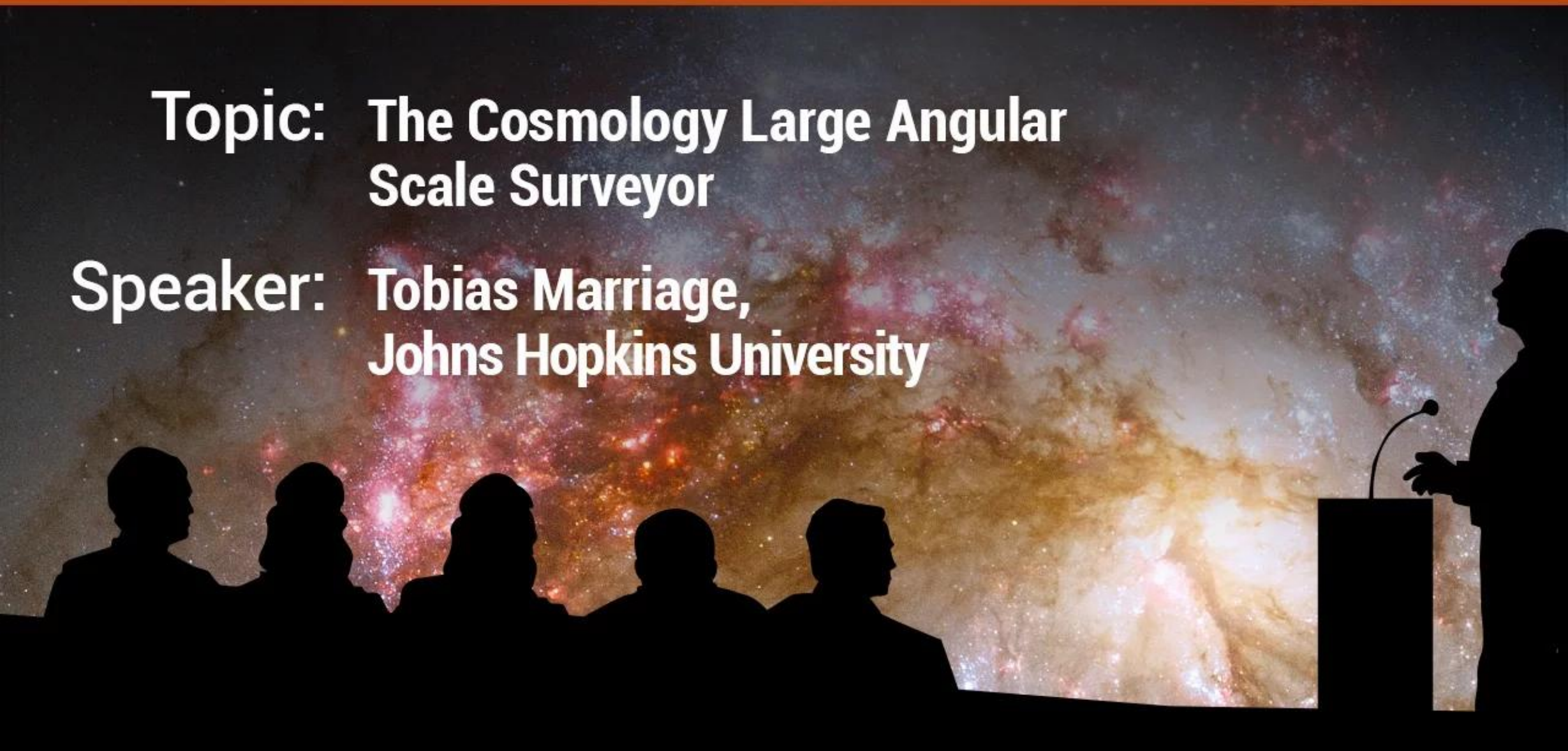
Hubble Public Lecture Series



Topic: The Cosmology Large Angular Scale Surveyor

Speaker: Tobias Marriage, Johns Hopkins University

1
00:00:09,230 --> 00:00:02,690
hey Thomas are we all ready he gives us

2
00:00:10,459 --> 00:00:09,240
the thumbs-up all right let's begin good

3
00:00:14,200 --> 00:00:10,469
evening ladies and gentlemen and welcome

4
00:00:16,609 --> 00:00:14,210
to the space tusko public lecture series

5
00:00:18,920 --> 00:00:16,619
it is my pleasure to be your host

6
00:00:21,740 --> 00:00:18,930
tonight I am dr. Frank summers of the

7
00:00:25,550 --> 00:00:21,750
Space Telescope Science Institute office

8
00:00:26,870 --> 00:00:25,560
of public outreach when you came in I'm

9
00:00:28,550 --> 00:00:26,880
sorry I didn't put any pictures over

10
00:00:30,650 --> 00:00:28,560
this side over that side there's a

11
00:00:34,069 --> 00:00:30,660
plenty of pictures tonight's pictures

12
00:00:36,740 --> 00:00:34,079
are not the same there's a whole jumble

13
00:00:39,260 --> 00:00:36,750

of pictures we have a bunch of Oppo

14
00:00:40,580 --> 00:00:39,270
staff moving offices and when they move

15
00:00:43,130 --> 00:00:40,590
their offices they say where did these

16
00:00:44,840 --> 00:00:43,140
come from and then they go here Frank

17
00:00:47,000 --> 00:00:44,850
give these away at the public lecture

18
00:00:50,029 --> 00:00:47,010
series so tonight you have a whole bunch

19
00:00:51,889 --> 00:00:50,039
of cool images and random lithographs

20
00:00:53,930 --> 00:00:51,899
that have come out of people's offices

21
00:00:56,720 --> 00:00:53,940
if you can get one on the way in please

22
00:00:58,610 --> 00:00:56,730
pick one on the way out what do I have

23
00:01:04,609 --> 00:00:58,620
here it looks like this is a wonderful

24
00:01:07,100 --> 00:01:04,619
edge-on galaxy NGC 558 66 all right you

25
00:01:10,219 --> 00:01:07,110
want 58 66 hurry down here afterwards

26
00:01:13,670 --> 00:01:10,229
it'll be right here all right tonight's

27
00:01:16,670 --> 00:01:13,680
talk will be the cosmology large angular

28
00:01:19,370 --> 00:01:16,680
scale surveyor which in the tradition of

29
00:01:21,289 --> 00:01:19,380
physics and astronomy has a nice acronym

30
00:01:24,410 --> 00:01:21,299
of class okay so you're gonna get a

31
00:01:28,580 --> 00:01:24,420
classy talk tonight okay really classy

32
00:01:31,280 --> 00:01:28,590
all right next month we have Christine

33
00:01:35,359 --> 00:01:31,290
Chen talking about debris disks and the

34
00:01:37,370 --> 00:01:35,369
evolution of planetary systems January I

35
00:01:39,230 --> 00:01:37,380
don't have a speaker for January it's

36
00:01:41,450 --> 00:01:39,240
difficult to rope somebody in for

37
00:01:43,639 --> 00:01:41,460
January I will work very hard it over

38
00:01:45,819 --> 00:01:43,649

the next month and announce that so

39
00:01:48,980 --> 00:01:45,829
right now we still have our infamous TBA

40
00:01:53,990 --> 00:01:48,990
and in February we have a very special

41
00:01:55,910 --> 00:01:54,000
talk priyamvada nyah Rajan from Yale is

42
00:01:58,399 --> 00:01:55,920
coming down and she will be giving a

43
00:02:00,889 --> 00:01:58,409
talk on her book mapping the heavens

44
00:02:02,300 --> 00:02:00,899
okay so it's rare that I get speak

45
00:02:06,170 --> 00:02:02,310
because I have no travel budget for this

46
00:02:07,819 --> 00:02:06,180
lecture series okay so when I can get

47
00:02:09,380 --> 00:02:07,829
somebody in from outside I'm really

48
00:02:11,150 --> 00:02:09,390
happy to be able to bring you somebody

49
00:02:12,710 --> 00:02:11,160
who's not from Space Telescope AHA pants

50
00:02:13,490 --> 00:02:12,720
nothing against the Hopkinson Space

51
00:02:16,520 --> 00:02:13,500
Telescope you'll because

52
00:02:17,780 --> 00:02:16,530
you're wonderful folks but being able to

53
00:02:20,830 --> 00:02:17,790
bring you somebody from another

54
00:02:24,140 --> 00:02:20,840
university is also pleasant

55
00:02:25,310 --> 00:02:24,150
okay uh talk about construction since

56
00:02:26,950 --> 00:02:25,320
you're here you know about the

57
00:02:29,450 --> 00:02:26,960
construction but for the people on the

58
00:02:32,900 --> 00:02:29,460
watching this on the web if you come to

59
00:02:36,170 --> 00:02:32,910
visit us the road north of us is closed

60
00:02:38,150 --> 00:02:36,180
so you can see the map here this red

61
00:02:40,040 --> 00:02:38,160
stuff up here is closed if you try to

62
00:02:41,870 --> 00:02:40,050
come in here you won't be able to you

63
00:02:45,680 --> 00:02:41,880

have to come all the way around here and

64
00:02:48,130 --> 00:02:45,690
then back up to get to us all right

65
00:02:50,870 --> 00:02:48,140
if you want to know more about this here

66
00:02:53,210 --> 00:02:50,880
the website is here there's the website

67
00:02:55,640 --> 00:02:53,220
on the San Martin project this will

68
00:02:58,520 --> 00:02:55,650
probably last through next next month

69
00:03:01,190 --> 00:02:58,530
and will not be there in January we hope

70
00:03:05,180 --> 00:03:01,200
we don't know we'll let you know next

71
00:03:08,690 --> 00:03:05,190
month what the what the what the

72
00:03:11,180 --> 00:03:08,700
condition is okay all right let's see

73
00:03:13,310 --> 00:03:11,190
our website if you just search for

74
00:03:15,229 --> 00:03:13,320
Hubble public talks you should find this

75
00:03:17,979 --> 00:03:15,239
it has are a list of our upcoming

76
00:03:21,410 --> 00:03:17,989
lectures it has links to our online

77
00:03:23,900 --> 00:03:21,420
YouTube and webcasting and as well as

78
00:03:25,610 --> 00:03:23,910
the archives our playlists on YouTube

79
00:03:29,090 --> 00:03:25,620
and our archive from our wonderful

80
00:03:31,400 --> 00:03:29,100
webcasting folks there are ten years of

81
00:03:34,280 --> 00:03:31,410
these wonderful public lectures are

82
00:03:37,130 --> 00:03:34,290
there for you to peruse alright you can

83
00:03:39,080 --> 00:03:37,140
also sign up for our email list which

84
00:03:41,390 --> 00:03:39,090
will be helpful in December when we send

85
00:03:43,819 --> 00:03:41,400
out the email saying yes it's open no

86
00:03:48,259 --> 00:03:43,829
it's not open for the construction

87
00:03:49,910 --> 00:03:48,269
update okay we can also in these

88
00:03:52,970 --> 00:03:49,920

announcements can also be signed up at

89
00:03:55,250 --> 00:03:52,980
mail list at stsci de tu if you should

90
00:03:57,259 --> 00:03:55,260
so desire it's just much easier from our

91
00:03:59,930 --> 00:03:57,269
website if you would like to send us

92
00:04:04,449 --> 00:03:59,940
mail and Kev us a comment or question

93
00:04:07,729 --> 00:04:04,459
it's public lecture at STScI dot edu

94
00:04:11,900 --> 00:04:07,739
we're also on social media Facebook

95
00:04:14,630 --> 00:04:11,910
Twitter Google+ Pinterest I'm on

96
00:04:16,699 --> 00:04:14,640
Facebook and Google+ and Twitter and I

97
00:04:18,620 --> 00:04:16,709
have a blog on Hubbell site if you want

98
00:04:21,620 --> 00:04:18,630
to follow some of the things I like to

99
00:04:25,740 --> 00:04:21,630
talk about all right there will be no

100
00:04:28,320 --> 00:04:25,750
observatory tonight one it's cloudy

101
00:04:31,920 --> 00:04:28,330
and who we have a special treat for you

102
00:04:34,410 --> 00:04:31,930
tonight our speaker has invited you

103
00:04:36,270 --> 00:04:34,420
across the street to look at the Telus

104
00:04:39,630 --> 00:04:36,280
Lee the observatory that he's building

105
00:04:43,680 --> 00:04:39,640
the facility for the cosmology large

106
00:04:44,910 --> 00:04:43,690
angular scale surveyor so at the end of

107
00:04:47,610 --> 00:04:44,920
the lecture if you would like to go

108
00:04:50,280 --> 00:04:47,620
across Street to the facility hang

109
00:04:51,600 --> 00:04:50,290
around and and after Toby's finished

110
00:04:52,200 --> 00:04:51,610
answering his questions and put away his

111
00:04:53,910 --> 00:04:52,210
laptop

112
00:04:57,660 --> 00:04:53,920
we'll take you across the street for

113
00:04:58,320 --> 00:04:57,670

that okay all right now our news from

114
00:05:03,560 --> 00:04:58,330
the universe

115
00:05:08,930 --> 00:05:03,570
for November 2016 our top story tonight

116
00:05:13,350 --> 00:05:11,040
you knew I couldn't get through this

117
00:05:16,470 --> 00:05:13,360
without enough someone election pun in

118
00:05:20,580 --> 00:05:16,480
this right okay so what am I talking

119
00:05:23,880 --> 00:05:20,590
about well let's start back in 2004 with

120
00:05:26,370 --> 00:05:23,890
the Hubble Ultra Deep Field now this is

121
00:05:29,700 --> 00:05:26,380
a picture of lots and lots of galaxies

122
00:05:33,030 --> 00:05:29,710
how many galaxies well some of you may

123
00:05:35,159 --> 00:05:33,040
know but actually we do a educational

124
00:05:36,900 --> 00:05:35,169
activity where middle schoolers count

125
00:05:39,960 --> 00:05:36,910
all the galaxies in the Hubble Ultra

126
00:05:42,450 --> 00:05:39,970
Deep Field how do we do it well we

127
00:05:44,820 --> 00:05:42,460
divide it into a 100 smaller squares

128
00:05:47,460 --> 00:05:44,830
okay and then we have the middle

129
00:05:49,680 --> 00:05:47,470
schoolers look at these individual

130
00:05:52,140 --> 00:05:49,690
squares and then count the galaxies in

131
00:05:55,170 --> 00:05:52,150
them okay they usually come up with like

132
00:05:56,909 --> 00:05:55,180
50 or 70 galaxies in these and then if

133
00:05:59,490 --> 00:05:56,919
there are a hundred squares and they're

134
00:06:04,230 --> 00:05:59,500
say 50 galaxies in each how many are

135
00:06:07,380 --> 00:06:04,240
there total 50 times 100 5000 okay so

136
00:06:09,900 --> 00:06:07,390
they tend to get 5 10,000 galaxies or so

137
00:06:12,090 --> 00:06:09,910
in this and well 5 to 7,000 is what the

138
00:06:13,920 --> 00:06:12,100

middle schoolers usually estimate when

139
00:06:16,469 --> 00:06:13,930
you do it really carefully by

140
00:06:19,680 --> 00:06:16,479
astronomers they count about 10,000

141
00:06:22,920 --> 00:06:19,690
galaxies in this image now this is a

142
00:06:25,140 --> 00:06:22,930
really tiny image so if there are 10,000

143
00:06:27,900 --> 00:06:25,150
galaxies in this image how many are

144
00:06:30,180 --> 00:06:27,910
there in the entire universe well to do

145
00:06:32,310 --> 00:06:30,190
that you then have to know how big this

146
00:06:33,839 --> 00:06:32,320
is on the sky and so we walk the

147
00:06:36,180 --> 00:06:33,849
middle-schoolers through that part as

148
00:06:37,969 --> 00:06:36,190
well and we say that okay well here is

149
00:06:39,469 --> 00:06:37,979
the size of that Ultra Deep Field

150
00:06:41,810 --> 00:06:39,479
compared to the

151
00:06:44,400 --> 00:06:41,820
the size of the full moon on the sky

152
00:06:46,439 --> 00:06:44,410
alright and it's you know it's a small

153
00:06:49,980 --> 00:06:46,449
part of the full moon and the full moon

154
00:06:52,770 --> 00:06:49,990
itself is also a small part of the sky

155
00:06:55,290 --> 00:06:52,780
and if you do the mathematics

156
00:06:58,409 --> 00:06:55,300
alright the size of the Hubble lobe

157
00:07:01,560 --> 00:06:58,419
field compared to an entire sphere the

158
00:07:03,150 --> 00:07:01,570
number is across the entire sky there

159
00:07:04,530 --> 00:07:03,160
are twelve million seven hundred forty

160
00:07:06,870 --> 00:07:04,540
six thousand seven hundred and eighty

161
00:07:08,129 --> 00:07:06,880
four patches the same skies as the

162
00:07:11,790 --> 00:07:08,139
Hubble ultra-deep field

163
00:07:13,980 --> 00:07:11,800

okay so ten thousand galaxies now Hubble

164
00:07:15,990 --> 00:07:13,990
ultra-deep field twelve million

165
00:07:18,750 --> 00:07:16,000
Ultra Deep fields across the sky if it's

166
00:07:20,490 --> 00:07:18,760
representative then we get about a

167
00:07:22,230 --> 00:07:20,500
hundred and twenty billion galaxies

168
00:07:25,560 --> 00:07:22,240
across the night sky

169
00:07:28,200 --> 00:07:25,570
so using that Ultra Deep Field which we

170
00:07:30,390 --> 00:07:28,210
said we observed over a decade ago to

171
00:07:34,140 --> 00:07:30,400
the depth of the Ultra Deep Field there

172
00:07:36,840 --> 00:07:34,150
are roughly 100 billion galaxies in the

173
00:07:38,460 --> 00:07:36,850
universe okay and that has been sort of

174
00:07:40,200 --> 00:07:38,470
our standard number for number of

175
00:07:46,020 --> 00:07:40,210
galaxies in the universe for over a

176
00:07:49,650 --> 00:07:46,030
decade but what about the galaxies that

177
00:07:51,810 --> 00:07:49,660
Hubble doesn't see here's notice this

178
00:07:54,390 --> 00:07:51,820
says to the depth of the Hubble Ultra

179
00:07:56,339 --> 00:07:54,400
Deep Field there are things that Hubble

180
00:07:58,260 --> 00:07:56,349
doesn't see right they could be too

181
00:07:59,940 --> 00:07:58,270
faint for Hubble to see them or they

182
00:08:02,760 --> 00:07:59,950
could be too small for Hubble to see

183
00:08:06,060 --> 00:08:02,770
them or they could radiate in infrared

184
00:08:09,779 --> 00:08:06,070
or other wave bat'leth wavelengths that

185
00:08:12,360 --> 00:08:09,789
Hubble doesn't de see right so we

186
00:08:14,460 --> 00:08:12,370
recently had a paper called the

187
00:08:16,080 --> 00:08:14,470
evolution of the galaxy number density

188
00:08:18,089 --> 00:08:16,090

at Z less than eight and its

189
00:08:21,990 --> 00:08:18,099
implications which may not make much

190
00:08:24,180 --> 00:08:22,000
sense to you but the idea is to try and

191
00:08:26,120 --> 00:08:24,190
account for all the galaxies that we

192
00:08:30,000 --> 00:08:26,130
don't see in the Hubble ultra-deep field

193
00:08:32,940 --> 00:08:30,010
so here is the study and I'm gonna read

194
00:08:35,310 --> 00:08:32,950
this verbatim because it there's a lot

195
00:08:37,230 --> 00:08:35,320
to it Nautilus I think how many galaxies

196
00:08:40,649 --> 00:08:37,240
are potentially detectable within the

197
00:08:42,600 --> 00:08:40,659
universe if deep imaging over all

198
00:08:45,420 --> 00:08:42,610
wavelengths could be carried out in

199
00:08:47,699 --> 00:08:45,430
every location of the sky without any

200
00:08:50,460 --> 00:08:47,709
interference from the galaxies or other

201
00:08:53,310 --> 00:08:50,470
contamination so that covers all the

202
00:08:55,889 --> 00:08:53,320
things that I just said the entire sky

203
00:08:57,900 --> 00:08:55,899
in all wavelengths without any of this

204
00:08:59,819 --> 00:08:57,910
foreground contamination or stuff

205
00:09:01,410 --> 00:08:59,829
blocking right which you could see every

206
00:09:03,389 --> 00:09:01,420
single galaxy out there that's what this

207
00:09:07,079 --> 00:09:03,399
stuff this the study is trying to do

208
00:09:08,759 --> 00:09:07,089
okay what is a galaxy for them they say

209
00:09:11,430 --> 00:09:08,769
well they consider galaxies down to a

210
00:09:14,910 --> 00:09:11,440
million solar masses our Milky Way

211
00:09:17,490 --> 00:09:14,920
galaxy total mass is about 10 to the 12

212
00:09:20,069 --> 00:09:17,500
solar masses maybe 10 to the 11 solar

213
00:09:22,110 --> 00:09:20,079

masses and stars they're considering

214
00:09:24,180 --> 00:09:22,120
things much much much much smaller okay

215
00:09:26,189 --> 00:09:24,190
even the Large Magellanic Cloud is like

216
00:09:28,079 --> 00:09:26,199
a billion solar masses so this is one

217
00:09:29,699 --> 00:09:28,089
one thousandth of even you know our

218
00:09:31,050 --> 00:09:29,709
satellite galaxies so these are really

219
00:09:33,600 --> 00:09:31,060
down turn they're trying to look at the

220
00:09:36,540 --> 00:09:33,610
very smallest type stuff for galaxies

221
00:09:38,699 --> 00:09:36,550
and also they're looking at the number

222
00:09:40,199 --> 00:09:38,709
for per comoving volume I need to point

223
00:09:42,660 --> 00:09:40,209
this out because we're gonna talk about

224
00:09:45,300 --> 00:09:42,670
number density and we know the universe

225
00:09:47,009 --> 00:09:45,310
is expanding and so as the universe gets

226
00:09:51,240 --> 00:09:47,019
bigger of course we have fewer galaxies

227
00:09:52,860 --> 00:09:51,250
per volume right no not in this we're

228
00:09:55,110 --> 00:09:52,870
talking about what we call comoving

229
00:09:57,240 --> 00:09:55,120
volume so the expansion of the universe

230
00:09:59,009 --> 00:09:57,250
is already factored out okay so the

231
00:10:00,300 --> 00:09:59,019
densities are our Faculty of the

232
00:10:01,019 --> 00:10:00,310
expansion the universe has been factored

233
00:10:05,129 --> 00:10:01,029
out when we're talking about the

234
00:10:07,800 --> 00:10:05,139
densities here okay so this is the one

235
00:10:10,079 --> 00:10:07,810
of the key figures in their paper all

236
00:10:12,540 --> 00:10:10,089
right and this on the y-axis is the

237
00:10:15,780 --> 00:10:12,550
number density of galaxies all right and

238
00:10:17,879 --> 00:10:15,790

on the x-axis is time in billions of

239
00:10:20,759 --> 00:10:17,889
years all right starting at the Big Bang

240
00:10:23,790 --> 00:10:20,769
here up to almost the present day over

241
00:10:25,740 --> 00:10:23,800
here and there's lots and lots of points

242
00:10:29,970 --> 00:10:25,750
because they're trying to normalize it

243
00:10:32,579 --> 00:10:29,980
to data that as observed galaxy surveys

244
00:10:33,030 --> 00:10:32,589
looking deeply at the various galaxies

245
00:10:34,650 --> 00:10:33,040
in the universe

246
00:10:36,259 --> 00:10:34,660
counting up galaxies and they're trying

247
00:10:39,179 --> 00:10:36,269
to normalize their theoretical

248
00:10:41,730 --> 00:10:39,189
prediction to that and this solid line

249
00:10:44,460 --> 00:10:41,740
is their best fit to the model results

250
00:10:46,439 --> 00:10:44,470
and you'll note that it's down around

251
00:10:48,809 --> 00:10:46,449
point one for most of its length and

252
00:10:50,790 --> 00:10:48,819
then in the first billion years of the

253
00:10:54,540 --> 00:10:50,800
universe it jumps up by a factor of 10

254
00:10:57,780 --> 00:10:54,550
or more okay the number of galaxies per

255
00:11:02,460 --> 00:10:57,790
unit volume and the first billion years

256
00:11:05,100 --> 00:11:02,470
is much much larger than what we see out

257
00:11:06,809 --> 00:11:05,110
here and where are we going to see most

258
00:11:08,369 --> 00:11:06,819
of our galaxies with Hubble well

259
00:11:10,619 --> 00:11:08,379
we're gonna see them mostly out here

260
00:11:13,919 --> 00:11:10,629
that first billion years the universe is

261
00:11:16,799 --> 00:11:13,929
extremely difficult to look at okay

262
00:11:18,569 --> 00:11:16,809
so they're saying that we're missing a

263
00:11:20,549 --> 00:11:18,579

lot of galaxies over here because the

264
00:11:23,279 --> 00:11:20,559
number density is so high we're not

265
00:11:25,799 --> 00:11:23,289
seeing them they say that there are more

266
00:11:27,960 --> 00:11:25,809
low mass galaxies per massive galaxy at

267
00:11:30,599 --> 00:11:27,970
high redshifts than in the local

268
00:11:33,599 --> 00:11:30,609
universe by a large factor a factor of

269
00:11:35,989 --> 00:11:33,609
10 or so and the result is the total

270
00:11:39,599 --> 00:11:35,999
number of galaxies the universe is two

271
00:11:42,539 --> 00:11:39,609
trillion almost a factor of 10 higher

272
00:11:47,489 --> 00:11:42,549
than we would be seen in an all-sky

273
00:11:49,319 --> 00:11:47,499
survey @hud a depth so if we could do

274
00:11:52,499 --> 00:11:49,329
the Hubble ultra-deep field across the

275
00:11:55,049 --> 00:11:52,509
entire night sky they're still saying we

276
00:11:59,549 --> 00:11:55,059
would only see 10% of the galaxies in

277
00:12:02,969 --> 00:11:59,559
the universe kind of impressive huh all

278
00:12:05,279 --> 00:12:02,979
right I will caution however that's

279
00:12:06,779 --> 00:12:05,289
still it's a theoretical study it's not

280
00:12:09,779 --> 00:12:06,789
an observational study nobody has

281
00:12:12,210 --> 00:12:09,789
actually seen these galaxies okay so

282
00:12:15,840 --> 00:12:12,220
what questions does it bring up in an

283
00:12:18,379 --> 00:12:15,850
astrophysicists mind first of all are

284
00:12:21,210 --> 00:12:18,389
the extrapolations too low mass robust

285
00:12:23,549 --> 00:12:21,220
we have some good observations that go

286
00:12:26,309 --> 00:12:23,559
down to 10 to the seventh solar masses

287
00:12:27,689 --> 00:12:26,319
okay and they sort of disagree with some

288
00:12:30,749 --> 00:12:27,699

of these predictions but they sort of

289
00:12:32,939 --> 00:12:30,759
agree you find really good agreement up

290
00:12:34,379 --> 00:12:32,949
to like 10 to the 10th solar masses but

291
00:12:35,159 --> 00:12:34,389
when you start going below that you

292
00:12:36,509 --> 00:12:35,169
start getting a little bit of

293
00:12:38,519 --> 00:12:36,519
disagreement and here they're

294
00:12:41,129 --> 00:12:38,529
extrapolating down to 10 to the 6 solar

295
00:12:43,889 --> 00:12:41,139
masses so I'm not quite sure as I read

296
00:12:46,079 --> 00:12:43,899
the paper you know is it really robust

297
00:12:47,699 --> 00:12:46,089
down to 10 to the 6 you know it's a very

298
00:12:49,349 --> 00:12:47,709
good paper okay I'm not trying to knock

299
00:12:50,909 --> 00:12:49,359
it I'm just trying to give you ideas of

300
00:12:53,219 --> 00:12:50,919
what an astronomer thinks when they see

301
00:12:55,109 --> 00:12:53,229
things like this and then my second

302
00:12:57,359 --> 00:12:55,119
question would have been will Jay doest

303
00:12:58,590 --> 00:12:57,369
T be able to see these galaxies as you

304
00:13:01,769 --> 00:12:58,600
know we've got the James Webb Space

305
00:13:03,840 --> 00:13:01,779
Telescope launching in 2018 we're gonna

306
00:13:06,269 --> 00:13:03,850
be the scientific home of it here we

307
00:13:08,579 --> 00:13:06,279
want to know hey if there are all these

308
00:13:10,769 --> 00:13:08,589
if we're only seeing 10% of the galaxies

309
00:13:13,529 --> 00:13:10,779
in the universe can j2s t see those

310
00:13:17,729 --> 00:13:13,539
other 90% the answer is unfortunately

311
00:13:19,919 --> 00:13:17,739
not we're talking 10 to the 6 solar

312
00:13:20,400 --> 00:13:19,929
masses we're just getting too small for

313
00:13:25,079 --> 00:13:20,410

J 2 as

314
00:13:27,059 --> 00:13:25,089
t2c okay so we won't be able to verify

315
00:13:28,259 --> 00:13:27,069
this result with James Webb okay which

316
00:13:29,910 --> 00:13:28,269
is of course one of the things that we

317
00:13:32,850 --> 00:13:29,920
would love to be able to do around here

318
00:13:34,949 --> 00:13:32,860
but if this is true all right if this

319
00:13:38,150 --> 00:13:34,959
prediction is true we'll figure out some

320
00:13:40,439 --> 00:13:38,160
way to figure out how to constrain it

321
00:13:41,639 --> 00:13:40,449
with the James Webb Space Telescope or

322
00:13:44,610 --> 00:13:41,649
maybe even with later Hubble

323
00:13:46,079 --> 00:13:44,620
observations and then finally it brings

324
00:13:49,290 --> 00:13:46,089
up a question that's sort of a classic

325
00:13:52,170 --> 00:13:49,300
in my mind what really qualifies as a

326
00:13:53,490 --> 00:13:52,180
galaxy okay because we start talking

327
00:13:54,809 --> 00:13:53,500
about the early universe and we're

328
00:13:56,429 --> 00:13:54,819
talking about the building blocks that

329
00:13:58,619 --> 00:13:56,439
will come together to form what we

330
00:14:01,019 --> 00:13:58,629
considered a you know a real galaxy like

331
00:14:03,629 --> 00:14:01,029
this this is a real galaxy okay it's a

332
00:14:06,900 --> 00:14:03,639
nice big large galaxy all right but if

333
00:14:10,619 --> 00:14:06,910
you take something that is one 100,000

334
00:14:12,809 --> 00:14:10,629
the size of this okay is that does that

335
00:14:13,829 --> 00:14:12,819
get to count as a full galaxy all right

336
00:14:16,139 --> 00:14:13,839
so when we're talking about these

337
00:14:18,749 --> 00:14:16,149
numbers of a hundred billion versus two

338
00:14:21,480 --> 00:14:18,759

trillion galaxies we're talking about

339
00:14:23,579 --> 00:14:21,490
the evolution of galaxies over time the

340
00:14:25,499 --> 00:14:23,589
development of them from these small

341
00:14:29,009 --> 00:14:25,509
things to these big things than mergers

342
00:14:30,689 --> 00:14:29,019
you know you may have you know a

343
00:14:32,100 --> 00:14:30,699
trillion galaxies early on simply

344
00:14:34,290 --> 00:14:32,110
because so many of them merged together

345
00:14:38,400 --> 00:14:34,300
to form much smaller number later on

346
00:14:41,730 --> 00:14:38,410
right so you really you're getting into

347
00:14:44,340 --> 00:14:41,740
not just galaxies across space but

348
00:14:45,749 --> 00:14:44,350
galaxies across time it's a time warped

349
00:14:48,809 --> 00:14:45,759
view of the universe that you have to

350
00:14:51,269 --> 00:14:48,819
think about and do these small little

351
00:14:52,590 --> 00:14:51,279
objects you know there are what we would

352
00:14:56,759 --> 00:14:52,600
normally consider galaxies in the local

353
00:14:58,079 --> 00:14:56,769
universe does how much does it count and

354
00:15:00,150 --> 00:14:58,089
so you get some very interesting

355
00:15:01,800 --> 00:15:00,160
questions so this was a major press

356
00:15:04,170 --> 00:15:01,810
release for us this month got a lot of

357
00:15:06,990 --> 00:15:04,180
attention and I think it brings up some

358
00:15:09,780 --> 00:15:07,000
really great questions as to where we

359
00:15:11,999 --> 00:15:09,790
would want to look in cosmology for

360
00:15:13,290 --> 00:15:12,009
these very earliest galaxies in the

361
00:15:15,720 --> 00:15:13,300
universe and it brings up an amazing

362
00:15:17,220 --> 00:15:15,730
prospect that you know hey 90% of the

363
00:15:19,259 --> 00:15:17,230

galaxies out there still have yet to be

364
00:15:22,410 --> 00:15:19,269
discovered which is always fun as an

365
00:15:26,400 --> 00:15:22,420
astronomer alright our second story

366
00:15:30,509 --> 00:15:26,410
tonight the ghost of a star

367
00:15:33,900 --> 00:15:30,519
we had a Halloween release last week and

368
00:15:39,210 --> 00:15:33,910
I couldn't be happy with just this

369
00:15:52,200 --> 00:15:39,220
also called it a bootiful nebula so we

370
00:15:55,650 --> 00:15:52,210
released this image on Thursday tell you

371
00:15:57,360 --> 00:15:55,660
the story behind this image okay it's a

372
00:16:00,330 --> 00:15:57,370
signal filter image that was colored

373
00:16:04,860 --> 00:16:00,340
green actually so it's a broadband image

374
00:16:07,980 --> 00:16:04,870
a wave of wave band so it does actually

375
00:16:09,630 --> 00:16:07,990
have a green tinge to it but let me

376
00:16:12,090 --> 00:16:09,640
explain a little bit more about it okay

377
00:16:18,960 --> 00:16:12,100
so the story starts a little while ago

378
00:16:22,020 --> 00:16:18,970
on July 4th 1054 as you can read here if

379
00:16:24,900 --> 00:16:22,030
you read shine ancient chinese the

380
00:16:28,560 --> 00:16:24,910
chinese astronomers on July 4th 1054 saw

381
00:16:30,840 --> 00:16:28,570
a guest star appear in the sky

382
00:16:33,530 --> 00:16:30,850
I don't read Chinese so this could be

383
00:16:37,640 --> 00:16:33,540
recipe for moo shu pork as far as I know

384
00:16:42,210 --> 00:16:37,650
but I can look at the hieroglyphs in

385
00:16:44,310 --> 00:16:42,220
Chaco Canyon and here is the full here's

386
00:16:46,140 --> 00:16:44,320
the crescent moon and here is the guest

387
00:16:50,040 --> 00:16:46,150
star depicted there about a hands length

388
00:16:54,240 --> 00:16:50,050

away from the crescent moon on the sky

389
00:16:55,890 --> 00:16:54,250
which also is believed to depict this a

390
00:16:59,070 --> 00:16:55,900
guest star appearing in the sky a

391
00:17:01,440 --> 00:16:59,080
thousand years ago all right if it was

392
00:17:03,390 --> 00:17:01,450
in the constellation Taurus and when we

393
00:17:09,780 --> 00:17:03,400
look at the constellation Taurus today

394
00:17:12,780 --> 00:17:09,790
we see that the Crab Nebula ok what this

395
00:17:15,690 --> 00:17:12,790
was was a super nova explosion the

396
00:17:18,000 --> 00:17:15,700
explosion of a star becoming so bright

397
00:17:20,070 --> 00:17:18,010
that it could be seen during the daytime

398
00:17:23,640 --> 00:17:20,080
here on earth

399
00:17:26,100 --> 00:17:23,650
alright and this star the guts of it has

400
00:17:26,970 --> 00:17:26,110
blown across space at 10 million miles

401
00:17:29,070 --> 00:17:26,980
an hour

402
00:17:32,040 --> 00:17:29,080
for a thousand years and created this

403
00:17:36,020 --> 00:17:32,050
gorgeous nebula now this nebula is shown

404
00:17:38,520 --> 00:17:36,030
in three filters hydrogen nitrogen and

405
00:17:40,050 --> 00:17:38,530
the broadband a little bit of the

406
00:17:41,280 --> 00:17:40,060
broadband one that I think maybe it's

407
00:17:43,020 --> 00:17:41,290
hydrogen nitrogen oxygen and a little

408
00:17:45,600 --> 00:17:43,030
bit of the broadband and you can see all

409
00:17:47,580 --> 00:17:45,610
this film entery stuff out here well

410
00:17:48,000 --> 00:17:47,590
that's the narrow band filters that just

411
00:17:50,640 --> 00:17:48,010
put

412
00:17:52,830 --> 00:17:50,650
pull out the individual elements okay

413
00:17:57,000 --> 00:17:52,840

the ghost image that I showed you before

414
00:17:58,289 --> 00:17:57,010
when I overlay it on top is there all

415
00:18:00,330 --> 00:17:58,299
right so I'm gonna blink back and forth

416
00:18:04,220 --> 00:18:00,340
so here's the normal crab that we're

417
00:18:08,010 --> 00:18:04,230
used to and there's the ghost normal

418
00:18:10,980 --> 00:18:08,020
ghost normal you can look right in here

419
00:18:13,530 --> 00:18:10,990
you can see that stuff that's not filled

420
00:18:17,880 --> 00:18:13,540
in in the ghost all right so what we're

421
00:18:21,150 --> 00:18:17,890
seeing here with this wide ban why this

422
00:18:24,360 --> 00:18:21,160
broadband image is that it is filling in

423
00:18:26,010 --> 00:18:24,370
in much the sort of egg shape of all

424
00:18:27,930 --> 00:18:26,020
this all this filament restructure short

425
00:18:30,960 --> 00:18:27,940
um it creates an egg shape and the

426
00:18:33,030 --> 00:18:30,970
interior is filled in with this ghost

427
00:18:35,190 --> 00:18:33,040
image all right so here are the two

428
00:18:36,659 --> 00:18:35,200
images on the same scale just separated

429
00:18:39,060 --> 00:18:36,669
so you can take a look at them and you

430
00:18:40,799 --> 00:18:39,070
can see this blue image here roughly

431
00:18:44,010 --> 00:18:40,809
corresponds to the green that we

432
00:18:46,289 --> 00:18:44,020
released in the image on Friday but

433
00:18:49,020 --> 00:18:46,299
there's even more cool stuff in this

434
00:18:51,000 --> 00:18:49,030
image if we look straight in here in the

435
00:18:52,440 --> 00:18:51,010
interior you can see there's something

436
00:18:54,930 --> 00:18:52,450
funky going on in there

437
00:18:57,750 --> 00:18:54,940
well Hubble released an image of that

438
00:19:00,240 --> 00:18:57,760

previously this is the central region

439
00:19:02,250 --> 00:19:00,250
you see sort of ring structure here well

440
00:19:03,480 --> 00:19:02,260
that comes out beautifully when you look

441
00:19:06,480 --> 00:19:03,490
in x-rays with the Chandra x-ray

442
00:19:08,159 --> 00:19:06,490
telescope all right you have a beautiful

443
00:19:09,740 --> 00:19:08,169
ring structure here you have a bright

444
00:19:13,919 --> 00:19:09,750
dot in the center and you have this

445
00:19:17,549 --> 00:19:13,929
material being spewed off this is the

446
00:19:21,200 --> 00:19:17,559
dead star this is the stellar remnant it

447
00:19:23,400 --> 00:19:21,210
is a neutron star a ball of neutrons

448
00:19:28,680 --> 00:19:23,410
about the size of the Baltimore Beltway

449
00:19:31,650 --> 00:19:28,690
okay just all packed in spinning 30

450
00:19:33,630 --> 00:19:31,660
times a second we know it's spinning 30

451
00:19:36,570 --> 00:19:33,640
times a second because that neutron star

452
00:19:38,760 --> 00:19:36,580
has an immense magnetic field all right

453
00:19:41,010 --> 00:19:38,770
that creates pulses when that magnetic

454
00:19:43,110 --> 00:19:41,020
field sweeps across our line of view 30

455
00:19:47,250 --> 00:19:43,120
times a second we get pulses from this

456
00:19:49,560 --> 00:19:47,260
and hence we call it a pulsar so the

457
00:19:52,049 --> 00:19:49,570
Pulsar at the center of a Crab Nebula

458
00:19:54,299 --> 00:19:52,059
has this amazing magnetic field that's

459
00:19:56,820 --> 00:19:54,309
sweeping around 30 times a second which

460
00:20:01,320 --> 00:19:56,830
of course is creating tremendous amounts

461
00:20:02,850 --> 00:20:01,330
of energy so if you look at that

462
00:20:04,380 --> 00:20:02,860
polarize light and you're gonna learn a

463
00:20:05,600 --> 00:20:04,390

lot about polarized light tonight right

464
00:20:08,430 --> 00:20:05,610
Toby yes

465
00:20:11,640 --> 00:20:08,440
if you look at in polarized light you

466
00:20:13,920 --> 00:20:11,650
could actually see some of the pulsation

467
00:20:17,310 --> 00:20:13,930
some of the effects of the magnetic

468
00:20:21,450 --> 00:20:17,320
field this is a seer time-lapse series

469
00:20:23,850 --> 00:20:21,460
okay all right and you can see material

470
00:20:28,320 --> 00:20:23,860
flowing away from that central neutron

471
00:20:31,230 --> 00:20:28,330
star and it is a broadband image plus

472
00:20:33,990 --> 00:20:31,240
some polarized light in order to see the

473
00:20:36,420 --> 00:20:34,000
material flowing away all right and so

474
00:20:38,580 --> 00:20:36,430
in the Halloween spirit

475
00:20:41,430 --> 00:20:38,590
since we're Baltimore and Edgar Allan

476
00:20:44,190 --> 00:20:41,440
Poe is related here we called this the

477
00:20:47,730 --> 00:20:44,200
tell-tale heart or the beating heart of

478
00:20:50,220 --> 00:20:47,740
the ghost of the Crab Nebula so even

479
00:20:53,100 --> 00:20:50,230
though it's a dead star it still has a

480
00:20:58,410 --> 00:20:53,110
beating heart and that was our Halloween

481
00:21:01,560 --> 00:20:58,420
release for this year now to our

482
00:21:04,920 --> 00:21:01,570
featured speaker our speaker tonight is

483
00:21:06,810 --> 00:21:04,930
Toby marriage he is from the across the

484
00:21:10,110 --> 00:21:06,820
stree the Johns Hopkins University where

485
00:21:13,620 --> 00:21:10,120
he is an assistant professor he has been

486
00:21:16,620 --> 00:21:13,630
there for seven years after having come

487
00:21:18,390 --> 00:21:16,630
to us from Princeton University and he

488
00:21:21,180 --> 00:21:18,400

was kind of unusual that he was at

489
00:21:24,540 --> 00:21:21,190
Princeton for 14 years he just couldn't

490
00:21:26,340 --> 00:21:24,550
graduate no he did his undergraduate

491
00:21:28,140 --> 00:21:26,350
work at Princeton and then he did his

492
00:21:30,210 --> 00:21:28,150
graduate work at Princeton with a

493
00:21:32,490 --> 00:21:30,220
one-year hiatus at Cambridge in England

494
00:21:34,830 --> 00:21:32,500
right okay so you had to get out of

495
00:21:36,420 --> 00:21:34,840
Princeton for just one year but that's

496
00:21:39,720 --> 00:21:36,430
kind of unusual to be able to spend that

497
00:21:41,250 --> 00:21:39,730
long at one institution and obviously we

498
00:21:43,320 --> 00:21:41,260
are very fortunate to have him here in

499
00:21:58,430 --> 00:21:43,330
Baltimore ladies and gentlemen Toby

500
00:22:04,890 --> 00:22:00,470
you can hear me okay

501
00:22:08,700 --> 00:22:04,900
all right good back there all right I'll

502
00:22:11,820 --> 00:22:08,710
soon so okay great well it's a real

503
00:22:14,870 --> 00:22:11,830
pleasure to be here tonight this is a

504
00:22:17,760 --> 00:22:14,880
really excellent forum I mean I try to

505
00:22:21,269 --> 00:22:17,770
encourage my students to you know learn

506
00:22:23,159 --> 00:22:21,279
for the joy of learning as sort of for

507
00:22:25,500 --> 00:22:23,169
grades and I think this is a good

508
00:22:30,539 --> 00:22:25,510
example of people learning for the for

509
00:22:32,700 --> 00:22:30,549
the joy of learning so tonight I'm going

510
00:22:35,010 --> 00:22:32,710
to tell you about a project we have

511
00:22:37,549 --> 00:22:35,020
across the street at the department of

512
00:22:40,380 --> 00:22:37,559
physics and astronomy at johns hopkins

513
00:22:43,220 --> 00:22:40,390

called the cosmology large angular scale

514
00:22:47,370 --> 00:22:43,230
surveyor and i'm going to keep the talk

515
00:22:50,100 --> 00:22:47,380
relatively short and with the hope that

516
00:22:53,700 --> 00:22:50,110
some of you will join me for a tour of

517
00:22:57,810 --> 00:22:53,710
our telescope building facility across

518
00:23:00,899 --> 00:22:57,820
the street so I'm going to begin with

519
00:23:04,139 --> 00:23:00,909
the scientific goals of the of the of

520
00:23:06,389 --> 00:23:04,149
the cosmology large angular scale say a

521
00:23:09,990 --> 00:23:06,399
surveyor which from now on I'll referred

522
00:23:11,970 --> 00:23:10,000
to as his class so with class we're

523
00:23:13,669 --> 00:23:11,980
trying to end our primary the primary

524
00:23:18,210 --> 00:23:13,679
question we're trying to answer is this

525
00:23:23,700 --> 00:23:18,220
how did this happen so that is how did

526
00:23:24,990 --> 00:23:23,710
the universe happen and you know in

527
00:23:26,820 --> 00:23:25,000
order to answer that we need to

528
00:23:29,370 --> 00:23:26,830
essentially look back in time we need to

529
00:23:32,370 --> 00:23:29,380
but go back we need to be able to probe

530
00:23:36,720 --> 00:23:32,380
the earliest moments of the universe to

531
00:23:40,680 --> 00:23:36,730
say how did this all get started and the

532
00:23:43,889 --> 00:23:40,690
tool we astronomers have for that is is

533
00:23:46,080 --> 00:23:43,899
life of course so the light that we see

534
00:23:48,149 --> 00:23:46,090
on the sky is essentially a cosmic

535
00:23:50,940 --> 00:23:48,159
fossil record and this comes from the

536
00:23:53,669 --> 00:23:50,950
fact that it takes light time to travel

537
00:23:56,000 --> 00:23:53,679
to us from distant objects so if you

538
00:23:59,120 --> 00:23:56,010

consider for instance the Sun

539
00:24:01,310 --> 00:23:59,130
that takes it takes light eight minutes

540
00:24:04,580 --> 00:24:01,320
to reach us from the Sun so we're seeing

541
00:24:07,820 --> 00:24:04,590
the Sun as it was eight minutes ago if

542
00:24:09,680 --> 00:24:07,830
God forgive bid the Sun went out we

543
00:24:13,700 --> 00:24:09,690
wouldn't know to a pleasant eight

544
00:24:16,130 --> 00:24:13,710
minutes if you look further out of

545
00:24:18,740 --> 00:24:16,140
course you see stars those stars we're

546
00:24:22,550 --> 00:24:18,750
seeing as they were tens of years ago

547
00:24:24,680 --> 00:24:22,560
and look further out you get two nearby

548
00:24:26,590 --> 00:24:24,690
galaxies now you're now you're looking

549
00:24:29,930 --> 00:24:26,600
back in the past a million years

550
00:24:32,180 --> 00:24:29,940
millions of years look even further out

551
00:24:34,340 --> 00:24:32,190
you see the earlier galaxies in their

552
00:24:38,510 --> 00:24:34,350
universe you're looking back billions of

553
00:24:40,490 --> 00:24:38,520
years and if you look all the way back

554
00:24:43,310 --> 00:24:40,500
all the way back to before these

555
00:24:45,410 --> 00:24:43,320
galaxies formed you see a wall of light

556
00:24:47,840 --> 00:24:45,420
and that wall of light is called the

557
00:24:49,460 --> 00:24:47,850
Cosmic Microwave Background what's

558
00:24:51,710 --> 00:24:49,470
happened at this point is you've looked

559
00:24:54,410 --> 00:24:51,720
all the way back to the very earliest

560
00:24:58,940 --> 00:24:54,420
moments of the universe some 13.7

561
00:25:03,230 --> 00:24:58,950
billion years ago and at that point the

562
00:25:07,220 --> 00:25:03,240
universe was so dense that hydrogen

563
00:25:10,250 --> 00:25:07,230

which makes up most of the gas or normal

564
00:25:12,940 --> 00:25:10,260
particles in the universe was ionized

565
00:25:16,190 --> 00:25:12,950
and you just see this opaque plasma of

566
00:25:18,140 --> 00:25:16,200
photons and electrons and protons ooming

567
00:25:21,200 --> 00:25:18,150
around and so it just looks like a

568
00:25:24,320 --> 00:25:21,210
cosmic soup and if you look very closely

569
00:25:27,530 --> 00:25:24,330
with the contrast of better than one and

570
00:25:29,420 --> 00:25:27,540
a hundred thousand you'll see bumps in

571
00:25:32,420 --> 00:25:29,430
the brightness brightness and dark spots

572
00:25:33,830 --> 00:25:32,430
and this in this bright wall and that is

573
00:25:37,960 --> 00:25:33,840
what we study with the Cosmic Microwave

574
00:25:42,830 --> 00:25:37,970
Background this is how it all began and

575
00:25:44,930 --> 00:25:42,840
from this all of this formed so we have

576
00:25:47,810 --> 00:25:44,940
an answer we can look back in time we

577
00:25:51,380 --> 00:25:47,820
can use our time machine looking out is

578
00:25:54,800 --> 00:25:51,390
looking back and we can say that these

579
00:26:01,230 --> 00:25:54,810
came from this or to put it in pictures

580
00:26:06,240 --> 00:26:04,110
there's layers to everything so of

581
00:26:08,060 --> 00:26:06,250
course the next question is well how did

582
00:26:10,260 --> 00:26:08,070
this happen

583
00:26:13,710 --> 00:26:10,270
unfortunately you can't look past this

584
00:26:15,840 --> 00:26:13,720
wall in light and so we have to infer

585
00:26:19,590 --> 00:26:15,850
from our physics what happened before

586
00:26:22,529 --> 00:26:19,600
this what put this in place and one of

587
00:26:25,639 --> 00:26:22,539
the best theories we have for how this

588
00:26:29,370 --> 00:26:25,649

got there is called inflation theory and

589
00:26:31,970 --> 00:26:29,380
inflation theory posits that all of this

590
00:26:36,269 --> 00:26:31,980
structure in the very early universe

591
00:26:40,320 --> 00:26:36,279
grew from quantum fluctuations these are

592
00:26:43,590 --> 00:26:40,330
subatomic fluctuations that quantum

593
00:26:47,010 --> 00:26:43,600
physics says have to be there and the

594
00:26:49,200 --> 00:26:47,020
inflation theory posits that the early

595
00:26:52,380 --> 00:26:49,210
universe grew out of these random

596
00:26:57,060 --> 00:26:52,390
quantum fluctuations I know it sounds

597
00:27:00,690 --> 00:26:57,070
crazy but it explains a lot in addition

598
00:27:03,330 --> 00:27:00,700
to the bumps in the early universe that

599
00:27:07,200 --> 00:27:03,340
grew into galaxies inflation theory

600
00:27:11,460 --> 00:27:07,210
predicts that not only are there quantum

601
00:27:14,460 --> 00:27:11,470
fluctuations in this energy density that

602
00:27:17,880 --> 00:27:14,470
gives rise to gravitational wells that

603
00:27:21,659 --> 00:27:17,890
into which pool are matter and into

604
00:27:24,919 --> 00:27:21,669
which grow our galaxy's there are also

605
00:27:28,080 --> 00:27:24,929
cosmic fluctuations in space-time itself

606
00:27:31,049 --> 00:27:28,090
so space-time is rippling stretching

607
00:27:33,870 --> 00:27:31,059
squishing squashing in the early

608
00:27:37,789 --> 00:27:33,880
universe and these get blown up to

609
00:27:40,950 --> 00:27:37,799
cosmic scales as well and these become

610
00:27:42,690 --> 00:27:40,960
universe sized gravitational waves

611
00:27:45,779 --> 00:27:42,700
so the squishing and squashing of

612
00:27:50,330 --> 00:27:45,789
space-time writ large across the entire

613
00:27:56,639 --> 00:27:54,029

so speaking of squishing and squashing

614
00:27:59,130 --> 00:27:56,649
so this is a picture of a gravitational

615
00:28:02,010 --> 00:27:59,140
wave and what a gravitational wave does

616
00:28:05,039 --> 00:28:02,020
is it squashes space in one direction

617
00:28:08,789 --> 00:28:05,049
and it stretches it in the other so this

618
00:28:12,149 --> 00:28:08,799
is a little animation see if it works

619
00:28:14,340 --> 00:28:12,159
there we go so squish squash squish

620
00:28:18,539 --> 00:28:14,350
stretch squash etc

621
00:28:20,639 --> 00:28:18,549
so as you can see when it pulls in this

622
00:28:23,519 --> 00:28:20,649
direction it pushes in that direction

623
00:28:26,669 --> 00:28:23,529
and when it pushes in this direction it

624
00:28:28,409 --> 00:28:26,679
pulls in that direction so this is going

625
00:28:32,249 --> 00:28:28,419
to affect the light in the early

626
00:28:34,470 --> 00:28:32,259
universe and in particular what's going

627
00:28:36,769 --> 00:28:34,480
to happen is when you squish the Y when

628
00:28:40,590 --> 00:28:36,779
you squish space like this you're gonna

629
00:28:42,360 --> 00:28:40,600
you basically boost the CMB the Cosmic

630
00:28:44,100 --> 00:28:42,370
Microwave Background the light in the

631
00:28:46,169 --> 00:28:44,110
early universe you boost the light in

632
00:28:49,619 --> 00:28:46,179
that direction so you basically have you

633
00:28:53,180 --> 00:28:49,629
know light beams travelling in like this

634
00:28:57,779 --> 00:28:53,190
in the middle of a gravitational wave

635
00:28:59,759 --> 00:28:57,789
and what this does is it produces what

636
00:29:01,680 --> 00:28:59,769
happens is these light beams come in and

637
00:29:03,869 --> 00:29:01,690
they scatter they scatter off of that

638
00:29:08,249 --> 00:29:03,879

plasma in the early universe and then

639
00:29:10,169 --> 00:29:08,259
they come to us polarized so you're so

640
00:29:12,840 --> 00:29:10,179
you may be familiar with the

641
00:29:16,049 --> 00:29:12,850
polarization of light from say if you're

642
00:29:18,180 --> 00:29:16,059
a fishing and sunlight comes off it

643
00:29:19,409 --> 00:29:18,190
comes off the comes off the water and

644
00:29:23,009 --> 00:29:19,419
it's bright and you can put on your

645
00:29:25,769 --> 00:29:23,019
polarized sunglasses and and and and

646
00:29:29,669 --> 00:29:25,779
brought and block the glare from from

647
00:29:31,499 --> 00:29:29,679
the lake but and this this is exactly

648
00:29:35,850 --> 00:29:31,509
the same kind of thing there's another

649
00:29:39,659 --> 00:29:35,860
analogy again with sunlight in the sky

650
00:29:42,450 --> 00:29:39,669
so as sunlight passes through the

651
00:29:44,039 --> 00:29:42,460
atmosphere and it scatters it's actually

652
00:29:48,210 --> 00:29:44,049
ends up being polarized so you're

653
00:29:50,999 --> 00:29:48,220
outside on a nice day and especially as

654
00:29:53,129 --> 00:29:51,009
the sun's going going down towards the

655
00:29:56,629 --> 00:29:53,139
horizon you'll have a you'll have a

656
00:29:59,720 --> 00:29:56,639
clearer polarized pattern on the sky in

657
00:30:05,159 --> 00:29:59,730
particular here is is sort of

658
00:30:07,980 --> 00:30:05,169
schematically depicted the polarization

659
00:30:09,659 --> 00:30:07,990
here of the light is mostly vertical so

660
00:30:12,240 --> 00:30:09,669
the light oscillates in this direction

661
00:30:13,769 --> 00:30:12,250
and out here the scattered light

662
00:30:16,499 --> 00:30:13,779
oscillates in this direction and out

663
00:30:19,799 --> 00:30:16,509

here the light is relatively on

664
00:30:23,940 --> 00:30:19,809
polarized so if we apply a polarizing

665
00:30:26,700 --> 00:30:23,950
filter to this image such that we block

666
00:30:28,140 --> 00:30:26,710
that vertical polarization where we have

667
00:30:32,040 --> 00:30:28,150
vertically polarized light

668
00:30:34,440 --> 00:30:32,050
it's going to go dark and that's what

669
00:30:36,810 --> 00:30:34,450
you see so if you walked outside with a

670
00:30:39,060 --> 00:30:36,820
polarized filter on your eyes at this

671
00:30:40,920 --> 00:30:39,070
time you would actually see a dark band

672
00:30:43,860 --> 00:30:40,930
on the sky so you can go out in an

673
00:30:47,540 --> 00:30:43,870
experiment with this the skies actually

674
00:30:49,980 --> 00:30:47,550
ends up being polarized in this way and

675
00:30:50,610 --> 00:30:49,990
we're not the only ones that know about

676
00:31:00,330 --> 00:30:50,620
this

677
00:31:02,730 --> 00:31:00,340
polarization sensitive photoreceptors in

678
00:31:05,310 --> 00:31:02,740
their eyes and they can use this

679
00:31:09,180 --> 00:31:05,320
polarization effect to tell the other

680
00:31:12,630 --> 00:31:09,190
bees where to get palling they can tell

681
00:31:14,520 --> 00:31:12,640
east from north from west using the fact

682
00:31:17,160 --> 00:31:14,530
that the sky is polarized here towards

683
00:31:19,440 --> 00:31:17,170
the north and not towards the east so

684
00:31:21,120 --> 00:31:19,450
again the point here is that when you

685
00:31:28,050 --> 00:31:21,130
get scattering of light you get this

686
00:31:31,440 --> 00:31:28,060
polarization okay so just to realize so

687
00:31:35,490 --> 00:31:31,450
an analogy with scattered sunlight the

688
00:31:37,200 --> 00:31:35,500

CMB is scattered through polarization

689
00:31:41,910 --> 00:31:37,210
due to this gravitational wave

690
00:31:45,990 --> 00:31:41,920
enhancement good news for bees in the

691
00:31:47,360 --> 00:31:46,000
early universe no there weren't any bees

692
00:31:51,380 --> 00:31:47,370
in the earlier

693
00:31:56,240 --> 00:31:51,390
okay all right so but the point here is

694
00:31:58,610 --> 00:31:56,250
that gravitational waves produce this

695
00:32:01,130 --> 00:31:58,620
polarization in the CMB and we can go

696
00:32:02,920 --> 00:32:01,140
out and look for that in order to find

697
00:32:07,640 --> 00:32:02,930
evidence for these gravitational waves

698
00:32:10,760 --> 00:32:07,650
so to completely stretch my analogy to

699
00:32:13,060 --> 00:32:10,770
it's breaking strength the bees use the

700
00:32:16,250 --> 00:32:13,070
polarization of the Sun to find Paul and

701
00:32:18,320 --> 00:32:16,260
we use the polarization of the CMB to

702
00:32:23,360 --> 00:32:18,330
find the primordial gravitational waves

703
00:32:24,860 --> 00:32:23,370
from inflation all right so here we go

704
00:32:27,440 --> 00:32:24,870
so how do we do that we don't have

705
00:32:29,720 --> 00:32:27,450
photoreceptors that our polarization

706
00:32:31,550 --> 00:32:29,730
sensitive in our eyes to see the CMB we

707
00:32:35,150 --> 00:32:31,560
have to build telescopes and so that's

708
00:32:38,440 --> 00:32:35,160
what we're doing so this is class so

709
00:32:41,810 --> 00:32:38,450
this is a artist's rendition of class

710
00:32:43,010 --> 00:32:41,820
it's an array of four telescopes what

711
00:32:45,770 --> 00:32:43,020
you're looking at here are two

712
00:32:48,410 --> 00:32:45,780
structures two pedestals and on each

713
00:32:50,600 --> 00:32:48,420

pedestal there are two telescopes with

714
00:32:53,540 --> 00:32:50,610
beams looking at the sky through beams

715
00:32:59,420 --> 00:32:53,550
represented by these four these four

716
00:33:02,150 --> 00:32:59,430
green columns and in particular these

717
00:33:03,800 --> 00:33:02,160
telescopes operate at four different

718
00:33:06,560 --> 00:33:03,810
wavelengths or four different

719
00:33:08,690 --> 00:33:06,570
frequencies going from here at about a

720
00:33:10,910 --> 00:33:08,700
millimeter wavelength so these are very

721
00:33:13,820 --> 00:33:10,920
long frequencies compared to say optical

722
00:33:15,890 --> 00:33:13,830
light which is a micron so we're looking

723
00:33:18,500 --> 00:33:15,900
at millimeter wavelengths so this is a

724
00:33:20,120 --> 00:33:18,510
the this telescope here looks at a

725
00:33:22,370 --> 00:33:20,130
millimeter and two millimeter light

726
00:33:24,170 --> 00:33:22,380
these two telescopes look at light

727
00:33:26,780 --> 00:33:24,180
that's about three millimeters long and

728
00:33:29,210 --> 00:33:26,790
wavelength and this telescope looks like

729
00:33:30,890 --> 00:33:29,220
it looks at an even longer wavelength in

730
00:33:36,860 --> 00:33:30,900
this sort of six to seven millimeter

731
00:33:39,800 --> 00:33:36,870
range so so so for telescopes for

732
00:33:42,860 --> 00:33:39,810
frequencies in the middle of the Atacama

733
00:33:45,260 --> 00:33:42,870
Desert of northern Chile at 5200 meters

734
00:33:47,810 --> 00:33:45,270
and we'll have more on that on the site

735
00:33:49,670 --> 00:33:47,820
in a little bit but let's let's let's

736
00:33:53,240 --> 00:33:49,680
dig in a little bit to the design of the

737
00:33:57,020 --> 00:33:53,250
telescope so one first question is you

738
00:33:59,169 --> 00:33:57,030

know why for frequencies right and you

739
00:34:02,419 --> 00:33:59,179
know it's all about fruit

740
00:34:05,690 --> 00:34:02,429
but it's a good analogy so basically

741
00:34:07,930 --> 00:34:05,700
these frequencies of in the microwave

742
00:34:10,309 --> 00:34:07,940
the frequencies were looking at

743
00:34:11,780 --> 00:34:10,319
correspond to colors now if you're

744
00:34:13,849 --> 00:34:11,790
looking at the sky

745
00:34:15,559 --> 00:34:13,859
or any other picture without color if

746
00:34:18,349 --> 00:34:15,569
you're looking at stuff that looks

747
00:34:23,389 --> 00:34:18,359
similar say an orange a lime and a lemon

748
00:34:26,510 --> 00:34:23,399
or is it a lime and orange and well I

749
00:34:28,909 --> 00:34:26,520
can't tell because there's not color but

750
00:34:31,399 --> 00:34:28,919
but yeah so so the point here is that

751
00:34:33,520 --> 00:34:31,409
without colors it's hard to tell things

752
00:34:37,069 --> 00:34:33,530
apart both on the sky and in real life

753
00:34:39,290 --> 00:34:37,079
so you add colors and you can tell your

754
00:34:41,149 --> 00:34:39,300
oranges from your lemons or in our game

755
00:34:42,980 --> 00:34:41,159
you can tell the Cosmic Microwave

756
00:34:46,190 --> 00:34:42,990
Background from other sources of

757
00:34:48,440 --> 00:34:46,200
microwave radiation mainly from our

758
00:34:53,869 --> 00:34:48,450
galaxy you're talking about a mission

759
00:34:58,160 --> 00:34:53,879
from hot from warm dust and/or a mission

760
00:35:00,800 --> 00:34:58,170
from light via mission you saw from the

761
00:35:03,920 --> 00:35:00,810
Crab Nebula from accelerated electrons

762
00:35:06,589 --> 00:35:03,930
in any case you want to be able to you

763
00:35:09,800 --> 00:35:06,599

basically what we you know just like you

764
00:35:12,079 --> 00:35:09,810
need red blue and green in this picture

765
00:35:17,240 --> 00:35:12,089
to tell these fruit apart

766
00:35:19,460 --> 00:35:17,250
we need 40 gigahertz 90 gigahertz 150

767
00:35:23,240 --> 00:35:19,470
gigahertz and 220 gigahertz in order to

768
00:35:26,210 --> 00:35:23,250
tell the dust apart from the cosmic

769
00:35:27,890 --> 00:35:26,220
microwave background so that's why we

770
00:35:29,960 --> 00:35:27,900
have the four frequencies is basically

771
00:35:32,510 --> 00:35:29,970
to make a color picture of the sky to

772
00:35:34,400 --> 00:35:32,520
know that what we're looking at is

773
00:35:36,579 --> 00:35:34,410
actually the is actually this

774
00:35:42,020 --> 00:35:36,589
polarization signature from primordial

775
00:35:44,089 --> 00:35:42,030
gravitational waves all right so let's

776
00:35:45,890 --> 00:35:44,099
look under the hood all right so this is

777
00:35:48,859 --> 00:35:45,900
one of the telescopes and all the

778
00:35:50,120 --> 00:35:48,869
telescopes look look similar but Optima

779
00:35:52,970 --> 00:35:50,130
but operate at these different

780
00:35:55,990 --> 00:35:52,980
frequencies so let's follow the light so

781
00:35:58,640 --> 00:35:56,000
the light enters the telescope here and

782
00:36:00,260 --> 00:35:58,650
the light comes in and it reflects off

783
00:36:02,450 --> 00:36:00,270
of this thing color that I've got

784
00:36:04,849 --> 00:36:02,460
labeled here as the BPM the stands for

785
00:36:06,410 --> 00:36:04,859
variable delay polarization modulator

786
00:36:07,640 --> 00:36:06,420
and let's just leave that for now I'm

787
00:36:10,789 --> 00:36:07,650
going to talk a lot about that later

788
00:36:12,190 --> 00:36:10,799

because this is really really what makes

789
00:36:15,140 --> 00:36:12,200
class special

790
00:36:17,990 --> 00:36:15,150
but let's just let the light reflect off

791
00:36:21,200 --> 00:36:18,000
of that now it bounces off of the it

792
00:36:24,260 --> 00:36:21,210
reflects off these mirrors primary

793
00:36:27,860 --> 00:36:24,270
secondary and the light travels into

794
00:36:29,780 --> 00:36:27,870
this into this what we call a cryogenic

795
00:36:32,240 --> 00:36:29,790
receiver which in the sense that it

796
00:36:36,050 --> 00:36:32,250
receives the light cryogenic in the

797
00:36:39,290 --> 00:36:36,060
sense that it's cold and it goes through

798
00:36:42,650 --> 00:36:39,300
these cryogenic lenses this lens sits at

799
00:36:43,550 --> 00:36:42,660
4 Kelvin so for 4 degrees above absolute

800
00:36:46,160 --> 00:36:43,560
zero

801
00:36:49,040 --> 00:36:46,170
this lens sits at 1 Kelvin and it

802
00:36:50,810 --> 00:36:49,050
finally reaches our detectors that's it

803
00:36:53,120 --> 00:36:50,820
in the focal plane of the telescope and

804
00:36:55,370 --> 00:36:53,130
these are only one tenth of a Kelvin

805
00:36:58,760 --> 00:36:55,380
above absolute zero we need them to be

806
00:37:01,580 --> 00:36:58,770
that cold because the signal that we're

807
00:37:03,650 --> 00:37:01,590
looking at is exceptionally faint and if

808
00:37:06,650 --> 00:37:03,660
we have thermal fluctuations that are

809
00:37:08,720 --> 00:37:06,660
say the level of thermal fluctuations in

810
00:37:10,730 --> 00:37:08,730
this room then the noise from those

811
00:37:12,680 --> 00:37:10,740
thermal fluctuations completely swamp

812
00:37:15,040 --> 00:37:12,690
our signal so that's why we need to cool

813
00:37:17,540 --> 00:37:15,050

our detectors so cold

814
00:37:21,310 --> 00:37:17,550
zooming into the detectors here they are

815
00:37:23,720 --> 00:37:21,320
these are actually microfabricated

816
00:37:25,370 --> 00:37:23,730
detectors that are made just down the

817
00:37:27,680 --> 00:37:25,380
street at NASA Goddard Space Flight

818
00:37:29,540 --> 00:37:27,690
Center and we collaborate with the

819
00:37:35,360 --> 00:37:29,550
scientists there to build these

820
00:37:38,090 --> 00:37:35,370
detectors all right so I promise I

821
00:37:41,960 --> 00:37:38,100
talked about this BPM or this variable

822
00:37:44,180 --> 00:37:41,970
delay polarization modulator so the BPM

823
00:37:46,610 --> 00:37:44,190
is it shown here it's about 60

824
00:37:48,200 --> 00:37:46,620
centimeters across and what you're

825
00:37:51,320 --> 00:37:48,210
looking at here you can sort of see a

826
00:37:54,380 --> 00:37:51,330
haze in front of the circular circular

827
00:37:56,690 --> 00:37:54,390
mirror that haze is about a few

828
00:37:58,850 --> 00:37:56,700
kilometers worth of a hundred micron

829
00:38:03,110 --> 00:37:58,860
wire stretched to its breaking strength

830
00:38:04,640 --> 00:38:03,120
and separated by about as much space so

831
00:38:07,100 --> 00:38:04,650
you know the few kilometers of wire

832
00:38:11,390 --> 00:38:07,110
stretched in the 60 cent is centimeter

833
00:38:15,560 --> 00:38:11,400
aperture and supported by this frame and

834
00:38:19,570 --> 00:38:15,570
if you add a few tons of force in it so

835
00:38:22,370 --> 00:38:19,580
the idea here is that this wire grid

836
00:38:23,560 --> 00:38:22,380
reflects one polarization because the

837
00:38:29,700 --> 00:38:23,570
grids in one direction

838
00:38:34,360 --> 00:38:32,860

that's the group that's that's the VP

839
00:38:36,700 --> 00:38:34,370
I'm deployed in the field with its

840
00:38:39,370 --> 00:38:36,710
creator Katie she's a she's a graduate

841
00:38:41,470 --> 00:38:39,380
student over and in our labs but this is

842
00:38:43,540 --> 00:38:41,480
she spent about three months up in the

843
00:38:52,060 --> 00:38:43,550
desert and this was this is a good

844
00:38:53,560 --> 00:38:52,070
moment for her okay so okay so to say

845
00:38:56,050 --> 00:38:53,570
what's going on with this polarization

846
00:38:58,450 --> 00:38:56,060
modulator a little bit more

847
00:39:01,780 --> 00:38:58,460
schematically here's that wire grid that

848
00:39:05,170 --> 00:39:01,790
kilometer worth of wires stretched in a

849
00:39:07,240 --> 00:39:05,180
comb like this and we have the mirror

850
00:39:10,150 --> 00:39:07,250
right up against the wires and what

851
00:39:12,340 --> 00:39:10,160
we're going to do is we're going to move

852
00:39:17,710 --> 00:39:12,350
that mirror and this is what the VPM

853
00:39:20,410 --> 00:39:17,720
does it has a very tense wire grid in

854
00:39:22,390 --> 00:39:20,420
front and it has a mirror that sits

855
00:39:24,880 --> 00:39:22,400
behind it and moves back and forth and

856
00:39:27,070 --> 00:39:24,890
so what you can see is happening here is

857
00:39:29,890 --> 00:39:27,080
that one polarization state the

858
00:39:32,560 --> 00:39:29,900
polarization state that's like this is

859
00:39:34,600 --> 00:39:32,570
transmitting through the wire grid going

860
00:39:38,020 --> 00:39:34,610
to the mirror and the other polarization

861
00:39:41,430 --> 00:39:38,030
state is is is reflecting off the grid

862
00:39:44,050 --> 00:39:41,440
and so in this way we separate in phase

863
00:39:49,300 --> 00:39:44,060

one polarization state from the other

864
00:39:51,930 --> 00:39:49,310
and we move this mirror at about ten ten

865
00:39:55,360 --> 00:39:51,940
Hertz so up and down ten times a second

866
00:39:59,740 --> 00:39:55,370
and in this way we modulate this

867
00:40:03,160 --> 00:39:59,750
polarization signal so the picture is

868
00:40:04,630 --> 00:40:03,170
this we have this we have the signal

869
00:40:06,700 --> 00:40:04,640
coming in from the CMB

870
00:40:09,160 --> 00:40:06,710
and we run it through this variable

871
00:40:11,140 --> 00:40:09,170
delay polarization modulator and we move

872
00:40:13,510 --> 00:40:11,150
that mirror up and down and so the

873
00:40:15,790 --> 00:40:13,520
signal gets encoded at this ten Hertz

874
00:40:19,510 --> 00:40:15,800
frequency at this high frequency and

875
00:40:21,600 --> 00:40:19,520
then you have this noise from from the

876
00:40:25,090 --> 00:40:21,610
telescope and from say the atmosphere

877
00:40:26,920 --> 00:40:25,100
that on which this this frequency rides

878
00:40:29,200 --> 00:40:26,930
so this is a little bit like your car

879
00:40:31,720 --> 00:40:29,210
radius you can tune in to a station and

880
00:40:33,040 --> 00:40:31,730
hear a signal you turn it tune a little

881
00:40:35,500 --> 00:40:33,050
bit to the right from that station all

882
00:40:36,580 --> 00:40:35,510
you hear is fuzz and so this is what

883
00:40:39,430 --> 00:40:36,590
we're doing we're two

884
00:40:41,560 --> 00:40:39,440
we're basically putting our using this

885
00:40:44,050 --> 00:40:41,570
variable delay polarization modulator

886
00:40:46,540 --> 00:40:44,060
where we're putting our cosmic microwave

887
00:40:50,230 --> 00:40:46,550
background signal at a specific

888
00:40:54,210 --> 00:40:50,240

frequency that's away from our noise so

889
00:40:56,320 --> 00:40:54,220
I've designed a look at we we've we've

890
00:41:00,130 --> 00:40:56,330
we've created a little audio

891
00:41:02,380 --> 00:41:00,140
demonstration of this soso which will

892
00:41:03,700 --> 00:41:02,390
sort of demonstrate how this how this

893
00:41:06,730 --> 00:41:03,710
techniques work and it techniques

894
00:41:10,480 --> 00:41:06,740
technique works so the cosmic microwave

895
00:41:13,120 --> 00:41:10,490
background polarization is going to be

896
00:41:15,100 --> 00:41:13,130
represented by a voice here and we're

897
00:41:16,900 --> 00:41:15,110
going to show how that can get drowned

898
00:41:18,910 --> 00:41:16,910
out but then when you move it to a

899
00:41:21,070 --> 00:41:18,920
higher frequency you'll be able to hear

900
00:41:24,610 --> 00:41:21,080
it despite the noise so let's let's see

901
00:41:27,850 --> 00:41:24,620
how this goes so here's the signal the

902
00:41:40,450 --> 00:41:27,860
cosmic microwave background polarization

903
00:41:43,030 --> 00:41:40,460
okay and here's the noise now we put

904
00:41:51,250 --> 00:41:43,040
them together and it's gonna be hard to

905
00:41:52,780 --> 00:41:51,260
hear this signal hard to hear the signal

906
00:42:00,580 --> 00:41:52,790
now we're going to boost the signal a

907
00:42:11,560 --> 00:42:00,590
higher frequency okay now we're gonna

908
00:42:17,020 --> 00:42:14,950
that's exactly our class works so we

909
00:42:18,520 --> 00:42:17,030
take that we take the we we take this

910
00:42:20,830 --> 00:42:18,530
this signal that what other bye

911
00:42:23,710 --> 00:42:20,840
otherwise be you know a low frequency

912
00:42:25,900 --> 00:42:23,720
like my voice and drowned in this low

913
00:42:28,660 --> 00:42:25,910

frequency noise and we boost it to this

914
00:42:30,250 --> 00:42:28,670
higher frequency using that BPM and then

915
00:42:32,110 --> 00:42:30,260
we can disentangle that from the noise

916
00:42:35,290 --> 00:42:32,120
just like your ear could disentangle the

917
00:42:38,110 --> 00:42:35,300
higher frequency signal from the low

918
00:42:43,090 --> 00:42:38,120
frequency noise this is very good

919
00:42:46,270 --> 00:42:43,100
analogy okay so we build this thing and

920
00:42:47,950 --> 00:42:46,280
then what do we do so the first step is

921
00:42:50,530 --> 00:42:47,960
you know we bring this all together we

922
00:42:57,370 --> 00:42:50,540
put the vpm on the telescope over in in

923
00:43:02,200 --> 00:42:57,380
in in the physics department that's step

924
00:43:04,860 --> 00:43:02,210
one step two we tear it down and put it

925
00:43:07,810 --> 00:43:04,870
into containers shipping containers and

926
00:43:11,170 --> 00:43:07,820
then we put it on a boat in Baltimore

927
00:43:13,990 --> 00:43:11,180
Harbor and that boat goes down goes

928
00:43:15,430 --> 00:43:14,000
through the Panama Canal and to a port

929
00:43:20,110 --> 00:43:15,440
in northern Chile

930
00:43:22,240 --> 00:43:20,120
and then the put it on trucks and then

931
00:43:27,370 --> 00:43:22,250
we truck it up to the site at 5200

932
00:43:31,180 --> 00:43:27,380
meters here and install it so and to

933
00:43:33,670 --> 00:43:31,190
zoom into the site so here's our site so

934
00:43:35,830 --> 00:43:33,680
this is this is basically completely

935
00:43:38,920 --> 00:43:35,840
isolated we have to have our own

936
00:43:41,880 --> 00:43:38,930
generators have our fuel delivered this

937
00:43:44,230 --> 00:43:41,890
was installed by you know you know

938
00:43:47,940 --> 00:43:44,240

postdocs graduate students and the

939
00:43:50,590 --> 00:43:47,950
occasional professor this is we

940
00:43:52,660 --> 00:43:50,600
contracted a company to put in these and

941
00:43:56,290 --> 00:43:52,670
put in these and putting these slabs and

942
00:43:57,880 --> 00:43:56,300
put in some put in some conduit but it

943
00:43:59,470 --> 00:43:57,890
was the students pulling the power

944
00:44:01,530 --> 00:43:59,480
cables through these conduit and

945
00:44:04,450 --> 00:44:01,540
connecting these these these these

946
00:44:07,690 --> 00:44:04,460
telescopes so this is the first

947
00:44:10,480 --> 00:44:07,700
telescope that 40 gigahertz telescope in

948
00:44:12,280 --> 00:44:10,490
the in the desert and you can see what

949
00:44:13,750 --> 00:44:12,290
we've done is we've retrofitted some of

950
00:44:15,550 --> 00:44:13,760
these shipping containers to be our

951
00:44:20,770 --> 00:44:15,560
control room our machine shop or

952
00:44:27,700 --> 00:44:25,180
again I yeah and hey and and it's very

953
00:44:30,010 --> 00:44:27,710
excited back in May to get our our first

954
00:44:31,480 --> 00:44:30,020
light this is when the telescope first

955
00:44:34,030 --> 00:44:31,490
sees something in our case it was the

956
00:44:38,110 --> 00:44:34,040
moon which you know we confirmed it was

957
00:44:40,360 --> 00:44:38,120
there it's good but we were mainly just

958
00:44:42,010 --> 00:44:40,370
excited to see the detectors light up of

959
00:44:46,020 --> 00:44:42,020
course and and we've been we've been

960
00:44:48,640 --> 00:44:46,030
making cosmological observations sense

961
00:44:50,670 --> 00:44:48,650
and and one thing I really want to

962
00:44:56,410 --> 00:44:50,680
emphasize here is that it really is a

963
00:44:59,800 --> 00:44:56,420

student and young scientist training

964
00:45:05,080 --> 00:44:59,810
training ground these guys do so much

965
00:45:08,470 --> 00:45:05,090
and you they really are the engine for

966
00:45:13,870 --> 00:45:08,480
this project and a lot of these folks

967
00:45:17,080 --> 00:45:13,880
are over here across the street and so I

968
00:45:20,380 --> 00:45:17,090
wanted to leave you with a little bit of

969
00:45:24,040 --> 00:45:20,390
a so I said a few things about the site

970
00:45:26,440 --> 00:45:24,050
but I wanted to play something for you

971
00:45:28,090 --> 00:45:26,450
that we made this summer that gives you

972
00:45:30,640 --> 00:45:28,100
an even better idea of our of our

973
00:45:33,250 --> 00:45:30,650
operations of our operations out there

974
00:45:41,470 --> 00:45:33,260
so this is about a few couple minute

975
00:45:43,750 --> 00:45:41,480
video and then we'll wrap up welcome to

976
00:45:46,840 --> 00:45:43,760
the class low altitude headquarters in

977
00:45:49,780 --> 00:45:46,850
san pedro de atacama chile at 2,400

978
00:45:52,840 --> 00:45:49,790
meters or 8000 feet this is where the

979
00:45:55,360 --> 00:45:52,850
class team eats and sleeps above me you

980
00:45:57,660 --> 00:45:55,370
can see the radio link that the class

981
00:46:00,490 --> 00:45:57,670
team uses to talk to the mountain site

982
00:46:03,610 --> 00:46:00,500
they use this link to beam down data and

983
00:46:06,910 --> 00:46:03,620
also to control the telescope's san

984
00:46:09,070 --> 00:46:06,920
pedro de atacama chile the rural oasis

985
00:46:11,530 --> 00:46:09,080
town in the middle of the Atacama Desert

986
00:46:14,350 --> 00:46:11,540
it has striking geological features such

987
00:46:16,660 --> 00:46:14,360
as that which you see behind me this is

988
00:46:21,140 --> 00:46:16,670

the landscape on the drive up to the

989
00:46:31,820 --> 00:46:24,750
this is Sarah toko this is the mountain

990
00:46:38,630 --> 00:46:35,510
Sara toko is an extinct volcano there

991
00:46:41,240 --> 00:46:38,640
used to be a sulfur mine on saratoga but

992
00:46:44,570 --> 00:46:41,250
now it's dedicated to observations of

993
00:46:48,480 --> 00:46:44,580
the Cosmic Microwave Background or C and

994
00:46:55,349 --> 00:46:50,540
welcome to the class high-altitude

995
00:46:58,050 --> 00:46:55,359
mountain site at 5200 meters this is the

996
00:47:00,720 --> 00:46:58,060
first of four class telescopes which was

997
00:47:03,240 --> 00:47:00,730
installed in the spring of 2016

998
00:47:07,050 --> 00:47:03,250
this telescope scans the sky as you can

999
00:47:09,180 --> 00:47:07,060
see here as the telescope scans the

1000
00:47:11,730 --> 00:47:09,190
light from the CMB enters the cone at

1001
00:47:13,980 --> 00:47:11,740
the top of the telescope reflects off of

1002
00:47:16,920 --> 00:47:13,990
mirrors and is focused onto cryogenic

1003
00:47:18,000 --> 00:47:16,930
detectors operating in near absolute

1004
00:47:21,660 --> 00:47:18,010
zero temperature

1005
00:47:24,810 --> 00:47:21,670
this telescope scans the sky night and

1006
00:47:27,690 --> 00:47:24,820
day in order to make a map we search

1007
00:47:29,400 --> 00:47:27,700
this map for the faint signal in the

1008
00:47:32,520 --> 00:47:29,410
polarization of the Cosmic Microwave

1009
00:47:36,030 --> 00:47:32,530
Background from gravitational radiation

1010
00:47:39,510 --> 00:47:36,040
in the early universe which can tell us

1011
00:47:42,270 --> 00:47:39,520
how the universe began from this

1012
00:47:45,000 --> 00:47:42,280
perspective you can see the entire last

1013
00:47:46,500 --> 00:47:45,010

sight to my right is the telescope

1014
00:47:49,200 --> 00:47:46,510
scanning the CMB

1015
00:47:50,880 --> 00:47:49,210
you can see into the cone at the top of

1016
00:47:54,180 --> 00:47:50,890
the telescope into which the light

1017
00:47:56,520 --> 00:47:54,190
enters to the right of the telescope you

1018
00:47:59,730 --> 00:47:56,530
see our control room our laboratory

1019
00:48:02,609 --> 00:47:59,740
container machine-shop container where

1020
00:48:06,300 --> 00:48:02,619
we put together the telescope so this is

1021
00:48:08,579 --> 00:48:06,310
Denise paya and manwich and they're the

1022
00:48:11,760 --> 00:48:08,589
engineers that operate the class

1023
00:48:14,280 --> 00:48:11,770
telescope they're here year-round Denise

1024
00:48:18,440 --> 00:48:14,290
just graduated from the federal

1025
00:48:21,780 --> 00:48:18,450
University of ouro preto in Brazil and

1026
00:48:25,039 --> 00:48:21,790
man way just graduated from Johns

1027
00:48:30,620 --> 00:48:27,049
Denise how the cryogenic temperatures

1028
00:48:35,449 --> 00:48:30,630
good 30 meter Kelvin what are their

1029
00:48:37,399 --> 00:48:35,459
colors ready 30 degrees all right

1030
00:48:55,440 --> 00:48:37,409
another good day at the site let's go

1031
00:49:03,760 --> 00:49:02,110
all right so this is just starting we

1032
00:49:06,070 --> 00:49:03,770
just moved that first telescope out we

1033
00:49:08,260 --> 00:49:06,080
got another three telescopes to deploy

1034
00:49:11,500 --> 00:49:08,270
over the next couple years the survey

1035
00:49:42,200 --> 00:49:11,510
goes for five years so you can follow us

1036
00:49:50,160 --> 00:49:45,480
no no it's a pretty compact site so so

1037
00:49:51,900 --> 00:49:50,170
it's within that fenced area so so the

1038
00:49:53,760 --> 00:49:51,910

the second telescope actually goes on

1039
00:49:55,650 --> 00:49:53,770
the same pedestal as the one you saw

1040
00:50:04,020 --> 00:49:55,660
there and we'll be shipping out the

1041
00:50:09,089 --> 00:50:04,030
other pedestal next year well this look

1042
00:50:12,990 --> 00:50:09,099
like Nova didn't it no no we've had

1043
00:50:15,630 --> 00:50:13,000
we've we've enjoyed some work with the

1044
00:50:18,240 --> 00:50:15,640
Sun and and and other and other media

1045
00:50:21,930 --> 00:50:18,250
outlets but not over yet we're working

1046
00:50:25,620 --> 00:50:21,940
on yeah yeah there's there's a lot of

1047
00:50:27,960 --> 00:50:25,630
great stuff going on so yeah okay so

1048
00:50:29,339 --> 00:50:27,970
that may have been right next door it's

1049
00:50:33,690 --> 00:50:29,349
the most expensive ground-based

1050
00:50:35,970 --> 00:50:33,700
telescope in the in in the world it's

1051
00:50:38,700 --> 00:50:35,980
called the Atacama Large millimeter

1052
00:50:42,660 --> 00:50:38,710
Array or Alma and it's a six it's sixty

1053
00:50:44,730 --> 00:50:42,670
dishes not four and the yeah they do

1054
00:50:48,870 --> 00:50:44,740
they do wonderful stuff all the way from

1055
00:50:52,829 --> 00:50:48,880
study hi high-redshift galaxies to look

1056
00:50:56,250 --> 00:50:52,839
for you know you know the discs out from

1057
00:50:59,010 --> 00:50:56,260
which out of which planets form so it's

1058
00:51:01,109 --> 00:50:59,020
there's a lot going on out there so I

1059
00:51:03,150 --> 00:51:01,119
said the site is isolated and it is

1060
00:51:18,830 --> 00:51:03,160
quite isolated but we do have other a

1061
00:51:24,000 --> 00:51:22,770
exactly we need to I always forget we

1062
00:51:26,250 --> 00:51:24,010
need to repeat the questions for the

1063
00:51:27,780 --> 00:51:26,260

folks on the website la webcast can hear

1064
00:51:29,760 --> 00:51:27,790
the questions okay sounds good sounds

1065
00:51:31,290 --> 00:51:29,770
good is it oh that's great so the

1066
00:51:34,380 --> 00:51:31,300
question is given the four frequencies

1067
00:51:37,859 --> 00:51:34,390
will we be pointing the telescope at the

1068
00:51:40,050 --> 00:51:37,869
same sky in order to make this yeah

1069
00:51:42,900 --> 00:51:40,060
color image basically of the early

1070
00:51:46,980 --> 00:51:42,910
universe and and absolutely will we'll

1071
00:51:49,680 --> 00:51:46,990
be doing that the but it's helped by the

1072
00:51:52,590 --> 00:51:49,690
fact that we're mapping 70% of the sky

1073
00:51:55,140 --> 00:51:52,600
so it's hard not to point it the the sky

1074
00:51:57,630 --> 00:51:55,150
that we're looking at and we don't have

1075
00:52:00,840 --> 00:51:57,640
to point it exactly the same time so so

1076
00:52:02,700 --> 00:52:00,850
basically just you know the universe

1077
00:52:04,859 --> 00:52:02,710
isn't going anywhere so just like if you

1078
00:52:07,290 --> 00:52:04,869
had a family standing for a portrait you

1079
00:52:10,800 --> 00:52:07,300
could come by and take RGB pictures of

1080
00:52:12,180 --> 00:52:10,810
them and to sing subsequent times and

1081
00:52:14,490 --> 00:52:12,190
put them together that's sort of what

1082
00:52:18,750 --> 00:52:14,500
we're doing we're imaging the universe

1083
00:52:21,440 --> 00:52:18,760
with with the different frequencies the

1084
00:52:23,640 --> 00:52:21,450
same the same part of the universe and

1085
00:52:25,520 --> 00:52:23,650
and putting them together but we don't

1086
00:52:40,070 --> 00:52:25,530
necessarily have to have them pointed

1087
00:52:44,370 --> 00:52:42,060
that's a great question yeah absolutely

1088
00:52:47,690 --> 00:52:44,380

there are other so the question is

1089
00:52:54,840 --> 00:52:47,700
thanks are there are there other are

1090
00:52:58,470 --> 00:52:54,850
there I'm going to learn are there other

1091
00:53:00,000 --> 00:52:58,480
species on planet earth which which can

1092
00:53:04,080 --> 00:53:00,010
see this polarization with their eyes

1093
00:53:07,020 --> 00:53:04,090
and yeah and in it turns out to be sort

1094
00:53:08,760 --> 00:53:07,030
of other insects for some reason this

1095
00:53:14,150 --> 00:53:08,770
seems to be the particular domain of

1096
00:53:18,300 --> 00:53:14,160
these animals these creatures although I

1097
00:53:19,710 --> 00:53:18,310
yeah and and yeah I I learned about this

1098
00:53:24,120 --> 00:53:19,720
through this magical place called

1099
00:53:25,050 --> 00:53:24,130
Wikipedia and so so so you can read

1100
00:54:07,099 --> 00:53:25,060
about it there too

1101
00:54:19,589 --> 00:54:14,280
sure so the question is is going back to

1102
00:54:22,200 --> 00:54:19,599
the point about modulation and yeah

1103
00:54:24,210 --> 00:54:22,210
correctly describing how in the example

1104
00:54:27,240 --> 00:54:24,220
a voice which was a signal was was

1105
00:54:30,810 --> 00:54:27,250
brought to higher frequency such that

1106
00:54:32,520 --> 00:54:30,820
you could hear it despite the low the

1107
00:54:37,109 --> 00:54:32,530
low frequency noise in which it was

1108
00:54:41,970 --> 00:54:37,119
otherwise drowned out so and and then

1109
00:54:45,089 --> 00:54:41,980
the question is is there a particular

1110
00:54:48,240 --> 00:54:45,099
aspect of our signal say at 40 gigahertz

1111
00:54:53,730 --> 00:54:48,250
that's that makes it possible to

1112
00:55:00,839 --> 00:54:53,740
modulate it up oh the noise spectral

1113
00:55:02,700 --> 00:55:00,849

density yeah sure sure yeah so the noise

1114
00:55:05,370 --> 00:55:02,710
in our the noise that we get in our

1115
00:55:07,620 --> 00:55:05,380
telescope you can classify noise by

1116
00:55:11,579 --> 00:55:07,630
colors so the noise that we see in our

1117
00:55:13,710 --> 00:55:11,589
telescope is usually it can be referred

1118
00:55:15,930 --> 00:55:13,720
to as brown noise so this is this is

1119
00:55:20,609 --> 00:55:15,940
noise that is higher at lower

1120
00:55:24,960 --> 00:55:20,619
frequencies and and and and lower at

1121
00:55:28,020 --> 00:55:24,970
higher higher frequencies and and so so

1122
00:55:30,390 --> 00:55:28,030
and essentially what happens here is

1123
00:55:34,200 --> 00:55:30,400
it's it's important to just a it's a

1124
00:55:36,510 --> 00:55:34,210
there's a a essentially what we're doing

1125
00:55:39,359 --> 00:55:36,520
with the with what the telescope is

1126
00:55:42,930 --> 00:55:39,369
we're removing the basically we're

1127
00:55:46,020 --> 00:55:42,940
observing the sky and looking at the CMB

1128
00:55:48,569 --> 00:55:46,030
polarization and it's coming in at 40

1129
00:55:51,180 --> 00:55:48,579
gigahertz right but what we're doing is

1130
00:55:53,220 --> 00:55:51,190
we're just just like you know when you

1131
00:55:57,660 --> 00:55:53,230
see blue light you don't see you know

1132
00:55:59,220 --> 00:55:57,670
the electromagnetic signal from that

1133
00:56:01,109 --> 00:55:59,230
blue light going up and down you just

1134
00:56:02,520 --> 00:56:01,119
see some blue intensity so we're just

1135
00:56:06,030 --> 00:56:02,530
imaging the intensity or the

1136
00:56:08,280 --> 00:56:06,040
polarization magnitude of the light at

1137
00:56:10,260 --> 00:56:08,290
40 gigahertz and then what we're doing

1138
00:56:12,690 --> 00:56:10,270

is taking that signal and we're putting

1139
00:56:17,760 --> 00:56:12,700
it at just 10 Hertz so something quite

1140
00:56:19,920 --> 00:56:17,770
you know quite manageable and the point

1141
00:56:22,560 --> 00:56:19,930
here is that if you take it

1142
00:56:24,960 --> 00:56:22,570
for the way you saw the telescope

1143
00:56:26,730 --> 00:56:24,970
scanning on the sky and in the

1144
00:56:29,760 --> 00:56:26,740
atmosphere is blowing by so that

1145
00:56:32,730 --> 00:56:29,770
atmosphere is is a significant source of

1146
00:56:34,890 --> 00:56:32,740
noise it has it has structure in it and

1147
00:56:38,070 --> 00:56:34,900
different it's bright and dark and it

1148
00:56:39,870 --> 00:56:38,080
blows across what happens is that we see

1149
00:56:42,030 --> 00:56:39,880
that in the telescope the brightness of

1150
00:56:43,170 --> 00:56:42,040
the atmosphere and it's much much

1151
00:56:46,950 --> 00:56:43,180
brighter than the CMB

1152
00:56:49,260 --> 00:56:46,960
and and and basically the the spectrum

1153
00:56:52,920 --> 00:56:49,270
of that of that signal from or the noise

1154
00:56:55,590 --> 00:56:52,930
if you will of that atmosphere has this

1155
00:56:58,380 --> 00:56:55,600
brown noise spectrum and so we modulate

1156
00:57:00,390 --> 00:56:58,390
up above that it basically goes away by

1157
00:57:03,060 --> 00:57:00,400
about it hurts so we get to 10 Hertz

1158
00:57:04,860 --> 00:57:03,070
above that noise actually a really cool

1159
00:57:07,290 --> 00:57:04,870
thing to do is you can again it goes

1160
00:57:09,960 --> 00:57:07,300
back to what Coupee do you can if you

1161
00:57:11,490 --> 00:57:09,970
look up the color of noise this is

1162
00:57:14,550 --> 00:57:11,500
another this is actually what gave me

1163
00:57:17,970 --> 00:57:14,560

the idea for this for this demo is on

1164
00:57:19,560 --> 00:57:17,980
Wikipedia you have they actually have

1165
00:57:21,240 --> 00:57:19,570
the sound of different noise

1166
00:57:23,430 --> 00:57:21,250
so there's you've probably heard of

1167
00:57:26,310 --> 00:57:23,440
white noise so you're the brown noise

1168
00:57:29,370 --> 00:57:26,320
sort of sounded like the ocean but but

1169
00:57:31,380 --> 00:57:29,380
but white noise you know it sounds it

1170
00:57:33,780 --> 00:57:31,390
sounds like here so that sounds like HBO

1171
00:57:37,770 --> 00:57:33,790
use white noise and one of their promo

1172
00:57:39,810 --> 00:57:37,780
yeah yeah but but you can hear there's

1173
00:57:41,130 --> 00:57:39,820
pink noise there's red noise there's you

1174
00:57:44,460 --> 00:57:41,140
know there's all kinds of not gray noise

1175
00:57:45,960 --> 00:57:44,470
and what color is your noise yeah that's

1176
00:58:04,290 --> 00:57:45,970
right that's great so you can go find

1177
00:58:07,290 --> 00:58:04,300
your color more questions that's a great

1178
00:58:09,450 --> 00:58:07,300
question so um yeah so so repeat the

1179
00:58:11,490 --> 00:58:09,460
quiz so sorry

1180
00:58:14,190 --> 00:58:11,500
the I said the question is how do we

1181
00:58:19,260 --> 00:58:14,200
maintain the cold temperatures of our of

1182
00:58:22,650 --> 00:58:19,270
our of our telescope for Kelvin all the

1183
00:58:27,660 --> 00:58:22,660
way down to a fraction of a Kelvin in

1184
00:58:29,610 --> 00:58:27,670
the field and basically it's it's it's

1185
00:58:31,260 --> 00:58:29,620
it's it's not too different from your

1186
00:58:32,339 --> 00:58:31,270
refrigerator at home except we're really

1187
00:58:35,460 --> 00:58:32,349
souped up

1188
00:58:38,910 --> 00:58:35,470

you have a really high electric bill if

1189
00:58:41,759 --> 00:58:38,920
you had our refrigerators so but and we

1190
00:58:43,829 --> 00:58:41,769
use helium so we use we compress helium

1191
00:58:47,069 --> 00:58:43,839
and then we expand helium and when you

1192
00:58:49,079 --> 00:58:47,079
when you expand the gas it cools alright

1193
00:58:52,410 --> 00:58:49,089
and so that's that's basically how we

1194
00:58:55,650 --> 00:58:52,420
get down to 4 Kelvin and it's a closed

1195
00:58:58,499 --> 00:58:55,660
cycle just like the fridge where the

1196
00:59:01,890 --> 00:58:58,509
where the material comes in you expand

1197
00:59:03,930 --> 00:59:01,900
it and and it cools down and then you

1198
00:59:06,989 --> 00:59:03,940
can then then you basically use that

1199
00:59:08,880 --> 00:59:06,999
cold material to cool your food in this

1200
00:59:12,960 --> 00:59:08,890
case we're cooling our cryogenic

1201
00:59:14,460 --> 00:59:12,970
detectors and then that gives us 2 4

1202
00:59:16,380 --> 00:59:14,470
Kelvin and then we want to get even

1203
00:59:18,809 --> 00:59:16,390
colder we want to get to a fraction of a

1204
00:59:20,759 --> 00:59:18,819
Kelvin and we use another closed system

1205
00:59:24,779 --> 00:59:20,769
but now we use and which still uses

1206
00:59:28,140 --> 00:59:24,789
helium helium but it uses an exotic

1207
00:59:32,640 --> 00:59:28,150
isotope of helium helium 3 so uses a

1208
00:59:34,589 --> 00:59:32,650
mixture of regular helium helium 4 and

1209
00:59:37,079 --> 00:59:34,599
helium 3 and it's essentially

1210
00:59:41,219 --> 00:59:37,089
evaporating helium 3 through a mixture

1211
00:59:43,200 --> 00:59:41,229
of through a helium 3 deprived mixture

1212
00:59:45,599 --> 00:59:43,210
of helium three and four and so it's

1213
00:59:49,229 --> 00:59:45,609

it's fancy kind of evaporative cooling

1214
00:59:50,640 --> 00:59:49,239
that gets us down to down to the coldest

1215
00:59:52,049 --> 00:59:50,650
temperatures a little bit like the

1216
01:00:01,079 --> 00:59:52,059
evaporative cooling on your skin but

1217
01:00:02,609 --> 01:00:01,089
more so absolutely yeah yeah for

1218
01:00:05,430 --> 01:00:02,619
instance our detectors are

1219
01:00:08,489 --> 01:00:05,440
superconductors so they are detected or

1220
01:00:10,890 --> 01:00:08,499
we actually operate our detectors right

1221
01:00:12,719 --> 01:00:10,900
at the transition between being a normal

1222
01:00:15,660 --> 01:00:12,729
metal and a metal without any resistance

1223
01:00:17,819 --> 01:00:15,670
so we use a lot of fancy tricks in there

1224
01:00:19,289 --> 01:00:17,829
we used we use quantum interference to

1225
01:00:28,180 --> 01:00:19,299
read out our detectors it just gets

1226
01:00:31,880 --> 01:00:30,440
that's a great question okay so the

1227
01:00:35,570 --> 01:00:31,890
question is what is the resolution of

1228
01:00:38,710 --> 01:00:35,580
the telescope so the the this signal

1229
01:00:42,770 --> 01:00:38,720
like I said it we're going for these

1230
01:00:45,320 --> 01:00:42,780
universe sized gravitational waves and

1231
01:00:48,320 --> 01:00:45,330
even even if you put it even if you put

1232
01:00:50,060 --> 01:00:48,330
these waves at a very far distance as

1233
01:00:55,460 --> 01:00:50,070
far out as we're looking at they're

1234
01:00:57,560 --> 01:00:55,470
still really big so so our telescopes

1235
01:00:59,630 --> 01:00:57,570
are essentially have degree scale

1236
01:01:02,150 --> 01:00:59,640
resolution so you saw them you saw the

1237
01:01:05,480 --> 01:01:02,160
moon right at the at the beginning

1238
01:01:09,170 --> 01:01:05,490

comparing the Hubble Deep Field our you

1239
01:01:12,530 --> 01:01:09,180
know our our beams are twice that big so

1240
01:01:15,200 --> 01:01:12,540
it's our resolution which the moon looks

1241
01:01:17,690 --> 01:01:15,210
like a point tell us okay so let me just

1242
01:01:20,180 --> 01:01:17,700
get for that into perspective Hubble's

1243
01:01:24,050 --> 01:01:20,190
resolution is a 20th of an arc second

1244
01:01:29,360 --> 01:01:24,060
and an arc second is one 3600 of a

1245
01:01:32,720 --> 01:01:29,370
degree so that makes about what seventy

1246
01:01:34,370 --> 01:01:32,730
thousand his resolution is 70 house

1247
01:01:36,890 --> 01:01:34,380
resolution is seventy thousand times

1248
01:01:38,390 --> 01:01:36,900
better than his resolution okay but

1249
01:01:40,130 --> 01:01:38,400
Hubble is looking at really tiny things

1250
01:01:41,510 --> 01:01:40,140
in the sky he's looking at really big

1251
01:01:50,060 --> 01:01:41,520
big things in the sky

1252
01:01:53,390 --> 01:01:50,070
okay different tool different job it

1253
01:01:54,920 --> 01:01:53,400
yeah yeah I mean I think there's so many

1254
01:01:56,750 --> 01:01:54,930
bells and whistles with this thing that

1255
01:01:59,750 --> 01:01:56,760
it's it's almost more like an apparatus

1256
01:02:01,580 --> 01:01:59,760
yeah but it is a telescope forty

1257
01:02:03,560 --> 01:02:01,590
thousand square degrees in the sky so

1258
01:02:05,180 --> 01:02:03,570
he's still got a good number of pixels

1259
01:02:06,920 --> 01:02:05,190
to look at ya know ya know we're

1260
01:02:09,740 --> 01:02:06,930
definitely still doing what one would

1261
01:02:11,510 --> 01:02:09,750
would eventually call imaging but like

1262
01:02:13,880 --> 01:02:11,520
in the 40 gigahertz receiver we only

1263
01:02:19,270 --> 01:02:13,890

have what would be called you know you

1264
01:02:21,260 --> 01:02:19,280
know 30 32 32 pixels in our camera so

1265
01:02:31,690 --> 01:02:21,270
it's a different it's a different game

1266
01:02:36,170 --> 01:02:34,309
that's a great that's a great question

1267
01:02:39,529 --> 01:02:36,180
is are we going to build more cameras in

1268
01:02:41,660 --> 01:02:39,539
order to get to the whole sky and from

1269
01:02:43,789 --> 01:02:41,670
the Atacama Desert there so that's

1270
01:02:44,240 --> 01:02:43,799
that's that's in the tropics you can

1271
01:02:46,130 --> 01:02:44,250
believe it

1272
01:02:49,039 --> 01:02:46,140
actually most of the deserts in the

1273
01:02:52,490 --> 01:02:49,049
world are sir presently any case the the

1274
01:02:54,440 --> 01:02:52,500
it's a subtopic so so so but in any case

1275
01:02:57,799 --> 01:02:54,450
the point is it's not far from the

1276
01:03:00,529 --> 01:02:57,809
equator so so from that location we can

1277
01:03:04,160 --> 01:03:00,539
actually image most of the sky but yeah

1278
01:03:07,220 --> 01:03:04,170
there are there are there are you know

1279
01:03:10,069 --> 01:03:07,230
thinking more than five years out and

1280
01:03:12,799 --> 01:03:10,079
north northern hemisphere excite there

1281
01:03:14,690 --> 01:03:12,809
there there there there are reasonably

1282
01:03:16,579 --> 01:03:14,700
good sites and in the in the northern

1283
01:03:18,970 --> 01:03:16,589
hemisphere that are being explored the

1284
01:03:21,920 --> 01:03:18,980
two main places people look for the CMB

1285
01:03:23,990 --> 01:03:21,930
are well bit here in the auto common

1286
01:03:51,320 --> 01:03:24,000
desert and the other one is the South

1287
01:03:57,720 --> 01:03:55,890
everything no the question is and

1288
01:03:59,760 --> 01:03:57,730

actually that's the Chantal she was

1289
01:04:03,560 --> 01:03:59,770
helpful she's she's helped make this

1290
01:04:06,150 --> 01:04:03,570
earlier issues there at the beginning

1291
01:04:10,380 --> 01:04:06,160
it's it's a so the question is what

1292
01:04:13,760 --> 01:04:10,390
what's been the most challenging what's

1293
01:04:16,920 --> 01:04:13,770
been the most challenging part of class

1294
01:04:19,790 --> 01:04:16,930
and I think I you know I think for a lot

1295
01:04:23,070 --> 01:04:19,800
of us I mean we're all most of us having

1296
01:04:25,290 --> 01:04:23,080
are pretty young I mean the in in the

1297
01:04:27,000 --> 01:04:25,300
context in class and I and I think I

1298
01:04:29,550 --> 01:04:27,010
think probably the biggest challenge is

1299
01:04:31,890 --> 01:04:29,560
just realizing we could do it and you

1300
01:04:33,839 --> 01:04:31,900
know and just sort of overcoming this

1301
01:04:38,250 --> 01:04:33,849
sort of perception of like wow this is a

1302
01:04:40,650 --> 01:04:38,260
huge project and and and and and and

1303
01:04:43,410 --> 01:04:40,660
sort of yeah and you know now we got it

1304
01:04:46,230 --> 01:04:43,420
in the field so this is related to that

1305
01:04:47,040 --> 01:04:46,240
I mean when starting the James Webb

1306
01:04:49,109 --> 01:04:47,050
Space Telescope

1307
01:04:51,300 --> 01:04:49,119
you know they had several new

1308
01:04:53,280 --> 01:04:51,310
technologies they had to invent while

1309
01:04:55,560 --> 01:04:53,290
building the new series fair and you're

1310
01:04:57,960 --> 01:04:55,570
talking about using quantum interference

1311
01:05:01,349 --> 01:04:57,970
to read out your detectors right and

1312
01:05:04,109 --> 01:05:01,359
working with you know the liquid helium

1313
01:05:06,510 --> 01:05:04,119

the helium cooling and tritium cooling

1314
01:05:08,730 --> 01:05:06,520
and such how much of that was already

1315
01:05:10,589 --> 01:05:08,740
known versus how much did you have any

1316
01:05:12,450 --> 01:05:10,599
major technologies you had to invent to

1317
01:05:16,320 --> 01:05:12,460
try and get some of this working

1318
01:05:18,329 --> 01:05:16,330
yeah those detectors that that are made

1319
01:05:20,790 --> 01:05:18,339
at NASA Goddard we've been working with

1320
01:05:23,550 --> 01:05:20,800
them to develop them over the last the

1321
01:05:26,880 --> 01:05:23,560
last six years they're they're they're

1322
01:05:29,430 --> 01:05:26,890
unique in the field of CMB observations

1323
01:05:34,170 --> 01:05:29,440
so that was that's that's required a lot

1324
01:05:36,329 --> 01:05:34,180
of development and for instance that 40

1325
01:05:38,990 --> 01:05:36,339
gigahertz telescope and the array of

1326
01:05:44,640 --> 01:05:39,000
detectors there there's that's the first

1327
01:05:52,230 --> 01:05:44,650
ever camera like that the those those be

1328
01:05:54,210 --> 01:05:52,240
PM's you saw the KT built those those

1329
01:05:57,890 --> 01:05:54,220
are yeah those have never been built

1330
01:06:00,359 --> 01:05:57,900
before so so it's or used in this way I

1331
01:06:02,010 --> 01:06:00,369
find that the public likes to hear about

1332
01:06:04,140 --> 01:06:02,020
you know what's the

1333
01:06:06,600 --> 01:06:04,150
you know highlight the real R&D aspect

1334
01:06:07,859 --> 01:06:06,610
of science I mean sometimes people think

1335
01:06:10,200 --> 01:06:07,869
that oh well we'll just build another

1336
01:06:12,180 --> 01:06:10,210
telescope and it's just the same old

1337
01:06:14,070 --> 01:06:12,190
telescope but really there's so many of

1338
01:06:15,420 --> 01:06:14,080

these science experiments that you know

1339
01:06:16,920 --> 01:06:15,430
are pushing the edge boundaries of

1340
01:06:18,960 --> 01:06:16,930
science but they're also pushing the

1341
01:06:20,850 --> 01:06:18,970
boundaries of technology you know in

1342
01:06:23,070 --> 01:06:20,860
order to enable new science and yeah

1343
01:06:25,590 --> 01:06:23,080
yeah I mean there's basically three main

1344
01:06:27,270 --> 01:06:25,600
parts to class one is the the first one

1345
01:06:30,390 --> 01:06:27,280
is of course the science that we're

1346
01:06:32,670 --> 01:06:30,400
going after and then the second one is

1347
01:06:34,770 --> 01:06:32,680
training scientists and and then the

1348
01:06:43,890 --> 01:06:34,780
third is this technology development so

1349
01:06:46,320 --> 01:06:43,900
so yeah absolutely yeah okay the

1350
01:06:53,550 --> 01:06:46,330
question is who is funding us so why you

1351
01:06:57,359 --> 01:06:53,560
of course no of course that's the truth

1352
01:07:01,380 --> 01:06:57,369
right so we're primarily funded to the

1353
01:07:03,180 --> 01:07:01,390
National Science Foundation and they've

1354
01:07:06,900 --> 01:07:03,190
supported that both the developments of

1355
01:07:11,099 --> 01:07:06,910
the instrument and now they've just

1356
01:07:15,210 --> 01:07:11,109
recently funded us to execute the the

1357
01:07:19,770 --> 01:07:15,220
five-year survey we also have helped

1358
01:07:22,349 --> 01:07:19,780
from from a lot of other sources the

1359
01:07:25,530 --> 01:07:22,359
detector development is like I said it's

1360
01:07:26,880 --> 01:07:25,540
done at NASA so NASA supports the

1361
01:07:28,590 --> 01:07:26,890
technology development of those

1362
01:07:30,650 --> 01:07:28,600
detectors looking ahead towards the

1363
01:07:35,040 --> 01:07:30,660

space mission to do this type of thing

1364
01:07:38,870 --> 01:07:35,050
and we also have we also have private

1365
01:07:41,070 --> 01:07:38,880
contributions through through through

1366
01:07:46,290 --> 01:07:41,080
through folks who are just excited about

1367
01:07:50,670 --> 01:07:46,300
the about the telescope the total amount

1368
01:07:52,080 --> 01:07:50,680
this is the sum it's it's in the twenty

1369
01:07:58,880 --> 01:07:52,090
thousand it's use hype twenty thousand

1370
01:08:06,200 --> 01:08:01,579
so this what I'm showing you here is

1371
01:08:10,550 --> 01:08:06,210
sort of roughly seven years in the

1372
01:08:12,500 --> 01:08:10,560
making from from sort of serious

1373
01:08:15,260 --> 01:08:12,510
building and then it's going to be

1374
01:08:18,079 --> 01:08:15,270
another five years to the science so

1375
01:08:20,539 --> 01:08:18,089
these projects end up being on this sort

1376
01:08:22,280 --> 01:08:20,549
of this sort of medium scale project is

1377
01:08:33,019 --> 01:08:22,290
on the is on the sort of ten year

1378
01:08:35,689 --> 01:08:33,029
timescale the question is are we on the

1379
01:08:38,740 --> 01:08:35,699
right track and yes there's there's

1380
01:08:43,370 --> 01:08:38,750
we're still the data is just coming in

1381
01:08:46,400 --> 01:08:43,380
and and I can't say much about it until

1382
01:09:03,250 --> 01:08:46,410
we fully tease these things out but yes

1383
01:09:10,010 --> 01:09:06,680
the question is yeah how much power does

1384
01:09:13,970 --> 01:09:10,020
it take to to to to run these telescopes

1385
01:09:17,420 --> 01:09:13,980
and yes so those the generators that

1386
01:09:21,289 --> 01:09:17,430
were in the in the site picture those

1387
01:09:23,480 --> 01:09:21,299
are sort of D rated for it so where it

1388
01:09:25,700 --> 01:09:23,490

said we're at 17,000 feet it's half an

1389
01:09:29,450 --> 01:09:25,710
atmosphere so those generators are about

1390
01:09:33,620 --> 01:09:29,460
200 kilowatt generators and UD rate them

1391
01:09:35,780 --> 01:09:33,630
by you know roughly half and and so and

1392
01:09:40,849 --> 01:09:35,790
and that's roughly the power consumption

1393
01:09:42,530 --> 01:09:40,859
of the folds or Observatory and so so

1394
01:09:45,590 --> 01:09:42,540
yeah so each one of the like for each

1395
01:09:48,260 --> 01:09:45,600
each one of those helium refrigerators

1396
01:09:50,360 --> 01:09:48,270
takes about ten kilowatts and then

1397
01:09:51,829 --> 01:09:50,370
you've got to move the telescopes you

1398
01:09:53,800 --> 01:09:51,839
got to keep people from freezing when

1399
01:09:57,350 --> 01:09:53,810
they're at the site you know run heaters

1400
01:10:00,920 --> 01:09:57,360
we we have oxygen we have we have oxygen

1401
01:10:05,360 --> 01:10:00,930
oxygen concentrators for folks to be

1402
01:10:09,100 --> 01:10:05,370
smarter at the site and those take each

1403
01:10:11,060 --> 01:10:09,110
take four kilowatts and you have -

1404
01:10:15,500 --> 01:10:11,070
nothing nothing not that much for the

1405
01:10:17,000 --> 01:10:15,510
Yankees Yankees yeah a lot of power okay

1406
01:10:18,650 --> 01:10:17,010
yeah just a couple more because you want

1407
01:10:19,430 --> 01:10:18,660
to take people across the street yeah be

1408
01:10:26,250 --> 01:10:19,440
great Hank Tilly

1409
01:10:36,720 --> 01:10:34,799
oh yeah okay I mean I think the there's

1410
01:10:38,970 --> 01:10:36,730
two there's two different aspects right

1411
01:10:40,950 --> 01:10:38,980
there's the there's the science aspect

1412
01:10:43,169 --> 01:10:40,960
and that one's just looking way out

1413
01:10:46,169 --> 01:10:43,179

right so that's you know you know what

1414
01:10:49,500 --> 01:10:46,179
it was you know how does understanding

1415
01:10:51,959 --> 01:10:49,510
the how the universe was created you

1416
01:10:55,410 --> 01:10:51,969
know you know how is that going to

1417
01:10:58,129 --> 01:10:55,420
enable us to you know advance humanity

1418
01:11:01,319 --> 01:10:58,139
and you know we don't know that yet but

1419
01:11:03,450 --> 01:11:01,329
certainly would be good to know to make

1420
01:11:05,430 --> 01:11:03,460
progress so that's the big play that

1421
01:11:08,129 --> 01:11:05,440
sets the one side and then the other

1422
01:11:10,020 --> 01:11:08,139
side is is this technology development

1423
01:11:13,169 --> 01:11:10,030
like for instance these cold detectors

1424
01:11:15,540 --> 01:11:13,179
or that are so sensitive to find faint

1425
01:11:18,919 --> 01:11:15,550
ripples of polarization in the early

1426
01:11:21,390 --> 01:11:18,929
universe can be used for remote sensing

1427
01:11:23,399 --> 01:11:21,400
and other applications you can use them

1428
01:11:26,729 --> 01:11:23,409
in different wave fans look for

1429
01:11:28,339 --> 01:11:26,739
radiation this type of thing so that

1430
01:11:30,689 --> 01:11:28,349
that's that's that's one example

1431
01:11:33,000 --> 01:11:30,699
polarization modulation polarizations

1432
01:11:35,939 --> 01:11:33,010
everywhere if bees got a hold of that

1433
01:11:38,359 --> 01:11:35,949
modulate now honey all over the place

1434
01:11:42,540 --> 01:11:38,369
we'd like to have super bees yeah

1435
01:11:45,029 --> 01:11:42,550
controlling the universe yeah but no but

1436
01:11:47,850 --> 01:11:45,039
but yeah that's seriously um the the

1437
01:11:50,330 --> 01:11:47,860
benefits of the the researcher to this

1438
01:11:53,549 --> 01:11:50,340

you know sort of big picture science

1439
01:11:56,910 --> 01:11:53,559
where where is that going to take us you

1440
01:11:59,700 --> 01:11:56,920
know you have to you have to you have to

1441
01:12:04,229 --> 01:11:59,710
think far out and but the technology

1442
01:12:05,819 --> 01:12:04,239
transfer okay Peter I have to cut you

1443
01:12:07,140 --> 01:12:05,829
off as though there was a gentleman in

1444
01:12:09,149 --> 01:12:07,150
the back there and this gentleman over

1445
01:12:19,180 --> 01:12:09,159
there I have to have done it last two

1446
01:12:25,700 --> 01:12:22,970
sure sure yeah so the question is where

1447
01:12:28,629 --> 01:12:25,710
does the spectral selectivity of the of

1448
01:12:32,509 --> 01:12:28,639
the telescope come in and it's actually

1449
01:12:37,069 --> 01:12:32,519
built right on to those built right on

1450
01:12:40,359 --> 01:12:37,079
to those chips so so what happens is the

1451
01:12:42,589 --> 01:12:40,369
light comes into the detector from the

1452
01:12:45,140 --> 01:12:42,599
telescope focuses the light onto the

1453
01:12:48,470 --> 01:12:45,150
detector and the detector actually picks

1454
01:12:50,629 --> 01:12:48,480
up the electromagnetic waves and sends

1455
01:12:52,490 --> 01:12:50,639
it sends it through code sends it

1456
01:12:54,109 --> 01:12:52,500
through circuitry it's a microwave

1457
01:12:56,299 --> 01:12:54,119
surgical history so high-speed

1458
01:13:00,470 --> 01:12:56,309
electronic circuitry and we actually

1459
01:13:03,080 --> 01:13:00,480
implement filters on on the silicon

1460
01:13:04,700 --> 01:13:03,090
there to define to define the bands

1461
01:13:07,100 --> 01:13:04,710
there are other places where we can

1462
01:13:09,290 --> 01:13:07,110
choke down and and and limit long

1463
01:13:11,540 --> 01:13:09,300

wavelengths and things like that and we

1464
01:13:14,089 --> 01:13:11,550
we play a lot of games to make sure that

1465
01:13:16,160 --> 01:13:14,099
we don't see that that pesky high

1466
01:13:17,990 --> 01:13:16,170
frequencies short wavelength light

1467
01:13:19,640 --> 01:13:18,000
doesn't get in and that's that's one of

1468
01:13:20,839 --> 01:13:19,650
the innovations with this detector so

1469
01:13:23,299 --> 01:13:20,849
there's a bunch of different ways which

1470
01:13:25,759 --> 01:13:23,309
we we sort of select out our specific

1471
01:13:28,279 --> 01:13:25,769
band so we don't look at something we

1472
01:13:43,979 --> 01:13:28,289
don't want to see okay and you have last

1473
01:13:50,459 --> 01:13:48,089
no no I probably just said it okay so

1474
01:13:54,450 --> 01:13:50,469
the question is in what way does the the

1475
01:13:56,910 --> 01:13:54,460
CMB help us understand the early

1476
01:13:58,620 --> 01:13:56,920
universe sir okay great now that's a

1477
01:14:00,299 --> 01:13:58,630
great question to end on

1478
01:14:02,459 --> 01:14:00,309
so basically basically this is a

1479
01:14:05,549 --> 01:14:02,469
snapshot of the early universe so the

1480
01:14:10,140 --> 01:14:05,559
first answer is simply like it is the

1481
01:14:12,390 --> 01:14:10,150
early Earth so so it you know it in the

1482
01:14:14,430 --> 01:14:12,400
same way as Hubble can can image you

1483
01:14:17,089 --> 01:14:14,440
know what the galaxies look like you

1484
01:14:19,739 --> 01:14:17,099
know 11 billion years ago or whatever

1485
01:14:22,859 --> 01:14:19,749
we're saying what does the universe look

1486
01:14:24,930 --> 01:14:22,869
like when it was 13.7 billion years old

1487
01:14:27,439 --> 01:14:24,940
before all the galaxies were around so

1488
01:14:30,299 --> 01:14:27,449

you so there's a literal image you know

1489
01:14:33,989 --> 01:14:30,309
it's basically a thermal soup it's like

1490
01:14:35,549 --> 01:14:33,999
looking into a kiln and it's hot and so

1491
01:14:38,580 --> 01:14:35,559
that's what we're seeing we're imaging

1492
01:14:41,489 --> 01:14:38,590
that heat from the early universe so so

1493
01:14:45,270 --> 01:14:41,499
that's that's sort of the the basic

1494
01:14:47,069 --> 01:14:45,280
level and then what the the really

1495
01:14:49,410 --> 01:14:47,079
awesome thing about the early universe

1496
01:14:52,080 --> 01:14:49,420
is it's a lot simpler than the late

1497
01:14:53,970 --> 01:14:52,090
universe so you look around and you see

1498
01:14:57,029 --> 01:14:53,980
all these different types of galaxies

1499
01:14:59,310 --> 01:14:57,039
red blue some of them with jets shooting

1500
01:15:01,680 --> 01:14:59,320
out of them stuff like that this is hard

1501
01:15:03,089 --> 01:15:01,690
to understand this has very complicated

1502
01:15:05,100 --> 01:15:03,099
these things have very complicated

1503
01:15:08,700 --> 01:15:05,110
physics and very complicated histories

1504
01:15:12,899 --> 01:15:08,710
the early universe is it does not have a

1505
01:15:15,600 --> 01:15:12,909
long long history and because it's just

1506
01:15:17,669 --> 01:15:15,610
this soup right our physics actually

1507
01:15:19,859 --> 01:15:17,679
describe it pretty well so what we can

1508
01:15:21,810 --> 01:15:19,869
do is we can take that picture and use

1509
01:15:24,359 --> 01:15:21,820
pretty basic physics you know modern

1510
01:15:26,390 --> 01:15:24,369
physics but not you know not too much

1511
01:15:28,799 --> 01:15:26,400
more than you know electromagnetism

1512
01:15:30,839 --> 01:15:28,809
thermodynamics throw in some nuclear

1513
01:15:32,250 --> 01:15:30,849

physics but you know some stuff we know

1514
01:15:33,930 --> 01:15:32,260
pretty well and we've constrained from

1515
01:15:35,850 --> 01:15:33,940
the laboratory and you can take that

1516
01:15:39,120 --> 01:15:35,860
picture and you can go backwards and you

1517
01:15:42,779 --> 01:15:39,130
can go forwards with it and so and so so

1518
01:15:44,250 --> 01:15:42,789
we can we so the so the so the basic

1519
01:15:48,899 --> 01:15:44,260
answer is that physics of the early

1520
01:15:51,060 --> 01:15:48,909
universe is actually relatively you know

1521
01:15:53,370 --> 01:15:51,070
it's sort of fundamental in some sort of

1522
01:15:55,590 --> 01:15:53,380
sense that our laws can

1523
01:15:58,200 --> 01:15:55,600
and and simple in the way that our law

1524
01:15:59,760 --> 01:15:58,210
in the sense that it's not doesn't have

1525
01:16:01,710 --> 01:15:59,770
all this complexity like these

1526
01:16:03,510 --> 01:16:01,720
life-forms in this room are so complex

1527
01:16:05,340 --> 01:16:03,520
we can't describe them but we can't

1528
01:16:14,880 --> 01:16:05,350
describe the early universe with our

1529
01:16:15,060 --> 01:16:14,890
laws okay so give a hand give a hand all

1530
01:16:17,490 --> 01:16:15,070
right

1531
01:16:19,110 --> 01:16:17,500
Toby's gonna pack up his stuff and then

1532
01:16:20,340 --> 01:16:19,120
you'll be able to take whoever wants to

1533
01:16:22,650 --> 01:16:20,350
go across the street

1534
01:16:25,920 --> 01:16:22,660
next month we have Christine Chen

1535
01:16:27,750 --> 01:16:25,930
talking about debris disks and you won't

1536
01:16:29,610 --> 01:16:27,760
want to miss it but I will miss it

1537
01:16:31,830 --> 01:16:29,620
because I will be in San Francisco next

1538
01:16:35,370 --> 01:16:31,840

month giving a talk at the Morrison

1539
01:16:37,380 --> 01:16:35,380
planetarium and in the day at night

1540
01:16:39,720 --> 01:16:37,390
before this I won't be back in time so

1541
01:16:42,390 --> 01:16:39,730
I'll have a great Thanksgiving all have

1542
01:16:44,520 --> 01:16:42,400
a great holiday season else I won't see

1543
01:16:46,860 --> 01:16:44,530
you till 2017 but I'll have a guest host

1544
01:16:48,990 --> 01:16:46,870
here to help Christine Chen give you an