:48:13,360

from Barbara, who's a PhD student here.

1262
00:48:13,360 --> 00:48:16,017
She asks, "If you could know one thing,

1263
00:48:16,017 --> 00:48:18,670
"anything you want, what would it be?"

1264
00:48:18,670 --> 00:48:21,810
- I would want to know
how the universe began,

1265
00:48:21,810 --> 00:48:23,730
if inflation really happened,

1266
00:48:23,730 --> 00:48:27,340
if there was ever a singularity,
how that came about.

1267
00:48:27,340 --> 00:48:28,520
I guess that's asking a lot,

1268
00:48:28,520 --> 00:48:32,730
but I really want to know
what set off the universe,

1269
00:48:32,730 --> 00:48:34,150
what set off the Big Bang.

1270
00:48:34,150 --> 00:48:36,913
- If you had to take a guess
today, we won't hold you to it.

1271
00:48:36,913 --> 00:48:37,762
- If I had to take a guess, oh my gosh.

1272
00:48:37,762 --> 00:48:39,442
- Was there a universe
before the Big Bang?

1273
00:48:39,442 --> 00:48:40,503
- I don't know.

1274
00:48:40,503 --> 00:48:41,336
- That's okay.

1275
00:48:41,336 --> 00:48:42,169
It's an unfair question.

1276
00:48:42,169 --> 00:48:44,240
I know it requires a lot
of research and math,

1277
00:48:44,240 --> 00:48:45,720
but I thought I'd just ask you.

1278
00:48:45,720 --> 00:48:46,880
- I don't know.

1279
00:48:48,190 --> 00:48:52,340
I think I like the idea that
the universe came from nothing

1280
00:48:52,340 --> 00:48:54,440
and there was some kind of singularity

1281
00:48:54,440 --> 00:48:57,243
and then the inflation period
and then the hot Big Bang.

1282
00:48:58,780 --> 00:49:00,350
Aesthetically, I kind of like that idea.

1283
00:49:00,350 --> 00:49:01,183
I don't know.

1284
00:49:01,183 --> 00:49:04,810

I can't support that on physics grounds

1285
00:49:04,810 --> 00:49:07,540
'cause we just don't have that
much information about that,

1286
00:49:07,540 --> 00:49:08,430
but it's a neat idea.

1287
00:49:08,430 --> 00:49:09,510
I don't know, I don't know.

1288
00:49:09,510 --> 00:49:11,130
It's a good question, but
anyway, I want to know.

1289
00:49:11,130 --> 00:49:12,964
That's what I want to know.

1290
00:49:12,964 --> 00:49:14,660
It'd be great to know what dark matter is.

1291
00:49:14,660 --> 00:49:15,770
I think we'll figure that out.

1292
00:49:15,770 --> 00:49:18,860
We may never know what
the first moment was.

1293
00:49:18,860 --> 00:49:21,070
- And our next question is from Anna,

1294
00:49:21,070 --> 00:49:23,730
who's a student in our
PSI master's program.

1295
00:49:23,730 --> 00:49:24,563
I think you met with her.

1296
00:49:24,563 --> 00:49:25,870
- I've met Anna, yeah.

1297
00:49:25,870 --> 00:49:28,900
- Has the process of communicating science

1298
00:49:28,900 --> 00:49:32,250
and the scientific method to
the public changed the way

1299
00:49:32,250 --> 00:49:34,960
you actually do your own research?

1300
00:49:34,960 --> 00:49:37,800
- I think it definitely has changed

1301
00:49:37,800 --> 00:49:39,930
what I work on to some degree.

1302
00:49:39,930 --> 00:49:41,770
I mentioned that a lot of what I do is

1303
00:49:41,770 --> 00:49:42,910
I talk to the theorists,

1304
00:49:42,910 --> 00:49:44,100
I find out what they're excited about,

1305
00:49:44,100 --> 00:49:44,933
I talk to the observers,

1306
00:49:44,933 --> 00:49:46,060
I find out what they're excited about,

1307
00:49:46,060 --> 00:49:47,290
and I try and make connections,

1308

00:49:47,290 --> 00:49:49,740
and there have definitely been times when,

1309
00:49:49,740 --> 00:49:53,680
because I was excited about something

1310
00:49:53,680 --> 00:49:55,120
to share it with the public

1311
00:49:55,120 --> 00:49:57,560
or give a talk on it
or something like that,

1312
00:49:57,560 --> 00:49:58,880
I learned more about a topic

1313
00:49:58,880 --> 00:50:02,730
and then used that
information in my research.

1314
00:50:02,730 --> 00:50:04,140
So there's definitely been times like,

1315
00:50:04,140 --> 00:50:06,980
as somebody who's really trying
to do big-picture science,

1316
00:50:06,980 --> 00:50:08,240
really trying to...

1317
00:50:08,240 --> 00:50:11,270
Cosmology in general, you
have to know a lot of things

1318
00:50:11,270 --> 00:50:12,500
about a lot of different topics,

1319
00:50:12,500 --> 00:50:14,330
and then the area I work in,

1320
00:50:14,330 --> 00:50:16,090
it's helpful to have that big picture,

1321
00:50:16,090 --> 00:50:19,110
helpful to know what a lot
of different people are doing

1322
00:50:19,110 --> 00:50:21,290
and what the big exciting things are.

1323
00:50:21,290 --> 00:50:24,480
It's an area where talking
to the public a lot is good

1324
00:50:24,480 --> 00:50:28,230
because it really forces
you to read more broadly

1325
00:50:28,230 --> 00:50:32,620
and to talk to more people
and get that big picture,

1326
00:50:32,620 --> 00:50:35,290
and so certainly the public
engagement has changed

1327
00:50:35,290 --> 00:50:37,020
what I work on to some degree

1328
00:50:37,020 --> 00:50:39,900
just by giving me sort of
more tools, more information.

1329
00:50:39,900 --> 00:50:42,020
In terms of if it's changed how I work,

1330
00:50:42,020 --> 00:50:42,970
that's hard to say.

1331
00:50:44,270 --> 00:50:48,500
It's probably changed how I
write my papers to some degree.

1332
00:50:48,500 --> 00:50:50,250
It's certainly changed how I give talks.

1333
00:50:50,250 --> 00:50:52,390
I used to give talks with way more words

1334
00:50:52,390 --> 00:50:53,900
and equations and bullet points,

1335
00:50:53,900 --> 00:50:55,470
and now it's way more pictures

1336
00:50:55,470 --> 00:50:58,830
just because when you give a
talk to the public audience,

1337
00:50:58,830 --> 00:51:00,110
you get used to the fact

1338
00:51:00,110 --> 00:51:01,700
that you can't just put
a bunch of words up there

1339
00:51:01,700 --> 00:51:02,920
'cause it's distracting,

1340
00:51:02,920 --> 00:51:04,810
and people will try and
read while you're talking

1341
00:51:04,810 --> 00:51:07,180
and you can't communicate well that way,

1342

00:51:07,180 --> 00:51:10,230
and I realized that
actually that also applies

1343
00:51:10,230 --> 00:51:12,380
to professional talks, to research talks.

1344
00:51:12,380 --> 00:51:14,750
Unless you're really going
through the information

1345
00:51:14,750 --> 00:51:18,440
on the page as you go,
people are not going to...

1346
00:51:18,440 --> 00:51:19,670
It's just going to distract people,

1347
00:51:19,670 --> 00:51:22,140
so I use more pictures,
I do more explaining,

1348
00:51:22,140 --> 00:51:24,970
I bring information on more slowly

1349
00:51:24,970 --> 00:51:26,830
because of the experience
I've had with the public

1350
00:51:26,830 --> 00:51:28,830
where I've just learned a lot more

1351
00:51:28,830 --> 00:51:31,650
about how people absorb information.

1352
00:51:31,650 --> 00:51:33,050
- Okay, and our last question is

1353
00:51:33,050 --> 00:51:37,080

from another PhD student named
Nitika here at Perimeter.

1354
00:51:37,080 --> 00:51:39,747
She asks, "What would you
like to share with students

1355
00:51:39,747 --> 00:51:42,800
"who are entering your field of research?"

1356
00:51:42,800 --> 00:51:44,930
- I think that as a student,

1357
00:51:44,930 --> 00:51:47,790
and as a PhD student especially,

1358
00:51:47,790 --> 00:51:50,840
it can get very lonely and very stressful.

1359
00:51:50,840 --> 00:51:54,370
There are times when it's just a hard,

1360
00:51:54,370 --> 00:51:55,620
it's a hard field to be in.

1361
00:51:55,620 --> 00:51:56,980
Academia in general is just,

1362
00:51:56,980 --> 00:52:00,000
it can be sort of
mentally, emotionally hard.

1363
00:52:00,000 --> 00:52:02,620
I think the pieces of advice
I would give to people

1364
00:52:02,620 --> 00:52:03,870
who are embarking on something like that

1365
00:52:03,870 --> 00:52:06,660
would be look after yourself.

1366
00:52:06,660 --> 00:52:09,470
Don't sacrifice your mind
and body to the field.

1367
00:52:09,470 --> 00:52:12,200
Try and stay healthy as much as you can

1368
00:52:12,200 --> 00:52:15,070
and get sleep if you can,

1369
00:52:15,070 --> 00:52:18,720
and really look after your wellbeing

1370
00:52:18,720 --> 00:52:19,807
so it doesn't destroy you

1371
00:52:19,807 --> 00:52:22,340
so you don't burn out and get sick.

1372
00:52:22,340 --> 00:52:23,750
- Have you had to learn that the hard way?

1373
00:52:23,750 --> 00:52:24,583
Have you pushed yourself too hard?

1374
00:52:24,583 --> 00:52:27,320
- Of course, of course,
yeah, at times, at times.

1375
00:52:27,320 --> 00:52:29,840
And then also you're going
to be around a lot of people

1376
00:52:29,840 --> 00:52:32,520
who are really smart and

doing really amazing things,

1377
00:52:32,520 --> 00:52:36,270
and you can't constantly
be comparing yourself.

1378
00:52:36,270 --> 00:52:39,450
Everybody feels levels of inadequacy

1379
00:52:39,450 --> 00:52:40,930
when getting into physics.

1380
00:52:40,930 --> 00:52:43,210
That is a normal feeling,
but also it's important

1381
00:52:43,210 --> 00:52:45,080
to remind yourself you
really do know stuff

1382
00:52:45,080 --> 00:52:48,970
and try and maintain
that sort of enthusiasm

1383
00:52:48,970 --> 00:52:51,210
and excitement about the field.

1384
00:52:51,210 --> 00:52:53,980
For me, one of the ways
that I dealt with that

1385
00:52:53,980 --> 00:52:57,260
when I was going through
my academic career was

1386
00:52:57,260 --> 00:52:58,950
to do a lot of public engagement

1387
00:52:58,950 --> 00:53:01,140

because when I'm around my colleagues,

1388
00:53:01,140 --> 00:53:02,150
a lot of times, it's like,

1389
00:53:02,150 --> 00:53:04,590
oh, I feel like I'm the
stupidest person in the room,

1390
00:53:04,590 --> 00:53:06,140
like I can't keep up or whatever.

1391
00:53:06,140 --> 00:53:07,590
Everybody has those feelings.

1392
00:53:08,510 --> 00:53:09,930
You can get caught up in that mindset,

1393
00:53:09,930 --> 00:53:13,170
but then when you go and talk
to a general public audience,

1394
00:53:13,170 --> 00:53:14,957
you know so much more about
the topic than they do,

1395
00:53:14,957 --> 00:53:16,777
and so people will come up
to you and they'll be like,

1396
00:53:16,777 --> 00:53:17,610
"Wow, that's amazing.

1397
00:53:17,610 --> 00:53:18,647
"You're really smart," and you're like,

1398
00:53:18,647 --> 00:53:21,437
"Oh yeah, I know some stuff." (laughs)

1399
00:53:22,465 --> 00:53:24,410
- Imposter syndrome is context-dependent.

1400
00:53:24,410 --> 00:53:26,010
- Yeah, yeah, yeah, so it's really good

1401
00:53:26,010 --> 00:53:27,640
for keeping up the morale.

1402
00:53:27,640 --> 00:53:29,640
And the thing about imposter
syndrome specifically,

1403
00:53:29,640 --> 00:53:32,130
so the idea behind imposter syndrome is

1404
00:53:32,130 --> 00:53:33,460
you're really not good enough,

1405
00:53:33,460 --> 00:53:34,740
but you've fooled everyone,

1406
00:53:34,740 --> 00:53:36,820
and they're going to find you out someday.

1407
00:53:36,820 --> 00:53:38,070
My impression of that is like,

1408
00:53:38,070 --> 00:53:39,930
if you really think
that you're an imposter,

1409
00:53:39,930 --> 00:53:41,100
just keep doing what you're doing

1410
00:53:41,100 --> 00:53:43,520
'cause it's going great. (laughs)

1411
00:53:43,520 --> 00:53:45,630
You're doing way better
than you ought to be,

1412
00:53:45,630 --> 00:53:46,830
so just keep doing that.

1413
00:53:46,830 --> 00:53:48,310
- Until you get heckled
by Stephen Hawking,

1414
00:53:48,310 --> 00:53:50,770
just assume that you're
doing everything right.

1415
00:53:50,770 --> 00:53:52,670
- Yeah, it's obviously going super well,

1416
00:53:52,670 --> 00:53:53,503
much better than it should be,

1417
00:53:53,503 --> 00:53:56,750
and you can just go with
that as long as you can.

1418
00:53:56,750 --> 00:53:58,983
Milk it. (laughs)

1419
00:54:00,280 --> 00:54:03,040
I try and keep that perspective
on imposter syndrome.

1420
00:54:03,040 --> 00:54:04,380
- If you could travel back in time

1421
00:54:04,380 --> 00:54:08,090
to give yourself advice,
would it be the same advice?

1422
00:54:08,090 --> 00:54:10,220
- I would tell myself
those things for sure.

1423
00:54:10,220 --> 00:54:12,500
Depends on how far back I get to travel.

1424
00:54:12,500 --> 00:54:14,130
- Big Bang.

1425
00:54:14,130 --> 00:54:15,056
The initial conditions-
- Well, there are a lot

1426
00:54:15,056 --> 00:54:18,056
of things I would change if I
could go back to the Big Bang.

1427
00:54:19,490 --> 00:54:20,760
I would also try desperately

1428
00:54:20,760 --> 00:54:23,230
to learn some better time
management skills early on

1429
00:54:23,230 --> 00:54:25,990
'cause it's really hard
to pick those up later,

1430
00:54:25,990 --> 00:54:27,170
and there are a lot of things

1431
00:54:27,170 --> 00:54:30,050
where I just really wish I
had better balanced my time,

1432
00:54:30,050 --> 00:54:32,110
but I think that's
just, that's a challenge

1433
00:54:32,110 --> 00:54:35,434
that exists throughout
life for all people.

1434
00:54:35,434 --> 00:54:37,130
I don't know, but maybe
I would've been able

1435
00:54:37,130 --> 00:54:40,070
to get some habits that would
serve me well in the future.

1436
00:54:40,070 --> 00:54:40,903
I'm not sure.

1437
00:54:40,903 --> 00:54:42,450
I feel like I balance a lot of things

1438
00:54:42,450 --> 00:54:44,590
and I don't always do a good job of that,

1439
00:54:44,590 --> 00:54:47,230
and it would be nice to be better at it.

1440
00:54:47,230 --> 00:54:48,470
- One last question from me:

1441
00:54:48,470 --> 00:54:49,680
Is there anything in particular

1442
00:54:49,680 --> 00:54:52,190
that you're really excited
about scientifically

1443
00:54:52,190 --> 00:54:54,440
or personally and professionally?

1444

00:54:54,440 --> 00:54:56,080
- Scientifically, I'm excited

1445
00:54:56,080 --> 00:54:59,220
by what these new observational
programs are going to show us,

1446
00:54:59,220 --> 00:55:02,000
so the space telescopes
that are coming up,

1447
00:55:02,000 --> 00:55:03,460
the Square Kilometer Array,

1448
00:55:03,460 --> 00:55:05,470
the radio telescope array
that's going to show us a lot

1449
00:55:05,470 --> 00:55:07,290
about the first stars and galaxies.

1450
00:55:07,290 --> 00:55:10,200
The Vera Ruben Observatory
is going to show us,

1451
00:55:10,200 --> 00:55:11,033
it's doing a survey

1452
00:55:11,033 --> 00:55:12,657
that's going to show us
like a billion galaxies

1453
00:55:12,657 --> 00:55:14,957
and a million supernovae,
something like that.

1454
00:55:15,987 --> 00:55:17,100
We're going to get a ton of data,

1455

00:55:17,100 --> 00:55:19,060
and then we're going to have
much better maps of the universe

1456
00:55:19,060 --> 00:55:21,300
than we ever did before, and
that's going to be exciting,

1457
00:55:21,300 --> 00:55:24,140
and gravitational waves
are a huge, huge deal,

1458
00:55:24,140 --> 00:55:26,060
and I'm very excited
to see where that goes.

1459
00:55:26,060 --> 00:55:28,560
I'm not specifically working
in gravitational waves myself,

1460
00:55:28,560 --> 00:55:31,500
but I think that it's
just such an exciting area

1461
00:55:31,500 --> 00:55:33,740
and we're going to learn
so much about the universe.

1462
00:55:33,740 --> 00:55:35,850
It's just astonishing technology,

1463
00:55:35,850 --> 00:55:38,500
so I'm very excited about that.

1464
00:55:38,500 --> 00:55:40,840
And personally, I'm
excited to move to Canada.

1465
00:55:40,840 --> 00:55:43,040
I'm excited to live here

1466
00:55:43,040 --> 00:55:46,590
and start this new chapter in my life.

1467
00:55:46,590 --> 00:55:48,620
- Have you lived in a
place with snow before?

1468
00:55:48,620 --> 00:55:49,880
- Yes, I have. (laughs)

1469
00:55:49,880 --> 00:55:52,700
Not quite like this, but yes.

1470
00:55:52,700 --> 00:55:54,220
Princeton got snow.

1471
00:55:54,220 --> 00:55:56,590
I did my grad school there.

1472
00:55:56,590 --> 00:55:58,030
I've got good boots.

1473
00:55:58,030 --> 00:55:59,620
I've got a couple of nice coats.

1474
00:55:59,620 --> 00:56:01,510
I've got scarves and things.

1475
00:56:01,510 --> 00:56:02,610
I think I'll make it.

1476
00:56:02,610 --> 00:56:04,370
- There's a pretty much endless supply

1477
00:56:04,370 --> 00:56:05,706
of coffee, hot drinks here.

1478
00:56:05,706 --> 00:56:06,800
- Yeah, that's true.

1479
00:56:06,800 --> 00:56:09,800
- Well, we're so excited that
you are going to be joining us

1480
00:56:09,800 --> 00:56:11,810
at Perimeter very soon,
and we're really grateful

1481
00:56:11,810 --> 00:56:13,397
that you took the time to chat with us.

1482
00:56:13,397 --> 00:56:14,950
- Thank you so much.

1483
00:56:14,950 --> 00:56:16,597
This has been really great,

1484
00:56:16,597 --> 00:56:20,093
and I'm excited to become
part of the institute.

1485
00:56:23,970 --> 00:56:26,750
- Thanks so much for stepping
inside the Perimeter.

1486
00:56:26,750 --> 00:56:29,870
Be sure to subscribe so you
don't miss a conversation.

1487
00:56:29,870 --> 00:56:32,940
We've interviewed a lot of
really brilliant scientists

1488
00:56:32,940 --> 00:56:36,010
whose research spans from
the quantum to the cosmos,

1489
00:56:36,010 --> 00:56:38,530
and we can't wait for you to hear more.

1490
00:56:38,530 --> 00:56:39,840
And if you like what you hear,

1491
00:56:39,840 --> 00:56:41,510
please give us a rating or a review

1492
00:56:41,510 --> 00:56:43,614
wherever you get your podcasts.

1493
00:56:43,614 --> 00:56:46,197
(bright music)