1
00:00:00,172 --> 00:00:02,755
(bright music)

2
00:00:09,030 --> 00:00:12,270
- Hello, and welcome back to
Conversations at the Perimeter.

3
00:00:12,270 --> 00:00:14,040
Today, Lauren and I are really excited

4
00:00:14,040 --> 00:00:16,890
to share this conversation
that we had with Jessie Muir

5
00:00:16,890 --> 00:00:19,770
who's a postdoc here
at Perimeter Institute,

6
00:00:19,770 --> 00:00:23,250
and she studies the mysterious
phenomena of dark energy,

7
00:00:23,250 --> 00:00:25,500
which is believed to
drive the acceleration

8
00:00:25,500 --> 00:00:27,630
of our universe's expansion.

9
00:00:27,630 --> 00:00:29,580
- I learned so many things
from this conversation

10
00:00:29,580 --> 00:00:31,890
that I didn't know
before about dark matter,

11
00:00:31,890 --> 00:00:34,410
dark energy, gravitational lensing,

12
00:00:34,410 --> 00:00:37,470
and I even learned a new
scientific term that I really love

13
00:00:37,470 --> 00:00:39,900
called galaxy clumpiness.

14
00:00:39,900 --> 00:00:42,990
It was just fascinating to
hear about how Jessie's work

15
00:00:42,990 --> 00:00:46,800
really relies on an interplay
between theory and experiment.

16
00:00:46,800 --> 00:00:48,330
And she told us about her work

17
00:00:48,330 --> 00:00:50,880
as part of the Dark Energy
Survey collaboration

18
00:00:50,880 --> 00:00:52,470
and how her team works

19
00:00:52,470 --> 00:00:56,040
to process and analyze mind
boggling amounts of data.

20
00:00:56,040 --> 00:00:57,480
- What I found also fascinating

21
00:00:57,480 --> 00:01:00,480
was not only does she do all
of this computational work,

22
00:01:00,480 --> 00:01:03,210
but she actually went to

the telescope in Chile

23
00:01:03,210 --> 00:01:04,320
on top of a mountain

24
00:01:04,320 --> 00:01:07,410
where this Dark Energy Survey
is doing its observations,

25
00:01:07,410 --> 00:01:09,930
so she got a real hands-on experience

26
00:01:09,930 --> 00:01:11,790
of what it's like to be an astronomer.

27
00:01:11,790 --> 00:01:14,220
- She also told us about
a series of cartoons

28
00:01:14,220 --> 00:01:17,220
that she works on to help
communicate her science

29
00:01:17,220 --> 00:01:19,560
and make it more accessible for everyone.

30
00:01:19,560 --> 00:01:21,720
I know you're gonna
enjoy this conversation,

31
00:01:21,720 --> 00:01:24,442
so let's step inside the
perimeter with Jessie.

32
00:01:24,442 --> 00:01:27,000
(bright music continues)

33
00:01:27,000 --> 00:01:28,860
- Hello, Jessie, and

thank you for being here

34
00:01:28,860 --> 00:01:30,810
at Conversations at The Perimeter.

35
00:01:30,810 --> 00:01:32,160
- Hey, thanks for having me.

36
00:01:32,160 --> 00:01:34,260
- We're really excited
to chat with you today.

37
00:01:34,260 --> 00:01:37,710
In particular, I'm excited
to learn about dark energy,

38
00:01:37,710 --> 00:01:39,690
which is related to some work

39
00:01:39,690 --> 00:01:41,250
that you're gonna tell us about,

40
00:01:41,250 --> 00:01:43,230
and dark matter, all things dark,

41
00:01:43,230 --> 00:01:45,870
because we haven't really
talked to any experts

42
00:01:45,870 --> 00:01:48,870
about what these things really
are or what they aren't.

43
00:01:48,870 --> 00:01:50,580
Can you start us off by telling us,

44
00:01:50,580 --> 00:01:53,400
what do we know about dark
energy and dark matter?

45
00:01:53,400 --> 00:01:54,510
Are they even related

46
00:01:54,510 --> 00:01:56,790
aside from both having dark in the name?

47
00:01:56,790 --> 00:01:58,964
- I think the main thing that relates them

48
00:01:58,964 --> 00:02:01,140
is that they have dark in the name,

49
00:02:01,140 --> 00:02:03,210
and they're labels that we give

50
00:02:03,210 --> 00:02:07,140
to components of the matter
and energy in the universe

51
00:02:07,140 --> 00:02:09,180
that we are fairly sure are there

52
00:02:09,180 --> 00:02:11,640
based on how they influence visible matter

53
00:02:11,640 --> 00:02:14,280
that we can see and measure
and detect and study,

54
00:02:14,280 --> 00:02:16,440
but we fundamentally
don't know what they are.

55
00:02:16,440 --> 00:02:19,470
But these are two
different unknown things.

56

00:02:19,470 --> 00:02:20,940
We can get into this in more detail,

57
00:02:20,940 --> 00:02:23,130
but sort of the simplistic
description I give

58
00:02:23,130 --> 00:02:24,210
of what makes them different

59
00:02:24,210 --> 00:02:27,150
is dark matter seems to
be some type of particle,

60
00:02:27,150 --> 00:02:29,880
but it clumps up under
the influence of gravity,

61
00:02:29,880 --> 00:02:31,680
so it's not uniform in space.

62
00:02:31,680 --> 00:02:34,470
It behaves in some ways
like ordinary matter

63
00:02:34,470 --> 00:02:35,303
that we're familiar with.

64
00:02:35,303 --> 00:02:37,080
It just doesn't seem to
interact through light

65
00:02:37,080 --> 00:02:37,913
or through other forces or if it-

66
00:02:37,913 --> 00:02:39,960
- Because ordinary matter
does that as well, right?

67

00:02:39,960 --> 00:02:42,570
It clumps in areas of high gravity?

68
00:02:42,570 --> 00:02:44,780
- Yeah, yeah, so the
thing that gravity does

69
00:02:44,780 --> 00:02:47,910
is it causes mass to wanna
fall towards other mass.

70
00:02:47,910 --> 00:02:49,650
And it seems, as far as we can tell,

71
00:02:49,650 --> 00:02:51,420
that both dark matter and ordinary matter

72
00:02:51,420 --> 00:02:53,640
seem to feel gravity in the same way,

73
00:02:53,640 --> 00:02:56,880
whereas dark energy seems like
we're not sure what it is,

74
00:02:56,880 --> 00:03:00,960
but it seems to be more like
some property of space itself.

75
00:03:00,960 --> 00:03:03,810
So dark matter clumps up
under the influence of gravity

76
00:03:03,810 --> 00:03:06,420
and we can see how it influences
the formation of galaxies

77
00:03:06,420 --> 00:03:09,060
and how stars move in
galaxies among other things.

78
00:03:09,060 --> 00:03:11,730
And dark energy, we learn
about and we've detected

79
00:03:11,730 --> 00:03:14,610
based on its influence of the
very large-scale universe.

80
00:03:14,610 --> 00:03:16,710
So large and small scales

81
00:03:16,710 --> 00:03:18,000
kind of have somewhat different meanings

82
00:03:18,000 --> 00:03:19,440
depending on what field you're in.

83
00:03:19,440 --> 00:03:22,530
In cosmology, we tend
to refer to small scales

84
00:03:22,530 --> 00:03:26,132
as anything under about
30 million light years.

85
00:03:26,132 --> 00:03:27,510
- (laughs) Just tiny.
- So it's, you know,

86
00:03:27,510 --> 00:03:29,520
maybe a little bit
different than the scales

87
00:03:29,520 --> 00:03:32,578
of, like, colleagues over
doing quantum stuff here at PI.

88
00:03:32,578 --> 00:03:35,010
- So if that's small, what is large?

89
00:03:35,010 --> 00:03:37,830
- Generally, we work in a
little bit of different units

90
00:03:37,830 --> 00:03:39,590
in cosmology, but like
30 million light years

91
00:03:39,590 --> 00:03:43,800
is kind of the benchmark for
once you're looking above that,

92
00:03:43,800 --> 00:03:45,390
the universe isn't necessarily uniform

93
00:03:45,390 --> 00:03:48,270
but in a statistical
sense, it becomes uniform.

94
00:03:48,270 --> 00:03:50,370
So I guess you can maybe picture

95
00:03:50,370 --> 00:03:53,460
looking at, like, a zoomed-in
or zoomed-out picture

96
00:03:53,460 --> 00:03:54,720
of, like, a lawn of grass.

97
00:03:54,720 --> 00:03:56,640
If you're looking on small scales

98
00:03:56,640 --> 00:03:57,870
that are sort of comparable to the size

99
00:03:57,870 --> 00:03:59,550
of, like, little clumps of grass,

100
00:03:59,550 --> 00:04:00,383
you might be concerned

101
00:04:00,383 --> 00:04:02,160
with, like, oh, how is
this blade of grass growing

102
00:04:02,160 --> 00:04:03,600
and how is it interacting
with its neighbors?

103
00:04:03,600 --> 00:04:06,300
And so that would be
like individual galaxies

104
00:04:06,300 --> 00:04:07,133
forming and observing.

105
00:04:07,133 --> 00:04:09,090
And when you zoom out, you
know, you can still see

106
00:04:09,090 --> 00:04:10,890
that, you know, the ground
isn't completely uniform,

107
00:04:10,890 --> 00:04:12,720
there's still blades of grass there,

108
00:04:12,720 --> 00:04:14,970
but you can sort of get a sense

109
00:04:14,970 --> 00:04:16,350
of, like, the global properties

110
00:04:16,350 --> 00:04:18,990
of, like, this grass tends
to grow in little clumps

111
00:04:18,990 --> 00:04:20,280
or is it more spread out

112
00:04:20,280 --> 00:04:22,800
or, you know, do we think
it was grown there wildly

113
00:04:22,800 --> 00:04:25,440
or using sod, or I don't
know, maybe this is getting

114
00:04:25,440 --> 00:04:26,880
a little bit obtuse-
- No, I actually like that.

115
00:04:26,880 --> 00:04:28,410
You know, it made me
think of a golf course

116
00:04:28,410 --> 00:04:29,520
where it's all grass,

117
00:04:29,520 --> 00:04:30,353
but you look from above

118
00:04:30,353 --> 00:04:32,040
and there's different characteristics,

119
00:04:32,040 --> 00:04:33,030
different ways it grows.

120
00:04:33,030 --> 00:04:35,700
And you mentioned dark
energy in comparison

121
00:04:35,700 --> 00:04:39,355
sort of being an element of
space-time, is that right?

122
00:04:39,355 --> 00:04:41,640
It's something intrinsic to it?

123
00:04:41,640 --> 00:04:43,170
- For this, maybe it's kind of useful

124
00:04:43,170 --> 00:04:44,540
to, like, tell a little bit of the story

125
00:04:44,540 --> 00:04:47,160
of how we learned about dark energy.

126
00:04:47,160 --> 00:04:49,140
Up until the '90s,

127
00:04:49,140 --> 00:04:50,880
we knew that there's
matter in the universe.

128
00:04:50,880 --> 00:04:52,020
We've known there's dark matter,

129
00:04:52,020 --> 00:04:54,030
sort of first hints showed
up in, like, the '30s,

130
00:04:54,030 --> 00:04:55,640
and then Vera Rubin made some measurements

131
00:04:55,640 --> 00:04:57,210
of the motion of stars and galaxies

132
00:04:57,210 --> 00:05:00,120
in, I believe, the '60s, maybe '70s.

133
00:05:00,120 --> 00:05:01,710
So we've kind of known about dark matter.

134
00:05:01,710 --> 00:05:04,320
We've had a good understanding
of how gravity works

135
00:05:04,320 --> 00:05:07,170
since Einstein published his
theory of general relativity.

136
00:05:07,170 --> 00:05:08,190
And given those things,

137
00:05:08,190 --> 00:05:11,220
we know that mass attracts
mass through gravity,

138
00:05:11,220 --> 00:05:13,107
we know there's matter in the universe,

139
00:05:13,107 --> 00:05:14,520
and so your expectation

140
00:05:14,520 --> 00:05:17,190
is even if everything
is sort of thrown out

141
00:05:17,190 --> 00:05:19,860
by the Big Bang in the early universe,

142
00:05:19,860 --> 00:05:22,020
what you'd expect gravity to be doing

143
00:05:22,020 --> 00:05:23,430
is that all that matter
is being thrown out,

144
00:05:23,430 --> 00:05:24,263
the universe is expanding,

145

00:05:24,263 --> 00:05:25,620
gravity should be acting
sort of as a friction.

146
00:05:25,620 --> 00:05:27,390
It should be slowing that down.

147
00:05:27,390 --> 00:05:30,270
Given a universe that contains
matter and that has gravity,

148
00:05:30,270 --> 00:05:31,103
you expect to see

149
00:05:31,103 --> 00:05:33,960
that the expansion of the
universe is decelerating.

150
00:05:33,960 --> 00:05:37,170
And what we found, or what
several teams of scientists

151
00:05:37,170 --> 00:05:40,620
and since many have
confirmed in the late '90s,

152
00:05:40,620 --> 00:05:45,210
was that the universe's
expansion is not slowing down,

153
00:05:45,210 --> 00:05:47,160
it's actually accelerating.

154
00:05:47,160 --> 00:05:49,020
And so previous to that,
people were kind of looking

155
00:05:49,020 --> 00:05:50,520
at, like, all right,
we can measure the rate

156
00:05:50,520 --> 00:05:52,440
at which it's decelerating

157
00:05:52,440 --> 00:05:53,607
to learn about how much matter there is

158
00:05:53,607 --> 00:05:55,530
and some stuff about the geometry

159
00:05:55,530 --> 00:05:57,030
of the large-scale universe.

160
00:05:57,030 --> 00:06:00,423
And this finding that the
universe is accelerating,

161
00:06:01,587 --> 00:06:03,990
like, it's like if you threw
a baseball up in the air

162
00:06:03,990 --> 00:06:05,370
and instead of coming back down,

163
00:06:05,370 --> 00:06:07,200
it, like, zips off in
some other direction.

164
00:06:07,200 --> 00:06:10,320
So there's gotta be some
other sorts of energy there,

165
00:06:10,320 --> 00:06:13,350
and the simplest description
that we can come up with

166
00:06:13,350 --> 00:06:14,460
that dark energy could be

167
00:06:14,460 --> 00:06:16,440
that would give us the sort
of observable properties

168
00:06:16,440 --> 00:06:17,273
that we're seeing

169
00:06:17,273 --> 00:06:20,640
is that if empty space just had
some intrinsic energy to it.

170
00:06:20,640 --> 00:06:23,280
So sometimes people will
call this vacuum energy,

171
00:06:23,280 --> 00:06:25,890
sometimes people will call
it the cosmological constant,

172
00:06:25,890 --> 00:06:28,050
and so what that means is
it's some energy density

173
00:06:28,050 --> 00:06:31,080
associated with empty space
that's both constant in space,

174
00:06:31,080 --> 00:06:32,730
so same everywhere in the universe,

175
00:06:32,730 --> 00:06:35,610
and constant in time, so
the same energy density

176
00:06:35,610 --> 00:06:37,410
throughout the history of the universe.

177
00:06:37,410 --> 00:06:40,200
And it seems to have

been causing acceleration

178
00:06:40,200 --> 00:06:41,280
of the expansion of the universe

179
00:06:41,280 --> 00:06:43,410
just in the relatively recent past.

180
00:06:43,410 --> 00:06:45,020
Here, recent being on cosmologist scales

181
00:06:45,020 --> 00:06:47,010
of the last couple billion years.

182
00:06:47,010 --> 00:06:48,630
And so the picture you can have there

183
00:06:48,630 --> 00:06:51,630
is the universe is expanding
and it has some matter density,

184
00:06:51,630 --> 00:06:53,460
but as the universe expands,

185
00:06:53,460 --> 00:06:56,400
the same number of particles
are around roughly,

186
00:06:56,400 --> 00:06:57,900
and that matter gets diluted.

187
00:06:57,900 --> 00:07:00,300
So as the universe progresses
through its history,

188
00:07:00,300 --> 00:07:02,070
the matter density will drop,

189

00:07:02,070 --> 00:07:02,970
and at a certain point,

190
00:07:02,970 --> 00:07:05,640
the average density of
matter in the universe

191
00:07:05,640 --> 00:07:09,990
drops below that vacuum energy,
that cosmological constant,

192
00:07:09,990 --> 00:07:12,780
and that's when the universe
starts accelerating.

193
00:07:12,780 --> 00:07:15,390
So these different components
have different influences

194
00:07:15,390 --> 00:07:17,460
on the behavior of the
space-time in the universe,

195
00:07:17,460 --> 00:07:18,293
and this is something

196
00:07:18,293 --> 00:07:20,550
we can get out of Einstein's
general relativity,

197
00:07:20,550 --> 00:07:22,890
we can relate the behavior of
space-time to the stuff in it.

198
00:07:22,890 --> 00:07:25,530
And so when the relative contribution

199
00:07:25,530 --> 00:07:28,650
to the total energy
density of the universe

200
00:07:28,650 --> 00:07:30,060
switches from being matter-dominated

201
00:07:30,060 --> 00:07:31,650
to dark energy-dominated

202
00:07:31,650 --> 00:07:33,030
or cosmological constant-dominated

203
00:07:33,030 --> 00:07:35,160
depending on which model you wanna use,

204
00:07:35,160 --> 00:07:38,070
the expansion starts
getting faster and faster.

205
00:07:38,070 --> 00:07:39,450
So we don't know what dark energy is,

206
00:07:39,450 --> 00:07:40,830
but we can sort of place constraints

207
00:07:40,830 --> 00:07:42,390
and say, is it a constant?

208
00:07:42,390 --> 00:07:44,520
Does it have some time evolution?

209
00:07:44,520 --> 00:07:46,530
Is it something that maybe
interacts with matter?

210
00:07:46,530 --> 00:07:48,360
And given one of these assumptions,

211
00:07:48,360 --> 00:07:50,100
you can go through and

do your calculations

212
00:07:50,100 --> 00:07:51,960
for how that should affect
the expansion history,

213
00:07:51,960 --> 00:07:54,510
how it'll affect how the
matter is clumping up

214
00:07:54,510 --> 00:07:56,190
to form galaxies and things,

215
00:07:56,190 --> 00:07:58,770
and we can kind of test
and constrain those.

216
00:07:58,770 --> 00:08:00,120
That's a lot of the motivation

217
00:08:00,120 --> 00:08:02,640
behind what I and a lot
of other cosmologists do.

218
00:08:02,640 --> 00:08:06,150
- It seems like a lot of the
work that you specifically do

219
00:08:06,150 --> 00:08:08,670
is trying to look at
the role of statistics

220
00:08:08,670 --> 00:08:10,590
in understanding some of these properties,

221
00:08:10,590 --> 00:08:13,953
so can you tell us in general
how statistics comes in?

222

00:08:14,940 --> 00:08:16,560
- So it comes in in a
couple different ways.

223
00:08:16,560 --> 00:08:18,390
One is, you know, if
we're trying to describe

224
00:08:18,390 --> 00:08:20,310
the large-scale universe,

225
00:08:20,310 --> 00:08:21,360
you know, we look out in the universe

226
00:08:21,360 --> 00:08:23,790
and we see millions and
millions of galaxies,

227
00:08:23,790 --> 00:08:25,050
like the experiment I work on,

228
00:08:25,050 --> 00:08:26,250
which I think we'll touch on later.

229
00:08:26,250 --> 00:08:27,480
Like, we're working with a data set

230
00:08:27,480 --> 00:08:30,510
with a couple hundred
million galaxies imaged,

231
00:08:30,510 --> 00:08:32,310
and that's only, like,
one part of the sky,

232
00:08:32,310 --> 00:08:33,420
and it's not looking out

233
00:08:33,420 --> 00:08:37,140

as far as, like, future
telescopes will be able to look.

234
00:08:37,140 --> 00:08:39,420
We want to be able to test our theories

235
00:08:39,420 --> 00:08:40,830
or to constrain the question

236
00:08:40,830 --> 00:08:42,660
of whether dark energy's density,

237
00:08:42,660 --> 00:08:44,160
like, varies in time or not,

238
00:08:44,160 --> 00:08:45,990
which is sort of one of the
straightforward questions

239
00:08:45,990 --> 00:08:47,850
you can ask about that model.

240
00:08:47,850 --> 00:08:51,090
You wanna find things about
those measurements we're making

241
00:08:51,090 --> 00:08:52,800
that you can actually
predict with your theory.

242
00:08:52,800 --> 00:08:55,020
And with our theory of the universe,

243
00:08:55,020 --> 00:08:57,900
we're not able to say, "I
think I'm gonna see a galaxy

244
00:08:57,900 --> 00:09:01,140
at this location in space or

this coordinate on the sky."

245
00:09:01,140 --> 00:09:05,460
What we can say is we have some
picture or some description

246
00:09:05,460 --> 00:09:08,850
of how a universe that
started out very uniform,

247
00:09:08,850 --> 00:09:11,820
so the density being basically
almost the same everywhere

248
00:09:11,820 --> 00:09:14,190
but with tiny density fluctuations,

249
00:09:14,190 --> 00:09:15,990
and then over time,
given our understanding

250
00:09:15,990 --> 00:09:18,030
of, like, what types of
matter are contributing

251
00:09:18,030 --> 00:09:20,730
to those fluctuations
and how gravity works,

252
00:09:20,730 --> 00:09:21,563
how they grow over time.

253
00:09:21,563 --> 00:09:23,130
So what you get is not a description

254
00:09:23,130 --> 00:09:25,750
of, okay, I expect to
see a galaxy in spot A

255

00:09:25,750 --> 00:09:27,180
and a galaxy in spot B,

256
00:09:27,180 --> 00:09:32,180
but you can say I expect
that the sort of size

257
00:09:32,340 --> 00:09:33,810
and fluctuations in density,

258
00:09:33,810 --> 00:09:34,770
so, like, how do you compare

259
00:09:34,770 --> 00:09:36,440
sort of the highest
densities in the universe

260
00:09:36,440 --> 00:09:38,310
to the lowest densities,

261
00:09:38,310 --> 00:09:40,350
and you can make predictions about that.

262
00:09:40,350 --> 00:09:41,820
And you can also, in the same way

263
00:09:41,820 --> 00:09:45,750
that, you know, our tortured
lawn of grass analogy,

264
00:09:45,750 --> 00:09:47,070
like, you might be able to tie,

265
00:09:47,070 --> 00:09:50,220
like, how you put the
seeds down on the ground

266
00:09:50,220 --> 00:09:53,040
to how, like, clustered the grass is.

267
00:09:53,040 --> 00:09:54,600
Are you seeing grass in
a bunch of little tufts,

268
00:09:54,600 --> 00:09:56,670
or is it pretty spread out uniformly?

269
00:09:56,670 --> 00:09:57,600
We can make predictions

270
00:09:57,600 --> 00:10:00,090
for, like, do we expect to see galaxies

271
00:10:00,090 --> 00:10:01,230
distributed at random,

272
00:10:01,230 --> 00:10:03,090
or do we expect to see
them clumped together?

273
00:10:03,090 --> 00:10:04,200
And we can make predictions

274
00:10:04,200 --> 00:10:07,080
for basically the probability
of finding galaxies

275
00:10:07,080 --> 00:10:09,510
separated by a given
distance in the universe

276
00:10:09,510 --> 00:10:11,580
compared to an average distribution.

277
00:10:11,580 --> 00:10:13,620
So we're describing statistical properties

278

00:10:13,620 --> 00:10:17,070
of the distribution of
matter in the universe.

279
00:10:17,070 --> 00:10:19,317
And then statistics
comes in in another way

280
00:10:19,317 --> 00:10:21,120
as, like, all right,
given these measurements

281
00:10:21,120 --> 00:10:22,650
of statistical properties in the universe,

282
00:10:22,650 --> 00:10:23,483
how can we use that

283
00:10:23,483 --> 00:10:25,800
to tell us about the physics of our model?

284
00:10:25,800 --> 00:10:29,130
We have these measurements of,
like, how close or far away

285
00:10:29,130 --> 00:10:31,410
we expect to see galaxies to one another.

286
00:10:31,410 --> 00:10:32,670
We can predict that with our model,

287
00:10:32,670 --> 00:10:35,310
but we know our model has
some assumptions in it

288
00:10:35,310 --> 00:10:37,140
and we need to be able
to do these calculations,

289

00:10:37,140 --> 00:10:38,310
we need to make some assumptions.

290
00:10:38,310 --> 00:10:40,320
But a lot of my day

291
00:10:40,320 --> 00:10:42,090
and a lot of the work I do
with my close colleagues

292
00:10:42,090 --> 00:10:43,680
is making sure that, all right,

293
00:10:43,680 --> 00:10:45,060
we're trying to use these measurements

294
00:10:45,060 --> 00:10:46,500
to say something very fundamental

295
00:10:46,500 --> 00:10:47,700
about physics in the universe

296
00:10:47,700 --> 00:10:50,760
of, like, does dark energy
vary with time or not?

297
00:10:50,760 --> 00:10:51,870
And we wanna make sure

298
00:10:51,870 --> 00:10:54,180
that we don't mistake some complication

299
00:10:54,180 --> 00:10:56,730
in, like, how supernova

300
00:10:56,730 --> 00:10:59,370
blow gas out of galaxies or something.

301

00:10:59,370 --> 00:11:01,560
Like, one of our big
challenges in cosmology

302
00:11:01,560 --> 00:11:03,930
is trying to make sure uncertainties

303
00:11:03,930 --> 00:11:05,640
about the detailed calculations

304
00:11:05,640 --> 00:11:09,450
of that smaller-scale astrophysics,
so just galaxy scales,

305
00:11:09,450 --> 00:11:11,730
doesn't influence the inferences

306
00:11:11,730 --> 00:11:13,170
that we're making from the larger scales,

307
00:11:13,170 --> 00:11:16,200
or wanna get as much
information out as possible

308
00:11:16,200 --> 00:11:17,580
without biasing ourselves

309
00:11:17,580 --> 00:11:18,930
and tricking ourselves into thinking

310
00:11:18,930 --> 00:11:20,580
we discovered something about dark energy

311
00:11:20,580 --> 00:11:22,440
when, really, we're not understanding

312
00:11:22,440 --> 00:11:23,670
our modeling predictions.

313
00:11:23,670 --> 00:11:26,310
So we do a ton of tests,
we use a ton of simulations

314
00:11:26,310 --> 00:11:28,980
to really make sure that
we do that rigorously,

315
00:11:28,980 --> 00:11:31,740
and then translating these comparisons

316
00:11:31,740 --> 00:11:33,060
of model predictions data

317
00:11:33,060 --> 00:11:36,660
into information about
parameters of a model

318
00:11:36,660 --> 00:11:39,300
or which model is better than another one

319
00:11:39,300 --> 00:11:42,760
is the whole sort of subfield
of study in cosmology itself.

320
00:11:42,760 --> 00:11:43,800
- Yeah, I would assume

321
00:11:43,800 --> 00:11:46,230
this must be a really challenging problem

322
00:11:46,230 --> 00:11:47,970
when you have so much data.

323
00:11:47,970 --> 00:11:50,550
And I'm just curious, like,
when you have all this data,

324

00:11:50,550 --> 00:11:52,620
how do you go about
approaching the problem

325
00:11:52,620 --> 00:11:55,440
of when you need to
look at the observations

326
00:11:55,440 --> 00:11:56,520
you already have

327
00:11:56,520 --> 00:11:59,430
versus when you need to
go and collect more data

328
00:11:59,430 --> 00:12:00,900
in a new way?

329
00:12:00,900 --> 00:12:02,760
- There's a lot of value

330
00:12:02,760 --> 00:12:05,400
in looking at what data we have on hand

331
00:12:05,400 --> 00:12:08,790
and looking for new ways to
extract information out of it.

332
00:12:08,790 --> 00:12:10,020
So a lot of the measurements we make

333
00:12:10,020 --> 00:12:11,460
of these statistical
properties of galaxies

334
00:12:11,460 --> 00:12:13,230
are looking at, like, the distances

335
00:12:13,230 --> 00:12:15,120

between pairs of galaxies,

336
00:12:15,120 --> 00:12:18,090
and you can go to sort of, we
say higher order statistics,

337
00:12:18,090 --> 00:12:20,550
so that's, you know, statistics
based on pairs of galaxies.

338
00:12:20,550 --> 00:12:21,990
You can look at triplets of galaxies

339
00:12:21,990 --> 00:12:24,780
and see, like, what kind of
triangles you expect to see

340
00:12:24,780 --> 00:12:27,090
of different sizes and length scales.

341
00:12:27,090 --> 00:12:28,530
And there's a whole field of research

342
00:12:28,530 --> 00:12:30,210
which these calculations
tend to be a bit harder

343
00:12:30,210 --> 00:12:31,290
and the measurements
tend to be a bit harder

344
00:12:31,290 --> 00:12:35,190
of understanding, like,
what kinds of physics,

345
00:12:35,190 --> 00:12:36,360
either new or what we know about,

346
00:12:36,360 --> 00:12:37,590

can you get more information from,

347
00:12:37,590 --> 00:12:39,930
like, taking these maps we already have

348
00:12:39,930 --> 00:12:41,280
and, like, pushing them harder

349
00:12:41,280 --> 00:12:43,770
to get more and more
information out of that.

350
00:12:43,770 --> 00:12:45,810
But then going and gathering more data

351
00:12:45,810 --> 00:12:48,480
'cause the more galaxies you
make these measurements for,

352
00:12:48,480 --> 00:12:50,610
the smaller the error bars
on those measurements are,

353
00:12:50,610 --> 00:12:52,350
so, like, when you make a comparison

354
00:12:52,350 --> 00:12:54,360
of your model prediction to the data,

355
00:12:54,360 --> 00:12:57,960
if your data are more precise,
like, they're measured well,

356
00:12:57,960 --> 00:12:59,940
having more galaxies is good for that.

357
00:12:59,940 --> 00:13:03,030
You can know that if you see
a little bit of a deviation

358
00:13:03,030 --> 00:13:05,010
between your prediction and the data,

359
00:13:05,010 --> 00:13:06,480
you can be more confident that it's real

360
00:13:06,480 --> 00:13:09,510
and not some, like, statistical
fluctuation or noise.

361
00:13:09,510 --> 00:13:12,000
And I think most, if not all, cosmologists

362
00:13:12,000 --> 00:13:15,240
are kind of engaged a bit
in both of these things.

363
00:13:15,240 --> 00:13:16,350
We're consistently planning,

364
00:13:16,350 --> 00:13:18,510
like, working on the current generation

365
00:13:18,510 --> 00:13:20,400
of experiments gathering data,

366
00:13:20,400 --> 00:13:24,120
and sort of looking to the
next generation of experiments

367
00:13:24,120 --> 00:13:25,080
which we'll be turning on.

368
00:13:25,080 --> 00:13:28,110
And also, there's sort of a
lot of complementarity there.

369

00:13:28,110 --> 00:13:30,990
So the experiment that I
work on is a galaxy survey

370
00:13:30,990 --> 00:13:33,120
called the Dark Energy Survey,

371
00:13:33,120 --> 00:13:35,330
which is a survey that's mapped
the distribution of matter

372
00:13:35,330 --> 00:13:36,540
in a patch of the sky

373
00:13:36,540 --> 00:13:38,880
measuring a couple
hundred million galaxies,

374
00:13:38,880 --> 00:13:42,660
and we have the biggest
data set of its type,

375
00:13:42,660 --> 00:13:45,300
so it's the most statistically
powerful galaxy survey

376
00:13:45,300 --> 00:13:48,030
of its type, which we can
maybe touch on it in a bit.

377
00:13:48,030 --> 00:13:49,830
And so the constraints we can get

378
00:13:49,830 --> 00:13:53,100
from studying that map of the
universe is really exciting

379
00:13:53,100 --> 00:13:54,660
and, you know, sort of pushing the bounds

380
00:13:54,660 --> 00:13:56,640
of what we can do in cosmology.

381
00:13:56,640 --> 00:13:59,940
It's also crucial as sort of a workshop

382
00:13:59,940 --> 00:14:01,380
for developing techniques we'll need

383
00:14:01,380 --> 00:14:04,170
when we go to the next
generation experiment,

384
00:14:04,170 --> 00:14:06,660
which we'll get even
more precise constraints,

385
00:14:06,660 --> 00:14:08,550
and, you know, I mentioned we
have to spend a lot of time

386
00:14:08,550 --> 00:14:11,580
accounting for, like, are the
approximations we're using

387
00:14:11,580 --> 00:14:13,350
for our calculations accurate enough?

388
00:14:13,350 --> 00:14:15,030
And as your measurements get more precise,

389
00:14:15,030 --> 00:14:17,280
that answer can very
easily turn from yes to no,

390
00:14:17,280 --> 00:14:19,080
and so we have to, like,
push the bounds on that

391
00:14:19,080 --> 00:14:21,990
every time our data get more precise.

392
00:14:21,990 --> 00:14:23,910
- You mentioned the Dark Energy Survey,

393
00:14:23,910 --> 00:14:26,520
the experiment that you're working on.

394
00:14:26,520 --> 00:14:30,930
Can you tell us sort of the
goals and motivations of that

395
00:14:30,930 --> 00:14:31,980
and how it actually works?

396
00:14:31,980 --> 00:14:35,070
Is this a telescope out
in space or on a mountain,

397
00:14:35,070 --> 00:14:37,173
or is it something else entirely?

398
00:14:38,220 --> 00:14:40,920
- I guess maybe as a,
like, basic definition,

399
00:14:40,920 --> 00:14:45,920
a galaxy survey is some
experiment usually run by,

400
00:14:46,020 --> 00:14:48,840
I think always run by
a large collaboration

401
00:14:48,840 --> 00:14:50,790
which you try to systematically,

402

00:14:50,790 --> 00:14:52,710
like, observe a patch of the sky

403
00:14:52,710 --> 00:14:54,870
and make a really uniform map

404
00:14:54,870 --> 00:14:56,580
of the distribution of galaxies.

405
00:14:56,580 --> 00:14:57,900
So instead of, like, pointing a telescope

406
00:14:57,900 --> 00:15:00,030
at an individual galaxy
or a group of galaxies

407
00:15:00,030 --> 00:15:00,930
and taking detailed pictures,

408
00:15:00,930 --> 00:15:02,940
we're trying to just map the sky

409
00:15:02,940 --> 00:15:05,430
so we can make these
statistical measurements.

410
00:15:05,430 --> 00:15:06,840
The Dark Energy Survey

411
00:15:06,840 --> 00:15:08,640
is what is known as an imaging survey,

412
00:15:08,640 --> 00:15:10,230
which means on our telescope,

413
00:15:10,230 --> 00:15:11,790
we basically have a giant digital camera,

414

00:15:11,790 --> 00:15:13,980
and we can, like, take pictures of the sky

415
00:15:13,980 --> 00:15:17,190
as opposed to, like, measuring
the colors very precisely.

416
00:15:17,190 --> 00:15:20,550
That giant digital camera is
called the Dark Energy Camera,

417
00:15:20,550 --> 00:15:21,383
which we're very creative

418
00:15:21,383 --> 00:15:22,530
with names clearly.
- That's a good name for it.

419
00:15:22,530 --> 00:15:25,260
- And it is on a four-meter telescope

420
00:15:25,260 --> 00:15:28,860
called the Blanco Telescope
in Cerro Tololo in Chile.

421
00:15:28,860 --> 00:15:30,750
So it's on a top of a mountain.

422
00:15:30,750 --> 00:15:32,400
You put telescopes on tops of mountains

423
00:15:32,400 --> 00:15:34,860
because there's water in the atmosphere

424
00:15:34,860 --> 00:15:36,210
and, like, turbulence in the atmosphere

425
00:15:36,210 --> 00:15:38,610
can make images of space look blurry,

426
00:15:38,610 --> 00:15:40,890
and so you wanna go to
where there's not much water

427
00:15:40,890 --> 00:15:42,780
in the atmosphere and
there's not much atmosphere,

428
00:15:42,780 --> 00:15:45,720
so, generally,
observatories are in deserts

429
00:15:45,720 --> 00:15:47,013
and on tops of mountains.

430
00:15:48,030 --> 00:15:50,160
- You've said this is a
really big collaboration.

431
00:15:50,160 --> 00:15:52,020
Can you give us a sense of how big

432
00:15:52,020 --> 00:15:53,160
and how the different teams

433
00:15:53,160 --> 00:15:55,320
in this collaboration are organized?

434
00:15:55,320 --> 00:15:59,550
- Dark Energy Survey has, I
think, about 400 people in it.

435
00:15:59,550 --> 00:16:02,010
It's been going for over a decade

436
00:16:02,010 --> 00:16:03,360
so I think the camera was installed

437
00:16:03,360 --> 00:16:05,310
on the telescope in 2011.

438
00:16:05,310 --> 00:16:08,760
So this camera was built
specifically for this survey.

439
00:16:08,760 --> 00:16:11,220
It's specialized to be
more sensitive to red light

440
00:16:11,220 --> 00:16:14,910
than your average chip that
would be in a digital camera.

441
00:16:14,910 --> 00:16:15,743
The CCD chips,

442
00:16:15,743 --> 00:16:17,400
or the little chip that would
be in your digital camera,

443
00:16:17,400 --> 00:16:20,430
for the telescope is like
three feet across so it's big.

444
00:16:20,430 --> 00:16:21,930
So this collaboration worked on things

445
00:16:21,930 --> 00:16:24,480
from planning the survey
to building the camera

446
00:16:24,480 --> 00:16:26,700
to installing it to running the shifts,

447
00:16:26,700 --> 00:16:29,820
so we did something like
760 nights of observing

448
00:16:29,820 --> 00:16:33,000
between, I think, 2013 and 2019.

449
00:16:33,000 --> 00:16:34,410
And then there's a whole team of people

450
00:16:34,410 --> 00:16:38,970
that go from sort of raw images
from the big digital camera

451
00:16:38,970 --> 00:16:42,060
and turn that into catalogs
of where do we see galaxies,

452
00:16:42,060 --> 00:16:44,310
what are their colors,
what are their shapes?

453
00:16:44,310 --> 00:16:46,290
These teams all overlap and
people move between them,

454
00:16:46,290 --> 00:16:47,970
but then there's going from those catalogs

455
00:16:47,970 --> 00:16:50,430
to making these statistical measurements.

456
00:16:50,430 --> 00:16:53,580
And then where I kind of
live within the collaboration

457
00:16:53,580 --> 00:16:55,170
at the sort of end of that

458
00:16:55,170 --> 00:16:58,110
is trying to go from those
statistical measurements

459
00:16:58,110 --> 00:17:00,150
to inferences about the physics.

460
00:17:00,150 --> 00:17:01,770
So I've been talking specifically

461
00:17:01,770 --> 00:17:04,770
about measurements of galaxy clustering.

462
00:17:04,770 --> 00:17:07,530
The image we have also lets
us map the distribution

463
00:17:07,530 --> 00:17:08,760
of structure in the universe

464
00:17:08,760 --> 00:17:11,310
using how the shapes of distant galaxies

465
00:17:11,310 --> 00:17:14,400
get a little bit distorted
by gravitational lensing

466
00:17:14,400 --> 00:17:16,950
when their light passes
through clumps of matter

467
00:17:16,950 --> 00:17:18,390
along the line of sight.

468
00:17:18,390 --> 00:17:20,340
- And then the light is
actually bent a little bit

469
00:17:20,340 --> 00:17:22,980
by the gravity of what is passing by?

470

00:17:22,980 --> 00:17:25,050
- Like a beam of light
will get a bit deflected

471
00:17:25,050 --> 00:17:26,670
by a gravitational potential.

472
00:17:26,670 --> 00:17:28,200
And, you know, if we're looking out

473
00:17:28,200 --> 00:17:31,380
over millions or billions of
light years in the universe,

474
00:17:31,380 --> 00:17:34,020
there's sort of structures
in the universe,

475
00:17:34,020 --> 00:17:36,060
these structures, I mean, like, galaxies

476
00:17:36,060 --> 00:17:37,230
and groups of galaxies

477
00:17:37,230 --> 00:17:38,700
and they kind of end up being aligned

478
00:17:38,700 --> 00:17:40,110
in this kind of filamentary structure.

479
00:17:40,110 --> 00:17:41,610
So light from more distant galaxies

480
00:17:41,610 --> 00:17:44,760
is going through the large-scale structure

481
00:17:44,760 --> 00:17:46,260
between us and them and getting deflected.

482
00:17:46,260 --> 00:17:49,500
So we can both look at the
fact that galaxies tend to live

483
00:17:49,500 --> 00:17:52,170
in high-density regions of the universe

484
00:17:52,170 --> 00:17:53,490
and that those high-density regions

485
00:17:53,490 --> 00:17:55,110
also cause the most deflection

486
00:17:55,110 --> 00:17:58,230
and therefore distortion to
background galaxy shapes.

487
00:17:58,230 --> 00:17:59,910
Those are both tools we have

488
00:17:59,910 --> 00:18:02,670
to map the distribution
of matter in the universe.

489
00:18:02,670 --> 00:18:05,010
There are other teams
in the collaboration.

490
00:18:05,010 --> 00:18:08,250
There's a team that
focuses on galaxy clusters,

491
00:18:08,250 --> 00:18:10,890
so, like, large groups of galaxies.

492
00:18:10,890 --> 00:18:12,840
There's a team that looks for supernova

493

00:18:12,840 --> 00:18:14,220
and uses those measurements

494
00:18:14,220 --> 00:18:15,780
to learn about the
expansion of the universe.

495
00:18:15,780 --> 00:18:17,220
But this data set is really rich

496
00:18:17,220 --> 00:18:20,310
and lets you do a lot of
things not just in cosmology,

497
00:18:20,310 --> 00:18:22,770
and I'm sure I'm leaving
out something in cosmology,

498
00:18:22,770 --> 00:18:26,970
but the fact that we have
760ish nights of observation

499
00:18:26,970 --> 00:18:29,160
over the course of six years,

500
00:18:29,160 --> 00:18:31,080
imaging each patch of the sky

501
00:18:31,080 --> 00:18:32,490
I think something like 50 times,

502
00:18:32,490 --> 00:18:34,980
so like 10 times in each of 5 colors.

503
00:18:34,980 --> 00:18:36,660
It also is really good
to see things moving.

504
00:18:36,660 --> 00:18:37,980

So there's a whole group,

505
00:18:37,980 --> 00:18:40,140
which I'm very impressed
by but I am not part of,

506
00:18:40,140 --> 00:18:43,650
but finding, like,
things like dwarf planets

507
00:18:43,650 --> 00:18:45,420
or comets in the solar system.

508
00:18:45,420 --> 00:18:49,170
- Wow, all from the same
essential piece of equipment

509
00:18:49,170 --> 00:18:50,910
and experiment?
- Exactly.

510
00:18:50,910 --> 00:18:52,230
- Maybe this is a silly question,

511
00:18:52,230 --> 00:18:53,970
but why so much observation?

512
00:18:53,970 --> 00:18:57,150
And how much of the sky are
you actually looking at?

513
00:18:57,150 --> 00:19:00,510
- The survey area covers about
one-eighth of the total sky,

514
00:19:00,510 --> 00:19:03,510
so it's kind of looking out
the south pole of our galaxy.

515

00:19:03,510 --> 00:19:04,343
So it turns out if you're trying

516
00:19:04,343 --> 00:19:05,640
to look at distant galaxies,

517
00:19:05,640 --> 00:19:06,960
the Milky Way is kind of a hindrance

518
00:19:06,960 --> 00:19:08,520
'cause it's hard to see stuff behind it

519
00:19:08,520 --> 00:19:11,010
when you're looking through
the disc of our galaxy.

520
00:19:11,010 --> 00:19:12,990
- So are you looking
perpendicular to the disc?

521
00:19:12,990 --> 00:19:14,490
- Yeah, sort of looking down,

522
00:19:14,490 --> 00:19:16,140
and there's some other patches

523
00:19:16,140 --> 00:19:17,580
added onto the survey footprint

524
00:19:17,580 --> 00:19:20,460
to increase overlap with
other kinds of measurements.

525
00:19:20,460 --> 00:19:21,990
So there are other experiments

526
00:19:21,990 --> 00:19:23,850
that map the large-scale universe

527
00:19:23,850 --> 00:19:27,390
using light from the very
early universe that was emitted

528
00:19:27,390 --> 00:19:29,370
in the first couple hundred
thousand years of the universe

529
00:19:29,370 --> 00:19:30,840
when atoms first formed.

530
00:19:30,840 --> 00:19:32,910
- Is this the cosmic microwave background?

531
00:19:32,910 --> 00:19:33,990
- Exactly, yeah.
- Okay.

532
00:19:33,990 --> 00:19:36,750
- And so there's a lot
of information gained

533
00:19:36,750 --> 00:19:38,735
by analyzing those data sets together,

534
00:19:38,735 --> 00:19:40,020
and so that's a whole team

535
00:19:40,020 --> 00:19:43,410
that's using the overlap where the DES map

536
00:19:43,410 --> 00:19:45,420
overlaps with the cosmic
microwave background map

537
00:19:45,420 --> 00:19:47,820
from something called
the South Pole Telescope.

538
00:19:47,820 --> 00:19:51,930
- Even though there's
billions of years duration

539
00:19:51,930 --> 00:19:55,170
between what's pictured in those maps,

540
00:19:55,170 --> 00:19:56,370
do you compare one to the other

541
00:19:56,370 --> 00:20:00,180
to show how things evolve
and change over time?

542
00:20:00,180 --> 00:20:01,140
- There's that element,

543
00:20:01,140 --> 00:20:04,170
so you can analyze the
cosmic microwave maps

544
00:20:04,170 --> 00:20:07,620
and see what inferences that
would give you about cosmology,

545
00:20:07,620 --> 00:20:08,970
and then say, given our model,

546
00:20:08,970 --> 00:20:10,680
what do we expect to see
in the late universe?

547
00:20:10,680 --> 00:20:12,420
If the maps are actually
on the same patch of sky,

548
00:20:12,420 --> 00:20:13,530
you get something additional.

549
00:20:13,530 --> 00:20:16,230
Whereas, like, we kind of know
the statistical properties

550
00:20:16,230 --> 00:20:19,230
of the CMB, cosmic
microwave background map,

551
00:20:19,230 --> 00:20:21,210
and that light is also traveling

552
00:20:21,210 --> 00:20:23,430
through the same
structures as the galaxies.

553
00:20:23,430 --> 00:20:26,670
So the same structures that are
distorting the galaxy shapes

554
00:20:26,670 --> 00:20:29,610
with, we call it, weak
gravitational lensing

555
00:20:29,610 --> 00:20:31,560
'cause it's, like, tiny distortions,

556
00:20:31,560 --> 00:20:33,450
and that same distortion
affects the CMB light,

557
00:20:33,450 --> 00:20:35,040
so you can use a cross correlation

558
00:20:35,040 --> 00:20:37,680
or, like, look at the
relationship between distortions

559
00:20:37,680 --> 00:20:40,200
in the cosmic microwave

background light and the galaxies

560
00:20:40,200 --> 00:20:42,810
to be extra sure that the distortion

561
00:20:42,810 --> 00:20:45,120
you're seeing in the
galaxies is from lensing

562
00:20:45,120 --> 00:20:47,730
and not through some other
properties of galaxies.

563
00:20:47,730 --> 00:20:49,350
So it's kind of an
additional piece of data

564
00:20:49,350 --> 00:20:50,183
you can throw at it

565
00:20:50,183 --> 00:20:52,440
to really make sure our
maps are more certain.

566
00:20:52,440 --> 00:20:55,620
- I wanna go back to some
terms you've said a few times,

567
00:20:55,620 --> 00:20:58,830
which are galaxy clusters
and galaxy clumps,

568
00:20:58,830 --> 00:21:01,440
because when I was reading
about this Dark Energy Survey,

569
00:21:01,440 --> 00:21:04,440
I found this really interesting
that galaxy clumpiness

570
00:21:04,440 --> 00:21:07,950
is something that people actually
say in a lot of this work.

571
00:21:07,950 --> 00:21:10,590
Can you tell us why these are useful terms

572
00:21:10,590 --> 00:21:12,690
to look into and define?

573
00:21:12,690 --> 00:21:15,060
- Saying clumpiness, and as you
say, a lot of people use it,

574
00:21:15,060 --> 00:21:18,630
is when we're describing
structure in the universe,

575
00:21:18,630 --> 00:21:21,180
you know, we've got this
story of the universe

576
00:21:21,180 --> 00:21:22,290
of, like, once upon a time,

577
00:21:22,290 --> 00:21:24,990
the universe was denser
and much more uniform,

578
00:21:24,990 --> 00:21:28,290
and over time, those small
fluctuations in density grow

579
00:21:28,290 --> 00:21:29,670
to form structures,

580
00:21:29,670 --> 00:21:31,230
and the properties of those structures

581
00:21:31,230 --> 00:21:34,530
and how fast they grow depend
on the physics of gravity,

582
00:21:34,530 --> 00:21:36,450
it depends on how much matter you have.

583
00:21:36,450 --> 00:21:37,977
If you turn up the amount of dark energy

584
00:21:37,977 --> 00:21:39,600
and the universe expands faster,

585
00:21:39,600 --> 00:21:42,120
that kind of acts against
the pull of gravity,

586
00:21:42,120 --> 00:21:44,520
so, like, the rate that
structure forms in the universe

587
00:21:44,520 --> 00:21:46,650
depends on the properties of dark energy

588
00:21:46,650 --> 00:21:48,573
because it influences the expansion.

589
00:21:49,440 --> 00:21:52,710
And so I guess I'm using
clumpiness or clumping

590
00:21:52,710 --> 00:21:54,030
as like a shorthand

591
00:21:54,030 --> 00:21:56,040
for the statistical
measurements we can make

592

00:21:56,040 --> 00:21:59,520
for how matter is
distributed in the universe.

593
00:21:59,520 --> 00:22:01,110
You know, sort of a key
piece of information

594
00:22:01,110 --> 00:22:03,810
is just, like, how big are
the density fluctuations.

595
00:22:03,810 --> 00:22:07,020
And by that, I don't mean like
if I hold up a ruler to them,

596
00:22:07,020 --> 00:22:07,853
how far apart are they?

597
00:22:07,853 --> 00:22:09,900
I mean, like, how much density

598
00:22:09,900 --> 00:22:11,640
deviates from the average density

599
00:22:11,640 --> 00:22:13,140
and how that varies when
you look at it in space,

600
00:22:13,140 --> 00:22:15,990
you can kind of make a
statistical measurement,

601
00:22:15,990 --> 00:22:17,910
which is, like, a statistical term

602
00:22:17,910 --> 00:22:20,670
would be you'd measure the
variance of the density.

603
00:22:20,670 --> 00:22:23,610
That variance will be small if
the universe is very uniform

604
00:22:23,610 --> 00:22:25,860
where the density is close
to average everywhere,

605
00:22:25,860 --> 00:22:27,600
but if you have a big clump in one spot

606
00:22:27,600 --> 00:22:29,970
and a void in another spot

607
00:22:29,970 --> 00:22:32,520
and there's an extreme difference,

608
00:22:32,520 --> 00:22:35,730
then this variance of the
density will be higher

609
00:22:35,730 --> 00:22:39,420
and sort of the universe
is less uniform or clumpy.

610
00:22:39,420 --> 00:22:41,307
- There's numerous teams
that are part of the DES,

611
00:22:41,307 --> 00:22:42,930
the Dark Energy Survey.

612
00:22:42,930 --> 00:22:44,280
Can you go a little bit more in depth

613
00:22:44,280 --> 00:22:47,460
about what you specifically are
trying to do with this work?

614
00:22:47,460 --> 00:22:49,320
- The working group within
DES that I'm part of

615
00:22:49,320 --> 00:22:51,150
is called Theory and Combined Probes,

616
00:22:51,150 --> 00:22:54,060
which I help work on
putting the pieces together

617
00:22:54,060 --> 00:22:57,420
that we need to use to be able
to make the model predictions

618
00:22:57,420 --> 00:22:59,400
that we compare to data,

619
00:22:59,400 --> 00:23:00,990
and then, you know, doing that comparison

620
00:23:00,990 --> 00:23:02,700
and doing the fits and
making all the plots

621
00:23:02,700 --> 00:23:03,900
and trying to make the plots pretty

622
00:23:03,900 --> 00:23:05,400
and all these kind of things.

623
00:23:05,400 --> 00:23:07,410
Like I was mentioning,
when we have the two maps

624
00:23:07,410 --> 00:23:10,620
from, say, the CMB and weak
lensing in the galaxies,

625
00:23:10,620 --> 00:23:12,420
having those two
measurements of the universe

626
00:23:12,420 --> 00:23:14,790
that you can put together,
use them together,

627
00:23:14,790 --> 00:23:16,050
it's greater than the sum of the parts

628
00:23:16,050 --> 00:23:17,220
'cause you can get extra information

629
00:23:17,220 --> 00:23:18,780
by combining these measurements.

630
00:23:18,780 --> 00:23:21,330
- Are they considered
probes, those different maps?

631
00:23:21,330 --> 00:23:22,860
- We use probe just to refer

632
00:23:22,860 --> 00:23:24,690
to, like, different kinds of measurements.

633
00:23:24,690 --> 00:23:27,750
And I've been mainly working
on, the last couple years,

634
00:23:27,750 --> 00:23:30,660
combined analysis of galaxy clustering,

635
00:23:30,660 --> 00:23:33,690
so, like, do galaxies tend to
be close together or far apart

636

00:23:33,690 --> 00:23:36,300
and how are they distributed,
and the weak lensing,

637
00:23:36,300 --> 00:23:38,880
so the distortions to the
distant galaxy shapes.

638
00:23:38,880 --> 00:23:40,410
You know, I was talking about
those paired measurements

639
00:23:40,410 --> 00:23:42,600
where you look at the distances
between pairs of galaxies.

640
00:23:42,600 --> 00:23:43,800
You can do an analogous thing

641
00:23:43,800 --> 00:23:46,320
by looking at how aligned are the shapes

642
00:23:46,320 --> 00:23:47,880
that we see of distant galaxies

643
00:23:47,880 --> 00:23:50,400
as a function of how far
apart they're on the sky.

644
00:23:50,400 --> 00:23:52,260
So if you have much more clumpy matter

645
00:23:52,260 --> 00:23:53,250
along the line of sight,

646
00:23:53,250 --> 00:23:54,690
you'll get more of this weak lensing,

647
00:23:54,690 --> 00:23:56,610

and that'll cause the
shapes of distant galaxies

648
00:23:56,610 --> 00:23:58,020
to look more aligned.

649
00:23:58,020 --> 00:24:00,900
Whereas if the universe is fairly uniform,

650
00:24:00,900 --> 00:24:01,733
you won't have much lensing

651
00:24:01,733 --> 00:24:05,100
and the shapes will look
pretty randomized on the sky.

652
00:24:05,100 --> 00:24:06,690
So those are sort of two different

653
00:24:06,690 --> 00:24:07,920
of these kind of measurements we can make

654
00:24:07,920 --> 00:24:08,760
using pairs of things,

655
00:24:08,760 --> 00:24:10,170
and then there's a third
one where you can say,

656
00:24:10,170 --> 00:24:12,120
all right, I've got these
positions of galaxies

657
00:24:12,120 --> 00:24:15,630
that are in the clumps of matter
that are doing the lensing

658
00:24:15,630 --> 00:24:17,490
and then the shapes of

galaxies behind them,

659
00:24:17,490 --> 00:24:18,810
and so putting those things together

660
00:24:18,810 --> 00:24:20,520
gives you some extra information.

661
00:24:20,520 --> 00:24:22,620
We've got three kinds
of measurements we make

662
00:24:22,620 --> 00:24:24,630
from two kinds of maps,

663
00:24:24,630 --> 00:24:27,423
and all of that together
is combined probes.

664
00:24:28,410 --> 00:24:30,870
- And I know you've said
that in the analysis you do,

665
00:24:30,870 --> 00:24:33,690
bias is something you
have to be careful about

666
00:24:33,690 --> 00:24:34,523
in different forms,

667
00:24:34,523 --> 00:24:36,120
and we had a question about this

668
00:24:36,120 --> 00:24:40,620
that was sent in from Estefania,
who's a student in Texas.

669
00:24:40,620 --> 00:24:41,820
- I've noticed your emphasis

670
00:24:41,820 --> 00:24:44,100
on the refinement of position cosmology.

671
00:24:44,100 --> 00:24:45,180
How has your research

672
00:24:45,180 --> 00:24:47,550
sought to alleviate
potential sources of bias

673
00:24:47,550 --> 00:24:50,400
in cosmological analysis?

674
00:24:50,400 --> 00:24:51,510
- I think that's a question

675
00:24:51,510 --> 00:24:53,700
that I spend most of
my time worrying about,

676
00:24:53,700 --> 00:24:55,350
so it's a good question.

677
00:24:55,350 --> 00:24:58,200
There are a lot of ways
that we approach this,

678
00:24:58,200 --> 00:24:59,910
and so there's not one panacea.

679
00:24:59,910 --> 00:25:03,510
It's a lot of trying to think
of all the possible ways

680
00:25:03,510 --> 00:25:05,550
that bias could enter our analyses

681

00:25:05,550 --> 00:25:08,670
and trying to test for them
and make analysis choices

682
00:25:08,670 --> 00:25:10,050
to help protect us against them.

683
00:25:10,050 --> 00:25:12,570
So one of the key things that we do

684
00:25:12,570 --> 00:25:16,050
is we try to make as many
choices about our analyses,

685
00:25:16,050 --> 00:25:18,840
like what length scales are we gonna use

686
00:25:18,840 --> 00:25:20,640
in comparing our model to measurements

687
00:25:20,640 --> 00:25:22,170
is, like, a very key one.

688
00:25:22,170 --> 00:25:23,790
We try to make a lot of those choices

689
00:25:23,790 --> 00:25:25,800
based on simulated data.

690
00:25:25,800 --> 00:25:27,927
So the sort of simplest
way we approach that

691
00:25:27,927 --> 00:25:29,430
is, you know, we've got our machinery

692
00:25:29,430 --> 00:25:31,140
to do a model prediction

693
00:25:31,140 --> 00:25:33,210
for the observables we're gonna measure,

694
00:25:33,210 --> 00:25:35,970
so we pick an input set of
cosmological parameters,

695
00:25:35,970 --> 00:25:38,550
an input model, we make
our model prediction,

696
00:25:38,550 --> 00:25:40,950
and then we treat that model
prediction as if it's data

697
00:25:40,950 --> 00:25:43,830
and analyze it using our planned analysis.

698
00:25:43,830 --> 00:25:45,420
And the reason why this is nice to do

699
00:25:45,420 --> 00:25:47,010
is 'cause you know what the truth is,

700
00:25:47,010 --> 00:25:50,550
you know what cosmology
that you computed it with.

701
00:25:50,550 --> 00:25:51,690
And so you can make sure,

702
00:25:51,690 --> 00:25:53,400
like, if that were the data you measured

703
00:25:53,400 --> 00:25:54,870
and you were to go analyze it

704
00:25:54,870 --> 00:25:57,270

using your parameter fitting methods

705
00:25:57,270 --> 00:26:00,120
and what length scales you're
comparing model to data on,

706
00:26:00,120 --> 00:26:01,500
you get out what you put in.

707
00:26:01,500 --> 00:26:05,220
- So you're essentially creating
a simulation for yourselves

708
00:26:05,220 --> 00:26:07,170
to make sure that what you get out

709
00:26:07,170 --> 00:26:08,640
corresponds to what you've created,

710
00:26:08,640 --> 00:26:10,890
even though that's not the actual data

711
00:26:10,890 --> 00:26:11,723
that you're working with.

712
00:26:11,723 --> 00:26:12,556
- Exactly.

713
00:26:12,556 --> 00:26:14,190
- You're making sure that
you can trust the data

714
00:26:14,190 --> 00:26:15,023
when you get it?

715
00:26:15,023 --> 00:26:17,940
- Exactly, and then we can sort
of take that a step further

716
00:26:17,940 --> 00:26:20,310
and say, all right, we know
that our model prediction

717
00:26:20,310 --> 00:26:22,830
has some approximations and
we had to make some choices

718
00:26:22,830 --> 00:26:24,360
over, you know, which software to use

719
00:26:24,360 --> 00:26:26,130
and what settings to use.

720
00:26:26,130 --> 00:26:27,680
Generally, the more accurate you wanna do

721
00:26:27,680 --> 00:26:29,700
or the more detailed
physics you wanna put in,

722
00:26:29,700 --> 00:26:31,050
the slower your calculation is.

723
00:26:31,050 --> 00:26:33,780
And, like, in practice, we can't
do the really slow versions

724
00:26:33,780 --> 00:26:36,630
for every single comparison
to model to data,

725
00:26:36,630 --> 00:26:38,130
or, you know, there might be some physics

726
00:26:38,130 --> 00:26:41,250
we just know that we
don't know how to model.

727
00:26:41,250 --> 00:26:42,900
So I was talking earlier about the effects

728
00:26:42,900 --> 00:26:45,180
of, like, galaxies and
supernova pushing gas out.

729
00:26:45,180 --> 00:26:47,040
On, like, cosmological small scales,

730
00:26:47,040 --> 00:26:48,240
that's very uncertain modeling

731
00:26:48,240 --> 00:26:50,550
and sort of figuring out feedback,

732
00:26:50,550 --> 00:26:52,080
we call it baryonic feedback,

733
00:26:52,080 --> 00:26:55,800
so supernova gas, stars,
dust, galaxy messiness

734
00:26:55,800 --> 00:26:58,560
can have a feedback effect
on the large-scale structure

735
00:26:58,560 --> 00:27:00,210
that we don't know how to model.

736
00:27:00,210 --> 00:27:03,030
Characterizing that is
like cutting-edge cosmology

737
00:27:03,030 --> 00:27:06,210
that people are debating
and figuring out actively.

738

00:27:06,210 --> 00:27:08,370
- I like that what most people, I think,

739
00:27:08,370 --> 00:27:10,380
consider the real stuff of the world,

740
00:27:10,380 --> 00:27:13,530
you know, stars and matter
and animals and trees,

741
00:27:13,530 --> 00:27:14,670
you're, like, eh, it's messiness,

742
00:27:14,670 --> 00:27:16,290
that's getting in the way.
- Exactly.

743
00:27:16,290 --> 00:27:17,670
So I was gonna say, like,
one thing that we can do

744
00:27:17,670 --> 00:27:18,890
with these simulated analysis

745
00:27:18,890 --> 00:27:21,810
is we can go get what's
sort of a large-ish

746
00:27:21,810 --> 00:27:24,810
but plausible amount of
this, like, baryonic,

747
00:27:24,810 --> 00:27:28,350
this supernova feedback stuff
that could influence our data

748
00:27:28,350 --> 00:27:30,690
that we know we're not modeling
so we can't model it well,

749
00:27:30,690 --> 00:27:33,300
and we can look at if that was real,

750
00:27:33,300 --> 00:27:35,820
so we'd throw out a lot of
our small-scale data points

751
00:27:35,820 --> 00:27:37,650
to, like, make sure we're
not sensitive to that.

752
00:27:37,650 --> 00:27:40,950
So we use these simulations
where the simulation is done

753
00:27:40,950 --> 00:27:43,230
with a more complicated model
than what we're fitting with,

754
00:27:43,230 --> 00:27:44,460
and we can make sure

755
00:27:44,460 --> 00:27:46,170
that we're not gonna falsely detect

756
00:27:46,170 --> 00:27:48,720
that dark energy is varying with time

757
00:27:48,720 --> 00:27:50,760
when it's just that
galaxies are hard to model.

758
00:27:50,760 --> 00:27:52,170
So that's one form of bias.

759
00:27:52,170 --> 00:27:55,140
Like, we're trying to find the true value

760

00:27:55,140 --> 00:27:58,770
or a range of values where
the true value may live

761
00:27:58,770 --> 00:28:00,750
for our cosmological model,

762
00:28:00,750 --> 00:28:02,790
and we wanna make sure those estimates

763
00:28:02,790 --> 00:28:04,920
have the true number in our error bars.

764
00:28:04,920 --> 00:28:06,777
One way that we talk
about bias in cosmology

765
00:28:06,777 --> 00:28:10,410
is, like, some effect that
you're not modeling correctly

766
00:28:10,410 --> 00:28:14,430
pushes your inferred
parameter values around enough

767
00:28:14,430 --> 00:28:15,660
that you might try to measure,

768
00:28:15,660 --> 00:28:18,090
like, a parameter described
as dark energy time dependence

769
00:28:18,090 --> 00:28:20,400
and it might move away
from what the true value is

770
00:28:20,400 --> 00:28:22,950
because you haven't accounted
for something in your model.

771
00:28:22,950 --> 00:28:25,620
We also try to account
for and protect against

772
00:28:25,620 --> 00:28:28,500
something that we call
unconscious experimenter bias.

773
00:28:28,500 --> 00:28:30,150
As scientists, we try as hard as we can

774
00:28:30,150 --> 00:28:32,880
to make all the decision
that goes into this analysis,

775
00:28:32,880 --> 00:28:33,713
what points to measure,

776
00:28:33,713 --> 00:28:36,330
what choices to make for
our model as objectively

777
00:28:36,330 --> 00:28:39,360
and in response to these
simulated analyses as possible,

778
00:28:39,360 --> 00:28:41,670
but, ultimately, you know,
science is done by people

779
00:28:41,670 --> 00:28:42,780
and people are subject

780
00:28:42,780 --> 00:28:45,060
to all kinds of pressures and assumptions

781
00:28:45,060 --> 00:28:47,610
and we might be interested in
seeing how our measurements

782
00:28:47,610 --> 00:28:49,560
are relating to previous measurements

783
00:28:49,560 --> 00:28:52,620
or, like, there are special
values in the parameter space,

784
00:28:52,620 --> 00:28:55,380
like detecting if dark
energy varies in time,

785
00:28:55,380 --> 00:28:58,830
it's a very different result
than if it's constant in time.

786
00:28:58,830 --> 00:29:01,620
And so you wanna make
sure, if at all possible,

787
00:29:01,620 --> 00:29:03,120
that, even subconsciously,

788
00:29:03,120 --> 00:29:06,330
our decisions on how to do
the analysis aren't influenced

789
00:29:06,330 --> 00:29:09,690
by whether the results
agree with our expectation.

790
00:29:09,690 --> 00:29:14,690
And so we use a, we call it
a blind analysis framework.

791
00:29:14,730 --> 00:29:17,400
Exactly what that means depends
a lot on the experiment,

792

00:29:17,400 --> 00:29:19,410
but, like, the main thing in
principle is you make sure

793
00:29:19,410 --> 00:29:21,810
that you're not looking
at your main results

794
00:29:21,810 --> 00:29:25,290
until you've frozen in all
the decisions to get there,

795
00:29:25,290 --> 00:29:27,480
and you hope that nothing
unexpected shows up

796
00:29:27,480 --> 00:29:29,820
after you, like, reveal the results.

797
00:29:29,820 --> 00:29:31,620
In practice, things are
not always that tidy,

798
00:29:31,620 --> 00:29:34,050
but generally, part of this
is if something does change

799
00:29:34,050 --> 00:29:35,280
or you find something afterwards,

800
00:29:35,280 --> 00:29:37,770
we really try to be rigorous
about, like, documenting it

801
00:29:37,770 --> 00:29:40,410
and being clear of, like, what
decisions were made before

802
00:29:40,410 --> 00:29:41,970
versus after unblinding.

803
00:29:41,970 --> 00:29:43,800
So it's kind of a similar motivation

804
00:29:43,800 --> 00:29:45,810
to if you hear about in,
like, medical fields,

805
00:29:45,810 --> 00:29:46,980
like double-blind trials

806
00:29:46,980 --> 00:29:50,190
where you test a new
medication against a placebo.

807
00:29:50,190 --> 00:29:51,240
Like, in those experiments,

808
00:29:51,240 --> 00:29:52,470
neither the patient nor the doctor

809
00:29:52,470 --> 00:29:55,110
knows which is the real pill
and which is the placebo.

810
00:29:55,110 --> 00:29:58,110
And you do that because you
don't want sort of expectations

811
00:29:58,110 --> 00:29:59,910
of whether somebody's
gonna feel better or worse

812
00:29:59,910 --> 00:30:02,280
to, like, influence your interpretation

813
00:30:02,280 --> 00:30:04,500
of some very complicated phenomena then.

814
00:30:04,500 --> 00:30:07,110
- I guess I just assume
that that kind of blinding

815
00:30:07,110 --> 00:30:08,340
was done in medicine

816
00:30:08,340 --> 00:30:12,030
and the more, I don't
know, human-scale sciences,

817
00:30:12,030 --> 00:30:14,030
and that when you're
dealing with the universe

818
00:30:14,030 --> 00:30:16,350
at these enormous scales and galaxies,

819
00:30:16,350 --> 00:30:19,710
my assumption was that, you
know, that's objective data

820
00:30:19,710 --> 00:30:22,110
and it's observables and
you don't need to do that,

821
00:30:22,110 --> 00:30:25,350
but clearly this is something
you need to be aware of.

822
00:30:25,350 --> 00:30:27,000
- Even though, you know,
we sort of guideline

823
00:30:27,000 --> 00:30:28,090
and try to be as transparent as possible

824
00:30:28,090 --> 00:30:29,250
about how choices are made,

825
00:30:29,250 --> 00:30:30,630
there are choices that need to be made.

826
00:30:30,630 --> 00:30:33,150
So, like, for example,
we use these simulations

827
00:30:33,150 --> 00:30:35,640
including all these messy galaxy physics,

828
00:30:35,640 --> 00:30:38,100
and we wanna make sure that
our cosmology inferences

829
00:30:38,100 --> 00:30:41,130
about dark energy aren't biased by that.

830
00:30:41,130 --> 00:30:42,750
But, like, how do you quantify that?

831
00:30:42,750 --> 00:30:45,930
What amount of bias is
little versus enough?

832
00:30:45,930 --> 00:30:49,290
And, like, you have to set a threshold

833
00:30:49,290 --> 00:30:51,480
and decide exactly what numbers

834
00:30:51,480 --> 00:30:53,910
you're gonna look at to assess that,

835
00:30:53,910 --> 00:30:56,310
and, you know, there's sort of things

836
00:30:56,310 --> 00:30:59,550

that are better choices than
others in sort of a broad sense

837
00:30:59,550 --> 00:31:01,950
but when you get down to the specifics,

838
00:31:01,950 --> 00:31:02,940
you wanna motivate things,

839
00:31:02,940 --> 00:31:04,440
but there's a certain
amount of arbitrariness

840
00:31:04,440 --> 00:31:05,757
that does come into it,

841
00:31:05,757 --> 00:31:07,320
and so we wanna make sure

842
00:31:07,320 --> 00:31:09,420
that, yeah, if we're making that choice,

843
00:31:09,420 --> 00:31:12,630
it's not informed in any way
by, like, what the science

844
00:31:12,630 --> 00:31:14,190
coming out the end of the pipeline is.

845
00:31:14,190 --> 00:31:16,530
It's part of the structure
of the whole analysis

846
00:31:16,530 --> 00:31:18,240
within our collaboration

847
00:31:18,240 --> 00:31:20,220
and in, you know, many cosmology analyses.

848
00:31:20,220 --> 00:31:22,710
So, recently finished a big analysis,

849
00:31:22,710 --> 00:31:24,690
and sort of one of the
dramatic stages at the end

850
00:31:24,690 --> 00:31:28,050
is you write up everything you
did and all the tests you do

851
00:31:28,050 --> 00:31:29,850
and have some collaborators
who are experts

852
00:31:29,850 --> 00:31:32,400
but not directly involved in
the project look that over

853
00:31:32,400 --> 00:31:34,080
and say, "All right, I think
you've checked everything

854
00:31:34,080 --> 00:31:35,220
you needed to check.

855
00:31:35,220 --> 00:31:38,790
You have our okay to reveal
your results or unblind them."

856
00:31:38,790 --> 00:31:40,470
And so it always feels
like a bit of an event,

857
00:31:40,470 --> 00:31:41,640
kind of a nerve-wracking event

858
00:31:41,640 --> 00:31:44,580
when you, like, look at the

results for the first time.

859
00:31:44,580 --> 00:31:46,080
So in that sense, it's definitely active.

860
00:31:46,080 --> 00:31:49,890
But, yeah, helping develop
the sort of technical method

861
00:31:49,890 --> 00:31:53,030
for hiding the results from
ourselves was my first project

862
00:31:53,030 --> 00:31:55,920
in the Dark Energy Survey
as a graduate student.

863
00:31:55,920 --> 00:31:57,390
There's varying degrees

864
00:31:57,390 --> 00:32:00,360
of technical manipulations you can do,

865
00:32:00,360 --> 00:32:02,310
'cause the trick is you wanna
hide the results for yourself,

866
00:32:02,310 --> 00:32:04,473
but you wanna give yourself
enough access to the data

867
00:32:04,473 --> 00:32:07,590
that you can test for all the
things you need to test for.

868
00:32:07,590 --> 00:32:10,410
And that ends up being
a pretty tricky question

869

00:32:10,410 --> 00:32:11,850
sort of on one extreme end

870
00:32:11,850 --> 00:32:14,280
of, like, not doing very
much technically for this

871
00:32:14,280 --> 00:32:16,170
is just you all agree as a collaboration,

872
00:32:16,170 --> 00:32:18,900
like, we're not gonna look
at plots of these parameters

873
00:32:18,900 --> 00:32:20,250
or something like that,

874
00:32:20,250 --> 00:32:22,470
which, like, does work for your purposes,

875
00:32:22,470 --> 00:32:24,210
but also, when you have
a big collaboration

876
00:32:24,210 --> 00:32:25,980
and, like, it can be
nice to have something

877
00:32:25,980 --> 00:32:28,860
a little bit harder to
accidentally peek at.

878
00:32:28,860 --> 00:32:30,840
The method that I worked
with some collaborators

879
00:32:30,840 --> 00:32:32,970
to develop and test and implement

880

00:32:32,970 --> 00:32:35,310
actually transforms these
statistical quantities

881
00:32:35,310 --> 00:32:36,143
that we measure

882
00:32:36,143 --> 00:32:38,340
from these three kinds of
statistical measurements,

883
00:32:38,340 --> 00:32:41,100
and we figured out a way
that you can transform them

884
00:32:41,100 --> 00:32:44,070
that, like, still keep them
all consistent with one another

885
00:32:44,070 --> 00:32:46,740
so they look like they came
from some valid universe,

886
00:32:46,740 --> 00:32:48,480
but it looks like they
came from a different set

887
00:32:48,480 --> 00:32:49,920
of cosmology parameters.

888
00:32:49,920 --> 00:32:53,520
So we have these, like,
transformed statistic measurements.

889
00:32:53,520 --> 00:32:55,170
Most of the other collaborations

890
00:32:55,170 --> 00:32:56,700
that are sort doing similar analyses,

891
00:32:56,700 --> 00:32:57,750
they have some mechanism

892
00:32:57,750 --> 00:33:00,450
for this kind of transformation
of data on some level.

893
00:33:00,450 --> 00:33:03,060
And I know in one of the other

894
00:33:03,060 --> 00:33:04,980
sort of weak lensing surveys out there,

895
00:33:04,980 --> 00:33:06,300
they have a much more technical,

896
00:33:06,300 --> 00:33:08,703
like, encryption double key
sort of way of doing this.

897
00:33:08,703 --> 00:33:11,130
It's the technical aspect of
how can we transform the data

898
00:33:11,130 --> 00:33:13,980
and make sure we preserve the
access we need to preserve,

899
00:33:13,980 --> 00:33:16,050
and then there's also, like,
how does your collaboration

900
00:33:16,050 --> 00:33:16,883
work as a group,

901
00:33:16,883 --> 00:33:19,860
and, you know, how do you decide
when to reveal the results,

902
00:33:19,860 --> 00:33:23,010
and what do you do if
something unexpected comes up?

903
00:33:23,010 --> 00:33:25,830
And, you know, this maybe
also ties into other ways

904
00:33:25,830 --> 00:33:27,420
that bias comes up in conversation

905
00:33:27,420 --> 00:33:30,450
of, like, personal
dynamics in collaborations

906
00:33:30,450 --> 00:33:32,820
and getting large groups
of people to work together.

907
00:33:32,820 --> 00:33:35,940
And so it's a challenge
within any collaboration

908
00:33:35,940 --> 00:33:37,320
and also, like, looking forward

909
00:33:37,320 --> 00:33:39,090
to next-generation galaxy surveys,

910
00:33:39,090 --> 00:33:40,680
which are gonna be even bigger,

911
00:33:40,680 --> 00:33:42,270
of, like, how do you make sure

912
00:33:42,270 --> 00:33:43,830
everyone has enough information

913

00:33:43,830 --> 00:33:45,690
to understand what tests are done?

914
00:33:45,690 --> 00:33:47,550
How can you make sure
everyone's voice gets heard

915
00:33:47,550 --> 00:33:49,020
when you're having these conversations?

916
00:33:49,020 --> 00:33:50,490
Often, when people are
kind of stressed out

917
00:33:50,490 --> 00:33:52,260
and pushing for results,

918
00:33:52,260 --> 00:33:54,150
it's an organizational challenge as well.

919
00:33:54,150 --> 00:33:56,430
And I think one additional benefit

920
00:33:56,430 --> 00:33:59,100
of these sort of blind
analysis frameworks,

921
00:33:59,100 --> 00:34:01,080
in addition to, you
know, helping make sure

922
00:34:01,080 --> 00:34:02,490
that you have the most robust

923
00:34:02,490 --> 00:34:04,140
and accurate science as possible,

924
00:34:04,140 --> 00:34:06,540
is it's kind of a little

bit of a sociological break.

925
00:34:06,540 --> 00:34:08,400
It's like if you all need to decide

926
00:34:08,400 --> 00:34:10,560
that you've checked all the
things you need to check

927
00:34:10,560 --> 00:34:12,030
to look at the results,

928
00:34:12,030 --> 00:34:13,290
I think it functions very well

929
00:34:13,290 --> 00:34:14,930
as sort of a pause for a collaboration

930
00:34:14,930 --> 00:34:17,280
to say, like, we've been
sprinting towards the end,

931
00:34:17,280 --> 00:34:18,390
let's take some time,

932
00:34:18,390 --> 00:34:20,030
take a week or two.
- Take a breather. (laughs)

933
00:34:20,030 --> 00:34:22,050
- In the same way as
developing, like, modeling

934
00:34:22,050 --> 00:34:23,430
and data analysis techniques,

935
00:34:23,430 --> 00:34:26,220
we're sort of a laboratory
for future analyses,

936
00:34:26,220 --> 00:34:28,800
these sort of blinding
analysis and strategies

937
00:34:28,800 --> 00:34:31,890
for how to make decisions
and how to organize people

938
00:34:31,890 --> 00:34:34,110
I think is another thing
that we learn a lot from

939
00:34:34,110 --> 00:34:35,850
and see what works and
what could work better.

940
00:34:35,850 --> 00:34:38,700
And that's very tied in with the science

941
00:34:38,700 --> 00:34:40,200
of how these large collaboration works.

942
00:34:40,200 --> 00:34:42,180
And these large collaborations are hard,

943
00:34:42,180 --> 00:34:44,250
we gather enough data
and do the work we need

944
00:34:44,250 --> 00:34:45,990
to, like, figure out what the universe

945
00:34:45,990 --> 00:34:47,130
can tell us about dark energy,

946
00:34:47,130 --> 00:34:49,440
so it's really crucial that
people who are interested

947
00:34:49,440 --> 00:34:51,126
can contribute and feel like their work

948
00:34:51,126 --> 00:34:53,220
is valued and important.
- It seems that

949
00:34:53,220 --> 00:34:56,550
a lot of your work also
pretty fundamentally relies

950
00:34:56,550 --> 00:34:58,170
on understanding this interplay

951
00:34:58,170 --> 00:34:59,970
between experiment and theory,

952
00:34:59,970 --> 00:35:01,170
so I'm wondering if you can tell us

953
00:35:01,170 --> 00:35:02,430
a little bit more about that

954
00:35:02,430 --> 00:35:06,240
and how experiments can
help us improve theory

955
00:35:06,240 --> 00:35:09,090
and theory can help us
improve experiments.

956
00:35:09,090 --> 00:35:11,730
- So I think cosmology as a field

957
00:35:11,730 --> 00:35:14,640
is really defined by this interplay.

958

00:35:14,640 --> 00:35:17,790
You can go back towards sort
of early days of cosmology

959
00:35:17,790 --> 00:35:21,450
where, you know, Einstein
developed general relativity

960
00:35:21,450 --> 00:35:25,260
and had this assumption that
the universe should be static.

961
00:35:25,260 --> 00:35:26,580
And when you look at what the equations

962
00:35:26,580 --> 00:35:27,570
tell you about the universe,

963
00:35:27,570 --> 00:35:29,340
it tells you it's gonna be
expanding or contracting,

964
00:35:29,340 --> 00:35:31,710
so we, you know, stuck a
constant in the equation,

965
00:35:31,710 --> 00:35:33,810
and if you tune it to a specific value,

966
00:35:33,810 --> 00:35:34,707
given the other properties
of the universe,

967
00:35:34,707 --> 00:35:35,540
you can get the universe

968
00:35:35,540 --> 00:35:37,950
to not be expanding or contracting at all.

969

00:35:37,950 --> 00:35:39,660
And then just a few years later,

970
00:35:39,660 --> 00:35:40,980
Edwin Hubble measured the fact

971
00:35:40,980 --> 00:35:42,930
that the universe was accelerating,

972
00:35:42,930 --> 00:35:45,090
so they throw out that
term, it's not needed,

973
00:35:45,090 --> 00:35:46,440
you know, we're gonna expect to find

974
00:35:46,440 --> 00:35:47,970
the universe that's decelerating.

975
00:35:47,970 --> 00:35:49,920
And then, you know, you get to the '90s

976
00:35:49,920 --> 00:35:51,030
when people go and measure that,

977
00:35:51,030 --> 00:35:53,700
and you realize, oh, it's
actually accelerating,

978
00:35:53,700 --> 00:35:54,870
which brings the constant back

979
00:35:54,870 --> 00:35:56,640
but tells you it needs a different value.

980
00:35:56,640 --> 00:35:59,130
And there's countless
stories within the field

981
00:35:59,130 --> 00:36:02,970
where the data tells you you
need some aspect of the theory,

982
00:36:02,970 --> 00:36:06,180
and then now, dark energy could
be a cosmological constant,

983
00:36:06,180 --> 00:36:08,190
and so far, sort of all the observations

984
00:36:08,190 --> 00:36:10,380
we've made of the universe
seem to prefer that

985
00:36:10,380 --> 00:36:12,510
or there's not evidence
for some other property,

986
00:36:12,510 --> 00:36:14,790
but we don't think that's the whole story.

987
00:36:14,790 --> 00:36:17,040
And why don't we think
it's the whole story

988
00:36:17,040 --> 00:36:18,990
would be a reasonable question.

989
00:36:18,990 --> 00:36:20,940
So, you know, this cosmological constant

990
00:36:20,940 --> 00:36:22,980
would be some, like, vacuum energy,

991
00:36:22,980 --> 00:36:26,640
and we can look to particle
physics colleagues down the hall

992
00:36:26,640 --> 00:36:29,400
and they predict that there
should be some vacuum energy.

993
00:36:29,400 --> 00:36:30,300
It's difficult to predict,

994
00:36:30,300 --> 00:36:32,220
but if you kind of make some estimates

995
00:36:32,220 --> 00:36:33,720
based on our knowledge of particle physics

996
00:36:33,720 --> 00:36:35,910
of what the value of that
energy density should be,

997
00:36:35,910 --> 00:36:37,980
you get a number that's,
like, absurdly larger

998
00:36:37,980 --> 00:36:39,600
than the number we measure.

999
00:36:39,600 --> 00:36:41,940
So given, like, particle
physics energy scales,

1000
00:36:41,940 --> 00:36:43,500
the value of this energy density we find

1001
00:36:43,500 --> 00:36:45,990
is, like, very tiny but nonzero.

1002
00:36:45,990 --> 00:36:49,860
And so you want to know
why that's the case,

1003

00:36:49,860 --> 00:36:51,600
and so there's a lot of
work being done by theorists

1004
00:36:51,600 --> 00:36:53,880
to think of different models
that could explain this.

1005
00:36:53,880 --> 00:36:57,450
Or you might ask, like, could
the universe be accelerating

1006
00:36:57,450 --> 00:36:58,980
not because there's some extra substance

1007
00:36:58,980 --> 00:37:01,140
but because we need to
extend general relativity

1008
00:37:01,140 --> 00:37:02,850
on large scales?

1009
00:37:02,850 --> 00:37:04,770
And then you can say like, all right,

1010
00:37:04,770 --> 00:37:07,560
but how would that
manifest in the universe?

1011
00:37:07,560 --> 00:37:08,970
Those models are predictions

1012
00:37:08,970 --> 00:37:11,400
for, like, ways that you
could extend your description

1013
00:37:11,400 --> 00:37:13,860
of gravity beyond general relativity

1014

00:37:13,860 --> 00:37:16,920
while still respecting all
the very tight constraints

1015
00:37:16,920 --> 00:37:17,940
we have on gravity

1016
00:37:17,940 --> 00:37:19,680
from, like, measurements
of the solar system

1017
00:37:19,680 --> 00:37:20,730
and lab experiments,

1018
00:37:20,730 --> 00:37:24,900
sort of gives you a set of
effects that you can go look for.

1019
00:37:24,900 --> 00:37:26,283
My team within the Dark Energy Survey

1020
00:37:26,283 --> 00:37:30,060
that I co-lead with another postdoc

1021
00:37:30,060 --> 00:37:33,210
who works at the Jet
Propulsion Laboratory for NASA

1022
00:37:33,210 --> 00:37:34,410
in particular focus

1023
00:37:34,410 --> 00:37:36,960
on taking these different proposed models

1024
00:37:36,960 --> 00:37:38,880
for, you know, maybe different ways

1025
00:37:38,880 --> 00:37:40,260
you could model dark energy

1026
00:37:40,260 --> 00:37:44,100
or modifications of your theory of gravity

1027
00:37:44,100 --> 00:37:46,200
and going and taking our galaxy cluster

1028
00:37:46,200 --> 00:37:49,260
and weak lensing data and
testing those extensions

1029
00:37:49,260 --> 00:37:52,320
to the sort of simplest
description of the universe.

1030
00:37:52,320 --> 00:37:55,110
In a similar way to when
we constrain properties

1031
00:37:55,110 --> 00:37:56,610
of the simplest model,

1032
00:37:56,610 --> 00:37:58,770
we can vary the input parameters

1033
00:37:58,770 --> 00:38:00,900
describing these kinds of
modifications of gravity

1034
00:38:00,900 --> 00:38:02,520
or dark energy properties

1035
00:38:02,520 --> 00:38:03,570
and place sort of limits

1036
00:38:03,570 --> 00:38:05,970
on what those parameters
are allowed to be.

1037
00:38:05,970 --> 00:38:07,620
Part of this big analysis we just finished

1038
00:38:07,620 --> 00:38:10,620
was testing a set of six
of these kinds of models,

1039
00:38:10,620 --> 00:38:14,110
and seems like the sort of
simplest cosmological model

1040
00:38:15,000 --> 00:38:16,740
lives to fight another day,

1041
00:38:16,740 --> 00:38:19,530
given our data, what's the largest amount

1042
00:38:19,530 --> 00:38:22,080
of, like, time dependence
that dark energy can have

1043
00:38:22,080 --> 00:38:23,610
in some range.

1044
00:38:23,610 --> 00:38:26,280
- That connection between
theory and experiment

1045
00:38:26,280 --> 00:38:28,590
is something that you very tangibly had

1046
00:38:28,590 --> 00:38:31,230
because you've not only
worked on the theory side

1047
00:38:31,230 --> 00:38:33,270
but you actually went
to the telescope, right?

1048
00:38:33,270 --> 00:38:36,120
- One benefit of working
in a large collaboration

1049
00:38:36,120 --> 00:38:38,880
that's trying to do over
700 nights of observing

1050
00:38:38,880 --> 00:38:40,140
over the course of six years

1051
00:38:40,140 --> 00:38:42,960
is they needed people to
do shifts on the telescope.

1052
00:38:42,960 --> 00:38:45,300
Some observatories, I think,
in next-generation survey,

1053
00:38:45,300 --> 00:38:46,860
they're doing a lot more,
like, remote observing,

1054
00:38:46,860 --> 00:38:49,410
but it can be helpful to
have people in the room.

1055
00:38:49,410 --> 00:38:52,650
So I did two observing shifts for DES.

1056
00:38:52,650 --> 00:38:54,360
You fly into a little beach town

1057
00:38:54,360 --> 00:38:56,910
and then ride a van for three
hours into the mountains,

1058
00:38:56,910 --> 00:38:59,850
and you stay in a astronomers' dorm

1059
00:38:59,850 --> 00:39:01,590
with, like, a little cafeteria

1060
00:39:01,590 --> 00:39:04,500
and go work on the telescope every night.

1061
00:39:04,500 --> 00:39:06,990
- After you told us about
it at first, I looked it up.

1062
00:39:06,990 --> 00:39:08,400
I wanted to see what it looked like,

1063
00:39:08,400 --> 00:39:10,920
and it looks so much like what I pictured,

1064
00:39:10,920 --> 00:39:14,130
you know, this classic
dome-shaped observatory,

1065
00:39:14,130 --> 00:39:15,870
but then there's these barren,

1066
00:39:15,870 --> 00:39:17,670
there's a few buildings around
at the top of this mountain,

1067
00:39:17,670 --> 00:39:20,130
but then it's sort of barren.
- Yeah, it's a desert.

1068
00:39:20,130 --> 00:39:22,470
- Yeah, what's it like to
go to the top of a mountain

1069
00:39:22,470 --> 00:39:26,400
and live in an astronomers' dormitory?

1070
00:39:26,400 --> 00:39:28,770
It seems like such a unique experience.

1071
00:39:28,770 --> 00:39:29,603
- I think it's probably

1072
00:39:29,603 --> 00:39:32,100
one of the most, like, incredible
experiences of my life,

1073
00:39:32,100 --> 00:39:34,080
and I feel very grateful
that I got to do it,

1074
00:39:34,080 --> 00:39:36,630
especially because, you know,
I usually work with data

1075
00:39:36,630 --> 00:39:39,030
that's in a very, like, processed form,

1076
00:39:39,030 --> 00:39:40,500
and so this is a very different way

1077
00:39:40,500 --> 00:39:42,240
of interacting with the experiment.

1078
00:39:42,240 --> 00:39:43,670
- That's data as it's pouring in

1079
00:39:43,670 --> 00:39:45,590
in real time from the universe, right?

1080
00:39:45,590 --> 00:39:49,110
- Yeah, so each exposure
with the Dark Energy Camera

1081
00:39:49,110 --> 00:39:50,760

is like 30-second exposures,

1082
00:39:50,760 --> 00:39:52,860
and you see, like, the raw image

1083
00:39:52,860 --> 00:39:56,520
of the different, like,
chips that make up the CCD

1084
00:39:56,520 --> 00:39:58,200
that measures the image.

1085
00:39:58,200 --> 00:40:00,840
And so they pop up on the
screen as they come in,

1086
00:40:00,840 --> 00:40:03,180
and the thing that I find really striking

1087
00:40:03,180 --> 00:40:04,650
is just how messy they look.

1088
00:40:04,650 --> 00:40:06,120
So you see a lot of noise,

1089
00:40:06,120 --> 00:40:09,150
you see, like, streaks from
satellites going through them.

1090
00:40:09,150 --> 00:40:10,080
One of the shifts I was on,

1091
00:40:10,080 --> 00:40:11,370
there was a bit of dust on one of them

1092
00:40:11,370 --> 00:40:12,210
so we spent a lot of time

1093

00:40:12,210 --> 00:40:13,590
trying to figure out if a little squiggle

1094
00:40:13,590 --> 00:40:15,750
was something we could do
something about or not.

1095
00:40:15,750 --> 00:40:17,130
- So even a mountaintop

1096
00:40:17,130 --> 00:40:19,781
is not completely free of distortions

1097
00:40:19,781 --> 00:40:21,507
and issues to deal with.
- Exactly.

1098
00:40:21,507 --> 00:40:23,610
And there is a lot of work

1099
00:40:23,610 --> 00:40:26,190
that goes into combining multiple images

1100
00:40:26,190 --> 00:40:27,360
to beat down the noise.

1101
00:40:27,360 --> 00:40:28,860
There's ways of correcting,

1102
00:40:28,860 --> 00:40:30,990
you know, so you can look at
the shapes of, like, stars,

1103
00:40:30,990 --> 00:40:32,130
which are, like, in principle,

1104
00:40:32,130 --> 00:40:33,960
from our point of view,
like point objects,

1105
00:40:33,960 --> 00:40:36,540
and people look at how
their shapes get distorted,

1106
00:40:36,540 --> 00:40:38,340
and there's a lot of complicated modeling

1107
00:40:38,340 --> 00:40:41,160
to correct for that kind of distortion.

1108
00:40:41,160 --> 00:40:43,710
And also, like, the
optics of the telescope

1109
00:40:43,710 --> 00:40:45,000
might be slightly
different towards the edge,

1110
00:40:45,000 --> 00:40:46,560
towards the center.

1111
00:40:46,560 --> 00:40:48,150
The science, the dark
energy constraints we do,

1112
00:40:48,150 --> 00:40:50,280
would not be possible
with all that hard work

1113
00:40:50,280 --> 00:40:53,190
and technology development
and analysis development

1114
00:40:53,190 --> 00:40:55,470
of my many colleagues.

1115
00:40:55,470 --> 00:40:56,760
So this is really a team effort

1116
00:40:56,760 --> 00:40:58,380
and is not something that's possible to do

1117
00:40:58,380 --> 00:41:00,510
without a big team of hardworking people,

1118
00:41:00,510 --> 00:41:03,030
and I think getting to go, you
know, sit in the control room

1119
00:41:03,030 --> 00:41:05,520
and sort of see the early
iteration of the data

1120
00:41:05,520 --> 00:41:08,220
I think felt very valuable
to me in that sense.

1121
00:41:08,220 --> 00:41:09,660
- I'm fascinated just by that idea

1122
00:41:09,660 --> 00:41:12,750
of going to work at this
telescope in this remote location.

1123
00:41:12,750 --> 00:41:14,670
Aside from looking at
the data as it comes in,

1124
00:41:14,670 --> 00:41:16,860
what do you do when you're
on top of the mountain?

1125
00:41:16,860 --> 00:41:18,840
- So generally, there's a 4:00 PM meeting

1126
00:41:18,840 --> 00:41:22,920
where you get on Zoom

with people at Fermilab

1127
00:41:22,920 --> 00:41:25,590
who, like, manage a lot of
the telescope operations,

1128
00:41:25,590 --> 00:41:28,440
and you check in about, like,
what the plan is for the day,

1129
00:41:28,440 --> 00:41:29,700
get everything set up,

1130
00:41:29,700 --> 00:41:32,100
you go eat dinner in the
astronomers' cafeteria,

1131
00:41:32,100 --> 00:41:35,670
you come back, you get, like,
the various scripts queued up

1132
00:41:35,670 --> 00:41:36,840
that you're gonna run,

1133
00:41:36,840 --> 00:41:38,790
and then you just have to
wait for the sun to go down.

1134
00:41:38,790 --> 00:41:40,717
And so, like, kind of part
of your job is to go, like,

1135
00:41:40,717 --> 00:41:42,450
"Well, there's nothing we
can do in the control room,

1136
00:41:42,450 --> 00:41:43,380
we're gonna go..."

1137

00:41:43,380 --> 00:41:46,470
Everyone goes and watches
the sun set over the ocean,

1138
00:41:46,470 --> 00:41:47,970
and you're on a mountain
that's somewhat taller

1139
00:41:47,970 --> 00:41:49,710
than all the other mountains,

1140
00:41:49,710 --> 00:41:53,160
and usually it's very clear
and it's just very beautiful.

1141
00:41:53,160 --> 00:41:55,297
And there's also these little
rodents called viscachas.

1142
00:41:55,297 --> 00:41:57,510
They look like rabbits with squirrel tails

1143
00:41:57,510 --> 00:41:59,490
that also seem to come
out and watch the sunset

1144
00:41:59,490 --> 00:42:01,120
so you're always kinda looking for those.

1145
00:42:01,120 --> 00:42:01,953
(Colin laughs)

1146
00:42:01,953 --> 00:42:02,786
And then, yeah, during the night,

1147
00:42:02,786 --> 00:42:05,160
you're kind of keeping an eye
on the images as they come in,

1148

00:42:05,160 --> 00:42:08,250
making sure that nothing's going wrong.

1149
00:42:08,250 --> 00:42:10,140
You also are supposed to monitor

1150
00:42:10,140 --> 00:42:12,210
how much cloud cover there is,

1151
00:42:12,210 --> 00:42:14,490
and it can be detected to
some extent with instruments.

1152
00:42:14,490 --> 00:42:15,420
But, like, part of your job

1153
00:42:15,420 --> 00:42:17,220
that you do sort of a little report

1154
00:42:17,220 --> 00:42:18,720
is you're supposed to step outside

1155
00:42:18,720 --> 00:42:21,120
and let your eyes adjust to
the dark once every hour.

1156
00:42:21,120 --> 00:42:23,280
So as you would expect from somewhere

1157
00:42:23,280 --> 00:42:24,210
where you put a telescope,

1158
00:42:24,210 --> 00:42:25,740
like, that's some of the most stars

1159
00:42:25,740 --> 00:42:26,760
I've ever seen in my life.

1160

00:42:26,760 --> 00:42:29,520
So you can see the
Milky Way super clearly,

1161
00:42:29,520 --> 00:42:30,390
especially when the moon is down,

1162
00:42:30,390 --> 00:42:32,280
you can see the Magellanic Clouds,

1163
00:42:32,280 --> 00:42:33,113
and it's just like

1164
00:42:33,113 --> 00:42:35,340
you're kind of like alone
on a windy mountaintop,

1165
00:42:35,340 --> 00:42:37,020
it makes you feel very small.

1166
00:42:37,020 --> 00:42:38,460
- I wanna go back to asking you

1167
00:42:38,460 --> 00:42:41,430
about the way you summarize
this result that has recently

1168
00:42:41,430 --> 00:42:44,310
come out of this Dark
Energy Survey collaboration.

1169
00:42:44,310 --> 00:42:45,420
You said this,

1170
00:42:45,420 --> 00:42:48,630
I think you said the Lambda-CDM
model survives another day,

1171
00:42:48,630 --> 00:42:50,220

or maybe another way to say that

1172
00:42:50,220 --> 00:42:53,670
is some relatively simple model

1173
00:42:53,670 --> 00:42:55,530
passes another series of tests.

1174
00:42:55,530 --> 00:42:58,260
And, you know, maybe on the surface,

1175
00:42:58,260 --> 00:43:00,450
this result could seem not so exciting

1176
00:43:00,450 --> 00:43:03,030
'cause we're not announcing
something big and new

1177
00:43:03,030 --> 00:43:04,140
that we couldn't expect.

1178
00:43:04,140 --> 00:43:07,080
But I think it must be pretty incredible

1179
00:43:07,080 --> 00:43:10,260
to think that all of
this observation time,

1180
00:43:10,260 --> 00:43:13,200
all of this noise and dust and clouds

1181
00:43:13,200 --> 00:43:14,460
that you had to account for

1182
00:43:14,460 --> 00:43:16,920
with so many people over so much time,

1183
00:43:16,920 --> 00:43:19,140

all of that was done and, in the end,

1184
00:43:19,140 --> 00:43:22,470
something pretty simple
can describe all of that,

1185
00:43:22,470 --> 00:43:24,540
and I'm just curious to get
your perspective on that.

1186
00:43:24,540 --> 00:43:26,970
Do you find that simplicity exciting?

1187
00:43:26,970 --> 00:43:30,450
Or do you find yourself
wanting to find something new?

1188
00:43:30,450 --> 00:43:32,940
- It is both exciting
and frustrating because,

1189
00:43:32,940 --> 00:43:34,350
so we have the simplest model,

1190
00:43:34,350 --> 00:43:36,240
so, yeah, Lambda-CDM

1191
00:43:36,240 --> 00:43:38,640
is sort of the maybe somewhat jargony name

1192
00:43:38,640 --> 00:43:40,950
that we often refer to this,
like, simplest model as.

1193
00:43:40,950 --> 00:43:43,560
So Lambda is the symbol
that we usually use

1194
00:43:43,560 --> 00:43:45,210

to represent the cosmological constant,

1195
00:43:45,210 --> 00:43:48,000
so this simplest
description of dark energy.

1196
00:43:48,000 --> 00:43:49,890
CDM stands for cold dark matter,

1197
00:43:49,890 --> 00:43:51,750
which is, you know, this matter

1198
00:43:51,750 --> 00:43:52,890
that doesn't interact with light

1199
00:43:52,890 --> 00:43:55,650
but clumps up under the
influence of gravity.

1200
00:43:55,650 --> 00:43:57,900
It is a real achievement of the field

1201
00:43:57,900 --> 00:43:59,130
that we have this model

1202
00:43:59,130 --> 00:44:01,950
that we can use to
describe pretty accurately

1203
00:44:01,950 --> 00:44:03,630
basically all of the observations

1204
00:44:03,630 --> 00:44:04,463
we've made of the universe.

1205
00:44:04,463 --> 00:44:06,330
There's a few exceptions that are debated,

1206

00:44:06,330 --> 00:44:08,280
but as I said earlier,
it's not the whole story.

1207
00:44:08,280 --> 00:44:09,267
Like, we don't know what dark energy is

1208
00:44:09,267 --> 00:44:11,040
and we don't what dark matter is,

1209
00:44:11,040 --> 00:44:14,883
and together, they make up 95%
of the stuff in the universe.

1210
00:44:15,750 --> 00:44:17,760
There are a lot of different models

1211
00:44:17,760 --> 00:44:19,680
or descriptions that people consider

1212
00:44:19,680 --> 00:44:22,290
that, you know, could dark
energy be like this or that,

1213
00:44:22,290 --> 00:44:25,140
or might dark matter have a
little bit of interaction,

1214
00:44:25,140 --> 00:44:26,970
or what kind of particle makes it up.

1215
00:44:26,970 --> 00:44:28,440
For neither of these things,

1216
00:44:28,440 --> 00:44:31,320
there is not a, like, clear front-runner,

1217
00:44:31,320 --> 00:44:32,970
like, oh, this must be it.

1218
00:44:32,970 --> 00:44:35,070
And so there's a lot of,
like, very important work

1219
00:44:35,070 --> 00:44:36,090
being done on the theory

1220
00:44:36,090 --> 00:44:38,040
and to think of different possibilities,

1221
00:44:38,040 --> 00:44:40,140
But, ultimately, on the data
end, what we're looking at

1222
00:44:40,140 --> 00:44:42,360
is trying to make more and
more precise measurements

1223
00:44:42,360 --> 00:44:45,360
of this simplest model Lambda-CDM

1224
00:44:45,360 --> 00:44:48,240
and kind of look for,
like, cracks in the facade

1225
00:44:48,240 --> 00:44:51,330
or places where the predictions
of the simplest model

1226
00:44:51,330 --> 00:44:52,680
don't match our observations

1227
00:44:52,680 --> 00:44:54,720
because if we find a mismatch

1228
00:44:54,720 --> 00:44:57,360
that holds up as our
data get more precise,

1229
00:44:57,360 --> 00:44:59,940
maybe holds up if
different teams measure it

1230
00:44:59,940 --> 00:45:00,810
and make different,

1231
00:45:00,810 --> 00:45:02,190
like, there's all these ways

1232
00:45:02,190 --> 00:45:03,630
that, I think if we start seeing hints,

1233
00:45:03,630 --> 00:45:05,490
we'll wanna really make
sure what we're seeing

1234
00:45:05,490 --> 00:45:06,360
is a hint of physics

1235
00:45:06,360 --> 00:45:08,040
and not of some modeling assumption

1236
00:45:08,040 --> 00:45:09,390
we don't understand well.

1237
00:45:09,390 --> 00:45:12,060
But ultimately, we're
looking for mismatches

1238
00:45:12,060 --> 00:45:13,110
that will give us a clue

1239
00:45:13,110 --> 00:45:16,770
for how to build a more
fundamental understanding

1240

00:45:16,770 --> 00:45:18,660
of 95% of the universe.

1241
00:45:18,660 --> 00:45:20,820
So it's frustrating that
the results match that

1242
00:45:20,820 --> 00:45:22,320
because it'd be very exciting

1243
00:45:22,320 --> 00:45:24,570
if we found, like, a
clear hint for something,

1244
00:45:24,570 --> 00:45:26,430
but, you know, it's all
part of the process.

1245
00:45:26,430 --> 00:45:29,880
Like, we can narrow in on,
like, what kinds of models

1246
00:45:29,880 --> 00:45:31,140
are allowed or not allowed

1247
00:45:31,140 --> 00:45:32,850
or at least, like, what are the ranges

1248
00:45:32,850 --> 00:45:34,410
of the size of effects

1249
00:45:34,410 --> 00:45:36,150
that deviations from general relativity

1250
00:45:36,150 --> 00:45:37,800
on large scales might have.

1251
00:45:37,800 --> 00:45:39,240
In my mind, a concrete example

1252
00:45:39,240 --> 00:45:41,580
is, like, one of the common
things you can sort of study

1253
00:45:41,580 --> 00:45:43,350
if you're looking for deviations

1254
00:45:43,350 --> 00:45:44,880
from the prediction of general relativity

1255
00:45:44,880 --> 00:45:48,540
is that theory will give
you a specific relationship

1256
00:45:48,540 --> 00:45:51,780
between the way that light interacts

1257
00:45:51,780 --> 00:45:53,040
with the gravitational potential,

1258
00:45:53,040 --> 00:45:55,290
so causing that gravitational lensing,

1259
00:45:55,290 --> 00:45:57,900
and the way that gravity affects matter,

1260
00:45:57,900 --> 00:45:58,800
like particles with mass,

1261
00:45:58,800 --> 00:46:01,203
so the galaxies and dark
matter clustering up.

1262
00:46:02,040 --> 00:46:04,320
If you're assuming general
relativity is part of your model

1263

00:46:04,320 --> 00:46:05,940
as you are in Lambda-CDM,

1264
00:46:05,940 --> 00:46:07,830
putting those different kinds
of measurements together

1265
00:46:07,830 --> 00:46:10,140
lets you really get precise constraints

1266
00:46:10,140 --> 00:46:13,230
on the parameters or the
properties of that model.

1267
00:46:13,230 --> 00:46:16,110
But if you relax that
assumption a little bit,

1268
00:46:16,110 --> 00:46:17,160
you can say, all right,

1269
00:46:17,160 --> 00:46:19,590
we're looking at the same sort
of structures in the universe

1270
00:46:19,590 --> 00:46:20,820
and we're seeing how they affect light

1271
00:46:20,820 --> 00:46:22,290
and how they affect matter,

1272
00:46:22,290 --> 00:46:23,970
and we can use that to test

1273
00:46:23,970 --> 00:46:26,700
whether or not they have
the expected relationship.

1274
00:46:26,700 --> 00:46:28,920

And like a weak lensing survey like DES,

1275
00:46:28,920 --> 00:46:31,290
and particularly, we're
making both measurements

1276
00:46:31,290 --> 00:46:33,150
of the lensing and the clustering,

1277
00:46:33,150 --> 00:46:35,040
lets us make the most precise version

1278
00:46:35,040 --> 00:46:36,660
of that kind of test available.

1279
00:46:36,660 --> 00:46:38,792
General relativity seems
to be doing very well.

1280
00:46:38,792 --> 00:46:39,900
(Jessie laughs)
(Colin laughs)

1281
00:46:39,900 --> 00:46:42,630
- Yeah, it seems to be standing
up to a lot of the tests

1282
00:46:42,630 --> 00:46:43,500
that it's being put under,

1283
00:46:43,500 --> 00:46:46,500
which is pretty amazing
for a century-old theory.

1284
00:46:46,500 --> 00:46:47,713
- Very much so, yeah.

1285
00:46:47,713 --> 00:46:49,290
- I was looking around your website,

1286
00:46:49,290 --> 00:46:51,390
learning about the Dark Energy Survey

1287
00:46:51,390 --> 00:46:52,950
and your role and your past,

1288
00:46:52,950 --> 00:46:55,080
and I have to say I enjoy,

1289
00:46:55,080 --> 00:46:58,110
on your website there's a
tab that just says Cartoons,

1290
00:46:58,110 --> 00:46:59,760
and you click Cartoons

1291
00:46:59,760 --> 00:47:02,010
and there's these
illustrations that you've made

1292
00:47:02,010 --> 00:47:05,340
of some pretty cool scientific concepts

1293
00:47:05,340 --> 00:47:08,580
in a really sort of fun,
bright, engaging way.

1294
00:47:08,580 --> 00:47:11,070
And one I keep thinking
of as you're talking

1295
00:47:11,070 --> 00:47:13,980
is there's a person at a desk in a room,

1296
00:47:13,980 --> 00:47:15,570
I'm assuming maybe it's you,

1297

00:47:15,570 --> 00:47:18,300
maybe it's, you know, it could be anybody,

1298
00:47:18,300 --> 00:47:20,730
but they're wearing, like, VR goggles.

1299
00:47:20,730 --> 00:47:24,180
What they see is this
beautiful expanse of galaxies

1300
00:47:24,180 --> 00:47:25,830
and swirls and stars and things,

1301
00:47:25,830 --> 00:47:27,630
but, really, they're at a desk in a room

1302
00:47:27,630 --> 00:47:29,550
and there's a cat sleeping
on the bed nearby.

1303
00:47:29,550 --> 00:47:32,040
And so I wondered, A, if that's you,

1304
00:47:32,040 --> 00:47:35,130
and B, more generally, can
you tell us about your artwork

1305
00:47:35,130 --> 00:47:38,580
and how, you know, I think
you're the first person

1306
00:47:38,580 --> 00:47:41,007
whose academic website I've gone on

1307
00:47:41,007 --> 00:47:43,170
and it has a tab that says Cartoons

1308
00:47:43,170 --> 00:47:44,610
for all their artwork.

1309
00:47:44,610 --> 00:47:46,320
How did that come to be?
- I have spent a lot of time

1310
00:47:46,320 --> 00:47:47,340
in the last couple years

1311
00:47:47,340 --> 00:47:49,940
working from home with a cat
sleeping on my bed so that

1312
00:47:49,940 --> 00:47:52,230
is an accurate representation.
- OK, so that one's accurate.

1313
00:47:52,230 --> 00:47:54,720
Is that a self portrait,
the person in the VR helmet?

1314
00:47:54,720 --> 00:47:56,040
- No, not necessarily,

1315
00:47:56,040 --> 00:47:58,500
but it was inspired by my roommate

1316
00:47:58,500 --> 00:48:00,930
who I shared an apartment
with during the pandemic

1317
00:48:00,930 --> 00:48:02,820
who would play a lot of
VR games in his room.

1318
00:48:02,820 --> 00:48:06,750
So, yeah, that cartoon
was part of a series

1319
00:48:06,750 --> 00:48:08,850

that I did with some collaborators in DES.

1320
00:48:09,930 --> 00:48:13,680
We released sort of the first
round of the cosmology results

1321
00:48:13,680 --> 00:48:15,960
from the galaxy clustering
and weak lensing measurements

1322
00:48:15,960 --> 00:48:18,380
from the first three years of DES data.

1323
00:48:18,380 --> 00:48:19,830
So I guess that's
something I didn't mention

1324
00:48:19,830 --> 00:48:21,120
when talking about the project before.

1325
00:48:21,120 --> 00:48:24,270
We've analyzed the first three
of six years of observations,

1326
00:48:24,270 --> 00:48:26,880
and we're just getting
started on the next round now.

1327
00:48:26,880 --> 00:48:28,103
Yeah, when we were releasing
those cosmology results,

1328
00:48:28,103 --> 00:48:29,940
there's the main cosmology paper,

1329
00:48:29,940 --> 00:48:31,590
but there's also like 30 other papers

1330
00:48:31,590 --> 00:48:33,390

documenting all the work
and tests and things

1331
00:48:33,390 --> 00:48:36,420
that go into making that
measurement possible.

1332
00:48:36,420 --> 00:48:37,830
And we were talking about how,

1333
00:48:37,830 --> 00:48:39,720
you know, we've got
the Dark Energy Survey,

1334
00:48:39,720 --> 00:48:41,010
like, Twitter account and things,

1335
00:48:41,010 --> 00:48:43,740
like it'd be fun to try and,
like, highlight these works

1336
00:48:43,740 --> 00:48:44,820
and try and figure out a way

1337
00:48:44,820 --> 00:48:48,210
to make them a bit more
accessible to the general public

1338
00:48:48,210 --> 00:48:50,673
even if, you know, people
aren't gonna go open up a PDF

1339
00:48:50,673 --> 00:48:52,200
of a very technical paper

1340
00:48:52,200 --> 00:48:54,930
about measuring, like, galaxy
distances or something.

1341

00:48:54,930 --> 00:48:57,660
A couple of years ago, my
colleague Chihway Chang,

1342
00:48:57,660 --> 00:48:59,463
who's now a professor at Chicago,

1343
00:49:00,300 --> 00:49:02,970
she had done this series
of, like, one cartoon a week

1344
00:49:02,970 --> 00:49:04,380
about different science concepts,

1345
00:49:04,380 --> 00:49:06,420
and so we decided it'd
be fun to revive that

1346
00:49:06,420 --> 00:49:08,130
to illustrate these like
30 different papers.

1347
00:49:08,130 --> 00:49:10,410
So we kind of split them
up and got the authors

1348
00:49:10,410 --> 00:49:14,070
to help us write sort of a
little, like, blurb description

1349
00:49:14,070 --> 00:49:16,110
of each of the papers,

1350
00:49:16,110 --> 00:49:18,420
and then we tried to figure
out ways to illustrate them.

1351
00:49:18,420 --> 00:49:20,970
So that cartoon that you're
mentioning was the one I drew

1352
00:49:20,970 --> 00:49:24,360
for a paper describing
some simulated analyses,

1353
00:49:24,360 --> 00:49:27,900
so the idea that we kind
of used simulated data,

1354
00:49:27,900 --> 00:49:30,060
analyzed it as, like, a
test run for our analysis.

1355
00:49:30,060 --> 00:49:32,280
And so partly 'cause my
roommate during the pandemic

1356
00:49:32,280 --> 00:49:35,400
was doing a lot of flight
simulators on VR in his room

1357
00:49:35,400 --> 00:49:36,360
during the pandemic,

1358
00:49:36,360 --> 00:49:38,427
and so that was kind of
the inspiration there.

1359
00:49:38,427 --> 00:49:39,270
I'm just kinda trying

1360
00:49:39,270 --> 00:49:40,170
to think of fun things.
- Yeah, my first thought

1361
00:49:40,170 --> 00:49:41,250
was flight simulators,

1362
00:49:41,250 --> 00:49:42,810

and even earlier in this conversation

1363
00:49:42,810 --> 00:49:46,050
when you were describing
the simulation process

1364
00:49:46,050 --> 00:49:47,100
and why you do it,

1365
00:49:47,100 --> 00:49:48,990
I thought, well, it's similar

1366
00:49:48,990 --> 00:49:51,120
to why pilots take flight simulators

1367
00:49:51,120 --> 00:49:53,070
'cause you don't wanna
crash the real plane

1368
00:49:53,070 --> 00:49:54,578
unless you know what you're doing, right?

1369
00:49:54,578 --> 00:49:55,560
- Exactly.
- You do the simulations

1370
00:49:55,560 --> 00:49:56,760
to figure it out.

1371
00:49:56,760 --> 00:49:58,553
There was one other that
I have to ask about.

1372
00:49:58,553 --> 00:50:02,880
There's one other cartoon
of two volleyball players.

1373
00:50:02,880 --> 00:50:03,990
One is setting the ball,

1374
00:50:03,990 --> 00:50:06,150
the other one's about to
spike it over the net.

1375
00:50:06,150 --> 00:50:09,810
And I didn't fully grasp
the science behind it,

1376
00:50:09,810 --> 00:50:12,060
but I think, you know, these things,

1377
00:50:12,060 --> 00:50:14,310
they're meant to invite
people in and and learn more,

1378
00:50:14,310 --> 00:50:16,980
so can you tell us what the
volleyball players are doing?

1379
00:50:16,980 --> 00:50:19,290
- That was to illustrate one of the papers

1380
00:50:19,290 --> 00:50:22,380
that starts combining these
different types of measurements.

1381
00:50:22,380 --> 00:50:23,850
So we've got the map of galaxy shapes,

1382
00:50:23,850 --> 00:50:26,130
we've got the map of galaxy positions.

1383
00:50:26,130 --> 00:50:28,560
You can either look at
pairs of galaxy positions,

1384
00:50:28,560 --> 00:50:31,680
pairs of galaxy shapes,

or the cross-correlation,

1385
00:50:31,680 --> 00:50:34,680
pairs where you have a
shape and a position.

1386
00:50:34,680 --> 00:50:35,850
These statistical things
I'm talking about,

1387
00:50:35,850 --> 00:50:37,080
we call them correlation functions,

1388
00:50:37,080 --> 00:50:38,760
that's the technical term.

1389
00:50:38,760 --> 00:50:39,930
That was meant to illustrate

1390
00:50:39,930 --> 00:50:43,050
that analyzing these types
of measurements together

1391
00:50:43,050 --> 00:50:46,290
gives you information
that you wouldn't get

1392
00:50:46,290 --> 00:50:47,610
by analyzing them separately,

1393
00:50:47,610 --> 00:50:50,356
so it's this kind of
combined probe analysis idea.

1394
00:50:50,356 --> 00:50:51,420
- Team sport.
- And so the volleyball thing

1395
00:50:51,420 --> 00:50:52,770

is to say they're working together,

1396
00:50:52,770 --> 00:50:54,750
it's teamwork to get the ball over the net

1397
00:50:54,750 --> 00:50:57,300
or to tell us what dark
energy is acting like.

1398
00:50:57,300 --> 00:50:58,133
- I don't wanna ask you

1399
00:50:58,133 --> 00:51:00,510
to describe your art in words too much

1400
00:51:00,510 --> 00:51:02,580
'cause I know everyone
should also go look at it,

1401
00:51:02,580 --> 00:51:04,831
but I also have to ask you
about the platypus comic.

1402
00:51:04,831 --> 00:51:06,120
(Lauren laughs)
(Colin laughs)

1403
00:51:06,120 --> 00:51:07,230
- One of these cartoons

1404
00:51:07,230 --> 00:51:11,400
is a little, like, three-panel
comic-looking thing

1405
00:51:11,400 --> 00:51:14,850
that has a bulletin board like you'd see

1406
00:51:14,850 --> 00:51:16,260
in, like, a detective movie,

1407
00:51:16,260 --> 00:51:18,570
so you've got photos on
it with, like, string.

1408
00:51:18,570 --> 00:51:20,460
So the scenario is you're trying to learn

1409
00:51:20,460 --> 00:51:21,780
about what an animal is

1410
00:51:21,780 --> 00:51:26,040
by getting, like, photos of
different parts of the animal.

1411
00:51:26,040 --> 00:51:27,180
You know, you have a photo of a foot

1412
00:51:27,180 --> 00:51:28,680
that's like a webbed foot,

1413
00:51:28,680 --> 00:51:30,660
and you have a photo of
a nose, which is a beak,

1414
00:51:30,660 --> 00:51:31,740
and so the working model,

1415
00:51:31,740 --> 00:51:35,940
sort of the simplest model,
Lambda-CDM, is that it's a duck.

1416
00:51:35,940 --> 00:51:39,120
Then you go, and a lot of
what we're doing in cosmology

1417
00:51:39,120 --> 00:51:41,820
is going and making either
more precise measurements,

1418
00:51:41,820 --> 00:51:42,653
which I guess would be like

1419
00:51:42,653 --> 00:51:45,330
a less blurry picture of your duck

1420
00:51:45,330 --> 00:51:48,180
or imaging different
aspects of the animal.

1421
00:51:48,180 --> 00:51:50,370
So the second panel of the comic

1422
00:51:50,370 --> 00:51:53,490
is the detective gets a
photo of the animal's tail,

1423
00:51:53,490 --> 00:51:56,310
and instead of looking like a duck tail,

1424
00:51:56,310 --> 00:51:58,440
it looks like a beaver tail.

1425
00:51:58,440 --> 00:52:01,500
If the new data doesn't
match your expectations

1426
00:52:01,500 --> 00:52:03,510
of the model given your previous data,

1427
00:52:03,510 --> 00:52:06,150
that might be a hint that you
need to develop a new model

1428
00:52:06,150 --> 00:52:07,740
for your description of the universe

1429

00:52:07,740 --> 00:52:09,480
or, like, what animal you're looking at.

1430
00:52:09,480 --> 00:52:12,750
And so in this case, the
new model is a platypus,

1431
00:52:12,750 --> 00:52:15,930
which has a duck-like beak and webbed feet

1432
00:52:15,930 --> 00:52:18,120
and a tail that looks like a beaver tail.

1433
00:52:18,120 --> 00:52:20,400
So that's sort of the analogy
for kind of what we're doing

1434
00:52:20,400 --> 00:52:22,110
and trying to test Lambda-CDM

1435
00:52:22,110 --> 00:52:23,670
by looking for sort of mismatches

1436
00:52:23,670 --> 00:52:26,010
between its predictions
and our measurements.

1437
00:52:26,010 --> 00:52:28,140
- Has it been useful
to you as a researcher

1438
00:52:28,140 --> 00:52:30,030
to take these long papers

1439
00:52:30,030 --> 00:52:33,000
and try to condense them
into these short comics?

1440
00:52:33,000 --> 00:52:33,833

- Yeah, I think so.

1441
00:52:33,833 --> 00:52:36,180
It's definitely a fun
brainstorming process.

1442
00:52:36,180 --> 00:52:38,040
You know, with this set of like 30 papers,

1443
00:52:38,040 --> 00:52:39,840
like, everyone's working together,

1444
00:52:39,840 --> 00:52:40,673
but there's definitely some

1445
00:52:40,673 --> 00:52:42,960
that I contribute more
directly to than others.

1446
00:52:42,960 --> 00:52:45,210
And so for doing illustrations
for all of these,

1447
00:52:45,210 --> 00:52:47,520
it was kind of fun to navigate the project

1448
00:52:47,520 --> 00:52:49,740
and try and help authors come up

1449
00:52:49,740 --> 00:52:51,630
with, all right, what is
the one- or two-sentence

1450
00:52:51,630 --> 00:52:53,640
sort of hopefully accessible description

1451
00:52:53,640 --> 00:52:54,930
we can come up with?

1452
00:52:54,930 --> 00:52:57,120
So it helps me have a
clearer understanding

1453
00:52:57,120 --> 00:52:58,140
of, like, the core concept

1454
00:52:58,140 --> 00:53:00,180
behind a number of my colleagues' papers

1455
00:53:00,180 --> 00:53:01,800
that are very important for my work

1456
00:53:01,800 --> 00:53:05,130
but I might not be, like, deeply
familiar with the details.

1457
00:53:05,130 --> 00:53:06,000
And then for things

1458
00:53:06,000 --> 00:53:08,010
that are more closely
related to what I work on,

1459
00:53:08,010 --> 00:53:10,410
so, like, model testing
by looking for mismatches

1460
00:53:10,410 --> 00:53:14,310
between model and data, or
platypus hunting, I guess,

1461
00:53:14,310 --> 00:53:15,780
it's just kind of fun to think through

1462
00:53:15,780 --> 00:53:18,690
and, like, come up with
analogies like that.

1463
00:53:18,690 --> 00:53:21,570
And, I mean, it was also,
like, one of my goals

1464
00:53:21,570 --> 00:53:22,403
over the last couple years

1465
00:53:22,403 --> 00:53:24,630
was to learn how to do
digital art on an iPad,

1466
00:53:24,630 --> 00:53:25,860
and this was was a very good project

1467
00:53:25,860 --> 00:53:27,210
for learning how to do that.

1468
00:53:27,210 --> 00:53:28,080
As an added benefit,

1469
00:53:28,080 --> 00:53:30,690
I now use a lot of these
cartoons when I give talks.

1470
00:53:30,690 --> 00:53:33,090
- Have you always been
artistically inclined?

1471
00:53:33,090 --> 00:53:36,450
Have you always expressed
yourself through drawing as well?

1472
00:53:36,450 --> 00:53:38,130
- I've definitely had it more as a habit

1473
00:53:38,130 --> 00:53:39,360
at some times in my life than others,

1474

00:53:39,360 --> 00:53:41,640
but, yeah, I always liked to draw.

1475
00:53:41,640 --> 00:53:43,620
I mean, I like drawing in general

1476
00:53:43,620 --> 00:53:45,720
and find it relaxing and enjoy doing it.

1477
00:53:45,720 --> 00:53:48,390
I think a thing I
struggle with especially,

1478
00:53:48,390 --> 00:53:50,580
I think we all, in the
past couple of years,

1479
00:53:50,580 --> 00:53:53,280
have a little bit of, like,
pandemic-related burnout

1480
00:53:53,280 --> 00:53:55,500
so it's a little hard
to, like, find motivation

1481
00:53:55,500 --> 00:53:57,090
or ideas during downtime.

1482
00:53:57,090 --> 00:54:00,270
And I think particularly this,
like, science cartoon project

1483
00:54:00,270 --> 00:54:02,340
was very nice 'cause it was
a little bit collaborative

1484
00:54:02,340 --> 00:54:04,170
and then it sort of
seeds a bunch of ideas.

1485
00:54:04,170 --> 00:54:05,280
And, like, once I have an idea,

1486
00:54:05,280 --> 00:54:07,920
like, the sort of type
of mental energy used

1487
00:54:07,920 --> 00:54:09,870
to, like, plan and figure out a drawing,

1488
00:54:09,870 --> 00:54:11,580
it's like a form of problem solving,

1489
00:54:11,580 --> 00:54:13,410
but it's a different
kind of problem solving

1490
00:54:13,410 --> 00:54:15,740
than, you know, working
on a scientific analysis

1491
00:54:15,740 --> 00:54:17,700
or a calculation.

1492
00:54:17,700 --> 00:54:20,040
So it's kind of fun to bring
those things together a bit

1493
00:54:20,040 --> 00:54:21,600
and to, like, get to share them

1494
00:54:21,600 --> 00:54:24,750
with both collaborators
and the general public.

1495
00:54:24,750 --> 00:54:26,430
- Colin talked about how unique

1496

00:54:26,430 --> 00:54:29,040
this Cartoons tab is on your website.

1497
00:54:29,040 --> 00:54:30,300
I wanted to tell you something else

1498
00:54:30,300 --> 00:54:31,980
that stood out to me on your website,

1499
00:54:31,980 --> 00:54:33,780
which is that right on your homepage,

1500
00:54:33,780 --> 00:54:36,360
you start by giving, you
know, a brief description

1501
00:54:36,360 --> 00:54:37,193
of your research,

1502
00:54:37,193 --> 00:54:38,857
and then right after that, you write,

1503
00:54:38,857 --> 00:54:41,340
"I'm also interested in science outreach

1504
00:54:41,340 --> 00:54:43,560
and in making STEM fields more accessible

1505
00:54:43,560 --> 00:54:45,390
and welcoming to everyone."

1506
00:54:45,390 --> 00:54:47,760
And we actually had a question sent in

1507
00:54:47,760 --> 00:54:50,373
about this sentence on your website.

1508
00:54:51,480 --> 00:54:53,730

– Matt Duschenes, a PhD
student at Perimeter.

1509
00:54:53,730 --> 00:54:55,470
I'm wondering what barriers
have you experienced

1510
00:54:55,470 --> 00:54:57,360
while trying to make
science more accessible

1511
00:54:57,360 --> 00:54:59,070
and more diverse?

1512
00:54:59,070 --> 00:55:01,500
– So the main way I
have engaged with this,

1513
00:55:01,500 --> 00:55:04,170
it's varied depending on
different stages of my career,

1514
00:55:04,170 --> 00:55:07,920
and sort of recognizing
the existence of barriers

1515
00:55:07,920 --> 00:55:09,240
and the ways that those can manifest

1516
00:55:09,240 --> 00:55:10,980
was definitely a progression.

1517
00:55:10,980 --> 00:55:13,260
Like, you know, I look back
at being an undergrad student,

1518
00:55:13,260 --> 00:55:14,460
and I had several classes

1519

00:55:14,460 --> 00:55:17,580
where I was, like, one
of two women in the room.

1520
00:55:17,580 --> 00:55:18,540
And at that point, I don't think

1521
00:55:18,540 --> 00:55:22,140
I would've identified anything
necessarily as a barrier.

1522
00:55:22,140 --> 00:55:24,690
The social dynamics, I think
I mostly experienced that,

1523
00:55:24,690 --> 00:55:25,860
and then a bit during my master's

1524
00:55:25,860 --> 00:55:28,200
is just being a little
bit of like an isolation.

1525
00:55:28,200 --> 00:55:30,300
There are more concrete
and more abstract ways

1526
00:55:30,300 --> 00:55:31,500
that that can manifest,

1527
00:55:31,500 --> 00:55:33,990
and, you know, they impact
different people differently.

1528
00:55:33,990 --> 00:55:35,970
Like on one hand, I may have been one

1529
00:55:35,970 --> 00:55:39,900
of the only couple women
in my physics classes

1530
00:55:39,900 --> 00:55:43,140
while also recognizing that I
was being supported partially

1531
00:55:43,140 --> 00:55:44,370
by my parents in undergrad

1532
00:55:44,370 --> 00:55:46,200
and so I could go work in a physics lab

1533
00:55:46,200 --> 00:55:49,830
and not have to, you know,
work other jobs after class.

1534
00:55:49,830 --> 00:55:53,640
You know, so there are some
ways that isolation can crop up

1535
00:55:53,640 --> 00:55:55,590
and can become barriers.

1536
00:55:55,590 --> 00:55:58,230
Definitely have had at
least a couple interactions

1537
00:55:58,230 --> 00:56:01,740
with professors assuming
I knew less than I did,

1538
00:56:01,740 --> 00:56:04,890
almost certainly a gendered point of view.

1539
00:56:04,890 --> 00:56:06,000
But, you know, there are other ways

1540
00:56:06,000 --> 00:56:07,410
in which I, you know, was privileged

1541

00:56:07,410 --> 00:56:10,170
and had this access to,
say, this research program

1542
00:56:10,170 --> 00:56:13,230
and had the support to, like,
go to Europe for a summer

1543
00:56:13,230 --> 00:56:14,610
and do physics research.

1544
00:56:14,610 --> 00:56:16,440
So there are ways I've faced barriers,

1545
00:56:16,440 --> 00:56:18,840
but also ways that I have not had barriers

1546
00:56:18,840 --> 00:56:19,710
that other people might have.

1547
00:56:19,710 --> 00:56:21,690
And I think in grad school,

1548
00:56:21,690 --> 00:56:24,083
I had a big learning experience with this

1549
00:56:24,083 --> 00:56:27,720
in that I helped organize the
Society for Women in Physics

1550
00:56:27,720 --> 00:56:29,130
at the University of Michigan

1551
00:56:29,130 --> 00:56:31,680
for most of my grad school career.

1552
00:56:31,680 --> 00:56:32,790
A big focus of that

1553
00:56:32,790 --> 00:56:34,800
was, you know, just
building sort of a community

1554
00:56:34,800 --> 00:56:37,170
within the department for
support and mentoring,

1555
00:56:37,170 --> 00:56:40,080
which, honestly, I think can
benefit everyone in academia,

1556
00:56:40,080 --> 00:56:42,240
but especially people who
might feel a bit isolated

1557
00:56:42,240 --> 00:56:44,040
or face some challenges.

1558
00:56:44,040 --> 00:56:46,260
And I think a big part of
that learning experience

1559
00:56:46,260 --> 00:56:48,540
was, often, we would also communicate with

1560
00:56:48,540 --> 00:56:51,210
and work jointly with other
student groups on campus.

1561
00:56:51,210 --> 00:56:53,370
For me, it's an ongoing
learning experience

1562
00:56:53,370 --> 00:56:54,900
of recognizing ways

1563
00:56:54,900 --> 00:56:57,000
in which, you know, I

might have faced barriers

1564
00:56:57,000 --> 00:56:59,070
or ways which people might
face barriers that aren't me.

1565
00:56:59,070 --> 00:57:01,410
So, like, things like making sure

1566
00:57:01,410 --> 00:57:02,970
that these kind of summer programs

1567
00:57:02,970 --> 00:57:04,590
have enough, like, financial support

1568
00:57:04,590 --> 00:57:07,650
that a student who might
otherwise need to work a job

1569
00:57:07,650 --> 00:57:09,810
can, like, participate

1570
00:57:09,810 --> 00:57:12,210
or trying to set up programs

1571
00:57:12,210 --> 00:57:14,520
where, you know, you don't
have to be in the know

1572
00:57:14,520 --> 00:57:16,440
to go seek out a research experience

1573
00:57:16,440 --> 00:57:18,810
that, like, might change the
trajectory of your career.

1574
00:57:18,810 --> 00:57:20,520
So I think that kind
of thing is important.

1575
00:57:20,520 --> 00:57:22,770
And, you know, also thinking through

1576
00:57:22,770 --> 00:57:24,630
these collaboration dynamics

1577
00:57:24,630 --> 00:57:27,300
of, like, if you have a
bunch of stressed out people

1578
00:57:27,300 --> 00:57:30,120
who are trying to pay attention
to too many things at once,

1579
00:57:30,120 --> 00:57:32,040
that's, like, a prime environment

1580
00:57:32,040 --> 00:57:36,240
for well-intentioned people
to make others feel excluded,

1581
00:57:36,240 --> 00:57:37,830
which I know I have been guilty of

1582
00:57:37,830 --> 00:57:41,220
and, you know, I think we're
all trying to work on it,

1583
00:57:41,220 --> 00:57:42,420
and so there's a lot of discussion

1584
00:57:42,420 --> 00:57:44,220
within, you know, Dark Energy Survey

1585
00:57:44,220 --> 00:57:45,210
and other collaborations

1586

00:57:45,210 --> 00:57:47,310
of, like, how can we make sure

1587
00:57:47,310 --> 00:57:49,080
people who are new to the experiment

1588
00:57:49,080 --> 00:57:50,910
or people who are not white

1589
00:57:50,910 --> 00:57:53,880
or women or other gender minorities,

1590
00:57:53,880 --> 00:57:56,460
like, can feel supported,
can find community,

1591
00:57:56,460 --> 00:57:58,170
know who to ask for advice

1592
00:57:58,170 --> 00:58:00,420
and, you know, can feel
heard in conversations,

1593
00:58:00,420 --> 00:58:03,240
recognizing that not everyone
communicates in the same way.

1594
00:58:03,240 --> 00:58:04,710
- And I know here at Perimeter,

1595
00:58:04,710 --> 00:58:07,050
you've become pretty involved in outreach

1596
00:58:07,050 --> 00:58:10,410
and in mentoring and supervising students

1597
00:58:10,410 --> 00:58:12,330
at more junior stages.

1598
00:58:12,330 --> 00:58:15,080
What motivates you to be
involved in that kind of work?

1599
00:58:15,960 --> 00:58:18,000
- I mean, kind of selfishly, I enjoy it.

1600
00:58:18,000 --> 00:58:20,520
I think I'm happiest doing science

1601
00:58:20,520 --> 00:58:22,950
when I'm, like, chatting
with other people about it.

1602
00:58:22,950 --> 00:58:24,420
You know, all these labs that I worked in,

1603
00:58:24,420 --> 00:58:27,090
I also did a little bit of
galaxy cluster cosmology

1604
00:58:27,090 --> 00:58:28,680
in undergrad as well.

1605
00:58:28,680 --> 00:58:30,600
And, like, all of the
professors I worked with

1606
00:58:30,600 --> 00:58:32,970
or more senior undergrads or grad students

1607
00:58:32,970 --> 00:58:35,340
that, like, helped me
learn how to do computer...

1608
00:58:35,340 --> 00:58:37,530
You know, it's a learning
process along the way,

1609
00:58:37,530 --> 00:58:40,140
and different mentors have made an impact

1610
00:58:40,140 --> 00:58:42,060
on the trajectory of my career,

1611
00:58:42,060 --> 00:58:43,560
and so the idea of being able

1612
00:58:43,560 --> 00:58:46,410
to, like, support and
introduce other people

1613
00:58:46,410 --> 00:58:48,870
and help them feel
supported feels important.

1614
00:58:48,870 --> 00:58:50,490
- That trajectory of your career,

1615
00:58:50,490 --> 00:58:53,130
where do you see or hope it's headed next?

1616
00:58:53,130 --> 00:58:56,010
You know, this is ongoing
work with the DES.

1617
00:58:56,010 --> 00:58:57,210
- Well I'm gonna be on the job market

1618
00:58:57,210 --> 00:58:59,237
for faculty jobs in the
next couple years so.

1619
00:58:59,237 --> 00:59:01,260
(Jessie laughs)
(Colin laughs)

1620

00:59:01,260 --> 00:59:03,780
Yeah, I would like to keep
doing cosmology research.

1621
00:59:03,780 --> 00:59:05,460
I would like to be able to teach as well

1622
00:59:05,460 --> 00:59:07,230
and keep mentoring students.

1623
00:59:07,230 --> 00:59:09,270
This analysis team that
I've been co-leading

1624
00:59:09,270 --> 00:59:11,913
with Agnes Ferte, who's
another postdoc in DES,

1625
00:59:12,900 --> 00:59:14,130
we've led this analysis

1626
00:59:14,130 --> 00:59:17,070
extending the year three
analysis, which we call it,

1627
00:59:17,070 --> 00:59:18,900
to extended cosmological models,

1628
00:59:18,900 --> 00:59:20,850
models beyond the simplest one.

1629
00:59:20,850 --> 00:59:23,940
The analysis of the full sort
of legacy data set for DES,

1630
00:59:23,940 --> 00:59:26,670
the year six analysis is ramping up.

1631
00:59:26,670 --> 00:59:28,950

I'm gonna be taking a little
bit more of a backseat.

1632
00:59:28,950 --> 00:59:30,180
Like, I'm still gonna be contributing

1633
00:59:30,180 --> 00:59:31,440
to different pieces of validation

1634
00:59:31,440 --> 00:59:33,420
for, like, the Lambda-CDM analysis

1635
00:59:33,420 --> 00:59:35,310
as well as the extended models.

1636
00:59:35,310 --> 00:59:36,720
Some people who are on our team

1637
00:59:36,720 --> 00:59:38,490
during this year three
analysis are stepping up

1638
00:59:38,490 --> 00:59:42,180
and are gonna have a chance
to lead the group as well now.

1639
00:59:42,180 --> 00:59:43,800
And part of this analysis,

1640
00:59:43,800 --> 00:59:45,450
there'd been a lot of
patches where we realized,

1641
00:59:45,450 --> 00:59:48,240
like, oh, this modeling tool
that we would need to do this

1642
00:59:48,240 --> 00:59:49,980
just doesn't exist,

1643
00:59:49,980 --> 00:59:51,900
and so we, you know,
kinda have to find ways

1644
00:59:51,900 --> 00:59:52,950
to work around that,

1645
00:59:52,950 --> 00:59:54,390
and so there are a couple of these things

1646
00:59:54,390 --> 00:59:57,420
that were not workable on the
time scale of that analysis,

1647
00:59:57,420 --> 00:59:59,610
but with a little bit more work, I think,

1648
00:59:59,610 --> 01:00:03,930
are gaps we can fill to let
us do a more precise analysis

1649
01:00:03,930 --> 01:00:05,250
of the data we already have

1650
01:00:05,250 --> 01:00:07,080
and also get it ready
for our next analysis.

1651
01:00:07,080 --> 01:00:09,660
So one of the students I'm supervising

1652
01:00:09,660 --> 01:00:12,480
here at PI as a summer student,

1653
01:00:12,480 --> 01:00:13,890
we're working on one of these projects.

1654

01:00:13,890 --> 01:00:15,540
And I was just at a meeting

1655
01:00:15,540 --> 01:00:17,580
where I was discussing
plans with a grad student

1656
01:00:17,580 --> 01:00:19,650
about sort of extending one
of these other analyses,

1657
01:00:19,650 --> 01:00:22,200
so there's sort of more
direct spinoff projects

1658
01:00:22,200 --> 01:00:24,990
and then I also want to get
a little bit more involved

1659
01:00:24,990 --> 01:00:27,330
in sort of the next-generation survey,

1660
01:00:27,330 --> 01:00:31,080
which is called the Vera
Rubin Observatory LSST.

1661
01:00:31,080 --> 01:00:32,670
- That's sort of the next evolution

1662
01:00:32,670 --> 01:00:35,220
in precision or in power?

1663
01:00:35,220 --> 01:00:36,780
- Yeah, so it's gonna be turning on

1664
01:00:36,780 --> 01:00:38,520
I think in the next year or so.

1665
01:00:38,520 --> 01:00:40,020

It's, like, on the next mountain over

1666
01:00:40,020 --> 01:00:42,450
from where the Dark Energy Camera is.

1667
01:00:42,450 --> 01:00:43,950
Many times we've heard, over
the course of six years,

1668
01:00:43,950 --> 01:00:46,290
that the LSST is gonna image

1669
01:00:46,290 --> 01:00:47,610
as much of the sky as you can image

1670
01:00:47,610 --> 01:00:49,800
without the Milky Way
getting too in the way.

1671
01:00:49,800 --> 01:00:50,700
It's also on the ground,

1672
01:00:50,700 --> 01:00:52,770
so the half of the sky it has access to,

1673
01:00:52,770 --> 01:00:55,530
like, basically every
night or every two nights.

1674
01:00:55,530 --> 01:00:58,410
Like, it has an even bigger
field of view than DES

1675
01:00:58,410 --> 01:01:00,420
and will be able to get more precise data

1676
01:01:00,420 --> 01:01:02,160
looking at fainter galaxies

1677
01:01:02,160 --> 01:01:03,450
and making more precise measurements

1678
01:01:03,450 --> 01:01:05,700
of shapes and other things.

1679
01:01:05,700 --> 01:01:07,560
You know, maybe outside
of survey science as well,

1680
01:01:07,560 --> 01:01:09,990
you know, if I'm
overcounting my free time,

1681
01:01:09,990 --> 01:01:11,760
look for more theoretical projects

1682
01:01:11,760 --> 01:01:13,830
looking for, like, what are
other ways we can use this data

1683
01:01:13,830 --> 01:01:16,620
or, like, the fact that
I'm interested in theory

1684
01:01:16,620 --> 01:01:19,140
and have this experience
working with data,

1685
01:01:19,140 --> 01:01:21,960
compared to your average theorist,

1686
01:01:21,960 --> 01:01:23,850
I have a good sense of the ways

1687
01:01:23,850 --> 01:01:26,190
that which data is messy and tough

1688

01:01:26,190 --> 01:01:28,950
and so, like, when you try to
bring those things together,

1689
01:01:28,950 --> 01:01:30,300
things that you don't
wanna have to care about,

1690
01:01:30,300 --> 01:01:31,710
you might have to care about.

1691
01:01:31,710 --> 01:01:33,930
So I'll probably continue
working at the interface of that,

1692
01:01:33,930 --> 01:01:35,310
both, you know, looking for ways

1693
01:01:35,310 --> 01:01:37,980
we can get more information
out of data we already have

1694
01:01:37,980 --> 01:01:39,690
and also making sure that when we do that,

1695
01:01:39,690 --> 01:01:42,150
we're doing it carefully and robustly.

1696
01:01:42,150 --> 01:01:45,570
- Well, thank you so much for
taking us on this journey.

1697
01:01:45,570 --> 01:01:46,917
There's so many things I didn't know about

1698
01:01:46,917 --> 01:01:49,470
and so many things that
I just find fascinating

1699

01:01:49,470 --> 01:01:51,930
and at scales that are just mind boggling.

1700
01:01:51,930 --> 01:01:53,280
And I hope you'll keep us posted

1701
01:01:53,280 --> 01:01:56,970
on the next stages of this
experiment and the ones after.

1702
01:01:56,970 --> 01:01:58,791
- Yeah, that would be great.
It was great talking to you.

1703
01:01:58,791 --> 01:02:02,010
(bright music)

1704
01:02:02,010 --> 01:02:03,540
- Thanks so much for listening.

1705
01:02:03,540 --> 01:02:04,560
Be sure to subscribe

1706
01:02:04,560 --> 01:02:07,050
so you don't miss any
of our conversations.

1707
01:02:07,050 --> 01:02:09,330
We've interviewed so
many brilliant scientists

1708
01:02:09,330 --> 01:02:12,240
whose research spans from
the quantum to the cosmos,

1709
01:02:12,240 --> 01:02:14,700
and we can't wait for you to hear more.

1710
01:02:14,700 --> 01:02:15,840

And if you like what you hear,

1711
01:02:15,840 --> 01:02:17,490
please rate and review our show

1712
01:02:17,490 --> 01:02:19,950
on your preferred podcast platform.

1713
01:02:19,950 --> 01:02:21,810
Great science is for everyone,

1714
01:02:21,810 --> 01:02:23,640
so please help us spread the word,

1715
01:02:23,640 --> 01:02:25,700
and thanks for being part of the equation.

1716
01:02:25,700 --> 01:02:29,117
(bright music continues)