1
00:00:00,000 --> 00:00:02,667
(bright music)

2
00:00:08,880 --> 00:00:10,260
- Hi, everyone, and welcome

3
00:00:10,260 --> 00:00:12,540
to "Conversations at the Perimeter."

4
00:00:12,540 --> 00:00:14,910
I'm Lauren Hayward here with Colin Hunter.

5
00:00:14,910 --> 00:00:16,050
- Hello.

6
00:00:16,050 --> 00:00:17,460
- Today we're excited to share

7
00:00:17,460 --> 00:00:19,980
with you our discussion with Dustin Lang.

8
00:00:19,980 --> 00:00:22,050
Dustin is a computational scientist

9
00:00:22,050 --> 00:00:23,700
here at Perimeter Institute

10
00:00:23,700 --> 00:00:26,460
who specializes in
astrophysical data sets,

11
00:00:26,460 --> 00:00:28,590
which means he works on software solutions

12
00:00:28,590 --> 00:00:30,180
that help researchers study some

13

00:00:30,180 --> 00:00:33,090
of the biggest open
questions in our universe.

14
00:00:33,090 --> 00:00:34,680
- And my mind really reeled

15
00:00:34,680 --> 00:00:37,620
when Dustin described
the enormous quantities

16
00:00:37,620 --> 00:00:39,480
of data involved in these projects

17
00:00:39,480 --> 00:00:41,400
that he and his colleagues are working on.

18
00:00:41,400 --> 00:00:44,130
It's literally astronomical
amounts of data

19
00:00:44,130 --> 00:00:46,080
that he and his colleagues
have to sift through

20
00:00:46,080 --> 00:00:48,840
looking for these faint
signatures of phenomena

21
00:00:48,840 --> 00:00:50,430
that are incredibly far away.

22
00:00:50,430 --> 00:00:54,150
- And they're far away
both in space and in time.

23
00:00:54,150 --> 00:00:56,100
Dustin tells us about his work

24

00:00:56,100 --> 00:00:58,620
with an international project called DESI,

25
00:00:58,620 --> 00:01:00,360
which is building maps of the universe

26
00:01:00,360 --> 00:01:02,100
to look back over its history

27
00:01:02,100 --> 00:01:04,680
and gain insight into dark energy.

28
00:01:04,680 --> 00:01:07,770
And he explains the Canadian
CHIME Project as well,

29
00:01:07,770 --> 00:01:10,830
which is searching for
mysterious fast radio bursts

30
00:01:10,830 --> 00:01:12,330
from deep in the cosmos.

31
00:01:12,330 --> 00:01:14,070
- Dustin tells us too about his work

32
00:01:14,070 --> 00:01:17,130
in both optical astronomy
and radio astronomy,

33
00:01:17,130 --> 00:01:19,230
which are more different
than I had realized.

34
00:01:19,230 --> 00:01:21,450
He also tells us about
the important roles played

35
00:01:21,450 --> 00:01:24,930

by chicken wire and a
metaphorical sad trombone.

36
00:01:24,930 --> 00:01:25,763
Whomp-whomp.

37
00:01:25,763 --> 00:01:27,360
It's a really fascinating chat.

38
00:01:27,360 --> 00:01:29,973
So let's step inside the
Perimeter with Dustin Lang.

39
00:01:33,330 --> 00:01:34,860
Dustin, thank you for being here

40
00:01:34,860 --> 00:01:36,360
at "Conversations at the Perimeter."

41
00:01:36,360 --> 00:01:37,380
- Oh, my pleasure.

42
00:01:37,380 --> 00:01:39,360
- We've been looking
forward to talking to you

43
00:01:39,360 --> 00:01:40,470
for a number of reasons.

44
00:01:40,470 --> 00:01:42,660
There's much that we
want to explore with you,

45
00:01:42,660 --> 00:01:44,580
including a number of acronyms

46
00:01:44,580 --> 00:01:46,050
of projects that you're working on

47
00:01:46,050 --> 00:01:47,730
that have to do with deep space

48
00:01:47,730 --> 00:01:50,070
and distant explosions
and everything else.

49
00:01:50,070 --> 00:01:54,270
But before we get to that,
you're a computer, No-

50
00:01:54,270 --> 00:01:56,880
- Computational scientist.
- Computational scientist.

51
00:01:56,880 --> 00:01:59,370
So first I wanna get into what that means,

52
00:01:59,370 --> 00:02:00,870
but I want to do so by saying

53
00:02:00,870 --> 00:02:04,170
that a couple years ago I
interviewed you for a story

54
00:02:04,170 --> 00:02:06,360
and you joke that when the job posting

55
00:02:06,360 --> 00:02:07,800
for a computational scientist

56
00:02:07,800 --> 00:02:09,720
came online at Perimeter Institute,

57
00:02:09,720 --> 00:02:11,737
that your friends basically said

58
00:02:11,737 --> 00:02:13,860

"This job was written for you Dustin,

59
00:02:13,860 --> 00:02:15,810
you have to get this job,"

60
00:02:15,810 --> 00:02:19,440
because it blended big data
analysis and astrophysics.

61
00:02:19,440 --> 00:02:22,190
So can you tell us what do you do

62
00:02:22,190 --> 00:02:23,910
as a computational scientist?

63
00:02:23,910 --> 00:02:26,220
- Sure. So I have a kind
of unusual job here.

64
00:02:26,220 --> 00:02:28,290
I'm half in the IT department

65
00:02:28,290 --> 00:02:31,110
helping other researchers
make use of computing

66
00:02:31,110 --> 00:02:33,060
and half a researcher myself.

67
00:02:33,060 --> 00:02:35,850
So I work on astronomical surveys,

68
00:02:35,850 --> 00:02:38,490
surveys that go out and
measure big chunks of sky,

69
00:02:38,490 --> 00:02:40,200
often without preconceived notions

70
00:02:40,200 --> 00:02:42,120
of what we're going to find

71
00:02:42,120 --> 00:02:44,730
in order to kind of make new discoveries.

72
00:02:44,730 --> 00:02:46,980
- And when you talk
about big chunks of sky,

73
00:02:46,980 --> 00:02:49,680
like how big are we talking here?

74
00:02:49,680 --> 00:02:52,860
- In the one project we
are looking at basically

75
00:02:52,860 --> 00:02:55,200
all of the sky we can see
from the Northern hemisphere

76
00:02:55,200 --> 00:02:56,940
except for the parts that are filled

77
00:02:56,940 --> 00:02:58,320
with the Milky Way galaxy.

78
00:02:58,320 --> 00:03:00,090
We care about things that
are beyond the Milky Way

79
00:03:00,090 --> 00:03:01,470
for this particular project

80
00:03:01,470 --> 00:03:02,979
so the Milky Way gets in the way.

81
00:03:02,979 --> 00:03:04,620

There are too many stars in our own galaxy

82
00:03:04,620 --> 00:03:05,820
to see the stuff behind it.

83
00:03:05,820 --> 00:03:07,980
- We're getting in our own
way, in our own galaxy?

84
00:03:07,980 --> 00:03:08,813
- Pretty much.

85
00:03:08,813 --> 00:03:10,590
And then you can't see the
southern part of the sky

86
00:03:10,590 --> 00:03:12,737
because there's too much dirt in the way.

87
00:03:12,737 --> 00:03:13,770
(Colin laughs)

88
00:03:13,770 --> 00:03:16,860
- So you're looking basically
everywhere you can look.

89
00:03:16,860 --> 00:03:17,693
- Pretty much.

90
00:03:17,693 --> 00:03:20,340
- And why is a computational scientist

91
00:03:20,340 --> 00:03:22,470
essential to doing this work?

92
00:03:22,470 --> 00:03:25,080
- So my degree was in computer science.

93

00:03:25,080 --> 00:03:27,939
I kind of picked up physics on the job

94
00:03:27,939 --> 00:03:28,772
(both laugh)

95
00:03:28,772 --> 00:03:31,800
and a lot of physicists are
in the opposite position

96
00:03:31,800 --> 00:03:33,450
where they know the physics

97
00:03:33,450 --> 00:03:36,780
and they're suddenly faced
with ever-growing data sets

98
00:03:36,780 --> 00:03:39,360
and there's just a real challenge
to process some of them.

99
00:03:39,360 --> 00:03:41,940
So having people with
expertise in both is kinda key

100
00:03:41,940 --> 00:03:44,130
to making some of the advancements

101
00:03:44,130 --> 00:03:45,570
that we want to do in this

102
00:03:45,570 --> 00:03:47,040
kinda to push the next generation

103
00:03:47,040 --> 00:03:49,410
of understanding of the universe.

104
00:03:49,410 --> 00:03:51,510
- Would you say that

astronomy and cosmology

105
00:03:51,510 --> 00:03:55,470
is an area in particular where
researchers with expertise

106
00:03:55,470 --> 00:03:58,830
in how to do these computations
is really necessary?

107
00:03:58,830 --> 00:04:00,420
- Lots of areas of physics

108
00:04:00,420 --> 00:04:02,700
are pushing computational boundaries.

109
00:04:02,700 --> 00:04:04,620
I know that our data rates, for example,

110
00:04:04,620 --> 00:04:06,570
aren't anywhere near
what you would encounter

111
00:04:06,570 --> 00:04:09,060
at CERN, at the Large Hadron Collider,

112
00:04:09,060 --> 00:04:10,650
but we're probably in the ballpark.

113
00:04:10,650 --> 00:04:13,260
I know that we use a Department
Of Energy supercomputer

114
00:04:13,260 --> 00:04:16,710
for one of my jobs and
my group uses basically

115
00:04:16,710 --> 00:04:19,590
the second or third largest

user of the whole center,

116
00:04:19,590 --> 00:04:21,060
which has like 1,000s of users.

117
00:04:21,060 --> 00:04:25,200
So we're kind of up there I
guess in terms of data rates.

118
00:04:25,200 --> 00:04:28,590
- Is there so much data because
the universe is so enormous

119
00:04:28,590 --> 00:04:30,570
and you're looking at so much of it?

120
00:04:30,570 --> 00:04:31,403
- Pretty much.

121
00:04:31,403 --> 00:04:33,930
- Like when we see images from telescopes,

122
00:04:33,930 --> 00:04:37,140
we see billions of stars
and billions of galaxies,

123
00:04:37,140 --> 00:04:40,500
is essentially all of that
stuff out there in the universe

124
00:04:40,500 --> 00:04:43,200
is data that needs to be crunched?

125
00:04:43,200 --> 00:04:44,033
- Yep. Exactly.

126
00:04:44,033 --> 00:04:45,780
Basically the sky is big

127
00:04:45,780 --> 00:04:48,030
at the scales that you
can see from the ground

128
00:04:48,030 --> 00:04:50,760
and that kind of sets the
basic scale of the problem.

129
00:04:50,760 --> 00:04:53,160
So with the largest
camera we have right now,

130
00:04:53,160 --> 00:04:56,940
it still takes 1,000s of
images to cover the entire sky.

131
00:04:56,940 --> 00:04:59,550
And we want not just one
image but multiple images

132
00:04:59,550 --> 00:05:02,460
to understand not only what's
going on at any instant,

133
00:05:02,460 --> 00:05:06,000
but trying to understand some
of the changes with time.

134
00:05:06,000 --> 00:05:09,270
- So some of the work that
you've done has been with DESI.

135
00:05:09,270 --> 00:05:12,060
That's one of the acronyms that
we'll be bringing up today.

136
00:05:12,060 --> 00:05:14,790
I like that one 'cause it's a nice name

137

00:05:14,790 --> 00:05:17,520
but it stands for more
than just a nice name.

138
00:05:17,520 --> 00:05:19,860
Can you tell us what DESI
is and what it's for?

139
00:05:19,860 --> 00:05:21,390
- Sure, so DESI stands for

140
00:05:21,390 --> 00:05:24,210
the Dark Energy Spectroscopic Instrument.

141
00:05:24,210 --> 00:05:28,313
So this is an instrument,
it's a device that is sitting

142
00:05:28,313 --> 00:05:31,650
at the top of a telescope in Arizona.

143
00:05:31,650 --> 00:05:34,980
Instruments on these telescopes
can be either cameras

144
00:05:34,980 --> 00:05:37,080
or spectrographs for the most part.

145
00:05:37,080 --> 00:05:40,170
Cameras, most people are
pretty familiar with.

146
00:05:40,170 --> 00:05:41,790
Spectrographs are a little bit different.

147
00:05:41,790 --> 00:05:43,860
This one is called a
multi-object spectrograph.

148

00:05:43,860 --> 00:05:48,860
So basically we can observe
many galaxies at once

149
00:05:48,870 --> 00:05:52,380
and break their light
into spectra or rainbows

150
00:05:52,380 --> 00:05:55,080
and take precise measurements
of like the brightness

151
00:05:55,080 --> 00:05:56,550
at each point in the rainbow.

152
00:05:56,550 --> 00:05:59,400
So the innovation with DESI

153
00:05:59,400 --> 00:06:02,250
is that it can take many more at once

154
00:06:02,250 --> 00:06:04,650
than previous generations of instruments.

155
00:06:04,650 --> 00:06:09,650
It can observe 5,000 stars
or galaxies every exposure.

156
00:06:09,660 --> 00:06:10,710
It's really cool.

157
00:06:10,710 --> 00:06:11,543
- That's like-
- Part of the-

158
00:06:11,543 --> 00:06:12,840
- One camera taking, well sorry,

159
00:06:12,840 --> 00:06:14,393

it's not a camera, it's a spectograph.

160
00:06:14,393 --> 00:06:16,950
But one instrument
taking 5,000 observations

161
00:06:16,950 --> 00:06:17,970
all at the same time.

162
00:06:17,970 --> 00:06:18,840
- Yeah, that's right.

163
00:06:18,840 --> 00:06:21,930
So this is the real
innovation of this instrument.

164
00:06:21,930 --> 00:06:24,390
So to give you a kind of a context,

165
00:06:24,390 --> 00:06:28,530
the previous generation
could take 1,000 at once.

166
00:06:28,530 --> 00:06:30,600
That was the Sloan Digital Sky Survey.

167
00:06:30,600 --> 00:06:32,940
And that project is also cool.

168
00:06:32,940 --> 00:06:35,100
But basically in these projects

169
00:06:35,100 --> 00:06:36,570
you have to choose ahead of time

170
00:06:36,570 --> 00:06:38,190
which objects you're going to observe

171

00:06:38,190 --> 00:06:43,190
because how they work is you
stick a fiber optic cable

172
00:06:43,620 --> 00:06:46,950
and point it directly at each
object that you wanna observe.

173
00:06:46,950 --> 00:06:50,160
The light comes from your galaxy
down the fiber optic cable

174
00:06:50,160 --> 00:06:53,610
to a spectrograph that actually
splits it into the rainbow.

175
00:06:53,610 --> 00:06:54,690
So then the challenge is, you know,

176
00:06:54,690 --> 00:06:58,680
how do you point 1,000 little
fiber optics at once and-

177
00:06:58,680 --> 00:07:01,170
- How do you point one at
once let alone 1,000 or 5,000?

178
00:07:01,170 --> 00:07:04,080
- Well so, and the other
challenge is you have to like,

179
00:07:04,080 --> 00:07:07,320
the fibers are like this kind
of the size of a human hair

180
00:07:07,320 --> 00:07:10,170
and you have to point them
to finer than that precision.

181
00:07:10,170 --> 00:07:11,784

- At galaxies that are-
- Yeah, exactly.

182
00:07:11,784 --> 00:07:14,040
- Billions of gajillions of miles-

183
00:07:14,040 --> 00:07:15,720
- And your telescope weighs many tons.

184
00:07:15,720 --> 00:07:17,400
So the thing like it's really,

185
00:07:17,400 --> 00:07:18,960
the engineering is really amazing.

186
00:07:18,960 --> 00:07:20,100
- How do you do it?

187
00:07:20,100 --> 00:07:21,977
It's not a person with tweezers, right?

188
00:07:21,977 --> 00:07:23,641
(both laugh)

189
00:07:23,641 --> 00:07:24,474
- Right, well...

190
00:07:24,474 --> 00:07:26,100
- Or is it?

191
00:07:26,100 --> 00:07:28,170
- In the Sloan Digital Sky Survey,

192
00:07:28,170 --> 00:07:31,350
what they did was they
chose which galaxies

193
00:07:31,350 --> 00:07:33,630

they want to observe ahead of time.

194
00:07:33,630 --> 00:07:36,270
They compute where
they'll appear on the sky.

195
00:07:36,270 --> 00:07:38,160
Oh, you have to choose a set of nights

196
00:07:38,160 --> 00:07:39,330
that you're going to observe it on

197
00:07:39,330 --> 00:07:40,650
and a time within that night.

198
00:07:40,650 --> 00:07:43,680
And given that, you can predict
where they're going to be,

199
00:07:43,680 --> 00:07:45,150
they take an aluminum plate,

200
00:07:45,150 --> 00:07:47,940
drill little precision holes in the plate,

201
00:07:47,940 --> 00:07:50,580
1,000 holes for 1,000 galaxies.

202
00:07:50,580 --> 00:07:51,990
Ship those plates to the mountain

203
00:07:51,990 --> 00:07:54,300
and then a crew of people, by hand,

204
00:07:54,300 --> 00:07:57,393
plug in fiber optic cables
into each of those holes.

205

00:07:58,260 --> 00:07:59,470
- Wow. That's not how I
imagine this would happen.

206
00:07:59,470 --> 00:08:01,260
- Yeah, exactly, it doesn't sound

207
00:08:01,260 --> 00:08:02,280
very high tech.
- Right.

208
00:08:02,280 --> 00:08:04,800
- So during the night they would go out

209
00:08:04,800 --> 00:08:07,260
and plug one of these
plates into the telescope

210
00:08:07,260 --> 00:08:09,840
and that plate steers the light.

211
00:08:09,840 --> 00:08:12,180
You know, the fibers are
in just the right place

212
00:08:12,180 --> 00:08:14,280
to steer the light down those fibers

213
00:08:14,280 --> 00:08:15,780
to be collected in the spectrographs

214
00:08:15,780 --> 00:08:19,290
and make those measurements
of 1,000 galaxies at once.

215
00:08:19,290 --> 00:08:21,090
Let me say just for a second,

216
00:08:21,090 --> 00:08:24,600

'cause I was talking about the
hand-plugged fibers in SDSS.

217
00:08:24,600 --> 00:08:28,590
When DESI was being designed or proposed,

218
00:08:28,590 --> 00:08:29,897
one of the challenges was scaling up

219
00:08:29,897 --> 00:08:32,190
from 1,000 to 5,000,

220
00:08:32,190 --> 00:08:34,290
doing that by hand just started

221
00:08:34,290 --> 00:08:36,480
to get like to be infeasible.

222
00:08:36,480 --> 00:08:40,380
So the way that DESI instrument
operates is really cool.

223
00:08:40,380 --> 00:08:43,620
It uses these little robots,

224
00:08:43,620 --> 00:08:48,360
so 5,000 of them and each of
them has two little motors

225
00:08:48,360 --> 00:08:52,020
that allow it to rotate the fiber

226
00:08:52,020 --> 00:08:54,360
to any place within its little region.

227
00:08:54,360 --> 00:08:57,720
So it's sort of like your
shoulder and elbow joints.

228
00:08:57,720 --> 00:08:59,630
One of the motors moves the shoulder

229
00:08:59,630 --> 00:09:01,800
or like rotates the shoulder in a circle

230
00:09:01,800 --> 00:09:04,080
and the other can rotate
the elbow in a circle.

231
00:09:04,080 --> 00:09:05,100
So between that,

232
00:09:05,100 --> 00:09:09,420
they can position the fiber
anywhere within their reach

233
00:09:09,420 --> 00:09:11,280
and then they're placed
close enough together

234
00:09:11,280 --> 00:09:13,350
that they can just reach
their, or like they have

235
00:09:13,350 --> 00:09:15,330
a little bit of overlap
with their neighbor.

236
00:09:15,330 --> 00:09:19,260
So no matter where a star or galaxy lands

237
00:09:19,260 --> 00:09:22,200
on the focal plane of the instrument,

238
00:09:22,200 --> 00:09:24,360
at least one of them can
reach it with its fiber

239
00:09:24,360 --> 00:09:25,830
and it holds out its fiber

240
00:09:25,830 --> 00:09:30,420
and the light pours down and
goes into our spectrographs.

241
00:09:30,420 --> 00:09:32,850
So another innovation of DESI

242
00:09:32,850 --> 00:09:35,370
was that in the previous generation,

243
00:09:35,370 --> 00:09:39,180
the spectrographs were bolted
to the side of the telescope

244
00:09:39,180 --> 00:09:41,460
and they flopped around during the night

245
00:09:41,460 --> 00:09:45,300
and were subject to the
surrounding temperature.

246
00:09:45,300 --> 00:09:47,220
So for DESI, what we do instead

247
00:09:47,220 --> 00:09:49,920
is the spectrographs are put

248
00:09:49,920 --> 00:09:53,073
in a nice climate-controlled cleanroom,

249
00:09:54,000 --> 00:09:55,440
but then we have to get the light

250
00:09:55,440 --> 00:09:58,560
from the top of the telescope

down through the telescope.

251
00:09:58,560 --> 00:10:00,900
It has moving parts of course.

252
00:10:00,900 --> 00:10:03,030
So there's a 50 meter run of fiber,

253
00:10:03,030 --> 00:10:06,600
5,000 fibers that goes
down to this cleanroom.

254
00:10:06,600 --> 00:10:09,863
So 500 fibers each plug
into these spectrographs,

255
00:10:09,863 --> 00:10:11,610
there's 10 of them.

256
00:10:11,610 --> 00:10:14,820
And the fibers come in in a big stack,

257
00:10:14,820 --> 00:10:16,680
like they're lined up in a big stack

258
00:10:16,680 --> 00:10:20,370
and then their light shines onto a prism,

259
00:10:20,370 --> 00:10:24,210
basically, that splits
their light into a rainbow.

260
00:10:24,210 --> 00:10:27,450
And then that rainbow
lands on like a sensor,

261
00:10:27,450 --> 00:10:30,720
a CCD sensor, like a camera basically.

262
00:10:30,720 --> 00:10:35,720
So what you see in the images
are 500 like rows of rainbows.

263
00:10:37,050 --> 00:10:38,350
But of course they're not,

264
00:10:39,270 --> 00:10:42,060
these sensors themselves are monochrome,

265
00:10:42,060 --> 00:10:44,130
like they only, they're just
measured black and white.

266
00:10:44,130 --> 00:10:48,360
So you see kind of a
brighter or fainter line,

267
00:10:48,360 --> 00:10:52,110
500 of those spaced
together across the chip.

268
00:10:52,110 --> 00:10:55,110
So brighter spots are
places in the spectrum

269
00:10:55,110 --> 00:10:56,040
that are brighter.

270
00:10:56,040 --> 00:11:00,240
So during the afternoon we
use these calibration sources.

271
00:11:00,240 --> 00:11:01,073
So like you know,

272
00:11:01,073 --> 00:11:03,450
you can shine light of a known wavelength

273
00:11:03,450 --> 00:11:05,520
and measure where it
appears in the images.

274
00:11:05,520 --> 00:11:07,260
So you can say, oh that little bump

275
00:11:07,260 --> 00:11:10,110
is red 540 nanometers

276
00:11:10,110 --> 00:11:13,260
and this little bump is
some other wavelength.

277
00:11:13,260 --> 00:11:15,360
The thing that's kind of amazing

278
00:11:15,360 --> 00:11:16,530
looking at the raw data though,

279
00:11:16,530 --> 00:11:19,650
is that all of them
look the same basically.

280
00:11:19,650 --> 00:11:22,950
And that's because the sky
is pretty bright, (chuckles)

281
00:11:22,950 --> 00:11:25,440
even the night sky at the darkest times

282
00:11:25,440 --> 00:11:26,273
is actually the thing

283
00:11:26,273 --> 00:11:28,260
that we detect most
strongly in the images.

284

00:11:28,260 --> 00:11:32,640
So it's only by subtracting
out the contribution of the sky

285
00:11:32,640 --> 00:11:35,580
that we get to see the
stars and galaxies in kind.

286
00:11:35,580 --> 00:11:37,057
It's not an easy way to live.

287
00:11:37,057 --> 00:11:38,580
(both laugh)

288
00:11:38,580 --> 00:11:40,500
- And once all that
information is collected

289
00:11:40,500 --> 00:11:43,350
from those 1,000 or 5,000 points,

290
00:11:43,350 --> 00:11:45,330
does it then go to you to figure out,

291
00:11:45,330 --> 00:11:46,170
or you and your team,

292
00:11:46,170 --> 00:11:51,150
to then do all of the computational
work to understand it?

293
00:11:51,150 --> 00:11:54,570
- Yeah, other people
on my teams. (chuckles)

294
00:11:54,570 --> 00:11:58,110
My work on DESI comes earlier actually.

295
00:11:58,110 --> 00:11:59,580

I've been involved in,

296
00:11:59,580 --> 00:12:01,170
remember I said you have
to choose ahead of time

297
00:12:01,170 --> 00:12:03,960
which things you want to
observe, which we do from images.

298
00:12:03,960 --> 00:12:06,450
So first you go out and
take an image of the sky.

299
00:12:06,450 --> 00:12:09,660
in our case in like three
different filters or three colors,

300
00:12:09,660 --> 00:12:12,390
and you measure all the stars and galaxies

301
00:12:12,390 --> 00:12:14,400
and measure their brightnesses and colors

302
00:12:14,400 --> 00:12:15,900
and choose some set of them

303
00:12:15,900 --> 00:12:17,430
that are interesting for follow up.

304
00:12:17,430 --> 00:12:19,410
We get to choose about 1% of them.

305
00:12:19,410 --> 00:12:21,240
So when we started DESI,

306
00:12:21,240 --> 00:12:23,580
there was no imaging survey that existed

307
00:12:23,580 --> 00:12:25,500
that was deep enough to make
those measurements, right.

308
00:12:25,500 --> 00:12:27,240
We wanted to measure things
that were faint enough

309
00:12:27,240 --> 00:12:29,100
that they just didn't appear

310
00:12:29,100 --> 00:12:31,800
in the existing generation
of imaging surveys

311
00:12:31,800 --> 00:12:34,290
so we had to go out and
do those imaging surveys.

312
00:12:34,290 --> 00:12:35,220
So that's the part

313
00:12:35,220 --> 00:12:37,560
that I was kind of most
mostly involved with.

314
00:12:37,560 --> 00:12:38,640
- And I'm hoping you can tell us

315
00:12:38,640 --> 00:12:41,460
a little bit more about
this idea you referred to

316
00:12:41,460 --> 00:12:43,590
as splitting up the
electromagnetic spectrum.

317
00:12:43,590 --> 00:12:46,470
So the electromagnetic

spectrum is quite wide

318
00:12:46,470 --> 00:12:49,050
and only a small portion of it is visible

319
00:12:49,050 --> 00:12:50,850
and then you also do some splitting up

320
00:12:50,850 --> 00:12:51,900
within that visible piece.

321
00:12:51,900 --> 00:12:53,760
Can you just tell us a
little bit more about that

322
00:12:53,760 --> 00:12:55,800
and how different telescopes

323
00:12:55,800 --> 00:12:58,320
focus on different parts of the spectrum?

324
00:12:58,320 --> 00:13:02,340
- Sure. I call myself mostly
an optical astronomer,

325
00:13:02,340 --> 00:13:04,200
which means I work in more or less

326
00:13:04,200 --> 00:13:06,150
the visible part of the spectrum,

327
00:13:06,150 --> 00:13:08,880
which then also now bleeds
into the infrared a little bit

328
00:13:08,880 --> 00:13:11,460
because you can use the same
technologies to do that,

329
00:13:11,460 --> 00:13:14,460
to observe light that
we can't quite observe.

330
00:13:14,460 --> 00:13:16,980
So different telescopes
tend to be optimized

331
00:13:16,980 --> 00:13:18,780
for observing different
parts of the spectrum.

332
00:13:18,780 --> 00:13:20,190
Partly from the ground,

333
00:13:20,190 --> 00:13:21,390
only parts of the spectrum

334
00:13:21,390 --> 00:13:23,310
actually make it through our atmosphere.

335
00:13:23,310 --> 00:13:26,820
If you go very much bluer
than we can see with our eyes,

336
00:13:26,820 --> 00:13:28,530
that atmosphere just blocks everything.

337
00:13:28,530 --> 00:13:31,200
Just the air absorbs all of that light.

338
00:13:31,200 --> 00:13:33,480
As you go toward the infrared,

339
00:13:33,480 --> 00:13:35,940
water is actually one of the annoyances.

340
00:13:35,940 --> 00:13:37,650

So water vapor in the atmosphere

341
00:13:37,650 --> 00:13:40,410
also emits at those
same frequencies, so...

342
00:13:40,410 --> 00:13:43,260
- You don't often hear
water called an annoyance.

343
00:13:43,260 --> 00:13:44,940
It's also essential for life on planet.

344
00:13:44,940 --> 00:13:46,695
- Some people enjoy it. Yeah.

345
00:13:46,695 --> 00:13:48,060
(all laughing)

346
00:13:48,060 --> 00:13:49,890
- It has its pros and cons.

347
00:13:49,890 --> 00:13:52,380
- Right. As long as it would just-

348
00:13:52,380 --> 00:13:53,700
- Stay outta the way.
- Stay outta the upper

349
00:13:53,700 --> 00:13:57,060
atmosphere or just the
couple of cubic kilometers

350
00:13:57,060 --> 00:13:58,740
around our telescopes,
that would be great.

351
00:13:58,740 --> 00:14:01,380
And then if you go

further into the infrared,

352
00:14:01,380 --> 00:14:04,230
that is just heat and
then it's really hard

353
00:14:04,230 --> 00:14:06,360
to observe something faint in the sky

354
00:14:06,360 --> 00:14:09,540
when like your telescope and
your mirrors are all glowing,

355
00:14:09,540 --> 00:14:11,670
which is basically what
happens in the infrared.

356
00:14:11,670 --> 00:14:13,260
And then so there's a
big chunk of the infrared

357
00:14:13,260 --> 00:14:14,250
that we can't reach,

358
00:14:14,250 --> 00:14:16,410
which is why people
launch things into space

359
00:14:16,410 --> 00:14:18,180
to observe in that frequency range.

360
00:14:18,180 --> 00:14:22,290
So JWST for example, and
a telescope I really love,

361
00:14:22,290 --> 00:14:26,070
the Wide-Field Infrared
Survey Explorer, WISE,

362

00:14:26,070 --> 00:14:28,500
also a NASA mission, and they go to space

363
00:14:28,500 --> 00:14:29,910
because basically you can't observe

364
00:14:29,910 --> 00:14:31,170
or it's very, very difficult

365
00:14:31,170 --> 00:14:33,090
to observe that from the ground.

366
00:14:33,090 --> 00:14:36,180
My advisor did a bunch
of infrared observing

367
00:14:36,180 --> 00:14:39,690
as part of his PhD and
spent many, many nights

368
00:14:39,690 --> 00:14:41,760
on some of the biggest
telescopes in the world

369
00:14:41,760 --> 00:14:43,560
in order to make these measurements,

370
00:14:43,560 --> 00:14:45,090
despite the fact that your telescope

371
00:14:45,090 --> 00:14:46,980
is glowing at those frequencies.

372
00:14:46,980 --> 00:14:50,340
And he said the Spitzer Space Telescope,

373
00:14:50,340 --> 00:14:52,320
one of the first infrared missions,

374
00:14:52,320 --> 00:14:55,020
totally made obsolete
all of his observations

375
00:14:55,020 --> 00:14:57,960
within its first second
of observation. (laughs)

376
00:14:57,960 --> 00:14:58,793
- Wow.

377
00:14:58,793 --> 00:14:59,700
- Like it's really good

378
00:14:59,700 --> 00:15:02,640
to observe when the
sky is dark, basically.

379
00:15:02,640 --> 00:15:05,493
It's not easy, basically,
observing during the daytime.

380
00:15:06,450 --> 00:15:09,060
I mean basically, the atmosphere sets

381
00:15:09,060 --> 00:15:10,590
what we can do from the ground

382
00:15:10,590 --> 00:15:12,750
and sets what we can do with telescopes.

383
00:15:12,750 --> 00:15:14,730
And then there's another
atmospheric window,

384
00:15:14,730 --> 00:15:16,110
we call it in the radio.

385

00:15:16,110 --> 00:15:18,150
So I think we'll come back to that later.

386
00:15:18,150 --> 00:15:19,920
- Mm-hmm, DESI is called

387
00:15:19,920 --> 00:15:22,590
the Dark Energy Spectroscopic Instrument.

388
00:15:22,590 --> 00:15:26,520
You've told us a bit about
the spectroscopic part.

389
00:15:26,520 --> 00:15:29,673
What is the dark energy
aspect of this experiment?

390
00:15:30,765 --> 00:15:32,337
- (laughs) Dark energy.

391
00:15:32,337 --> 00:15:33,300
- (laughs) Big subject?

392
00:15:33,300 --> 00:15:35,100
- Pretty big subject, yep.

393
00:15:35,100 --> 00:15:37,230
Dark energy is one of the real mysteries

394
00:15:37,230 --> 00:15:40,530
in astrophysics these days, or cosmology.

395
00:15:40,530 --> 00:15:42,600
To explain that, go right back

396
00:15:42,600 --> 00:15:44,730
to the beginning, to the Big Bang.

397

00:15:44,730 --> 00:15:49,140
Around 100 years ago, the
observation was made by Hubble

398
00:15:49,140 --> 00:15:53,790
that if you look at
galaxies, you can measure

399
00:15:53,790 --> 00:15:56,790
whether they're moving
towards us or away from us.

400
00:15:56,790 --> 00:15:58,500
And Hubble observed

401
00:15:58,500 --> 00:16:00,600
that all the galaxies
are moving away from us.

402
00:16:00,600 --> 00:16:01,433
And not only that,

403
00:16:01,433 --> 00:16:04,560
the ones that are further
away are moving away faster.

404
00:16:04,560 --> 00:16:07,620
So that tells you basically
that the universe is expanding,

405
00:16:07,620 --> 00:16:09,330
which then kind of leads you to the idea

406
00:16:09,330 --> 00:16:11,760
that, oh, in the past it
must have been smaller.

407
00:16:11,760 --> 00:16:13,020
What's the end point of that?

408
00:16:13,020 --> 00:16:16,200
Is all of the universe
being in a very small place

409
00:16:16,200 --> 00:16:17,790
and they're being kind of a big bang

410
00:16:17,790 --> 00:16:20,550
that makes it expand out from there.

411
00:16:20,550 --> 00:16:24,330
So if you just imagine there's a big bang,

412
00:16:24,330 --> 00:16:27,270
everything starts expanding
away from everything else

413
00:16:27,270 --> 00:16:29,730
and then gravity is trying
to pull it back together.

414
00:16:29,730 --> 00:16:32,670
You might think there're kind
of three possibilities there.

415
00:16:32,670 --> 00:16:36,180
So one would be like the
Big Bang gives it a kick,

416
00:16:36,180 --> 00:16:39,510
it expands and then gravity
starts pulling it back together.

417
00:16:39,510 --> 00:16:41,580
And then gravity is strong enough

418
00:16:41,580 --> 00:16:43,350
to pull everything back together

419
00:16:43,350 --> 00:16:46,950
and everything collapses again
and there's a big crunch.

420
00:16:46,950 --> 00:16:49,710
Option two is there's a big bang,

421
00:16:49,710 --> 00:16:52,110
gravity is trying to pull
everything back together

422
00:16:52,110 --> 00:16:54,420
and it's just not quite strong enough

423
00:16:54,420 --> 00:16:55,560
to pull everything back together.

424
00:16:55,560 --> 00:16:57,630
But everything kind of stops

425
00:16:57,630 --> 00:17:00,720
or slowly drifts down to zero speed.

426
00:17:00,720 --> 00:17:03,150
- So it's expanding but it's slowing down.

427
00:17:03,150 --> 00:17:03,983
- Yeah.

428
00:17:03,983 --> 00:17:06,322
- Until it reaches an equilibrium

429
00:17:06,322 --> 00:17:07,590
and stays there?
- Maybe, it's pretty hard

430
00:17:07,590 --> 00:17:10,860
to hit a perfect balance like that.

431
00:17:10,860 --> 00:17:13,050
So then the third option
is the big bang kick

432
00:17:13,050 --> 00:17:15,780
is big enough that gravity
can't pull it back together.

433
00:17:15,780 --> 00:17:18,420
It tries, but as you get further
apart, gravity gets weaker.

434
00:17:18,420 --> 00:17:20,670
So then it's sort of, you
hit a constant drift rate

435
00:17:20,670 --> 00:17:22,980
where everything's drifting further apart

436
00:17:22,980 --> 00:17:24,990
at a constant speed, basically.

437
00:17:24,990 --> 00:17:26,460
The mystery of dark energy,

438
00:17:26,460 --> 00:17:28,440
which was discovered in the '90s

439
00:17:28,440 --> 00:17:31,290
is that there's a
different thing going on.

440
00:17:31,290 --> 00:17:34,140
Not only the drifting
apart at a constant speed,

441
00:17:34,140 --> 00:17:36,450
it's drifting apart and

there's an acceleration

442
00:17:36,450 --> 00:17:38,520
that's pushing it faster than that.

443
00:17:38,520 --> 00:17:40,860
It's like not only was there the big bang,

444
00:17:40,860 --> 00:17:43,530
there's something else that's
continuing to give it a kick.

445
00:17:43,530 --> 00:17:45,780
So there's something that
we don't know what it is

446
00:17:45,780 --> 00:17:48,150
and things that we don't know
what they are in astronomy,

447
00:17:48,150 --> 00:17:49,050
we call them dark.

448
00:17:49,050 --> 00:17:51,540
So we've got dark matter,
we've got dark energy,

449
00:17:51,540 --> 00:17:52,680
we dunno what they are.

450
00:17:52,680 --> 00:17:57,390
And it's just making the size
of the universe accelerate,

451
00:17:57,390 --> 00:18:00,600
like grow larger and speed
up right in its growth.

452
00:18:00,600 --> 00:18:03,780

And it's a basically a
mystery of what it is.

453
00:18:03,780 --> 00:18:06,390
When Einstein first
wrote down the equations

454
00:18:06,390 --> 00:18:07,980
for general relativity

455
00:18:07,980 --> 00:18:09,900
that there is a term in those equations

456
00:18:09,900 --> 00:18:12,720
that Einstein put in to
keep the universe stable,

457
00:18:12,720 --> 00:18:14,940
to keep the universe from collapsing again

458
00:18:14,940 --> 00:18:18,270
'cause Einstein wanted the
universe to be able to be stable.

459
00:18:18,270 --> 00:18:21,300
And then with Hubble's findings,

460
00:18:21,300 --> 00:18:24,120
Einstein called that his greatest blunder.

461
00:18:24,120 --> 00:18:26,640
But then it turns out
that that same factor,

462
00:18:26,640 --> 00:18:28,770
that same constant in the equations,

463
00:18:28,770 --> 00:18:31,260
if you make it negative,

it gives you dark energy,

464
00:18:31,260 --> 00:18:32,520
it explains dark energy

465
00:18:32,520 --> 00:18:35,700
or like at least appears in the equations.

466
00:18:35,700 --> 00:18:36,600
That doesn't really help us

467
00:18:36,600 --> 00:18:38,410
to understand what it physically is.

468
00:18:38,410 --> 00:18:41,760
Is it something that we
can ever interact with

469
00:18:41,760 --> 00:18:44,220
in any kind of real way or is it just like

470
00:18:44,220 --> 00:18:47,790
a fact of the way space
and the universe works?

471
00:18:47,790 --> 00:18:48,990
There are lots of ideas

472
00:18:48,990 --> 00:18:52,497
about what dark energy
is or how it could work

473
00:18:52,497 --> 00:18:55,080
and with DESI we're basically just trying

474
00:18:55,080 --> 00:18:56,700
to go out and make the measurements

475

00:18:56,700 --> 00:19:00,000
and those measurements
will help to disentangle

476
00:19:00,000 --> 00:19:02,730
or to tell the difference
between different models

477
00:19:02,730 --> 00:19:04,380
of what dark energy might be.

478
00:19:04,380 --> 00:19:08,070
So the goal of DESI is to
measure the size of the universe

479
00:19:08,070 --> 00:19:10,140
at different times in the past.

480
00:19:10,140 --> 00:19:12,090
So basically we're trying to chart

481
00:19:12,090 --> 00:19:15,210
that growth of the size
of the universe over time

482
00:19:15,210 --> 00:19:18,210
and different models of what
dark energy will predict,

483
00:19:18,210 --> 00:19:20,130
different shapes of that curve

484
00:19:20,130 --> 00:19:22,590
of how fast the universe grows over time.

485
00:19:22,590 --> 00:19:25,419
So by just going out and
making the measurement,

486

00:19:25,419 --> 00:19:27,510
we should be able to kind
of tell the difference

487
00:19:27,510 --> 00:19:29,100
between different models of dark energy

488
00:19:29,100 --> 00:19:32,520
and help to rule out some
possible explanations.

489
00:19:32,520 --> 00:19:34,230
- When you mention over time,

490
00:19:34,230 --> 00:19:36,780
you don't mean you do
an observation one week

491
00:19:36,780 --> 00:19:37,980
and then the next week and the next week,

492
00:19:37,980 --> 00:19:40,170
you mean over like cosmic time, right?

493
00:19:40,170 --> 00:19:41,850
You're essentially looking back

494
00:19:41,850 --> 00:19:45,630
at where galaxies were
billions of years ago

495
00:19:45,630 --> 00:19:48,030
versus where they were, I dunno,

496
00:19:48,030 --> 00:19:50,070
another amount of billion years ago.

497
00:19:50,070 --> 00:19:52,133
Is that generally fair?

- Yeah, that's exactly right.

498
00:19:52,133 --> 00:19:54,930
- And how can you tell
how fast they're moving?

499
00:19:54,930 --> 00:19:57,600
Or if you know were they at
one point and another point,

500
00:19:57,600 --> 00:20:00,180
then you know the speed of acceleration?

501
00:20:00,180 --> 00:20:03,000
- So like you said, on human time-scales,

502
00:20:03,000 --> 00:20:06,000
basically the extra-galactic
universe is static.

503
00:20:06,000 --> 00:20:08,520
We can see the stars moving,
they don't move very much.

504
00:20:08,520 --> 00:20:09,810
But with precision instruments

505
00:20:09,810 --> 00:20:11,280
you can tell that they're moving.

506
00:20:11,280 --> 00:20:14,820
But the galaxies more or less
are stationary on the skies

507
00:20:14,820 --> 00:20:17,550
to the precisions that we can measure.

508
00:20:17,550 --> 00:20:20,061
Distances in cosmology

are really complicated.

509
00:20:20,061 --> 00:20:21,120
(both laugh)

510
00:20:21,120 --> 00:20:24,000
It's hard to just talk about
the distances between things

511
00:20:24,000 --> 00:20:27,480
when the whole fabric that
they're sitting on is growing.

512
00:20:27,480 --> 00:20:30,720
So distances in cosmology are complicated.

513
00:20:30,720 --> 00:20:33,900
So the two things we can really measure

514
00:20:33,900 --> 00:20:38,100
are angles on the sky and redshifts.

515
00:20:38,100 --> 00:20:41,970
So redshifts, lots of people
have heard explained before,

516
00:20:41,970 --> 00:20:45,240
but basically the light from the galaxy,

517
00:20:45,240 --> 00:20:48,060
if you break it into a rainbow
has a certain signature.

518
00:20:48,060 --> 00:20:51,390
And what we observe is not that signature

519
00:20:51,390 --> 00:20:52,950
as we'd expect to see it,

520
00:20:52,950 --> 00:20:55,020
but that signature shifted.

521
00:20:55,020 --> 00:20:57,000
It's sort of like the
Doppler effect when you know,

522
00:20:57,000 --> 00:20:59,310
when you hear the train goes
from moving towards you,

523
00:20:59,310 --> 00:21:00,360
from moving away from you,

524
00:21:00,360 --> 00:21:03,120
the whistle shifts from higher to lower.

525
00:21:03,120 --> 00:21:04,800
So if you're talking about light,

526
00:21:04,800 --> 00:21:08,100
lower is redder toward the red.

527
00:21:08,100 --> 00:21:11,070
So what we observe is all
the galaxies signatures

528
00:21:11,070 --> 00:21:13,590
are shifted toward the
red by different amounts.

529
00:21:13,590 --> 00:21:15,540
So they're redshifted
by different amounts.

530
00:21:15,540 --> 00:21:18,000
And that observation from Hubble was that

531

00:21:18,000 --> 00:21:21,480
galaxies that are more distant
are more shifted to the red.

532
00:21:21,480 --> 00:21:24,007
So that's one thing we can
actually measure, redshifts,

533
00:21:24,007 --> 00:21:26,610
and that's what DESI's real thing is.

534
00:21:26,610 --> 00:21:28,290
The other is angles on the sky.

535
00:21:28,290 --> 00:21:30,480
Another thing that DESI
is very good at doing,

536
00:21:30,480 --> 00:21:33,450
because we have to know
where the galaxies are

537
00:21:33,450 --> 00:21:35,010
to actually observe them.

538
00:21:35,010 --> 00:21:38,460
So the thing that lets us
tie those two things together

539
00:21:38,460 --> 00:21:41,280
and measure the scale of
the universe over time

540
00:21:41,280 --> 00:21:45,423
is this nice little feature
that the universe gave us.

541
00:21:46,260 --> 00:21:48,330
A little bit after the Big Bang

542
00:21:48,330 --> 00:21:52,200
the universe was this, we kinda
call it a hot soup I guess,

543
00:21:52,200 --> 00:21:54,690
of plasma and photons.

544
00:21:54,690 --> 00:21:57,270
Basically, everything's so
hot that there aren't atoms.

545
00:21:57,270 --> 00:22:01,140
There's basically just a
big roil of plasma and light

546
00:22:01,140 --> 00:22:03,450
and it's all exchanging energy

547
00:22:03,450 --> 00:22:05,880
and it wasn't uniformly spread.

548
00:22:05,880 --> 00:22:09,240
There were kind of denser
and less dense spots.

549
00:22:09,240 --> 00:22:12,900
And that soup kind of allows things

550
00:22:12,900 --> 00:22:14,550
like sound waves to propagate.

551
00:22:14,550 --> 00:22:17,580
So if you have like a dense spot,

552
00:22:17,580 --> 00:22:20,280
you get a ring that comes out from it.

553
00:22:20,280 --> 00:22:22,860

And then there's a magical point

554
00:22:22,860 --> 00:22:26,310
380,000 years after the Big Bang

555
00:22:26,310 --> 00:22:29,820
where the universe has
grown and cooled enough

556
00:22:29,820 --> 00:22:33,780
that plasma can cool down
and you can form atoms.

557
00:22:33,780 --> 00:22:34,860
It's not a soup anymore.

558
00:22:34,860 --> 00:22:38,670
The photons kind of get liberated
and are allowed to escape.

559
00:22:38,670 --> 00:22:41,490
But those rings of over densities

560
00:22:41,490 --> 00:22:43,200
are frozen-in at that point.

561
00:22:43,200 --> 00:22:45,000
- They're sort of imprinted for good?

562
00:22:45,000 --> 00:22:46,260
- That's right. They're
imprinted for good.

563
00:22:46,260 --> 00:22:49,980
We can see them by observing
the light from that time.

564
00:22:49,980 --> 00:22:54,240
That light is now really

redshifted into the microwave

565
00:22:54,240 --> 00:22:56,430
and we can see it in all directions.

566
00:22:56,430 --> 00:22:58,830
And it's called the cosmic
microwave background.

567
00:22:58,830 --> 00:23:02,700
It's currently three
degrees above absolute zero.

568
00:23:02,700 --> 00:23:03,810
So it's at three Calvin.

569
00:23:03,810 --> 00:23:06,120
- It's chilly.
- Yep. (laughs)

570
00:23:06,120 --> 00:23:09,120
And it looks like it's three
degrees in all directions,

571
00:23:09,120 --> 00:23:11,880
but if you make very,
very precise measurements,

572
00:23:11,880 --> 00:23:13,860
you see that there are little variations

573
00:23:13,860 --> 00:23:16,110
above and below that three degrees,

574
00:23:16,110 --> 00:23:19,500
1 part in 10,000 where you
can just see the places

575
00:23:19,500 --> 00:23:21,360

that were brighter and colder,

576
00:23:21,360 --> 00:23:23,940
more dense and less dense at that time.

577
00:23:23,940 --> 00:23:25,530
And the parts that were more dense,

578
00:23:25,530 --> 00:23:27,090
remember our good old friend gravity,

579
00:23:27,090 --> 00:23:29,640
pulls all of that matter together

580
00:23:29,640 --> 00:23:31,440
to form stars and galaxies.

581
00:23:31,440 --> 00:23:33,450
So that little ring

582
00:23:33,450 --> 00:23:37,170
that was frozen-in at that
point has stuck around.

583
00:23:37,170 --> 00:23:38,910
So what we get to observe

584
00:23:38,910 --> 00:23:41,610
is that if you look at a single galaxy,

585
00:23:41,610 --> 00:23:44,100
galaxies aren't spread uniformly
on the sky, they cluster.

586
00:23:44,100 --> 00:23:47,430
Around a galaxy, you're likely
to find other galaxies nearby

587

00:23:47,430 --> 00:23:50,610
and then they sort of drop off
in density around the galaxy.

588
00:23:50,610 --> 00:23:53,580
But then at the radius of that ring,

589
00:23:53,580 --> 00:23:56,010
there's a little bump where
you're a little bit more likely

590
00:23:56,010 --> 00:23:57,480
to find another galaxy.

591
00:23:57,480 --> 00:23:59,786
It's about 1% more likely.

592
00:23:59,786 --> 00:24:01,770
It's a little bit of a subtle signal.

593
00:24:01,770 --> 00:24:04,950
The universe is very kind to
give us anything but it's-

594
00:24:04,950 --> 00:24:06,180
- You may not wanna place money

595
00:24:06,180 --> 00:24:08,133
on it being there all the time 1% off.

596
00:24:08,133 --> 00:24:09,330
- Well by building DESI,

597
00:24:09,330 --> 00:24:12,450
we've placed a lot of
money on on it being there.

598
00:24:12,450 --> 00:24:14,400
But the beautiful thing about it is that

599
00:24:14,400 --> 00:24:16,350
that scale was frozen-in,

600
00:24:16,350 --> 00:24:18,600
there's kind of nothing you can do to it

601
00:24:18,600 --> 00:24:19,920
to change what that scale is.

602
00:24:19,920 --> 00:24:22,440
So it just basically gets stretched along

603
00:24:22,440 --> 00:24:25,830
with the fabric of the universe
or the fabric of spacetime.

604
00:24:25,830 --> 00:24:29,430
So what we can do, finally, with DESI

605
00:24:29,430 --> 00:24:31,980
is measure the angular scale

606
00:24:31,980 --> 00:24:34,560
of that feature at different redshifts.

607
00:24:34,560 --> 00:24:36,074
- Right.

608
00:24:36,074 --> 00:24:37,740
- Whew.
(Colin laughs)

609
00:24:37,740 --> 00:24:40,020
Remember when I said distances
in cosmology are complicated?

610
00:24:40,020 --> 00:24:40,853

- Yes. Yeah.

611
00:24:40,853 --> 00:24:42,180
- It's a long way to go from-

612
00:24:42,180 --> 00:24:45,300
- It's not how we think of,
you know, driving distances.

613
00:24:45,300 --> 00:24:47,580
This is, it's a very
different sense of distance.

614
00:24:47,580 --> 00:24:49,868
- Or just taking out a ruler or something.

615
00:24:49,868 --> 00:24:52,350
- (laughs) Well, so this
is called a standard ruler

616
00:24:52,350 --> 00:24:53,183
because it's a thing

617
00:24:53,183 --> 00:24:56,910
that we think we know the physical size of

618
00:24:56,910 --> 00:25:00,090
and then we measure what
angular scale on the sky

619
00:25:00,090 --> 00:25:01,710
it fills at different times.

620
00:25:01,710 --> 00:25:03,780
If you think about this
in your everyday life,

621
00:25:03,780 --> 00:25:06,570
you take a ruler and you

serve it at arms length,

622
00:25:06,570 --> 00:25:08,250
it fills a certain angle, right?

623
00:25:08,250 --> 00:25:09,990
If you move it twice as far away,

624
00:25:09,990 --> 00:25:12,840
it fills half the angle and so on.

625
00:25:12,840 --> 00:25:14,550
So the weird thing about cosmology is that

626
00:25:14,550 --> 00:25:18,000
that doesn't hold because
the universe was growing

627
00:25:18,000 --> 00:25:19,710
while all of this was going on.

628
00:25:19,710 --> 00:25:22,500
That angular diameter
distance, it's called,

629
00:25:22,500 --> 00:25:25,800
it's one of many different
kinds of distances in astronomy,

630
00:25:25,800 --> 00:25:27,690
angular diameter distance,

631
00:25:27,690 --> 00:25:30,300
gets smaller as things get further away,

632
00:25:30,300 --> 00:25:32,640
but then it turns over and
actually gets bigger again.

633
00:25:32,640 --> 00:25:35,430
Things that are very distant
are actually bigger in the sky.

634
00:25:35,430 --> 00:25:37,260
You know, with DESI we
get to kind of chart out

635
00:25:37,260 --> 00:25:41,190
this angular size of a
ruler of a known size.

636
00:25:41,190 --> 00:25:43,410
- And have you personally
been one of the people

637
00:25:43,410 --> 00:25:45,270
who pokes tiny holes in aluminum

638
00:25:45,270 --> 00:25:47,400
and feeds fiber optic cables through them?

639
00:25:47,400 --> 00:25:50,692
Have you been there on the
site doing this kind of work?

640
00:25:50,692 --> 00:25:52,350
- So it's embarrassing.

641
00:25:52,350 --> 00:25:55,020
I'm like an expert on
some of these telescopes

642
00:25:55,020 --> 00:25:56,849
that I've never been to

643
00:25:56,849 --> 00:25:58,380
and the Sloan telescope is one of them.

644
00:25:58,380 --> 00:26:01,980
I've still not managed
to get to that site.

645
00:26:01,980 --> 00:26:04,440
So in these projects,
they're large projects,

646
00:26:04,440 --> 00:26:06,600
they have 100s of people
involved, usually,

647
00:26:06,600 --> 00:26:08,610
dozens of institutions.

648
00:26:08,610 --> 00:26:10,710
So we do complicated time tracking

649
00:26:10,710 --> 00:26:13,110
to keep track of like who
has actually contributed

650
00:26:13,110 --> 00:26:14,070
and I'm a, what am I?

651
00:26:14,070 --> 00:26:16,560
I'm an architect in the SDSS project

652
00:26:16,560 --> 00:26:18,630
but I still haven't managed
to go to the telescope.

653
00:26:18,630 --> 00:26:19,650
It looks nice.

654
00:26:19,650 --> 00:26:20,700
(Colin laughs)

655

00:26:20,700 --> 00:26:24,300
I have seen the machine shop
in the University of Washington

656
00:26:24,300 --> 00:26:25,458
where they drill the holes

657
00:26:25,458 --> 00:26:27,570
but that's not quite as glamorous.

658
00:26:27,570 --> 00:26:29,940
- You were telling us before
that a lot of your work

659
00:26:29,940 --> 00:26:32,070
was in this pre-analysis stage

660
00:26:32,070 --> 00:26:35,310
to decide where the
instrument should be pointed.

661
00:26:35,310 --> 00:26:36,993
What are you doing now that

662
00:26:36,993 --> 00:26:40,050
that pre-analysis, I guess, is finished?

663
00:26:40,050 --> 00:26:41,310
- It's funny being involved

664
00:26:41,310 --> 00:26:42,750
in these projects from the early part

665
00:26:42,750 --> 00:26:44,580
because our work was mostly done

666
00:26:44,580 --> 00:26:47,070
by the time the instrument
was on the mountain

667
00:26:47,070 --> 00:26:49,980
mounted on the telescope,
taking observations.

668
00:26:49,980 --> 00:26:52,290
Because we're trying to measure
these really subtle signals

669
00:26:52,290 --> 00:26:54,300
where there's like a 1% more galaxies

670
00:26:54,300 --> 00:26:57,030
at a certain radius than you'd expect.

671
00:26:57,030 --> 00:26:57,930
It's pretty important

672
00:26:57,930 --> 00:26:59,580
to understand not only
the ones you observe

673
00:26:59,580 --> 00:27:01,170
but the ones you don't observe.

674
00:27:01,170 --> 00:27:05,040
So we go to a lot of effort
to track all of the effects,

675
00:27:05,040 --> 00:27:07,530
all of the statistical
effects that can cause us

676
00:27:07,530 --> 00:27:11,460
to not observe a galaxy
or observe more galaxies

677
00:27:11,460 --> 00:27:14,070
on a certain part of sky than uniform.

678
00:27:14,070 --> 00:27:16,920
For that reason, to make the
bookkeeping easier, basically,

679
00:27:16,920 --> 00:27:19,770
these projects usually freeze the sample

680
00:27:19,770 --> 00:27:22,650
like we choose the set of
galaxies we want to observe

681
00:27:22,650 --> 00:27:25,980
at the start of the project
and then hold that fixed.

682
00:27:25,980 --> 00:27:29,010
Like just proceed with that
plan for the next five years

683
00:27:29,010 --> 00:27:30,390
in the case of DESI.

684
00:27:30,390 --> 00:27:33,120
Our work had to be done before
the main survey started.

685
00:27:33,120 --> 00:27:34,740
So one of the things I'm doing

686
00:27:34,740 --> 00:27:37,200
is figuring out what we
should do with DESI next.

687
00:27:37,200 --> 00:27:40,470
It was funded for a five-year
mission or five-year survey,

688
00:27:40,470 --> 00:27:42,450

but at the end of that time
it's still gonna be the,

689
00:27:42,450 --> 00:27:43,860
or at least one of the best instruments

690
00:27:43,860 --> 00:27:45,120
in the world for this work.

691
00:27:45,120 --> 00:27:48,810
So we're currently kind of
trying to devise some plans

692
00:27:48,810 --> 00:27:51,060
of what to do with it next,

693
00:27:51,060 --> 00:27:52,380
which is kind of a combination

694
00:27:52,380 --> 00:27:54,540
of an interesting science case

695
00:27:54,540 --> 00:27:58,830
and a feasible set of galaxies to observe.

696
00:27:58,830 --> 00:28:00,870
And part of that might involve going out

697
00:28:00,870 --> 00:28:02,520
and doing more imaging.

698
00:28:02,520 --> 00:28:03,720
- Are you confident that

699
00:28:03,720 --> 00:28:07,260
the mystery of dark energy can be solved

700
00:28:07,260 --> 00:28:09,870

or maybe will be solved
through some of these efforts

701
00:28:09,870 --> 00:28:12,030
and the ones that will follow?

702
00:28:12,030 --> 00:28:14,493
- That is a fascinating question.

703
00:28:15,840 --> 00:28:17,490
- I know it requires some optimism

704
00:28:17,490 --> 00:28:19,530
and you don't have all the information

705
00:28:19,530 --> 00:28:22,800
but there's a lot of
progress being made it seems.

706
00:28:22,800 --> 00:28:26,880
- Yeah, it's one of the
big mysteries in cosmology

707
00:28:26,880 --> 00:28:30,000
so we're putting in a fair
bit of effort toward it.

708
00:28:30,000 --> 00:28:32,460
The thing that is a challenge

709
00:28:32,460 --> 00:28:36,360
is that all of the current
observations point to it,

710
00:28:36,360 --> 00:28:37,950
are consistent with it being kind of

711
00:28:37,950 --> 00:28:39,570
the simplest explanation,

712
00:28:39,570 --> 00:28:43,020
which is kind of that
cosmological constant

713
00:28:43,020 --> 00:28:44,973
that Einstein's equations allow.

714
00:28:45,930 --> 00:28:48,240
So everything so far is consistent

715
00:28:48,240 --> 00:28:50,403
with kind of the most boring explanation,

716
00:28:51,450 --> 00:28:53,520
which is still like mind boggling

717
00:28:53,520 --> 00:28:56,190
and really difficult to understand

718
00:28:56,190 --> 00:28:59,700
or like to have a a real
like intuitive sense for.

719
00:28:59,700 --> 00:29:01,440
We don't really have
an explanation for it,

720
00:29:01,440 --> 00:29:02,880
it's just kind of like,

721
00:29:02,880 --> 00:29:05,520
it's just a fact of how space behaves.

722
00:29:05,520 --> 00:29:09,900
That there's this weird
fluid kind of thing

723

00:29:09,900 --> 00:29:13,500
that pushes space apart (laughs)

724
00:29:13,500 --> 00:29:15,930
and when you push space
apart you make more space

725
00:29:15,930 --> 00:29:17,430
and then there's more of that stuff in it

726
00:29:17,430 --> 00:29:19,080
that's pushing it apart more.

727
00:29:19,080 --> 00:29:20,760
It's pretty noodle-bending.

728
00:29:20,760 --> 00:29:22,101
- Yeah. I was gonna say.

729
00:29:22,101 --> 00:29:23,220
(both laugh)

730
00:29:23,220 --> 00:29:25,980
Yeah, I saw it described sort of like:

731
00:29:25,980 --> 00:29:28,140
if you had a balloon, just
a normal party balloon

732
00:29:28,140 --> 00:29:30,930
and you squeezed it, the analog would be

733
00:29:30,930 --> 00:29:34,113
the balloon would just
keep collapsing even after,

734
00:29:34,113 --> 00:29:35,550
it wouldn't resume it's original shape.

735
00:29:35,550 --> 00:29:37,970
But in this case, no matter
what you do to the universe,

736
00:29:37,970 --> 00:29:40,200
it seems to be accelerating
and getting bigger.

737
00:29:40,200 --> 00:29:42,930
- Yeah, I guess with
DESI it's possible for us

738
00:29:42,930 --> 00:29:45,300
to make this next
generation of measurements

739
00:29:45,300 --> 00:29:47,490
of like how big the universe is over time.

740
00:29:47,490 --> 00:29:50,820
So for some of us that is good enough

741
00:29:50,820 --> 00:29:52,650
the fact that it's there and we can do it.

742
00:29:52,650 --> 00:29:56,340
And those measurements
then kind of push theorists

743
00:29:56,340 --> 00:29:58,680
toward coming up with
different explanations

744
00:29:58,680 --> 00:30:00,810
or refining their explanations.

745
00:30:00,810 --> 00:30:03,510
A lot of cosmology ends up being
this kind of back and forth

746
00:30:03,510 --> 00:30:05,250
between theory and observation

747
00:30:05,250 --> 00:30:07,560
and computation and simulation.

748
00:30:07,560 --> 00:30:09,780
So basically this is just our next step

749
00:30:09,780 --> 00:30:12,240
on the observational side
is to make the measurements

750
00:30:12,240 --> 00:30:13,917
and see what the theorists can do with it.

751
00:30:13,917 --> 00:30:16,110
- And you mentioned
observational astronomy

752
00:30:16,110 --> 00:30:19,140
being more of your bread and
butter than radio astronomy,

753
00:30:19,140 --> 00:30:21,660
but you're also involved
in radio astronomy.

754
00:30:21,660 --> 00:30:24,090
And until you told us this couple days ago

755
00:30:24,090 --> 00:30:24,923
when we were chatting,

756
00:30:24,923 --> 00:30:26,700
I never really made the
distinction in my head

757
00:30:26,700 --> 00:30:29,430
that there's two different,
or at least two different,

758
00:30:29,430 --> 00:30:30,750
could you tell us sort of the difference

759
00:30:30,750 --> 00:30:32,130
and then maybe tell us how you work

760
00:30:32,130 --> 00:30:34,170
in radio astronomy as well?

761
00:30:34,170 --> 00:30:35,010
- Yeah, it's funny,

762
00:30:35,010 --> 00:30:39,060
astronomy is not that big
of a scientific field,

763
00:30:39,060 --> 00:30:41,550
but we're still split into these silos

764
00:30:41,550 --> 00:30:45,060
and part of it is just
basically technologies.

765
00:30:45,060 --> 00:30:47,400
The trick with observational astronomy

766
00:30:47,400 --> 00:30:49,380
is focusing and capturing the light

767
00:30:49,380 --> 00:30:51,510
and the tools you need to do that

768
00:30:51,510 --> 00:30:53,820
depend on the kind of light

you're trying to gather.

769
00:30:53,820 --> 00:30:56,670
So for optical astronomy, the
wavelengths are really short.

770
00:30:56,670 --> 00:30:59,250
So if you wanna make a mirror
that focuses that light,

771
00:30:59,250 --> 00:31:01,860
it has to be ground really precisely.

772
00:31:01,860 --> 00:31:04,500
It takes years to make
an astronomical mirror.

773
00:31:04,500 --> 00:31:06,720
And when new projects get funded,

774
00:31:06,720 --> 00:31:08,280
that's often the first thing they do

775
00:31:08,280 --> 00:31:10,290
is book a spot in the mirror lab

776
00:31:10,290 --> 00:31:12,000
to get their mirror built and polished

777
00:31:12,000 --> 00:31:13,440
because that will take as long

778
00:31:13,440 --> 00:31:15,210
as the rest of the project put together.

779
00:31:15,210 --> 00:31:18,510
- 'Cause even if there's a tiny
little defect in the mirror

780
00:31:18,510 --> 00:31:19,980
it could ruin everything right?

781
00:31:19,980 --> 00:31:23,160
- As long as the whole thing
is basically the right shape,

782
00:31:23,160 --> 00:31:26,370
you can get away with small
parts of it being imperfect.

783
00:31:26,370 --> 00:31:28,140
But if the whole thing is the wrong shape,

784
00:31:28,140 --> 00:31:30,360
then you're just in a world of hurt.

785
00:31:30,360 --> 00:31:32,640
So when Hubble was originally launched,

786
00:31:32,640 --> 00:31:35,760
it had this issue and that
just means that you want

787
00:31:35,760 --> 00:31:38,250
all of the light that
comes from a distant point

788
00:31:38,250 --> 00:31:39,600
to bounce off your mirror

789
00:31:39,600 --> 00:31:41,850
and hit the sensor at the same place.

790
00:31:41,850 --> 00:31:44,400
And if your mirror's the wrong
shape, that doesn't happen.

791

00:31:44,400 --> 00:31:46,020
If your mirror is too rough,

792
00:31:46,020 --> 00:31:48,120
then that also doesn't happen

793
00:31:48,120 --> 00:31:51,420
because the wave's hitting
different parts of the mirror

794
00:31:51,420 --> 00:31:53,070
instead of adding together,

795
00:31:53,070 --> 00:31:54,660
interfere with each other and subtract.

796
00:31:54,660 --> 00:31:56,220
So in optical astronomy

797
00:31:56,220 --> 00:31:58,530
the mirrors have to be just beautiful.

798
00:31:58,530 --> 00:32:01,740
In radio astronomy, the
wavelengths are really long.

799
00:32:01,740 --> 00:32:03,360
So in CHIME,

800
00:32:03,360 --> 00:32:05,490
this experiment that I'm involved with,

801
00:32:05,490 --> 00:32:08,970
the radio waves are like
40 centimeters long.

802
00:32:08,970 --> 00:32:10,800
So if you wanna make something

803
00:32:10,800 --> 00:32:13,710
that looks like smooth to a radio wave

804
00:32:13,710 --> 00:32:14,850
that's 40 centimeters long,

805
00:32:14,850 --> 00:32:16,935
it doesn't have to be very smooth.

806
00:32:16,935 --> 00:32:17,768
You know, it has to be

807
00:32:17,768 --> 00:32:19,290
like within millimeters kind of smooth.

808
00:32:19,290 --> 00:32:20,640
So radio telescopes,

809
00:32:20,640 --> 00:32:23,580
the mirrors or reflectors
tend to be really cheap

810
00:32:23,580 --> 00:32:25,080
compared to everything else.

811
00:32:25,080 --> 00:32:27,570
In CHIME they're made
outta a kinda metal mesh.

812
00:32:27,570 --> 00:32:28,920
But then the challenge

813
00:32:28,920 --> 00:32:31,200
is collecting that
light and processing it.

814
00:32:31,200 --> 00:32:33,930
So radio astronomy's

often kinda thought of

815
00:32:33,930 --> 00:32:36,393
as chicken wire and supercomputers.

816
00:32:37,320 --> 00:32:38,670
- I love it.

817
00:32:38,670 --> 00:32:39,503
- I do too.

818
00:32:40,530 --> 00:32:42,810
- So I love how you say
that radio astronomy

819
00:32:42,810 --> 00:32:45,600
is basically chicken
wire and supercomputers.

820
00:32:45,600 --> 00:32:48,180
What really is the role
of the chicken wire?

821
00:32:48,180 --> 00:32:50,160
- The chicken wire is the mirror

822
00:32:50,160 --> 00:32:51,840
or the equivalent of the mirror.

823
00:32:51,840 --> 00:32:54,270
I'm kind of by training
an optical astronomer

824
00:32:54,270 --> 00:32:57,990
so it's really bizarre to be
working in radio astronomy

825
00:32:57,990 --> 00:33:01,170
where the light acts so differently

than what we're used to.

826
00:33:01,170 --> 00:33:03,810
But as far as a radio wave is concerned,

827
00:33:03,810 --> 00:33:07,740
a parabolic-shaped mesh of
wire looks like a mirror

828
00:33:07,740 --> 00:33:09,150
and it can focus it

829
00:33:09,150 --> 00:33:11,610
so it bounces right off the chicken wire.

830
00:33:11,610 --> 00:33:14,520
And if your chicken wire's
shaped in just the right way,

831
00:33:14,520 --> 00:33:17,790
it can focus it onto a place like onto,

832
00:33:17,790 --> 00:33:19,530
in the case of CHIME, onto the antennas.

833
00:33:19,530 --> 00:33:22,320
So the half-pipe shape is a parabola,

834
00:33:22,320 --> 00:33:24,090
so it focuses all of the light

835
00:33:24,090 --> 00:33:25,650
coming from one point on the sky

836
00:33:25,650 --> 00:33:28,410
to a point onto the antenna.

837
00:33:28,410 --> 00:33:30,990

- You mentioned CHIME, we
should explain a little bit.

838
00:33:30,990 --> 00:33:33,240
It's not like any
telescope I've seen before

839
00:33:33,240 --> 00:33:34,710
and when I first saw it,

840
00:33:34,710 --> 00:33:36,270
I don't know if I would've
guessed telescope,

841
00:33:36,270 --> 00:33:38,280
I might have guessed skateboard park.

842
00:33:38,280 --> 00:33:39,987
So can you tell us what CHIME is

843
00:33:39,987 --> 00:33:41,920
and why it's like the it is?

844
00:33:41,920 --> 00:33:43,770
- Yeah, CHIME is wonderful.

845
00:33:43,770 --> 00:33:47,640
CHIME is the Canadian Hydrogen
Intensity Mapping Experiment.

846
00:33:47,640 --> 00:33:49,713
You can see why you just use the acronym?

847
00:33:50,610 --> 00:33:52,890
And it's a radio telescope

848
00:33:52,890 --> 00:33:56,310
at the Dominion Radio
Astrophysical Observatory

849
00:33:56,310 --> 00:33:58,170
near Penticton, British Columbia.

850
00:33:58,170 --> 00:34:01,470
So it's a really unusual telescope design.

851
00:34:01,470 --> 00:34:04,200
It doesn't focus light in two dimensions,

852
00:34:04,200 --> 00:34:06,540
it only focuses light in one dimension.

853
00:34:06,540 --> 00:34:10,020
So it's made out of these parabola-shaped,

854
00:34:10,020 --> 00:34:12,210
like half-pipe-shaped tubes.

855
00:34:12,210 --> 00:34:16,950
So it focuses light in the
direction across the tube

856
00:34:16,950 --> 00:34:18,960
but not the direction along the tube.

857
00:34:18,960 --> 00:34:23,960
So if you have light coming
from a distant galaxy, say,

858
00:34:24,060 --> 00:34:28,500
it hits the reflector and
it's focused onto a line

859
00:34:28,500 --> 00:34:30,360
along the middle of that half-pipe

860
00:34:30,360 --> 00:34:33,510

and then CHIME has a bunch
of antennas along that line

861
00:34:33,510 --> 00:34:35,910
that gather all the light
and then it goes into

862
00:34:35,910 --> 00:34:38,010
our handy supercomputer.

863
00:34:38,010 --> 00:34:39,347
- Behind the chicken wire?

864
00:34:39,347 --> 00:34:41,956
(both laugh)

865
00:34:41,956 --> 00:34:43,720
- That's a-
- That's a different part?

866
00:34:43,720 --> 00:34:44,580
- That's a different challenge, so...

867
00:34:44,580 --> 00:34:46,057
- Yeah, we'll get to that.

868
00:34:46,057 --> 00:34:46,890
- Yep.

869
00:34:46,890 --> 00:34:48,000
And so the cool thing about that

870
00:34:48,000 --> 00:34:52,500
is that you can focus
in that other dimension

871
00:34:52,500 --> 00:34:55,890
after the fact in the supercomputer.

872
00:34:55,890 --> 00:34:57,540
So if you think about a star

873
00:34:57,540 --> 00:34:59,610
that's to the north of the telescope,

874
00:34:59,610 --> 00:35:02,700
it will hit the northern
part of the half-pipe

875
00:35:02,700 --> 00:35:04,440
sooner than the southern part

876
00:35:04,440 --> 00:35:06,270
and all those waves will bounce up

877
00:35:06,270 --> 00:35:08,790
to the antennas along that line.

878
00:35:08,790 --> 00:35:13,140
In the supercomputer, then take
the northernmost telescope,

879
00:35:13,140 --> 00:35:14,910
sorry, northernmost antenna

880
00:35:14,910 --> 00:35:16,680
and then take that value,

881
00:35:16,680 --> 00:35:18,690
the antenna just to the south of it,

882
00:35:18,690 --> 00:35:21,027
and delay it a little
bit and add them together

883
00:35:21,027 --> 00:35:22,740
and take the one just to the south of that

884
00:35:22,740 --> 00:35:24,390
and delay it a little bit more.

885
00:35:24,390 --> 00:35:26,040
You can add together the waves

886
00:35:26,040 --> 00:35:28,620
that hit the telescope at different times

887
00:35:28,620 --> 00:35:31,440
and that basically like acts

888
00:35:31,440 --> 00:35:34,080
as though you tilted the
telescope by that amount

889
00:35:34,080 --> 00:35:36,966
so that they would hit at the same time.

890
00:35:36,966 --> 00:35:39,600
- 'Cause the telescope itself,
it doesn't have moving parts.

891
00:35:39,600 --> 00:35:42,120
- Yeah, the telescope is huge.

892
00:35:42,120 --> 00:35:43,680
It's 20 meters wide.

893
00:35:43,680 --> 00:35:46,470
And sorry, each half-pipe
is 20 meters wide.

894
00:35:46,470 --> 00:35:48,690
There are four of them
and it's 100 meters long

895

00:35:48,690 --> 00:35:50,790
and it's heavy and huge.

896
00:35:50,790 --> 00:35:52,830
Yeah, so it has no moving parts.

897
00:35:52,830 --> 00:35:54,780
We can't steer it in any direction.

898
00:35:54,780 --> 00:35:57,900
It basically just sees a strip of the sky

899
00:35:57,900 --> 00:35:59,820
and then the Earth conveniently rotates.

900
00:35:59,820 --> 00:36:02,370
So we get to see basically half of the sky

901
00:36:02,370 --> 00:36:04,470
or two-thirds of the sky every day.

902
00:36:04,470 --> 00:36:05,520
- That's handy.

903
00:36:05,520 --> 00:36:06,990
Nice of the Earth to do that for you.

904
00:36:06,990 --> 00:36:09,030
- It's pretty kind.
- Yeah.

905
00:36:09,030 --> 00:36:10,500
- But the cool thing
then is that you know,

906
00:36:10,500 --> 00:36:13,230
we can by more or less delaying the signal

907

00:36:13,230 --> 00:36:15,270
from the different antennas
and adding them together,

908
00:36:15,270 --> 00:36:18,360
it acts like a telescope is
pointed in a certain direction

909
00:36:18,360 --> 00:36:20,880
but then if you just delay
it by a different amount,

910
00:36:20,880 --> 00:36:23,040
you can point it in another direction.

911
00:36:23,040 --> 00:36:24,510
- And this is all done by software?

912
00:36:24,510 --> 00:36:25,343
- Yeah, that's right.

913
00:36:25,343 --> 00:36:27,090
It's all done in software and
you can do it all at this,

914
00:36:27,090 --> 00:36:28,950
you can point it in
all of those directions

915
00:36:28,950 --> 00:36:29,910
at the same time.

916
00:36:29,910 --> 00:36:31,770
And then with the four half-pipes

917
00:36:31,770 --> 00:36:34,260
you can combine those in different ways

918
00:36:34,260 --> 00:36:36,720

and point it in-software in the other,

919
00:36:36,720 --> 00:36:38,640
in the east-west direction as well.

920
00:36:38,640 --> 00:36:41,010
- And this is not dark energy search,

921
00:36:41,010 --> 00:36:43,740
this is a different or is it related?

922
00:36:43,740 --> 00:36:44,910
- It is related.

923
00:36:44,910 --> 00:36:46,740
So the CHIME telescope was built

924
00:36:46,740 --> 00:36:50,100
for doing this thing called
hydrogen intensity mapping,

925
00:36:50,100 --> 00:36:51,573
the HIM part of CHIME,

926
00:36:52,740 --> 00:36:57,740
And the idea there is that
as you go further away

927
00:36:57,960 --> 00:37:01,740
or farther back in cosmic
time or to higher redshift,

928
00:37:01,740 --> 00:37:03,510
it gets harder and harder
to observe galaxies

929
00:37:03,510 --> 00:37:04,380
'cause they're just faint.

930
00:37:04,380 --> 00:37:06,390
So doing this trick that we do in DESI

931
00:37:06,390 --> 00:37:08,430
of trying to measure galaxies

932
00:37:08,430 --> 00:37:12,080
and then measure the slightly
more likely to observe one

933
00:37:12,080 --> 00:37:14,310
at that magical distance away,

934
00:37:14,310 --> 00:37:15,660
that trick just gets really hard

935
00:37:15,660 --> 00:37:17,160
'cause the galaxies are faint.

936
00:37:17,160 --> 00:37:19,350
And the thing that's kind
of frustrating about it

937
00:37:19,350 --> 00:37:21,330
is that you're gonna
measure a bunch of them,

938
00:37:21,330 --> 00:37:22,710
but you know that they cluster

939
00:37:22,710 --> 00:37:25,380
and like you have to measure
a whole bunch of them

940
00:37:25,380 --> 00:37:28,170
to kind of map out this cosmic web.

941
00:37:28,170 --> 00:37:30,180

So the idea with hydrogen
intensity mapping

942
00:37:30,180 --> 00:37:32,970
is let's not measure individual galaxies,

943
00:37:32,970 --> 00:37:35,910
let's just measure all of
the hydrogen collectively.

944
00:37:35,910 --> 00:37:38,670
And that hydrogen is
around all the galaxies

945
00:37:38,670 --> 00:37:41,490
and along the cosmic web
and filaments and everything

946
00:37:41,490 --> 00:37:45,000
so that to understand the growth
of the universe over time.

947
00:37:45,000 --> 00:37:47,850
So CHIME was built to do that experiment

948
00:37:47,850 --> 00:37:51,270
and they're trying to
map range of redshifts

949
00:37:51,270 --> 00:37:53,250
that slightly overlap DESI,

950
00:37:53,250 --> 00:37:55,920
but go further than we can
really go with galaxies.

951
00:37:55,920 --> 00:37:58,110
So it's looking back
closer toward the Big Bang

952
00:37:58,110 --> 00:37:59,460
with this totally different technique

953
00:37:59,460 --> 00:38:03,000
of mapping hydrogen
which emits in the radio

954
00:38:03,000 --> 00:38:04,830
and then gets stretched out.

955
00:38:04,830 --> 00:38:07,800
So I'm not actually
involved in that side of it,

956
00:38:07,800 --> 00:38:10,803
the cosmology side, the
hydrogen intensity mapping side.

957
00:38:11,640 --> 00:38:13,290
And this is another kind of cool thing

958
00:38:13,290 --> 00:38:14,850
about radio telescopes.

959
00:38:14,850 --> 00:38:16,950
While CHIME was being kind of proposed

960
00:38:16,950 --> 00:38:18,570
and built and designed,

961
00:38:18,570 --> 00:38:21,870
people realized that it would
also be really well-suited

962
00:38:21,870 --> 00:38:25,110
to uncovering another
astrophysical mystery.

963

00:38:25,110 --> 00:38:27,093
The mystery of fast radio bursts.

964
00:38:27,960 --> 00:38:30,510
So fast radio bursts

965
00:38:30,510 --> 00:38:35,079
were first discovered in 2007.

966
00:38:35,079 --> 00:38:36,720
(both laugh)

967
00:38:36,720 --> 00:38:39,270
- That's recent, that's
not that long ago in-

968
00:38:39,270 --> 00:38:40,590
- Yep, exactly.

969
00:38:40,590 --> 00:38:43,620
And they were discovered
in archival observations

970
00:38:43,620 --> 00:38:44,700
or rather the first one

971
00:38:44,700 --> 00:38:47,250
was discovered in archival observations

972
00:38:47,250 --> 00:38:49,650
and what fast radio bursts are

973
00:38:49,650 --> 00:38:52,110
or what we observe are these really brief,

974
00:38:52,110 --> 00:38:55,590
they're like a millisecond
long, burst of radio light.

975
00:38:55,590 --> 00:38:57,960
That's the (laughs) quick, they're fast,

976
00:38:57,960 --> 00:38:59,370
they're in the radio, they're bursts.

977
00:38:59,370 --> 00:39:01,140
- Oh, it's a good name for them. Yeah.

978
00:39:01,140 --> 00:39:03,330
- Yep, and in the time

979
00:39:03,330 --> 00:39:06,597
between the first one discovered in 2007

980
00:39:06,597 --> 00:39:09,270
and when CHIME was being constructed,

981
00:39:09,270 --> 00:39:11,280
a few more had been discovered.

982
00:39:11,280 --> 00:39:13,950
So they were getting to
be not a one-off event

983
00:39:13,950 --> 00:39:16,740
but something that kinda
existed in the universe

984
00:39:16,740 --> 00:39:20,250
that we could possibly go out
and try to measure a bunch of.

985
00:39:20,250 --> 00:39:22,170
So the fact that CHIME can see

986
00:39:22,170 --> 00:39:24,690
a huge chunk of the sky at once

987
00:39:24,690 --> 00:39:27,600
and observes the whole sky once a day

988
00:39:27,600 --> 00:39:29,190
thanks to the Earth rotating

989
00:39:29,190 --> 00:39:30,480
makes it a really good instrument

990
00:39:30,480 --> 00:39:33,270
for searching over the whole sky

991
00:39:33,270 --> 00:39:34,290
for something that you don't know

992
00:39:34,290 --> 00:39:35,520
where it's gonna come from.

993
00:39:35,520 --> 00:39:38,100
So funding was secured

994
00:39:38,100 --> 00:39:40,860
to build an addition to
the CHIME's telescope,

995
00:39:40,860 --> 00:39:44,730
which was just a fast radio
burst search part of CHIME.

996
00:39:44,730 --> 00:39:46,860
So it's called CHIME/FRB.

997
00:39:46,860 --> 00:39:49,320
So remember how I said in software

998
00:39:49,320 --> 00:39:52,980
you can focus the telescope

at different directions.

999
00:39:52,980 --> 00:39:56,040
Basically we ask that supercomputer

1000
00:39:56,040 --> 00:39:58,680
to do some different computations

1001
00:39:58,680 --> 00:40:02,670
and send the data to the CHIME/FRB system,

1002
00:40:02,670 --> 00:40:04,920
which is itself another
little supercomputer

1003
00:40:04,920 --> 00:40:07,650
that does this real-time
search for fast radio bursts.

1004
00:40:07,650 --> 00:40:09,180
So all over the sky.

1005
00:40:09,180 --> 00:40:12,600
- When you say a real-time
search all over the sky,

1006
00:40:12,600 --> 00:40:15,720
is this where the big data comes in?

1007
00:40:15,720 --> 00:40:17,400
Lots and lots of data?

1008
00:40:17,400 --> 00:40:18,233
- Yeah, that's right.

1009
00:40:18,233 --> 00:40:20,910
So the CHIME correlator, that's the,

1010

00:40:20,910 --> 00:40:24,840
well one of the supercomputers
involved in this whole thing,

1011
00:40:24,840 --> 00:40:28,380
focuses the light in 1,000
spots in the sky for us

1012
00:40:28,380 --> 00:40:31,890
and breaks it into 16,000
frequency channels.

1013
00:40:31,890 --> 00:40:33,420
So you know when you're tuning the radio

1014
00:40:33,420 --> 00:40:36,180
and you can choose different FM stations,

1015
00:40:36,180 --> 00:40:39,510
we have 16,000 stations to choose from.

1016
00:40:39,510 --> 00:40:40,770
Some of them are just full

1017
00:40:40,770 --> 00:40:43,747
of people's cell phone LTE traffic.

1018
00:40:43,747 --> 00:40:46,020
(both laugh)

1019
00:40:46,020 --> 00:40:48,330
Thankfully we can just ignore those ones.

1020
00:40:48,330 --> 00:40:50,160
Everyone has a radio station
they don't like, right?

1021
00:40:50,160 --> 00:40:52,170
- Yeah. Just tune them out.

1022
00:40:52,170 --> 00:40:53,490
- Yep. Just skip those ones.

1023
00:40:53,490 --> 00:40:57,000
- But how many of them are
taken up by the cell phone?

1024
00:40:57,000 --> 00:40:57,843
- More and more.

1025
00:40:58,731 --> 00:41:00,615
- It's a noisy world with
all the communication?

1026
00:41:00,615 --> 00:41:03,270
- It is a noisy world. Yeah, that's right.

1027
00:41:03,270 --> 00:41:05,910
We lose 10 or 20%.

1028
00:41:05,910 --> 00:41:07,334
It's pretty bad.

1029
00:41:07,334 --> 00:41:09,540
- But it's kind of a consistent range?

1030
00:41:09,540 --> 00:41:10,410
- For the most part.

1031
00:41:10,410 --> 00:41:14,460
The 4G LTE bands are just lost
to us entirely. (chuckles)

1032
00:41:14,460 --> 00:41:15,960
And then there's some other ones

1033
00:41:15,960 --> 00:41:17,550

that come on and off periodically

1034
00:41:17,550 --> 00:41:19,140
that we have to filter out.

1035
00:41:19,140 --> 00:41:21,223
So anyway, the correlator sends us

1036
00:41:21,223 --> 00:41:24,960
1,000 places on the sky, 16,000 channels,

1037
00:41:24,960 --> 00:41:28,533
and the brightness in each
channel one time per millisecond.

1038
00:41:29,815 --> 00:41:30,711
- Okay.

1039
00:41:30,711 --> 00:41:32,127
- So that's 1,000 times 1,000

1040
00:41:32,127 --> 00:41:33,930
times 16,000 per second.

1041
00:41:33,930 --> 00:41:36,783
And that is basically
just too fast for us.

1042
00:41:36,783 --> 00:41:39,060
It's too much data for
us to write to disc.

1043
00:41:39,060 --> 00:41:44,040
So those signals get sent
to this set of 128 computers

1044
00:41:44,040 --> 00:41:46,440
that are searching through
the data in real-time

1045
00:41:46,440 --> 00:41:49,890
looking for the signature
of a fast radio burst.

1046
00:41:49,890 --> 00:41:51,390
So I said that they're a burst,

1047
00:41:51,390 --> 00:41:53,820
but they're a burst at their origin

1048
00:41:53,820 --> 00:41:54,840
but then they have to travel

1049
00:41:54,840 --> 00:41:56,730
through a bunch of space to get to us

1050
00:41:56,730 --> 00:41:58,350
and space isn't quite empty.

1051
00:41:58,350 --> 00:42:02,430
So when those radio waves
interact with electrons,

1052
00:42:02,430 --> 00:42:06,570
what happens is the high
frequencies arrive first

1053
00:42:06,570 --> 00:42:08,280
and the lower frequencies arrive later.

1054
00:42:08,280 --> 00:42:09,330
It's called dispersion.

1055
00:42:09,330 --> 00:42:13,140
So what we observe is that
there's kind of a sweep down

1056

00:42:13,140 --> 00:42:15,300
from high frequency to low frequency

1057
00:42:15,300 --> 00:42:18,750
that can be tens of seconds
long or like a minute long.

1058
00:42:18,750 --> 00:42:22,740
So this real-time search has
to store like a minute of data

1059
00:42:22,740 --> 00:42:27,090
and look for kind of all the
possible different sweeps down

1060
00:42:27,090 --> 00:42:29,190
depending on how many electrons

1061
00:42:29,190 --> 00:42:30,690
were between us and the source

1062
00:42:30,690 --> 00:42:33,240
that determines the shape of that sweep.

1063
00:42:33,240 --> 00:42:35,550
So it's searching for all
these different sweeps

1064
00:42:35,550 --> 00:42:37,530
corresponding to kind
of different distances

1065
00:42:37,530 --> 00:42:39,990
of the fast radio burst being away from us

1066
00:42:39,990 --> 00:42:43,800
for these 1,000 places on
the sky simultaneously.

1067

00:42:43,800 --> 00:42:44,633
And then basically,

1068
00:42:44,633 --> 00:42:46,710
if we find something
that looks interesting

1069
00:42:46,710 --> 00:42:50,280
we write down just the data
around that place on the sky

1070
00:42:50,280 --> 00:42:54,330
and that little chunk of
time for later analysis.

1071
00:42:54,330 --> 00:42:57,300
- So in those cases you'll save
everything that's coming in,

1072
00:42:57,300 --> 00:42:58,500
but most of the time

1073
00:42:58,500 --> 00:43:00,780
you'll just get rid of most of the data?

1074
00:43:00,780 --> 00:43:01,613
- Yeah, that's right.

1075
00:43:01,613 --> 00:43:04,020
So we'll save everything that comes

1076
00:43:04,020 --> 00:43:06,210
to the CHIME fast radio burst side

1077
00:43:06,210 --> 00:43:07,830
that's been reduced a lot already

1078
00:43:07,830 --> 00:43:10,031
from the raw data rate collected

1079
00:43:10,031 --> 00:43:13,500
by the first supercomputer in the chain

1080
00:43:13,500 --> 00:43:14,940
for things that are really bright.

1081
00:43:14,940 --> 00:43:17,070
We'll also ask that one,

1082
00:43:17,070 --> 00:43:19,740
it also saves a little chunk of past data

1083
00:43:19,740 --> 00:43:22,470
and we can ask it to also
save a little chunk of data

1084
00:43:22,470 --> 00:43:23,940
around the sweep.

1085
00:43:23,940 --> 00:43:27,360
That one collects 800
gigabytes of data per second.

1086
00:43:27,360 --> 00:43:29,670
So we only ask it for a 10th of a second

1087
00:43:29,670 --> 00:43:31,500
around where the sweep was.

1088
00:43:31,500 --> 00:43:35,100
- Wow. Sorry, how much
per how little time?

1089
00:43:35,100 --> 00:43:36,543
I'm trying to wrap my head around this.

1090
00:43:36,543 --> 00:43:39,210

Like in the sense of data,
the way we understand it,

1091
00:43:39,210 --> 00:43:41,790
this is enormous right?
- Yeah that's right.

1092
00:43:41,790 --> 00:43:43,200
800 gigabytes a second.

1093
00:43:43,200 --> 00:43:46,920
So if you go out and buy the
biggest hard drive you can,

1094
00:43:46,920 --> 00:43:49,710
these days, say 12 terabytes,

1095
00:43:49,710 --> 00:43:53,550
that fills up in like 15 seconds.

1096
00:43:53,550 --> 00:43:57,420
- And this is the data to
CHIME or just CHIME/FRB.

1097
00:43:57,420 --> 00:43:59,520
- That's the data to CHIME. Yeah.

1098
00:43:59,520 --> 00:44:02,550
So that's reading all of the voltages

1099
00:44:02,550 --> 00:44:05,670
from all of the antennas
along the half-pipe of CHIME

1100
00:44:05,670 --> 00:44:07,950
that then can get added
together in different ways

1101
00:44:07,950 --> 00:44:11,533

to point the telescope in
different directions on the sky.

1102
00:44:11,533 --> 00:44:13,740
- You told us the other
day when we were chatting

1103
00:44:13,740 --> 00:44:18,390
that just the sheer volume
of data is equivalent to,

1104
00:44:18,390 --> 00:44:21,270
or it's a portion of
the entire data exchange

1105
00:44:21,270 --> 00:44:23,340
on our cell phone
networks in North America.

1106
00:44:23,340 --> 00:44:24,450
- So yeah, I looked it up.

1107
00:44:24,450 --> 00:44:26,880
It's a moving target but if you look

1108
00:44:26,880 --> 00:44:30,603
at the international data
transfers on the internet,

1109
00:44:31,740 --> 00:44:34,953
inside the CHIME supercomputer,
it's doing 1% of that.

1110
00:44:35,850 --> 00:44:39,390
So 1% of the world internet traffic

1111
00:44:39,390 --> 00:44:42,270
is being exchanged within
that CHIME correlator

1112
00:44:42,270 --> 00:44:45,210
to do those additions of like
the pointing the telescope

1113
00:44:45,210 --> 00:44:46,167
at different points on the sky.

1114
00:44:46,167 --> 00:44:48,120
- And it's doing that over and over again.

1115
00:44:48,120 --> 00:44:49,320
- Just continuously.

1116
00:44:49,320 --> 00:44:50,153
- It's amazing.
- Whoa.

1117
00:44:50,153 --> 00:44:52,890
- Yeah, during the day
radio telescopes don't care.

1118
00:44:52,890 --> 00:44:53,820
We can see the sun

1119
00:44:53,820 --> 00:44:55,380
but it's not the brightest
thing in the sky.

1120
00:44:55,380 --> 00:44:57,030
Rain is a little bit of a downer.

1121
00:44:57,030 --> 00:45:00,480
- And you mentioned airplanes
are a bit of a pain as well.

1122
00:45:00,480 --> 00:45:02,850
- Airplanes are terrible.

1123

00:45:02,850 --> 00:45:04,800
It's not so much the signals

1124
00:45:04,800 --> 00:45:06,510
that the airplanes themselves are emitting

1125
00:45:06,510 --> 00:45:08,100
as far as the radio waves are concerned,

1126
00:45:08,100 --> 00:45:09,900
they're a mirror in the sky so we can

1127
00:45:09,900 --> 00:45:13,650
like see over the horizon
down to the noisy cities

1128
00:45:13,650 --> 00:45:16,170
and cell phones and other things around.

1129
00:45:16,170 --> 00:45:17,760
The CHIME telescope's not that far

1130
00:45:17,760 --> 00:45:19,140
from the Kelowna Airport.

1131
00:45:19,140 --> 00:45:23,820
So we see many, many airplanes
and have to filter them out.

1132
00:45:23,820 --> 00:45:26,550
- The Milky Way's in our
way, waters in our way.

1133
00:45:26,550 --> 00:45:27,383
All these things

1134
00:45:27,383 --> 00:45:29,854
we take for granted.
- Noisy world out there. Yeah.

1135
00:45:29,854 --> 00:45:32,760
- And where do you
actually process this data?

1136
00:45:32,760 --> 00:45:34,290
- So for CHIME it's almost all on-site

1137
00:45:34,290 --> 00:45:35,430
just because the data rates

1138
00:45:35,430 --> 00:45:36,810
are too big to move anything off,

1139
00:45:36,810 --> 00:45:40,080
it would be way too much
traffic to try to compute,

1140
00:45:40,080 --> 00:45:41,970
like to move it somewhere
else and compute there.

1141
00:45:41,970 --> 00:45:45,180
So all the computing is
done on-site basically.

1142
00:45:45,180 --> 00:45:46,620
- When you say on-site,

1143
00:45:46,620 --> 00:45:49,590
my first thought maybe would
be this huge bank of computers

1144
00:45:49,590 --> 00:45:51,180
in a sophisticated room with monitors,

1145
00:45:51,180 --> 00:45:54,360
but there's steel shipping
containers on site, right?

1146
00:45:54,360 --> 00:45:56,640
- Yep. Steel shipping containers.

1147
00:45:56,640 --> 00:45:59,820
Good old 40' shipping cans or sea cans

1148
00:45:59,820 --> 00:46:03,120
are kind of the building of
choice to stick these things in.

1149
00:46:03,120 --> 00:46:05,820
They're cheap enough to get and robust.

1150
00:46:05,820 --> 00:46:07,080
So yeah, one of the challenges

1151
00:46:07,080 --> 00:46:08,910
is that a big computer cluster

1152
00:46:08,910 --> 00:46:10,830
is itself really noisy in the radio.

1153
00:46:10,830 --> 00:46:13,980
It emits a lot of, it just
makes a lot of electrical noise.

1154
00:46:13,980 --> 00:46:16,520
So inside of the steel shipping container

1155
00:46:16,520 --> 00:46:18,930
we also have to build like a shielded room

1156
00:46:18,930 --> 00:46:20,580
that the computers can go in

1157
00:46:20,580 --> 00:46:22,440
so that they don't make a bunch of noise

1158
00:46:22,440 --> 00:46:24,150
that we then hear with the telescope.

1159
00:46:24,150 --> 00:46:25,830
- So there's natural challenges

1160
00:46:25,830 --> 00:46:27,420
and challenge that we create ourselves

1161
00:46:27,420 --> 00:46:29,310
with our technology that
we have to get around.

1162
00:46:29,310 --> 00:46:30,147
- Yeah, that's right.

1163
00:46:30,147 --> 00:46:31,260
And the kind of fun thing

1164
00:46:31,260 --> 00:46:34,140
is that because the radio
waves are pretty long,

1165
00:46:34,140 --> 00:46:36,420
if you drill a small hole
in the shipping container,

1166
00:46:36,420 --> 00:46:37,800
the radio waves can't get through it.

1167
00:46:37,800 --> 00:46:40,740
So the shipping containers
have all of these, you know,

1168
00:46:40,740 --> 00:46:45,630
basically small holes where
all of the cables and power

1169
00:46:45,630 --> 00:46:48,210
and cooling and everything come
into the shipping container

1170
00:46:48,210 --> 00:46:50,460
and into the supercomputers inside.

1171
00:46:50,460 --> 00:46:52,050
- I'm wondering if you can also speak

1172
00:46:52,050 --> 00:46:53,880
maybe a little bit more broadly

1173
00:46:53,880 --> 00:46:56,160
to a challenge that you might face

1174
00:46:56,160 --> 00:46:59,430
when collecting all of
this data in an experiment

1175
00:46:59,430 --> 00:47:01,260
and then having to figure
out how to store it.

1176
00:47:01,260 --> 00:47:05,040
And maybe we can play the
question from Dominica.

1177
00:47:05,040 --> 00:47:06,330
- My name is Dominica,

1178
00:47:06,330 --> 00:47:08,490
I'm a student at the
Yachay Tech University

1179
00:47:08,490 --> 00:47:11,010
and the PSI Start Program.

1180

00:47:11,010 --> 00:47:14,220
I was wondering if, is
it a fundamental issue,

1181
00:47:14,220 --> 00:47:17,490
the fact that computations
depend on the discrete

1182
00:47:17,490 --> 00:47:20,073
whereas the physical laws
depend on the continuum?

1183
00:47:21,180 --> 00:47:22,860
- Yeah, that's a deep question.

1184
00:47:22,860 --> 00:47:26,430
The physical world is
continuous as far as we observe.

1185
00:47:26,430 --> 00:47:28,500
Quantum theorists might argue about that,

1186
00:47:28,500 --> 00:47:31,020
but at our scales it's continuous.

1187
00:47:31,020 --> 00:47:32,250
But we have to do all this.

1188
00:47:32,250 --> 00:47:34,770
Our current computing is all discrete.

1189
00:47:34,770 --> 00:47:37,350
So in CHIME the antennas

1190
00:47:37,350 --> 00:47:39,630
are really measuring
this continuous signal.

1191
00:47:39,630 --> 00:47:41,160

But those come through cables

1192
00:47:41,160 --> 00:47:44,040
into the first supercomputer in CHIME

1193
00:47:44,040 --> 00:47:45,540
and basically the first thing we do

1194
00:47:45,540 --> 00:47:47,910
is turn them into digital signals.

1195
00:47:47,910 --> 00:47:51,060
So there's a resolution
problem there basically

1196
00:47:51,060 --> 00:47:54,060
where you have to choose how many bits

1197
00:47:54,060 --> 00:47:55,650
to use to represent it.

1198
00:47:55,650 --> 00:47:59,030
So if you look at your
computer display, you know,

1199
00:47:59,030 --> 00:48:01,290
it sort of looks like it
can make all of the colors

1200
00:48:01,290 --> 00:48:02,940
that you can observe, right?

1201
00:48:02,940 --> 00:48:07,350
But modern computer
displays use eight bits

1202
00:48:07,350 --> 00:48:09,030
for each of red, green, and blue.

1203
00:48:09,030 --> 00:48:11,850
So they can make 256 different levels

1204
00:48:11,850 --> 00:48:13,140
of red, green, and blue.

1205
00:48:13,140 --> 00:48:14,040
And that's enough that we

1206
00:48:14,040 --> 00:48:16,230
kind of can't distinguish between them.

1207
00:48:16,230 --> 00:48:17,820
So as far as like, you know,

1208
00:48:17,820 --> 00:48:20,670
we can observe with our eyes or our brains

1209
00:48:20,670 --> 00:48:22,860
that's fine enough that a discrete set

1210
00:48:22,860 --> 00:48:25,470
of levels looks continuous to us.

1211
00:48:25,470 --> 00:48:28,680
And it's kind of, it's a little
bit similar in the radio.

1212
00:48:28,680 --> 00:48:31,740
It turns out that partly because
while the world is so noisy

1213
00:48:31,740 --> 00:48:33,840
and in radio you have to add together

1214
00:48:33,840 --> 00:48:35,970
a lot of individual samples

1215
00:48:35,970 --> 00:48:38,460
before you actually measure
something significant,

1216
00:48:38,460 --> 00:48:41,580
it turns out that it's okay
to do that discretization

1217
00:48:41,580 --> 00:48:44,100
or conversion from analog to digital.

1218
00:48:44,100 --> 00:48:46,380
In CHIME actually they only use four bits.

1219
00:48:46,380 --> 00:48:49,950
So there's only 16 levels of the signal

1220
00:48:49,950 --> 00:48:52,020
and that's still enough to kinda recover

1221
00:48:52,020 --> 00:48:54,870
the continuous phenomena
that are observed.

1222
00:48:54,870 --> 00:48:58,830
- CHIME has been extremely
successful in this FRB mission.

1223
00:48:58,830 --> 00:49:01,530
The fast radio bursts, they're
a relatively new phenomenon

1224
00:49:01,530 --> 00:49:03,630
and then there was only a few detected.

1225
00:49:03,630 --> 00:49:07,050
And then with chicken wire and
supercomputers and ingenuity,

1226
00:49:07,050 --> 00:49:09,150
CHIME ramped up the game so to speak.

1227
00:49:09,150 --> 00:49:11,340
Can you tell us, you
know, what it's discovered

1228
00:49:11,340 --> 00:49:14,040
and what we're learning
about fast radio bursts?

1229
00:49:14,040 --> 00:49:16,980
- Sure, so when CHIME came online,

1230
00:49:16,980 --> 00:49:20,070
there were about 50
fast radio bursts known

1231
00:49:20,070 --> 00:49:23,850
and intriguingly one of
them was seen to repeat.

1232
00:49:23,850 --> 00:49:25,620
So there's not only just one boom,

1233
00:49:25,620 --> 00:49:29,430
but then the same one was
emitting multiple bursts,

1234
00:49:29,430 --> 00:49:31,200
which really threw the
theorists for a loop

1235
00:49:31,200 --> 00:49:33,390
because some of their
explanations required the thing

1236
00:49:33,390 --> 00:49:35,490
to be destroyed to make a burst of energy.

1237
00:49:35,490 --> 00:49:37,410
The challenge is that fast radio bursts,

1238
00:49:37,410 --> 00:49:39,570
we've now discovered
that they're far away,

1239
00:49:39,570 --> 00:49:42,000
which means that they're
intrinsically really bright.

1240
00:49:42,000 --> 00:49:44,490
So it's hard for theorists
to come up with ways

1241
00:49:44,490 --> 00:49:46,500
of kind of generating
that much radio energy.

1242
00:49:46,500 --> 00:49:48,933
And if you don't get to destroy
the thing in the process

1243
00:49:48,933 --> 00:49:52,860
then that puts even more limits
on what you can contrive,

1244
00:49:52,860 --> 00:49:54,540
what can think of ways of explaining

1245
00:49:54,540 --> 00:49:56,880
what they can possibly be.

1246
00:49:56,880 --> 00:49:59,850
Right, so when CHIME came
online, about 50 were known

1247
00:49:59,850 --> 00:50:02,280

and the fun thing is there was a catalog

1248
00:50:02,280 --> 00:50:05,070
of known fast radio bursts
and there was also a catalog

1249
00:50:05,070 --> 00:50:06,870
of theories of what they could be

1250
00:50:06,870 --> 00:50:08,250
like, possible explanations

1251
00:50:08,250 --> 00:50:10,305
of what could produce a fast radio burst.

1252
00:50:10,305 --> 00:50:11,235
And there were more theories

1253
00:50:11,235 --> 00:50:12,690
than there were fast radio bursts.

1254
00:50:12,690 --> 00:50:14,580
(both laughing)

1255
00:50:14,580 --> 00:50:17,580
And then CHIME, in the first two months

1256
00:50:17,580 --> 00:50:20,370
while we were still kind of
putting the thing together,

1257
00:50:20,370 --> 00:50:21,540
the chicken wire was in place,

1258
00:50:21,540 --> 00:50:24,510
but the supercomputers
were still being built,

1259

00:50:24,510 --> 00:50:28,620
discovered 13 new ones
and one new repeating one.

1260
00:50:28,620 --> 00:50:32,100
And then after the first
year of observations,

1261
00:50:32,100 --> 00:50:37,100
our first catalog paper has 492 sources,

1262
00:50:37,320 --> 00:50:39,810
including 18 repeaters.

1263
00:50:39,810 --> 00:50:41,490
So basically just blew the lid

1264
00:50:41,490 --> 00:50:43,170
off the fast radio burst game.

1265
00:50:43,170 --> 00:50:46,020
But I think a lot of
the current feelings are

1266
00:50:46,020 --> 00:50:48,870
that the repeaters and the one-off bursts

1267
00:50:48,870 --> 00:50:50,400
are different populations.

1268
00:50:50,400 --> 00:50:52,050
Now the theorists can still destroy

1269
00:50:52,050 --> 00:50:53,370
the regular fast radio bursts,

1270
00:50:53,370 --> 00:50:55,200
but then they still have to explain

1271
00:50:55,200 --> 00:50:56,760
where the repeating ones come from

1272
00:50:56,760 --> 00:50:58,410
through some other mechanism.

1273
00:50:58,410 --> 00:50:59,640
- You've mentioned a term

1274
00:50:59,640 --> 00:51:03,510
that I just love in our
previous chat, sad trombone.

1275
00:51:03,510 --> 00:51:05,700
That actually has a
meaning in this research.

1276
00:51:05,700 --> 00:51:08,080
What is a sad trombone
in the CHIME effort?

1277
00:51:08,080 --> 00:51:08,913
- (laughs) This was one of those,

1278
00:51:08,913 --> 00:51:11,673
like when the term was coin,
you knew it would stick.

1279
00:51:12,780 --> 00:51:15,390
So the repeating fast radio bursts

1280
00:51:15,390 --> 00:51:17,430
tend to have this structure.

1281
00:51:17,430 --> 00:51:19,440
They're not just a single burst,

1282
00:51:19,440 --> 00:51:20,850

they kind of have a burst

1283
00:51:20,850 --> 00:51:23,340
and then maybe a few milliseconds later

1284
00:51:23,340 --> 00:51:25,740
a repeat at a lower frequency

1285
00:51:25,740 --> 00:51:27,720
and then it'll often in three like,

1286
00:51:27,720 --> 00:51:30,270
so they'll sort of have a
initial burst lower and lower.

1287
00:51:30,270 --> 00:51:33,090
So it's like whomp-whomp-whomp.

1288
00:51:33,090 --> 00:51:34,620
- Sad trombone.
- Sad trombone.

1289
00:51:34,620 --> 00:51:38,880
- But it's only these
repeating FRBs that do this?

1290
00:51:38,880 --> 00:51:39,713
- One of the things that

1291
00:51:39,713 --> 00:51:41,970
the CHIME data really contributed to this

1292
00:51:41,970 --> 00:51:43,680
is kind of understanding the diversity

1293
00:51:43,680 --> 00:51:44,940
of the fast radio bursts.

1294

00:51:44,940 --> 00:51:48,480
Like some of the non-repeating
ones cover the whole band.

1295
00:51:48,480 --> 00:51:50,010
Like we see them being bright

1296
00:51:50,010 --> 00:51:52,230
all across the frequencies
that we measure.

1297
00:51:52,230 --> 00:51:53,850
Some of them are just bright in the top,

1298
00:51:53,850 --> 00:51:55,410
some of them are just
bright in the bottom,

1299
00:51:55,410 --> 00:51:56,820
some in the middle even.

1300
00:51:56,820 --> 00:52:00,540
Some are really brief
and some are scattered,

1301
00:52:00,540 --> 00:52:01,890
which you get through kind of

1302
00:52:01,890 --> 00:52:03,840
traversing different kinds of material

1303
00:52:03,840 --> 00:52:05,340
between us and the source.

1304
00:52:05,340 --> 00:52:08,910
Part of the beauty of doing
this large-scale search,

1305
00:52:08,910 --> 00:52:11,370

observing 1,000 places
on the sky all the time

1306
00:52:11,370 --> 00:52:14,760
and observing the northern
half of the sky every day,

1307
00:52:14,760 --> 00:52:18,000
is that we get to build up
statistics about what they are

1308
00:52:18,000 --> 00:52:19,860
and collect it in a kind of uniform way

1309
00:52:19,860 --> 00:52:21,810
so that it's much easier
to try to understand

1310
00:52:21,810 --> 00:52:23,400
what the real population is

1311
00:52:23,400 --> 00:52:26,580
before whatever affects cause
you to observe some more,

1312
00:52:26,580 --> 00:52:29,730
like the unable to observe some or others.

1313
00:52:29,730 --> 00:52:31,830
So it looks like many of the repeaters

1314
00:52:31,830 --> 00:52:33,033
have the sad trombone.

1315
00:52:34,320 --> 00:52:37,470
So now sometimes if we
see a new burst in CHIME

1316
00:52:37,470 --> 00:52:39,120

and it has the sad trombone structure,

1317
00:52:39,120 --> 00:52:42,480
we'll say, "Oh maybe that
one's gonna come back again."

1318
00:52:42,480 --> 00:52:44,280
- Is there a prevailing theory or theories

1319
00:52:44,280 --> 00:52:45,780
about what these things actually,

1320
00:52:45,780 --> 00:52:47,910
what's causing these distant bursts?

1321
00:52:47,910 --> 00:52:50,400
Or do you need to do your cataloging

1322
00:52:50,400 --> 00:52:53,490
and tracking them first
to even come up with

1323
00:52:53,490 --> 00:52:55,340
an explanation of what they could be?

1324
00:52:56,190 --> 00:52:59,630
- One thing is just that
they're fast, right?

1325
00:52:59,630 --> 00:53:01,020
So they're a millisecond long,

1326
00:53:01,020 --> 00:53:04,080
so it's really hard to generate
something a millisecond long

1327
00:53:04,080 --> 00:53:05,640
from some astrophysical thing

1328
00:53:05,640 --> 00:53:08,730
that's bigger than a
light millisecond in size,

1329
00:53:08,730 --> 00:53:09,563
just 'cause you know,

1330
00:53:09,563 --> 00:53:11,010
you have to emit it all at the same time

1331
00:53:11,010 --> 00:53:12,780
from all over the source.

1332
00:53:12,780 --> 00:53:14,730
So you know, you can't
really generate something

1333
00:53:14,730 --> 00:53:16,080
that's that short from something

1334
00:53:16,080 --> 00:53:17,970
that's like the size of the sun

1335
00:53:17,970 --> 00:53:20,010
'cause it just won't all
arrive at the same time

1336
00:53:20,010 --> 00:53:22,080
so it won't be a millisecond-long burst.

1337
00:53:22,080 --> 00:53:24,660
So that pushes you toward
things that are small

1338
00:53:24,660 --> 00:53:28,230
and one of the like families of things

1339
00:53:28,230 --> 00:53:30,360

that could be are neutron stars.

1340
00:53:30,360 --> 00:53:33,660
So if you start with a star that's,

1341
00:53:33,660 --> 00:53:35,280
I forget the numbers exactly,

1342
00:53:35,280 --> 00:53:39,210
8 to 20ish times heavier than the sun.

1343
00:53:39,210 --> 00:53:42,300
It goes through its life burning hydrogen

1344
00:53:42,300 --> 00:53:44,070
and then burning some other things

1345
00:53:44,070 --> 00:53:48,270
toward the end of its desperate
life trying to stay a star

1346
00:53:48,270 --> 00:53:49,800
and eventually runs outta fuel

1347
00:53:49,800 --> 00:53:52,770
and collapses to a neutron star.

1348
00:53:52,770 --> 00:53:56,400
And neutron star material
is really bizarre

1349
00:53:56,400 --> 00:53:58,170
'cause you take all of like,

1350
00:53:58,170 --> 00:53:59,700
say something most of the size,

1351
00:53:59,700 --> 00:54:01,440

like bigger than the mass of the sun

1352
00:54:01,440 --> 00:54:04,560
and squeeze it down to
10 kilometers in size.

1353
00:54:04,560 --> 00:54:06,120
There aren't atoms anymore.

1354
00:54:06,120 --> 00:54:08,370
Everything's been squeezed so far together

1355
00:54:08,370 --> 00:54:11,310
that it's just like a
big ball of neutrons.

1356
00:54:11,310 --> 00:54:12,450
So it's really bizarre.

1357
00:54:12,450 --> 00:54:15,000
One teaspoon of neutron star material

1358
00:54:15,000 --> 00:54:17,430
weighs billions of tons.

1359
00:54:17,430 --> 00:54:19,200
Like it's just mind boggling.

1360
00:54:19,200 --> 00:54:21,600
- Right, it really does
make the mind reel.

1361
00:54:21,600 --> 00:54:22,433
- Like it's a number

1362
00:54:22,433 --> 00:54:25,350
that you just can't
really like comprehend.

1363
00:54:25,350 --> 00:54:29,370
So they're pretty weird. (laughs)

1364
00:54:29,370 --> 00:54:31,323
But the other interesting things are that,

1365
00:54:31,323 --> 00:54:33,330
like when this process happens,

1366
00:54:33,330 --> 00:54:36,960
if the star was spinning
initially, it keeps spinning,

1367
00:54:36,960 --> 00:54:38,143
but now instead of you know,

1368
00:54:38,143 --> 00:54:42,120
a very stately slow rotation
of something the size of a sun,

1369
00:54:42,120 --> 00:54:43,980
if you can picture a
figure skater spinning

1370
00:54:43,980 --> 00:54:45,990
and then pulling in their arms

1371
00:54:45,990 --> 00:54:48,150
and spinning faster and faster and faster,

1372
00:54:48,150 --> 00:54:51,000
imagine that just continuing on to go.

1373
00:54:51,000 --> 00:54:52,140
Instead of spinning, you know,

1374
00:54:52,140 --> 00:54:54,240
once a week or once a day or something,

1375
00:54:54,240 --> 00:54:56,430
some of the neutron
stars that are observed

1376
00:54:56,430 --> 00:54:59,400
will spin like 1,000
times a second or more.

1377
00:54:59,400 --> 00:55:02,310
So they're the like
incredibly heavy things

1378
00:55:02,310 --> 00:55:03,990
that can be spinning really fast.

1379
00:55:03,990 --> 00:55:07,290
And similarly their magnetic
fields, they often keep,

1380
00:55:07,290 --> 00:55:09,930
So then you have something
with a magnetic field

1381
00:55:09,930 --> 00:55:11,220
that's spinning really fast.

1382
00:55:11,220 --> 00:55:13,110
If you're a theorist,
that's good ingredients

1383
00:55:13,110 --> 00:55:15,870
to make something that
can emit radio waves.

1384
00:55:15,870 --> 00:55:19,770
So these pulsars are
known, like neutron stars

1385

00:55:19,770 --> 00:55:23,310
that are observed to emit
periodic pulses of radio waves.

1386
00:55:23,310 --> 00:55:24,200
They were first discovered

1387
00:55:24,200 --> 00:55:28,023
in 1967 by Jocelyn Bell
Burnell who is amazing.

1388
00:55:29,310 --> 00:55:33,660
Some of the theories for what
fast radio bursts could be

1389
00:55:33,660 --> 00:55:38,400
are kind of exotic types of
neutron stars of some kind.

1390
00:55:38,400 --> 00:55:40,740
The problem is that the fast radio bursts

1391
00:55:40,740 --> 00:55:44,070
are like millions of times
brighter than neutron stars

1392
00:55:44,070 --> 00:55:45,330
that we know in the Milky Way.

1393
00:55:45,330 --> 00:55:46,920
And you can't just make them bigger

1394
00:55:46,920 --> 00:55:48,210
because if you make them too big

1395
00:55:48,210 --> 00:55:49,410
they collapse to black holes.

1396
00:55:49,410 --> 00:55:51,930

So you can't just make
a bigger neutron star.

1397
00:55:51,930 --> 00:55:53,700
There has to be kind of
something else going on.

1398
00:55:53,700 --> 00:55:58,700
We got another kind of clue
or a hint maybe in 2021.

1399
00:55:58,950 --> 00:56:00,330
There was a fast radio burst

1400
00:56:00,330 --> 00:56:02,880
from a neutron star in our own galaxy,

1401
00:56:02,880 --> 00:56:04,590
a special kind called a magnetar.

1402
00:56:04,590 --> 00:56:06,120
So it has kind of neutron stars

1403
00:56:06,120 --> 00:56:08,580
with really extreme magnetic fields.

1404
00:56:08,580 --> 00:56:12,570
And CHIME observed that,
like we caught that one,

1405
00:56:12,570 --> 00:56:13,890
we saw it go streaming by

1406
00:56:13,890 --> 00:56:15,720
and we said, "Ooh, that's interesting."

1407
00:56:15,720 --> 00:56:18,870
And it kind of has an
energy that's in between.

1408
00:56:18,870 --> 00:56:21,540
So it's a few 100 times brighter,

1409
00:56:21,540 --> 00:56:24,990
I think, than usual pulsars.

1410
00:56:24,990 --> 00:56:26,850
So it's kind of filling in a bit of

1411
00:56:26,850 --> 00:56:29,610
that factor of a million you need

1412
00:56:29,610 --> 00:56:30,930
to get to fast radio bursts.

1413
00:56:30,930 --> 00:56:33,300
So maybe they're an extreme,

1414
00:56:33,300 --> 00:56:36,120
kind of this extreme kind of magnetar.

1415
00:56:36,120 --> 00:56:38,730
So there're kind of hints and clues,

1416
00:56:38,730 --> 00:56:41,490
but it's still a pretty big mystery

1417
00:56:41,490 --> 00:56:43,830
and we keep kind of finding odd things.

1418
00:56:43,830 --> 00:56:47,880
Another thing discovered last
year, or the year before,

1419
00:56:47,880 --> 00:56:49,740
by a graduate student in the CHIME group

1420
00:56:49,740 --> 00:56:53,130
was that one of the
repeaters not only repeats

1421
00:56:53,130 --> 00:56:56,070
but it repeats on a clock.

1422
00:56:56,070 --> 00:56:58,770
She found that if she
took all of the pulses,

1423
00:56:58,770 --> 00:56:59,940
she was looking at all

1424
00:56:59,940 --> 00:57:02,250
when we had observed the fast radio bursts

1425
00:57:02,250 --> 00:57:06,213
and she said it looks like
it's repeating every 16 days.

1426
00:57:07,650 --> 00:57:09,840
So she took the signal and like folded it

1427
00:57:09,840 --> 00:57:11,910
and found that all of the bursts

1428
00:57:11,910 --> 00:57:15,150
come within a five-day
period around that 16 days.

1429
00:57:15,150 --> 00:57:16,470
So it's like, you know,

1430
00:57:16,470 --> 00:57:19,470
on for five days and then off for 11 days,

1431
00:57:19,470 --> 00:57:21,630

on for five days off for 11.

1432
00:57:21,630 --> 00:57:22,980
And most of them appear

1433
00:57:22,980 --> 00:57:25,560
within like a one-day
window around the peak.

1434
00:57:25,560 --> 00:57:28,110
So it's like mostly on and on day one

1435
00:57:28,110 --> 00:57:31,440
and then it's kind of on a
little bit for the next four days

1436
00:57:31,440 --> 00:57:32,853
and then off for 11 days.

1437
00:57:34,170 --> 00:57:37,890
So that adds another
element to the mystery.

1438
00:57:37,890 --> 00:57:40,530
And we don't know if all
of the repeaters do this,

1439
00:57:40,530 --> 00:57:42,180
but maybe some of them we haven't,

1440
00:57:42,180 --> 00:57:43,440
maybe they have different periods

1441
00:57:43,440 --> 00:57:45,480
and we haven't observed
most of them for long enough

1442
00:57:45,480 --> 00:57:47,100
to be able to notice that.

1443
00:57:47,100 --> 00:57:49,110
So then that maybe makes you think

1444
00:57:49,110 --> 00:57:51,570
that maybe there's like a neutron star

1445
00:57:51,570 --> 00:57:54,690
and something else in a binary,
like orbiting each other.

1446
00:57:54,690 --> 00:57:55,770
And then when you have that,

1447
00:57:55,770 --> 00:57:59,610
you can get it so that the
neutron star is spinning

1448
00:57:59,610 --> 00:58:02,430
and it's sort of like a lighthouse

1449
00:58:02,430 --> 00:58:04,680
or like a top that's wobbling

1450
00:58:04,680 --> 00:58:07,050
and when you're looking
straight down on the top

1451
00:58:07,050 --> 00:58:08,730
you can see a burst from it.

1452
00:58:08,730 --> 00:58:10,920
So maybe that's what's doing it

1453
00:58:10,920 --> 00:58:13,470
and that, you know,
wobbles once every 16 days

1454

00:58:13,470 --> 00:58:15,720
and it's when it's pointed like more at us

1455
00:58:15,720 --> 00:58:17,130
that we see the bursts.

1456
00:58:17,130 --> 00:58:17,963
So now you know,

1457
00:58:17,963 --> 00:58:19,590
you make the picture more
and more complicated.

1458
00:58:19,590 --> 00:58:22,290
Like it has to be a really
extreme magnetar in a binary

1459
00:58:22,290 --> 00:58:25,133
with something else that's
giving it this wobble.

1460
00:58:25,133 --> 00:58:28,680
- The mystery remains.
- Yep. The mysteries remain.

1461
00:58:28,680 --> 00:58:30,150
- Well that's the exciting part.

1462
00:58:30,150 --> 00:58:32,490
There's lots for you to do. (chuckles)

1463
00:58:32,490 --> 00:58:34,050
- It's really, it's the first time

1464
00:58:34,050 --> 00:58:36,210
I've been involved in a project like this

1465
00:58:36,210 --> 00:58:40,110
that's kind of broken open a

new part of observing space

1466
00:58:40,110 --> 00:58:41,490
and is really just like finding

1467
00:58:41,490 --> 00:58:43,260
all kinds of cool things there.

1468
00:58:43,260 --> 00:58:45,720
So it's been really
fast-paced and really fun.

1469
00:58:45,720 --> 00:58:48,240
And part of the way
Canadian projects work,

1470
00:58:48,240 --> 00:58:50,160
there are a lot of
graduate students involved.

1471
00:58:50,160 --> 00:58:52,680
So a lot of the people
making these discoveries are,

1472
00:58:52,680 --> 00:58:54,870
you know, people who are
working on their PhDs

1473
00:58:54,870 --> 00:58:56,250
or master's degrees, you know,

1474
00:58:56,250 --> 00:58:57,990
they're just at the
forefront of this field.

1475
00:58:57,990 --> 00:59:00,120
So it's really exciting,

1476
00:59:00,120 --> 00:59:03,390

it's really neat to see all
the things they're discovering.

1477
00:59:03,390 --> 00:59:05,700
- On the topic of being at the forefront.

1478
00:59:05,700 --> 00:59:09,360
You have told us also that
lots of the work here relies

1479
00:59:09,360 --> 00:59:12,630
on being at the forefront
of computational technology

1480
00:59:12,630 --> 00:59:15,720
and we had a question sent
in on the topic of GPUs.

1481
00:59:15,720 --> 00:59:17,310
This was sent in from Craig

1482
00:59:17,310 --> 00:59:20,670
in the IT and AV department
here at Perimeter.

1483
00:59:20,670 --> 00:59:21,660
- Hi Dustin.

1484
00:59:21,660 --> 00:59:24,720
I heard it mentioned here
recently at Perimeter,

1485
00:59:24,720 --> 00:59:26,940
this specific piece of hardware known

1486
00:59:26,940 --> 00:59:29,340
as an Einstein equation code GPU,

1487
00:59:29,340 --> 00:59:33,000

which is the graphics
processor from a video card,

1488
00:59:33,000 --> 00:59:34,350
reprogrammed to run

1489
00:59:34,350 --> 00:59:37,680
the Einstein equation
code for simulations.

1490
00:59:37,680 --> 00:59:40,230
I wonder if you could explain
in a little more detail

1491
00:59:40,230 --> 00:59:44,130
what an Einstein equation code GPU is,

1492
00:59:44,130 --> 00:59:48,660
how one is programmed to run
the Einstein equation code

1493
00:59:48,660 --> 00:59:52,710
and how successful it has
actually been in simulations.

1494
00:59:52,710 --> 00:59:56,460
- I'm gonna first talk a little
bit about CHIME, I guess.

1495
00:59:56,460 --> 00:59:57,293
I said that, you know,

1496
00:59:57,293 --> 00:59:58,890
it's chicken wire and supercomputers,

1497
00:59:58,890 --> 01:00:00,750
multiple supercomputers in this case.

1498
01:00:00,750 --> 01:00:03,360

So in CHIME the first
supercomputer it comes into

1499
01:00:03,360 --> 01:00:06,300
are these custom-built computer boards

1500
01:00:06,300 --> 01:00:09,810
that use FPGAs,
field-programmable gate arrays.

1501
01:00:09,810 --> 01:00:11,550
And they're these kind
of really low-level,

1502
01:00:11,550 --> 01:00:13,170
it's sort of like a computer chip

1503
01:00:13,170 --> 01:00:15,900
where you get to choose
where the wires go.

1504
01:00:15,900 --> 01:00:18,000
So they're really difficult to program

1505
01:00:18,000 --> 01:00:19,620
but really fast at what they do.

1506
01:00:19,620 --> 01:00:22,770
Program them once and they
do a single task very fast.

1507
01:00:22,770 --> 01:00:25,290
The task that first computer has to do

1508
01:00:25,290 --> 01:00:28,200
is simple enough that this is achievable

1509
01:00:28,200 --> 01:00:31,200
and then it sends all the data

to the second supercomputer,

1510
01:00:31,200 --> 01:00:34,500
the CHIME correlator that has
to do more complicated tasks.

1511
01:00:34,500 --> 01:00:35,370
You can't do that

1512
01:00:35,370 --> 01:00:38,670
in these really
difficult-to-program FPGAs,

1513
01:00:38,670 --> 01:00:40,860
but it turns out that you can use

1514
01:00:40,860 --> 01:00:43,650
these GPUs, graphics processing units,

1515
01:00:43,650 --> 01:00:45,690
to do the computations.

1516
01:00:45,690 --> 01:00:50,690
And GPUs are harder to program
than garden-variety CPUs

1517
01:00:50,880 --> 01:00:54,120
but they're way more
flexible than like FPGAs.

1518
01:00:54,120 --> 01:00:57,390
So the CHIME correlator has
to use these GPUs basically

1519
01:00:57,390 --> 01:01:01,590
to get the amount of computation
out that that it has to do.

1520
01:01:01,590 --> 01:01:05,490

And it uses 1,024 what were at the time,

1521
01:01:05,490 --> 01:01:07,710
very cutting-edge GPUs.

1522
01:01:07,710 --> 01:01:08,610
I love the whole thing,

1523
01:01:08,610 --> 01:01:10,590
I love all of the
technology involved in it.

1524
01:01:10,590 --> 01:01:13,380
They're water-cooled and
the water kind of comes in

1525
01:01:13,380 --> 01:01:15,690
and goes over each GPU in turn

1526
01:01:15,690 --> 01:01:16,800
and we have sensors on them

1527
01:01:16,800 --> 01:01:18,900
and you can kind of see
the water heating up

1528
01:01:18,900 --> 01:01:22,200
as it goes through each GPU and cools it.

1529
01:01:22,200 --> 01:01:24,300
But yeah, basically these GPUs,

1530
01:01:24,300 --> 01:01:25,770
although they were originally built

1531
01:01:25,770 --> 01:01:28,470
for doing graphics for video games,

1532

01:01:28,470 --> 01:01:30,270
if you think about it,
graphics for video games,

1533
01:01:30,270 --> 01:01:33,120
a lot of the tasks are
like running something

1534
01:01:33,120 --> 01:01:36,120
that's going to produce, a color say,

1535
01:01:36,120 --> 01:01:37,890
for each pixel on your screen.

1536
01:01:37,890 --> 01:01:38,723
And you know,

1537
01:01:38,723 --> 01:01:42,240
if you have a screen that's
like 2000 by 2000 pixels,

1538
01:01:42,240 --> 01:01:43,200
I'm making that number up,

1539
01:01:43,200 --> 01:01:45,780
then you have 4 million computations to do

1540
01:01:45,780 --> 01:01:48,390
but you're doing kind of the
same thing for each one, right?

1541
01:01:48,390 --> 01:01:50,400
So GPUs are kind of specialized

1542
01:01:50,400 --> 01:01:54,780
for doing relatively simple
tasks but in massively parallel.

1543
01:01:54,780 --> 01:01:56,970

And that just turns out
to be a really good match

1544
01:01:56,970 --> 01:01:58,770
to some of the tasks that we have to do.

1545
01:01:58,770 --> 01:01:59,820
'Cause in radio, you know,

1546
01:01:59,820 --> 01:02:02,280
for the radio astronomy computations,

1547
01:02:02,280 --> 01:02:04,980
it's the same task done a
lot of times in parallel.

1548
01:02:04,980 --> 01:02:09,810
So say 1,000 places on the
sky or 16,000 frequencies,

1549
01:02:09,810 --> 01:02:12,480
that computation is the same for each one.

1550
01:02:12,480 --> 01:02:15,660
So it's basically, you know,
kind of a fairly simple process

1551
01:02:15,660 --> 01:02:17,250
that you just have to
repeat a bunch of times.

1552
01:02:17,250 --> 01:02:20,010
So that really works well for GPUs.

1553
01:02:20,010 --> 01:02:23,970
So GPUs are really widely
used for, also now,

1554
01:02:23,970 --> 01:02:26,850

a bunch of machine
learning or AI applications

1555
01:02:26,850 --> 01:02:28,230
because a lot of those problems

1556
01:02:28,230 --> 01:02:31,440
can also be phrased as doing
a fairly simple operation,

1557
01:02:31,440 --> 01:02:32,730
a lot of times in parallel.

1558
01:02:32,730 --> 01:02:34,080
They're kind of just a way of

1559
01:02:34,080 --> 01:02:36,360
accessing a lot of computing power

1560
01:02:36,360 --> 01:02:38,760
at the expense that you
they're harder to program

1561
01:02:38,760 --> 01:02:39,990
so you have to put more effort

1562
01:02:39,990 --> 01:02:42,630
into describing the
problem you want to solve

1563
01:02:42,630 --> 01:02:45,660
and especially how to solve
it in massive parallel.

1564
01:02:45,660 --> 01:02:48,423
So this Einstein equations,

1565
01:02:49,260 --> 01:02:51,450
this was actually work done by people

1566
01:02:51,450 --> 01:02:54,450
including my boss and office mate,

1567
01:02:54,450 --> 01:02:56,310
Erik Schnetter at Perimeter,

1568
01:02:56,310 --> 01:02:58,170
they work on computer programs

1569
01:02:58,170 --> 01:03:01,830
that solve the Einstein's
general relativity equations.

1570
01:03:01,830 --> 01:03:05,310
So you might have heard it
said that in general relativity

1571
01:03:05,310 --> 01:03:07,540
matter tells space how to bend

1572
01:03:08,580 --> 01:03:10,473
and space tells matter how to move.

1573
01:03:11,340 --> 01:03:16,080
So you know, when there's mass
it changes the shape of space

1574
01:03:16,080 --> 01:03:19,980
and then mass moves along
straight lines in bendy space.

1575
01:03:19,980 --> 01:03:22,350
So if you're a mathematician,

1576
01:03:22,350 --> 01:03:24,510
that sounds like differential equations.

1577

01:03:24,510 --> 01:03:25,797
It's, you know, there's sort of two things

1578
01:03:25,797 --> 01:03:27,480
and they're affecting each other.

1579
01:03:27,480 --> 01:03:29,280
Those are equations that you can solve.

1580
01:03:29,280 --> 01:03:31,020
You know, if you put a bunch of mass down,

1581
01:03:31,020 --> 01:03:33,690
you can compute how
this space will be bent

1582
01:03:33,690 --> 01:03:34,740
and then you can compute

1583
01:03:34,740 --> 01:03:37,440
how the mass will move
around in that bendy space.

1584
01:03:37,440 --> 01:03:38,273
And you only need this

1585
01:03:38,273 --> 01:03:42,030
when you're dealing with really
extreme kinds of situations.

1586
01:03:42,030 --> 01:03:45,000
So black holes often come
up, neutron stars probably,

1587
01:03:45,000 --> 01:03:47,190
but in order to understand
situations like that,

1588
01:03:47,190 --> 01:03:48,960

basically you can either try

1589
01:03:48,960 --> 01:03:51,090
to understand really simple situations

1590
01:03:51,090 --> 01:03:53,850
with math on a blackboard

1591
01:03:53,850 --> 01:03:56,880
or you can do computer
simulations of them.

1592
01:03:56,880 --> 01:03:58,650
And those computer simulations

1593
01:03:58,650 --> 01:04:02,650
involve doing a lot of the
same computation in parallel

1594
01:04:03,690 --> 01:04:06,900
so they lend themselves to GPUs.

1595
01:04:06,900 --> 01:04:09,390
Erik's group have made implementations

1596
01:04:09,390 --> 01:04:12,840
of solving the Einstein equations on GPUs.

1597
01:04:12,840 --> 01:04:14,880
That's the sense in which
there's a, you know,

1598
01:04:14,880 --> 01:04:17,520
a graphics card that can
solve the Einstein equations.

1599
01:04:17,520 --> 01:04:19,170
- Right, yeah. That's fascinating.

1600
01:04:19,170 --> 01:04:21,690
I knew that that question was coming up.

1601
01:04:21,690 --> 01:04:22,770
I was looking forward to your answer

1602
01:04:22,770 --> 01:04:25,020
'cause that's an area that
I know very little about

1603
01:04:25,020 --> 01:04:27,270
and now I know something
as opposed to nothing,

1604
01:04:27,270 --> 01:04:28,530
thanks to you.

1605
01:04:28,530 --> 01:04:32,253
We have two more questions
from students. Let's hear.

1606
01:04:33,210 --> 01:04:35,400
- Hi Dustin. I'm Summer from Waterloo.

1607
01:04:35,400 --> 01:04:37,290
If you could travel
anywhere in the universe

1608
01:04:37,290 --> 01:04:40,530
to see something with your
own eyes, what would it be?

1609
01:04:40,530 --> 01:04:41,580
- Oh goodness.

1610
01:04:41,580 --> 01:04:44,100
I don't think I'd wanna put
my own eyes close enough

1611
01:04:44,100 --> 01:04:46,230
to a fast radio burst to see it.

1612
01:04:46,230 --> 01:04:47,273
- Let's say you're safe,

1613
01:04:47,273 --> 01:04:50,133
you're in a safe space vehicle somehow.

1614
01:04:51,540 --> 01:04:54,570
- Okay good with enough
shielding, (laughs)

1615
01:04:54,570 --> 01:04:56,400
I would love to see a fast radio burst.

1616
01:04:56,400 --> 01:04:57,990
'Cause what on earth are they?

1617
01:04:57,990 --> 01:04:59,310
You know, like I said, you have to,

1618
01:04:59,310 --> 01:05:01,140
the theorists really are working hard

1619
01:05:01,140 --> 01:05:05,130
to contrive scenarios that
can make a fast radio burst.

1620
01:05:05,130 --> 01:05:07,500
So there's gonna be all
sorts of wild stuff going on

1621
01:05:07,500 --> 01:05:10,020
around something that can
make a fast radio burst

1622
01:05:10,020 --> 01:05:12,390

is my guess or my hope at least.

1623
01:05:12,390 --> 01:05:15,450
Black holes of course, or
like the accretion disc

1624
01:05:15,450 --> 01:05:16,620
and like the, you know,

1625
01:05:16,620 --> 01:05:19,320
we don't see bendy space
in our everyday lives.

1626
01:05:19,320 --> 01:05:22,110
So there was a recent news article

1627
01:05:22,110 --> 01:05:25,740
of looking at light behind a black hole

1628
01:05:25,740 --> 01:05:27,660
and it's bent all the way around

1629
01:05:27,660 --> 01:05:30,390
or sometimes bends around
and makes multiple laps

1630
01:05:30,390 --> 01:05:31,980
before it gets out and sees you.

1631
01:05:31,980 --> 01:05:34,020
So like we don't really experience

1632
01:05:34,020 --> 01:05:37,290
the fact that space is bendy
so it would be pretty cool

1633
01:05:37,290 --> 01:05:40,200
to see bendy space around a black hole.

1634
01:05:40,200 --> 01:05:42,390
- I agree. (laughs)

1635
01:05:42,390 --> 01:05:43,770
And we have a second question

1636
01:05:43,770 --> 01:05:45,870
that may follow from the first.

1637
01:05:45,870 --> 01:05:47,850
- Hi Dustin, I'm Justina from Waterloo.

1638
01:05:47,850 --> 01:05:48,930
I was wondering,

1639
01:05:48,930 --> 01:05:52,260
what's the most fascinating
thing to you about the universe?

1640
01:05:52,260 --> 01:05:53,991
- Wow that's going
right to the core of it.

1641
01:05:53,991 --> 01:05:55,350
(all laughing)

1642
01:05:55,350 --> 01:05:57,210
One of the really bizarre things

1643
01:05:57,210 --> 01:05:58,800
is that the universe seems

1644
01:05:58,800 --> 01:06:02,610
to be like kind of
comprehensible with math.

1645
01:06:02,610 --> 01:06:04,590
It's kind of bizarre that you can,

1646
01:06:04,590 --> 01:06:07,290
in cosmology you can
write down like, you know,

1647
01:06:07,290 --> 01:06:10,710
a set of equations with
like five or six parameters

1648
01:06:10,710 --> 01:06:13,170
that kind of explain at the large scales,

1649
01:06:13,170 --> 01:06:15,720
like how the universe grows over time.

1650
01:06:15,720 --> 01:06:17,880
Like that to me is just bizarre.

1651
01:06:17,880 --> 01:06:20,430
The weirdest thing is that it seems to be

1652
01:06:20,430 --> 01:06:24,600
like comprehensible or like
within the realm of possibility

1653
01:06:24,600 --> 01:06:25,860
that we could understand things

1654
01:06:25,860 --> 01:06:28,505
about the universe with
like basically math

1655
01:06:28,505 --> 01:06:30,930
and that we can like understand
things about the universe

1656
01:06:30,930 --> 01:06:32,070
by writing computer code

1657
01:06:32,070 --> 01:06:34,830
and that somehow people will
pay me to do this for a job.

1658
01:06:34,830 --> 01:06:36,869
Like it's... (laughs)

1659
01:06:36,869 --> 01:06:38,820
- Yeah, I suppose you would be,

1660
01:06:38,820 --> 01:06:41,670
that job posting that
your friends joked to you,

1661
01:06:41,670 --> 01:06:43,920
you had to go for it,
Perimeter wouldn't have existed

1662
01:06:43,920 --> 01:06:47,010
had the universe not been
somewhat comprehensible

1663
01:06:47,010 --> 01:06:50,250
and that there would be
mysteries for you to dive into.

1664
01:06:50,250 --> 01:06:51,750
- Yeah, well some people say that like,

1665
01:06:51,750 --> 01:06:54,510
we are like the universe's
way of understanding itself.

1666
01:06:54,510 --> 01:06:55,620
- Mm-hmm.

1667
01:06:55,620 --> 01:06:57,930
You mentioned that one of
the downsides of your job

1668
01:06:57,930 --> 01:07:00,450
is you don't always get
to go to the telescopes

1669
01:07:00,450 --> 01:07:01,380
that are doing the work

1670
01:07:01,380 --> 01:07:03,420
and you haven't been to CHIME

1671
01:07:03,420 --> 01:07:06,300
even though it's really close
to where you grew up, right?

1672
01:07:06,300 --> 01:07:08,970
- Yeah, it's just one mountain range away

1673
01:07:08,970 --> 01:07:11,400
from where I grew up in
Christina Lake, British Columbia.

1674
01:07:11,400 --> 01:07:12,870
- It's a long way, it's over the mountain.

1675
01:07:12,870 --> 01:07:15,180
So yeah, you're from
British Columbia originally

1676
01:07:15,180 --> 01:07:17,910
and you still haven't
made it to the telescope

1677
01:07:17,910 --> 01:07:19,403
that's one mountain range across the way.

1678
01:07:19,403 --> 01:07:24,403
- I know, I still have, my
mom is quite upset. (laughs)

1679
01:07:25,170 --> 01:07:27,690
My work somehow hasn't contrived

1680
01:07:27,690 --> 01:07:30,450
to manage to make me go out there.

1681
01:07:30,450 --> 01:07:33,660
We have staff members on-site
and team members on-site.

1682
01:07:33,660 --> 01:07:36,120
So the goal is for the whole system

1683
01:07:36,120 --> 01:07:38,070
to be remotely operable.

1684
01:07:38,070 --> 01:07:40,290
From time to time we have to get somebody

1685
01:07:40,290 --> 01:07:43,470
to go and unplug something
by hand or turn it off.

1686
01:07:43,470 --> 01:07:48,470
But for most of it, it's all
set up for remote observation

1687
01:07:48,540 --> 01:07:50,490
partly because whenever people are on-site

1688
01:07:50,490 --> 01:07:53,400
they just, they tend to, not the staff,

1689
01:07:53,400 --> 01:07:54,960
the staff are very good,

1690
01:07:54,960 --> 01:07:58,560

but whenever we have visitors,
contractors, whatever,

1691
01:07:58,560 --> 01:08:00,460
they never turn their cell phones off.

1692
01:08:01,504 --> 01:08:02,337
- And that interferes with-

1693
01:08:02,337 --> 01:08:03,960
- That's the loudest thing in the sky.

1694
01:08:03,960 --> 01:08:05,340
It's louder than anything in the sky.

1695
01:08:05,340 --> 01:08:07,890
So the fewer people on
the site the better,

1696
01:08:07,890 --> 01:08:09,390
actually for the most part.

1697
01:08:09,390 --> 01:08:11,430
During the building of CHIME

1698
01:08:11,430 --> 01:08:14,460
there was a huge amount
of physical effort put in

1699
01:08:14,460 --> 01:08:16,710
as far as as like pulling
cables, 'cause you know,

1700
01:08:16,710 --> 01:08:21,710
there's 2000 cables that
come from the half-pipes

1701
01:08:21,870 --> 01:08:23,670
into the first supercomputer

1702
01:08:23,670 --> 01:08:26,820
and then hundreds of fiber optic lines

1703
01:08:26,820 --> 01:08:28,950
that come from that one to
the next computer and so on.

1704
01:08:28,950 --> 01:08:31,080
So there was a huge amount of effort,

1705
01:08:31,080 --> 01:08:32,820
but I thankfully came on the project

1706
01:08:32,820 --> 01:08:33,653
a little bit after that.

1707
01:08:33,653 --> 01:08:35,040
It was all in place.

1708
01:08:35,040 --> 01:08:38,293
It is still a huge treat
to go to the telescopes.

1709
01:08:38,293 --> 01:08:40,800
I spent a lot of time at the DESI site

1710
01:08:40,800 --> 01:08:43,140
and at its twin telescope in Chile

1711
01:08:43,140 --> 01:08:45,660
and it's just beautiful up there.

1712
01:08:45,660 --> 01:08:46,980
It's a real treat too

1713
01:08:46,980 --> 01:08:49,320
to have the privilege to

observe from those places.

1714
01:08:49,320 --> 01:08:50,790
- Well, you'll have to get to CHIME

1715
01:08:50,790 --> 01:08:53,520
and then visit your mother or vice versa.

1716
01:08:53,520 --> 01:08:55,920
Your enthusiasm for this stuff,

1717
01:08:55,920 --> 01:08:59,760
especially the real mysterious
stuff is just infectious

1718
01:08:59,760 --> 01:09:01,437
and you know, I've learned so much

1719
01:09:01,437 --> 01:09:04,260
and my mind is reeling at some of the data

1720
01:09:04,260 --> 01:09:05,370
and the sizes and the scale.

1721
01:09:05,370 --> 01:09:08,040
So thank you so much for
sharing with us today.

1722
01:09:08,040 --> 01:09:09,241
- Thank you. It was my pleasure.

1723
01:09:09,241 --> 01:09:11,370
(bright music)

1724
01:09:11,370 --> 01:09:13,320
- Thanks so much for listening.

1725
01:09:13,320 --> 01:09:14,550

Perimeter Institute is

1726
01:09:14,550 --> 01:09:16,980
a not-for-profit charitable organization

1727
01:09:16,980 --> 01:09:19,260
that shares cutting-edge
ideas with the world

1728
01:09:19,260 --> 01:09:21,150
thanks to the ongoing support

1729
01:09:21,150 --> 01:09:23,550
of the governments of Ontario and Canada,

1730
01:09:23,550 --> 01:09:25,830
and also thanks to donors like you.

1731
01:09:25,830 --> 01:09:28,023
Thank you for being part of the equation.