

1  
00:00:00,030 --> 00:00:09,240  
hey Thomas are we all ready he gives us

2  
00:00:02,700 --> 00:00:10,469  
the thumbs-up all right let's begin good

3  
00:00:09,240 --> 00:00:14,210  
evening ladies and gentlemen and welcome

4  
00:00:10,468 --> 00:00:16,618  
to the space tusko public lecture series

5  
00:00:14,210 --> 00:00:18,929  
it is my pleasure to be your host

6  
00:00:16,618 --> 00:00:21,750  
tonight I am dr. Frank summers of the

7  
00:00:18,929 --> 00:00:25,559  
Space Telescope Science Institute office

8  
00:00:21,750 --> 00:00:26,879  
of public outreach when you came in I'm

9  
00:00:25,559 --> 00:00:28,559  
sorry I didn't put any pictures over

10  
00:00:26,879 --> 00:00:30,660  
this side over that side there's a

11  
00:00:28,559 --> 00:00:34,079  
plenty of pictures tonight's pictures

12  
00:00:30,660 --> 00:00:36,750  
are not the same there's a whole jumble

13  
00:00:34,079 --> 00:00:39,270  
of pictures we have a bunch of Oppo

14  
00:00:36,750 --> 00:00:40,590  
staff moving offices and when they move

15  
00:00:39,270 --> 00:00:43,140  
their offices they say where did these

16  
00:00:40,590 --> 00:00:44,850  
come from and then they go here Frank

17  
00:00:43,140 --> 00:00:47,009  
give these away at the public lecture

18  
00:00:44,850 --> 00:00:50,039  
series so tonight you have a whole bunch

19  
00:00:47,009 --> 00:00:51,899  
of cool images and random lithographs

20  
00:00:50,039 --> 00:00:53,939  
that have come out of people's offices

21  
00:00:51,899 --> 00:00:56,730  
if you can get one on the way in please

22  
00:00:53,939 --> 00:00:58,619  
pick one on the way out what do I have

23  
00:00:56,729 --> 00:01:04,618  
here it looks like this is a wonderful

24  
00:00:58,619 --> 00:01:07,109  
edge-on galaxy NGC 558 66 all right you

25  
00:01:04,618 --> 00:01:10,228  
want 58 66 hurry down here afterwards

26  
00:01:07,109 --> 00:01:13,680  
it'll be right here all right tonight's

27  
00:01:10,228 --> 00:01:16,679  
talk will be the cosmology large angular

28  
00:01:13,680 --> 00:01:19,380  
scale surveyor which in the tradition of

29

00:01:16,680 --> 00:01:21,299  
physics and astronomy has a nice acronym

30  
00:01:19,379 --> 00:01:24,420  
of class okay so you're gonna get a

31  
00:01:21,299 --> 00:01:28,590  
classy talk tonight okay really classy

32  
00:01:24,420 --> 00:01:31,290  
all right next month we have Christine

33  
00:01:28,590 --> 00:01:35,368  
Chen talking about debris disks and the

34  
00:01:31,290 --> 00:01:37,380  
evolution of planetary systems January I

35  
00:01:35,368 --> 00:01:39,239  
don't have a speaker for January it's

36  
00:01:37,379 --> 00:01:41,459  
difficult to rope somebody in for

37  
00:01:39,239 --> 00:01:43,649  
January I will work very hard it over

38  
00:01:41,459 --> 00:01:45,828  
the next month and announce that so

39  
00:01:43,649 --> 00:01:48,989  
right now we still have our infamous TBA

40  
00:01:45,828 --> 00:01:54,000  
and in February we have a very special

41  
00:01:48,989 --> 00:01:55,919  
talk priyamvada nyah Rajan from Yale is

42  
00:01:54,000 --> 00:01:58,409  
coming down and she will be giving a

43  
00:01:55,920 --> 00:02:00,899

talk on her book mapping the heavens

44

00:01:58,409 --> 00:02:02,310

okay so it's rare that I get speak

45

00:02:00,899 --> 00:02:06,180

because I have no travel budget for this

46

00:02:02,310 --> 00:02:07,829

lecture series okay so when I can get

47

00:02:06,180 --> 00:02:09,390

somebody in from outside I'm really

48

00:02:07,828 --> 00:02:11,159

happy to be able to bring you somebody

49

00:02:09,389 --> 00:02:12,719

who's not from Space Telescope AHA pants

50

00:02:11,159 --> 00:02:13,500

nothing against the Hopkinson Space

51

00:02:12,719 --> 00:02:16,530

Telescope you'll because

52

00:02:13,500 --> 00:02:17,789

you're wonderful folks but being able to

53

00:02:16,530 --> 00:02:20,840

bring you somebody from another

54

00:02:17,789 --> 00:02:24,150

university is also pleasant

55

00:02:20,840 --> 00:02:25,319

okay uh talk about construction since

56

00:02:24,150 --> 00:02:26,960

you're here you know about the

57

00:02:25,319 --> 00:02:29,459

construction but for the people on the

58  
00:02:26,960 --> 00:02:32,909  
watching this on the web if you come to

59  
00:02:29,460 --> 00:02:36,180  
visit us the road north of us is closed

60  
00:02:32,909 --> 00:02:38,159  
so you can see the map here this red

61  
00:02:36,180 --> 00:02:40,050  
stuff up here is closed if you try to

62  
00:02:38,159 --> 00:02:41,879  
come in here you won't be able to you

63  
00:02:40,050 --> 00:02:45,689  
have to come all the way around here and

64  
00:02:41,879 --> 00:02:48,139  
then back up to get to us all right

65  
00:02:45,689 --> 00:02:50,879  
if you want to know more about this here

66  
00:02:48,139 --> 00:02:53,219  
the website is here there's the website

67  
00:02:50,879 --> 00:02:55,650  
on the San Martin project this will

68  
00:02:53,219 --> 00:02:58,530  
probably last through next next month

69  
00:02:55,650 --> 00:03:01,200  
and will not be there in January we hope

70  
00:02:58,530 --> 00:03:05,189  
we don't know we'll let you know next

71  
00:03:01,199 --> 00:03:08,699  
month what the what the what the

72  
00:03:05,189 --> 00:03:11,189  
condition is okay all right let's see

73  
00:03:08,699 --> 00:03:13,319  
our website if you just search for

74  
00:03:11,189 --> 00:03:15,239  
Hubble public talks you should find this

75  
00:03:13,319 --> 00:03:17,989  
it has are a list of our upcoming

76  
00:03:15,239 --> 00:03:21,420  
lectures it has links to our online

77  
00:03:17,989 --> 00:03:23,909  
YouTube and webcasting and as well as

78  
00:03:21,419 --> 00:03:25,619  
the archives our playlists on YouTube

79  
00:03:23,909 --> 00:03:29,099  
and our archive from our wonderful

80  
00:03:25,620 --> 00:03:31,409  
webcasting folks there are ten years of

81  
00:03:29,099 --> 00:03:34,289  
these wonderful public lectures are

82  
00:03:31,409 --> 00:03:37,139  
there for you to peruse alright you can

83  
00:03:34,289 --> 00:03:39,090  
also sign up for our email list which

84  
00:03:37,139 --> 00:03:41,399  
will be helpful in December when we send

85  
00:03:39,090 --> 00:03:43,829  
out the email saying yes it's open no

86

00:03:41,400 --> 00:03:48,269  
it's not open for the construction

87  
00:03:43,829 --> 00:03:49,920  
update okay we can also in these

88  
00:03:48,269 --> 00:03:52,980  
announcements can also be signed up at

89  
00:03:49,919 --> 00:03:55,259  
mail list at stsci de tu if you should

90  
00:03:52,979 --> 00:03:57,268  
so desire it's just much easier from our

91  
00:03:55,259 --> 00:03:59,939  
website if you would like to send us

92  
00:03:57,269 --> 00:04:04,459  
mail and Kev us a comment or question

93  
00:03:59,939 --> 00:04:07,739  
it's public lecture at STSci dot edu

94  
00:04:04,459 --> 00:04:11,909  
we're also on social media Facebook

95  
00:04:07,739 --> 00:04:14,640  
Twitter Google+ Pinterest I'm on

96  
00:04:11,909 --> 00:04:16,709  
Facebook and Google+ and Twitter and I

97  
00:04:14,639 --> 00:04:18,629  
have a blog on Hubbell site if you want

98  
00:04:16,709 --> 00:04:21,629  
to follow some of the things I like to

99  
00:04:18,629 --> 00:04:25,750  
talk about all right there will be no

100  
00:04:21,629 --> 00:04:28,329

observatory tonight one it's cloudy

101

00:04:25,750 --> 00:04:31,930

and who we have a special treat for you

102

00:04:28,329 --> 00:04:34,419

tonight our speaker has invited you

103

00:04:31,930 --> 00:04:36,280

across the street to look at the Telus

104

00:04:34,420 --> 00:04:39,640

Lee the observatory that he's building

105

00:04:36,279 --> 00:04:43,689

the facility for the cosmology large

106

00:04:39,639 --> 00:04:44,919

angular scale surveyor so at the end of

107

00:04:43,689 --> 00:04:47,620

the lecture if you would like to go

108

00:04:44,920 --> 00:04:50,290

across Street to the facility hang

109

00:04:47,620 --> 00:04:51,610

around and and after Toby's finished

110

00:04:50,290 --> 00:04:52,210

answering his questions and put away his

111

00:04:51,610 --> 00:04:53,920

laptop

112

00:04:52,209 --> 00:04:57,669

we'll take you across the street for

113

00:04:53,920 --> 00:04:58,330

that okay all right now our news from

114

00:04:57,670 --> 00:05:03,569

the universe



115  
00:04:58,329 --> 00:05:08,370  
for November 2016 our top story tonight

116  
00:05:03,569 --> 00:05:08,370  
make the universe great again

117  
00:05:08,939 --> 00:05:13,360  
you knew I couldn't get through this

118  
00:05:11,050 --> 00:05:16,480  
without enough someone election pun in

119  
00:05:13,360 --> 00:05:20,590  
this right okay so what am I talking

120  
00:05:16,480 --> 00:05:23,890  
about well let's start back in 2004 with

121  
00:05:20,589 --> 00:05:26,379  
the Hubble Ultra Deep Field now this is

122  
00:05:23,889 --> 00:05:29,709  
a picture of lots and lots of galaxies

123  
00:05:26,379 --> 00:05:33,040  
how many galaxies well some of you may

124  
00:05:29,709 --> 00:05:35,168  
know but actually we do a educational

125  
00:05:33,040 --> 00:05:36,910  
activity where middle schoolers count

126  
00:05:35,168 --> 00:05:39,969  
all the galaxies in the Hubble Ultra

127  
00:05:36,910 --> 00:05:42,460  
Deep Field how do we do it well we

128  
00:05:39,970 --> 00:05:44,830  
divide it into a 100 smaller squares

129  
00:05:42,459 --> 00:05:47,469  
okay and then we have the middle

130  
00:05:44,829 --> 00:05:49,689  
schoolers look at these individual

131  
00:05:47,470 --> 00:05:52,150  
squares and then count the galaxies in

132  
00:05:49,689 --> 00:05:55,180  
them okay they usually come up with like

133  
00:05:52,149 --> 00:05:56,918  
50 or 70 galaxies in these and then if

134  
00:05:55,180 --> 00:05:59,500  
there are a hundred squares and they're

135  
00:05:56,918 --> 00:06:04,240  
say 50 galaxies in each how many are

136  
00:05:59,500 --> 00:06:07,389  
there total 50 times 100 5000 okay so

137  
00:06:04,240 --> 00:06:09,910  
they tend to get 5 10,000 galaxies or so

138  
00:06:07,389 --> 00:06:12,099  
in this and well 5 to 7,000 is what the

139  
00:06:09,910 --> 00:06:13,930  
middle schoolers usually estimate when

140  
00:06:12,100 --> 00:06:16,479  
you do it really carefully by

141  
00:06:13,930 --> 00:06:19,689  
astronomers they count about 10,000

142  
00:06:16,478 --> 00:06:22,930  
galaxies in this image now this is a

143

00:06:19,689 --> 00:06:25,149  
really tiny image so if there are 10,000

144  
00:06:22,930 --> 00:06:27,910  
galaxies in this image how many are

145  
00:06:25,149 --> 00:06:30,189  
there in the entire universe well to do

146  
00:06:27,910 --> 00:06:32,320  
that you then have to know how big this

147  
00:06:30,189 --> 00:06:33,848  
is on the sky and so we walk the

148  
00:06:32,319 --> 00:06:36,189  
middle-schoolers through that part as

149  
00:06:33,848 --> 00:06:37,978  
well and we say that okay well here is

150  
00:06:36,189 --> 00:06:39,478  
the size of that Ultra Deep Field

151  
00:06:37,978 --> 00:06:41,819  
compared to the

152  
00:06:39,478 --> 00:06:44,409  
the size of the full moon on the sky

153  
00:06:41,819 --> 00:06:46,449  
alright and it's you know it's a small

154  
00:06:44,410 --> 00:06:49,990  
part of the full moon and the full moon

155  
00:06:46,449 --> 00:06:52,780  
itself is also a small part of the sky

156  
00:06:49,990 --> 00:06:55,300  
and if you do the mathematics

157  
00:06:52,779 --> 00:06:58,418

alright the size of the Hubble lobe

158

00:06:55,300 --> 00:07:01,569  
field compared to an entire sphere the

159

00:06:58,418 --> 00:07:03,159  
number is across the entire sky there

160

00:07:01,569 --> 00:07:04,540  
are twelve million seven hundred forty

161

00:07:03,160 --> 00:07:06,880  
six thousand seven hundred and eighty

162

00:07:04,540 --> 00:07:08,139  
four patches the same skies as the

163

00:07:06,879 --> 00:07:11,800  
Hubble ultra-deep field

164

00:07:08,139 --> 00:07:13,990  
okay so ten thousand galaxies now Hubble

165

00:07:11,800 --> 00:07:16,000  
ultra-deep field twelve million

166

00:07:13,990 --> 00:07:18,759  
Ultra Deep fields across the sky if it's

167

00:07:16,000 --> 00:07:20,500  
representative then we get about a

168

00:07:18,759 --> 00:07:22,240  
hundred and twenty billion galaxies

169

00:07:20,500 --> 00:07:25,569  
across the night sky

170

00:07:22,240 --> 00:07:28,210  
so using that Ultra Deep Field which we

171

00:07:25,569 --> 00:07:30,399  
said we observed over a decade ago to

172  
00:07:28,209 --> 00:07:34,149  
the depth of the Ultra Deep Field there

173  
00:07:30,399 --> 00:07:36,849  
are roughly 100 billion galaxies in the

174  
00:07:34,149 --> 00:07:38,469  
universe okay and that has been sort of

175  
00:07:36,850 --> 00:07:40,210  
our standard number for number of

176  
00:07:38,470 --> 00:07:46,030  
galaxies in the universe for over a

177  
00:07:40,209 --> 00:07:49,659  
decade but what about the galaxies that

178  
00:07:46,029 --> 00:07:51,819  
Hubble doesn't see here's notice this

179  
00:07:49,660 --> 00:07:54,400  
says to the depth of the Hubble Ultra

180  
00:07:51,819 --> 00:07:56,348  
Deep Field there are things that Hubble

181  
00:07:54,399 --> 00:07:58,269  
doesn't see right they could be too

182  
00:07:56,348 --> 00:07:59,949  
faint for Hubble to see them or they

183  
00:07:58,269 --> 00:08:02,769  
could be too small for Hubble to see

184  
00:07:59,949 --> 00:08:06,069  
them or they could radiate in infrared

185  
00:08:02,769 --> 00:08:09,788  
or other wave bat'leth wavelengths that

186  
00:08:06,069 --> 00:08:12,370  
Hubble doesn't de see right so we

187  
00:08:09,788 --> 00:08:14,469  
recently had a paper called the

188  
00:08:12,370 --> 00:08:16,090  
evolution of the galaxy number density

189  
00:08:14,470 --> 00:08:18,099  
at Z less than eight and its

190  
00:08:16,089 --> 00:08:22,000  
implications which may not make much

191  
00:08:18,098 --> 00:08:24,189  
sense to you but the idea is to try and

192  
00:08:22,000 --> 00:08:26,129  
account for all the galaxies that we

193  
00:08:24,189 --> 00:08:30,009  
don't see in the Hubble ultra-deep field

194  
00:08:26,129 --> 00:08:32,950  
so here is the study and I'm gonna read

195  
00:08:30,009 --> 00:08:35,319  
this verbatim because it there's a lot

196  
00:08:32,950 --> 00:08:37,240  
to it Nautilus I think how many galaxies

197  
00:08:35,320 --> 00:08:40,659  
are potentially detectable within the

198  
00:08:37,240 --> 00:08:42,610  
universe if deep imaging over all

199  
00:08:40,658 --> 00:08:45,429  
wavelengths could be carried out in

200

00:08:42,610 --> 00:08:47,709  
every location of the sky without any

201  
00:08:45,429 --> 00:08:50,469  
interference from the galaxies or other

202  
00:08:47,708 --> 00:08:53,319  
contamination so that covers all the

203  
00:08:50,470 --> 00:08:55,899  
things that I just said the entire sky

204  
00:08:53,320 --> 00:08:57,910  
in all wavelengths without any of this

205  
00:08:55,899 --> 00:08:59,828  
foreground contamination or stuff

206  
00:08:57,909 --> 00:09:01,419  
blocking right which you could see every

207  
00:08:59,828 --> 00:09:03,399  
single galaxy out there that's what this

208  
00:09:01,419 --> 00:09:07,088  
stuff this the study is trying to do

209  
00:09:03,399 --> 00:09:08,769  
okay what is a galaxy for them they say

210  
00:09:07,089 --> 00:09:11,440  
well they consider galaxies down to a

211  
00:09:08,769 --> 00:09:14,919  
million solar masses our Milky Way

212  
00:09:11,440 --> 00:09:17,500  
galaxy total mass is about 10 to the 12

213  
00:09:14,919 --> 00:09:20,078  
solar masses maybe 10 to the 11 solar

214  
00:09:17,500 --> 00:09:22,120

masses and stars they're considering

215

00:09:20,078 --> 00:09:24,189

things much much much much smaller okay

216

00:09:22,120 --> 00:09:26,198

even the Large Magellanic Cloud is like

217

00:09:24,190 --> 00:09:28,089

a billion solar masses so this is one

218

00:09:26,198 --> 00:09:29,708

one thousandth of even you know our

219

00:09:28,089 --> 00:09:31,060

satellite galaxies so these are really

220

00:09:29,708 --> 00:09:33,609

down turn they're trying to look at the

221

00:09:31,059 --> 00:09:36,549

very smallest type stuff for galaxies

222

00:09:33,610 --> 00:09:38,709

and also they're looking at the number

223

00:09:36,549 --> 00:09:40,208

for per comoving volume I need to point

224

00:09:38,708 --> 00:09:42,669

this out because we're gonna talk about

225

00:09:40,208 --> 00:09:45,309

number density and we know the universe

226

00:09:42,669 --> 00:09:47,019

is expanding and so as the universe gets

227

00:09:45,309 --> 00:09:51,250

bigger of course we have fewer galaxies

228

00:09:47,019 --> 00:09:52,870

per volume right no not in this we're



229  
00:09:51,250 --> 00:09:55,120  
talking about what we call comoving

230  
00:09:52,870 --> 00:09:57,250  
volume so the expansion of the universe

231  
00:09:55,120 --> 00:09:59,019  
is already factored out okay so the

232  
00:09:57,250 --> 00:10:00,309  
densities are our Faculty of the

233  
00:09:59,019 --> 00:10:01,028  
expansion the universe has been factored

234  
00:10:00,309 --> 00:10:05,138  
out when we're talking about the

235  
00:10:01,028 --> 00:10:07,809  
densities here okay so this is the one

236  
00:10:05,139 --> 00:10:10,089  
of the key figures in their paper all

237  
00:10:07,809 --> 00:10:12,549  
right and this on the y-axis is the

238  
00:10:10,089 --> 00:10:15,790  
number density of galaxies all right and

239  
00:10:12,549 --> 00:10:17,889  
on the x-axis is time in billions of

240  
00:10:15,789 --> 00:10:20,769  
years all right starting at the Big Bang

241  
00:10:17,889 --> 00:10:23,799  
here up to almost the present day over

242  
00:10:20,769 --> 00:10:25,750  
here and there's lots and lots of points

243  
00:10:23,799 --> 00:10:29,979  
because they're trying to normalize it

244  
00:10:25,750 --> 00:10:32,589  
to data that as observed galaxy surveys

245  
00:10:29,980 --> 00:10:33,039  
looking deeply at the various galaxies

246  
00:10:32,589 --> 00:10:34,660  
in the universe

247  
00:10:33,039 --> 00:10:36,269  
counting up galaxies and they're trying

248  
00:10:34,659 --> 00:10:39,188  
to normalize their theoretical

249  
00:10:36,269 --> 00:10:41,740  
prediction to that and this solid line

250  
00:10:39,188 --> 00:10:44,469  
is their best fit to the model results

251  
00:10:41,740 --> 00:10:46,448  
and you'll note that it's down around

252  
00:10:44,470 --> 00:10:48,819  
point one for most of its length and

253  
00:10:46,448 --> 00:10:50,799  
then in the first billion years of the

254  
00:10:48,818 --> 00:10:54,549  
universe it jumps up by a factor of 10

255  
00:10:50,799 --> 00:10:57,789  
or more okay the number of galaxies per

256  
00:10:54,549 --> 00:11:02,469  
unit volume and the first billion years

257

00:10:57,789 --> 00:11:05,110  
is much much larger than what we see out

258  
00:11:02,470 --> 00:11:06,819  
here and where are we going to see most

259  
00:11:05,110 --> 00:11:08,379  
of our galaxies with Hubble well

260  
00:11:06,818 --> 00:11:10,628  
we're gonna see them mostly out here

261  
00:11:08,379 --> 00:11:13,928  
that first billion years the universe is

262  
00:11:10,629 --> 00:11:16,808  
extremely difficult to look at okay

263  
00:11:13,928 --> 00:11:18,578  
so they're saying that we're missing a

264  
00:11:16,808 --> 00:11:20,558  
lot of galaxies over here because the

265  
00:11:18,578 --> 00:11:23,288  
number density is so high we're not

266  
00:11:20,558 --> 00:11:25,808  
seeing them they say that there are more

267  
00:11:23,288 --> 00:11:27,970  
low mass galaxies per massive galaxy at

268  
00:11:25,808 --> 00:11:30,608  
high redshifts than in the local

269  
00:11:27,970 --> 00:11:33,609  
universe by a large factor a factor of

270  
00:11:30,609 --> 00:11:35,999  
10 or so and the result is the total

271  
00:11:33,609 --> 00:11:39,609

number of galaxies the universe is two

272

00:11:35,999 --> 00:11:42,548

trillion almost a factor of 10 higher

273

00:11:39,609 --> 00:11:47,499

than we would be seen in an all-sky

274

00:11:42,548 --> 00:11:49,328

survey @hud a depth so if we could do

275

00:11:47,499 --> 00:11:52,509

the Hubble ultra-deep field across the

276

00:11:49,328 --> 00:11:55,058

entire night sky they're still saying we

277

00:11:52,509 --> 00:11:59,558

would only see 10% of the galaxies in

278

00:11:55,058 --> 00:12:02,978

the universe kind of impressive huh all

279

00:11:59,558 --> 00:12:05,288

right I will caution however that's

280

00:12:02,979 --> 00:12:06,788

still it's a theoretical study it's not

281

00:12:05,288 --> 00:12:09,788

an observational study nobody has

282

00:12:06,788 --> 00:12:12,220

actually seen these galaxies okay so

283

00:12:09,788 --> 00:12:15,850

what questions does it bring up in an

284

00:12:12,220 --> 00:12:18,389

astrophysicists mind first of all are

285

00:12:15,850 --> 00:12:21,220

the extrapolations too low mass robust

286  
00:12:18,389 --> 00:12:23,558  
we have some good observations that go

287  
00:12:21,220 --> 00:12:26,319  
down to 10 to the seventh solar masses

288  
00:12:23,558 --> 00:12:27,698  
okay and they sort of disagree with some

289  
00:12:26,318 --> 00:12:30,759  
of these predictions but they sort of

290  
00:12:27,698 --> 00:12:32,948  
agree you find really good agreement up

291  
00:12:30,759 --> 00:12:34,389  
to like 10 to the 10th solar masses but

292  
00:12:32,948 --> 00:12:35,168  
when you start going below that you

293  
00:12:34,389 --> 00:12:36,519  
start getting a little bit of

294  
00:12:35,168 --> 00:12:38,528  
disagreement and here they're

295  
00:12:36,519 --> 00:12:41,139  
extrapolating down to 10 to the 6 solar

296  
00:12:38,528 --> 00:12:43,899  
masses so I'm not quite sure as I read

297  
00:12:41,139 --> 00:12:46,089  
the paper you know is it really robust

298  
00:12:43,899 --> 00:12:47,708  
down to 10 to the 6 you know it's a very

299  
00:12:46,089 --> 00:12:49,359  
good paper okay I'm not trying to knock

300  
00:12:47,708 --> 00:12:50,918  
it I'm just trying to give you ideas of

301  
00:12:49,359 --> 00:12:53,229  
what an astronomer thinks when they see

302  
00:12:50,918 --> 00:12:55,119  
things like this and then my second

303  
00:12:53,229 --> 00:12:57,369  
question would have been will Jay doest

304  
00:12:55,119 --> 00:12:58,600  
T be able to see these galaxies as you

305  
00:12:57,369 --> 00:13:01,778  
know we've got the James Webb Space

306  
00:12:58,600 --> 00:13:03,850  
Telescope launching in 2018 we're gonna

307  
00:13:01,778 --> 00:13:06,278  
be the scientific home of it here we

308  
00:13:03,850 --> 00:13:08,589  
want to know hey if there are all these

309  
00:13:06,278 --> 00:13:10,778  
if we're only seeing 10% of the galaxies

310  
00:13:08,589 --> 00:13:13,539  
in the universe can j2s t see those

311  
00:13:10,778 --> 00:13:17,739  
other 90% the answer is unfortunately

312  
00:13:13,538 --> 00:13:19,928  
not we're talking 10 to the 6 solar

313  
00:13:17,739 --> 00:13:20,410  
masses we're just getting too small for

314

00:13:19,928 --> 00:13:25,088

J 2 as

315

00:13:20,409 --> 00:13:27,068

t2c okay so we won't be able to verify

316

00:13:25,089 --> 00:13:28,269

this result with James Webb okay which

317

00:13:27,068 --> 00:13:29,919

is of course one of the things that we

318

00:13:28,269 --> 00:13:32,860

would love to be able to do around here

319

00:13:29,919 --> 00:13:34,958

but if this is true all right if this

320

00:13:32,860 --> 00:13:38,159

prediction is true we'll figure out some

321

00:13:34,958 --> 00:13:40,448

way to figure out how to constrain it

322

00:13:38,159 --> 00:13:41,649

with the James Webb Space Telescope or

323

00:13:40,448 --> 00:13:44,620

maybe even with later Hubble

324

00:13:41,649 --> 00:13:46,089

observations and then finally it brings

325

00:13:44,620 --> 00:13:49,299

up a question that's sort of a classic

326

00:13:46,089 --> 00:13:52,180

in my mind what really qualifies as a

327

00:13:49,299 --> 00:13:53,500

galaxy okay because we start talking

328

00:13:52,179 --> 00:13:54,818

about the early universe and we're

329

00:13:53,500 --> 00:13:56,438

talking about the building blocks that

330

00:13:54,818 --> 00:13:58,628

will come together to form what we

331

00:13:56,438 --> 00:14:01,028

considered a you know a real galaxy like

332

00:13:58,629 --> 00:14:03,639

this this is a real galaxy okay it's a

333

00:14:01,028 --> 00:14:06,909

nice big large galaxy all right but if

334

00:14:03,639 --> 00:14:10,629

you take something that is one 100,000

335

00:14:06,909 --> 00:14:12,818

the size of this okay is that does that

336

00:14:10,629 --> 00:14:13,839

get to count as a full galaxy all right

337

00:14:12,818 --> 00:14:16,149

so when we're talking about these

338

00:14:13,839 --> 00:14:18,759

numbers of a hundred billion versus two

339

00:14:16,149 --> 00:14:21,490

trillion galaxies we're talking about

340

00:14:18,759 --> 00:14:23,589

the evolution of galaxies over time the

341

00:14:21,490 --> 00:14:25,509

development of them from these small

342

00:14:23,589 --> 00:14:29,019

things to these big things than mergers



343

00:14:25,509 --> 00:14:30,699

you know you may have you know a

344

00:14:29,019 --> 00:14:32,110

trillion galaxies early on simply

345

00:14:30,698 --> 00:14:34,299

because so many of them merged together

346

00:14:32,110 --> 00:14:38,409

to form much smaller number later on

347

00:14:34,299 --> 00:14:41,740

right so you really you're getting into

348

00:14:38,409 --> 00:14:44,350

not just galaxies across space but

349

00:14:41,740 --> 00:14:45,759

galaxies across time it's a time warped

350

00:14:44,350 --> 00:14:48,819

view of the universe that you have to

351

00:14:45,759 --> 00:14:51,278

think about and do these small little

352

00:14:48,818 --> 00:14:52,599

objects you know there are what we would

353

00:14:51,278 --> 00:14:56,769

normally consider galaxies in the local

354

00:14:52,600 --> 00:14:58,089

universe does how much does it count and

355

00:14:56,769 --> 00:15:00,159

so you get some very interesting

356

00:14:58,089 --> 00:15:01,810

questions so this was a major press

357  
00:15:00,159 --> 00:15:04,179  
release for us this month got a lot of

358  
00:15:01,809 --> 00:15:07,000  
attention and I think it brings up some

359  
00:15:04,179 --> 00:15:09,789  
really great questions as to where we

360  
00:15:07,000 --> 00:15:12,009  
would want to look in cosmology for

361  
00:15:09,789 --> 00:15:13,299  
these very earliest galaxies in the

362  
00:15:12,009 --> 00:15:15,730  
universe and it brings up an amazing

363  
00:15:13,299 --> 00:15:17,229  
prospect that you know hey 90% of the

364  
00:15:15,730 --> 00:15:19,269  
galaxies out there still have yet to be

365  
00:15:17,230 --> 00:15:22,420  
discovered which is always fun as an

366  
00:15:19,269 --> 00:15:26,409  
astronomer alright our second story

367  
00:15:22,419 --> 00:15:30,519  
tonight the ghost of a star

368  
00:15:26,409 --> 00:15:33,909  
we had a Halloween release last week and

369  
00:15:30,519 --> 00:15:39,220  
I couldn't be happy with just this

370  
00:15:33,909 --> 00:15:52,209  
also called it a bootiful nebula so we

371

00:15:39,220 --> 00:15:55,660  
released this image on Thursday tell you

372  
00:15:52,210 --> 00:15:57,370  
the story behind this image okay it's a

373  
00:15:55,659 --> 00:16:00,339  
signal filter image that was colored

374  
00:15:57,370 --> 00:16:04,870  
green actually so it's a broadband image

375  
00:16:00,340 --> 00:16:07,990  
a wave of wave band so it does actually

376  
00:16:04,870 --> 00:16:09,639  
have a green tinge to it but let me

377  
00:16:07,990 --> 00:16:12,100  
explain a little bit more about it okay

378  
00:16:09,639 --> 00:16:18,970  
so the story starts a little while ago

379  
00:16:12,100 --> 00:16:22,029  
on July 4th 1054 as you can read here if

380  
00:16:18,970 --> 00:16:24,910  
you read shine ancient chinese the

381  
00:16:22,029 --> 00:16:28,569  
chinese astronomers on July 4th 1054 saw

382  
00:16:24,909 --> 00:16:30,850  
a guest star appear in the sky

383  
00:16:28,570 --> 00:16:33,540  
I don't read Chinese so this could be

384  
00:16:30,850 --> 00:16:37,649  
recipe for moo shu pork as far as I know

385  
00:16:33,539 --> 00:16:42,219

but I can look at the hieroglyphs in

386

00:16:37,649 --> 00:16:44,319

Chaco Canyon and here is the full here's

387

00:16:42,220 --> 00:16:46,149

the crescent moon and here is the guest

388

00:16:44,320 --> 00:16:50,050

star depicted there about a hands length

389

00:16:46,149 --> 00:16:54,250

away from the crescent moon on the sky

390

00:16:50,049 --> 00:16:55,899

which also is believed to depict this a

391

00:16:54,250 --> 00:16:59,080

guest star appearing in the sky a

392

00:16:55,899 --> 00:17:01,449

thousand years ago all right if it was

393

00:16:59,080 --> 00:17:03,400

in the constellation Taurus and when we

394

00:17:01,450 --> 00:17:09,789

look at the constellation Taurus today

395

00:17:03,399 --> 00:17:12,789

we see that the Crab Nebula ok what this

396

00:17:09,789 --> 00:17:15,700

was was a super nova explosion the

397

00:17:12,789 --> 00:17:18,009

explosion of a star becoming so bright

398

00:17:15,700 --> 00:17:20,080

that it could be seen during the daytime

399

00:17:18,009 --> 00:17:23,650

here on earth

400  
00:17:20,079 --> 00:17:26,109  
alright and this star the guts of it has

401  
00:17:23,650 --> 00:17:26,980  
blown across space at 10 million miles

402  
00:17:26,109 --> 00:17:29,079  
an hour

403  
00:17:26,980 --> 00:17:32,049  
for a thousand years and created this

404  
00:17:29,079 --> 00:17:36,029  
gorgeous nebula now this nebula is shown

405  
00:17:32,049 --> 00:17:38,529  
in three filters hydrogen nitrogen and

406  
00:17:36,029 --> 00:17:40,059  
the broadband a little bit of the

407  
00:17:38,529 --> 00:17:41,289  
broadband one that I think maybe it's

408  
00:17:40,059 --> 00:17:43,029  
hydrogen nitrogen oxygen and a little

409  
00:17:41,289 --> 00:17:45,609  
bit of the broadband and you can see all

410  
00:17:43,029 --> 00:17:47,589  
this film entry stuff out here well

411  
00:17:45,609 --> 00:17:48,009  
that's the narrow band filters that just

412  
00:17:47,589 --> 00:17:50,649  
put

413  
00:17:48,009 --> 00:17:52,839  
pull out the individual elements okay

414  
00:17:50,650 --> 00:17:57,009  
the ghost image that I showed you before

415  
00:17:52,839 --> 00:17:58,298  
when I overlay it on top is there all

416  
00:17:57,009 --> 00:18:00,339  
right so I'm gonna blink back and forth

417  
00:17:58,298 --> 00:18:04,230  
so here's the normal crab that we're

418  
00:18:00,339 --> 00:18:08,019  
used to and there's the ghost normal

419  
00:18:04,230 --> 00:18:10,990  
ghost normal you can look right in here

420  
00:18:08,019 --> 00:18:13,539  
you can see that stuff that's not filled

421  
00:18:10,990 --> 00:18:17,890  
in in the ghost all right so what we're

422  
00:18:13,539 --> 00:18:21,159  
seeing here with this wide ban why this

423  
00:18:17,890 --> 00:18:24,370  
broadband image is that it is filling in

424  
00:18:21,160 --> 00:18:26,019  
in much the sort of egg shape of all

425  
00:18:24,369 --> 00:18:27,939  
this all this filament restructure short

426  
00:18:26,019 --> 00:18:30,970  
um it creates an egg shape and the

427  
00:18:27,940 --> 00:18:33,039  
interior is filled in with this ghost

428

00:18:30,970 --> 00:18:35,200  
image all right so here are the two

429  
00:18:33,039 --> 00:18:36,668  
images on the same scale just separated

430  
00:18:35,200 --> 00:18:39,069  
so you can take a look at them and you

431  
00:18:36,669 --> 00:18:40,809  
can see this blue image here roughly

432  
00:18:39,069 --> 00:18:44,019  
corresponds to the green that we

433  
00:18:40,808 --> 00:18:46,298  
released in the image on Friday but

434  
00:18:44,019 --> 00:18:49,029  
there's even more cool stuff in this

435  
00:18:46,298 --> 00:18:51,009  
image if we look straight in here in the

436  
00:18:49,029 --> 00:18:52,450  
interior you can see there's something

437  
00:18:51,009 --> 00:18:54,940  
funky going on in there

438  
00:18:52,450 --> 00:18:57,759  
well Hubble released an image of that

439  
00:18:54,940 --> 00:19:00,250  
previously this is the central region

440  
00:18:57,759 --> 00:19:02,259  
you see sort of ring structure here well

441  
00:19:00,250 --> 00:19:03,490  
that comes out beautifully when you look

442  
00:19:02,259 --> 00:19:06,490

in x-rays with the Chandra x-ray

443

00:19:03,490 --> 00:19:08,169

telescope all right you have a beautiful

444

00:19:06,490 --> 00:19:09,750

ring structure here you have a bright

445

00:19:08,169 --> 00:19:13,929

dot in the center and you have this

446

00:19:09,750 --> 00:19:17,558

material being spewed off this is the

447

00:19:13,929 --> 00:19:21,210

dead star this is the stellar remnant it

448

00:19:17,558 --> 00:19:23,410

is a neutron star a ball of neutrons

449

00:19:21,210 --> 00:19:28,690

about the size of the Baltimore Beltway

450

00:19:23,410 --> 00:19:31,660

okay just all packed in spinning 30

451

00:19:28,690 --> 00:19:33,640

times a second we know it's spinning 30

452

00:19:31,660 --> 00:19:36,580

times a second because that neutron star

453

00:19:33,640 --> 00:19:38,770

has an immense magnetic field all right

454

00:19:36,579 --> 00:19:41,019

that creates pulses when that magnetic

455

00:19:38,769 --> 00:19:43,119

field sweeps across our line of view 30

456

00:19:41,019 --> 00:19:47,259

times a second we get pulses from this



457  
00:19:43,119 --> 00:19:49,569  
and hence we call it a pulsar so the

458  
00:19:47,259 --> 00:19:52,058  
Pulsar at the center of a Crab Nebula

459  
00:19:49,569 --> 00:19:54,308  
has this amazing magnetic field that's

460  
00:19:52,058 --> 00:19:56,829  
sweeping around 30 times a second which

461  
00:19:54,308 --> 00:20:01,329  
of course is creating tremendous amounts

462  
00:19:56,829 --> 00:20:02,859  
of energy so if you look at that

463  
00:20:01,329 --> 00:20:04,389  
polarize light and you're gonna learn a

464  
00:20:02,859 --> 00:20:05,609  
lot about polarized light tonight right

465  
00:20:04,390 --> 00:20:08,440  
Toby yes

466  
00:20:05,609 --> 00:20:11,649  
if you look at in polarized light you

467  
00:20:08,440 --> 00:20:13,930  
could actually see some of the pulsation

468  
00:20:11,650 --> 00:20:17,320  
some of the effects of the magnetic

469  
00:20:13,930 --> 00:20:21,460  
field this is a seer time-lapse series

470  
00:20:17,319 --> 00:20:23,859  
okay all right and you can see material

471  
00:20:21,460 --> 00:20:28,329  
flowing away from that central neutron

472  
00:20:23,859 --> 00:20:31,240  
star and it is a broadband image plus

473  
00:20:28,329 --> 00:20:34,000  
some polarized light in order to see the

474  
00:20:31,240 --> 00:20:36,430  
material flowing away all right and so

475  
00:20:34,000 --> 00:20:38,589  
in the Halloween spirit

476  
00:20:36,430 --> 00:20:41,440  
since we're Baltimore and Edgar Allan

477  
00:20:38,589 --> 00:20:44,199  
Poe is related here we called this the

478  
00:20:41,440 --> 00:20:47,740  
tell-tale heart or the beating heart of

479  
00:20:44,200 --> 00:20:50,230  
the ghost of the Crab Nebula so even

480  
00:20:47,740 --> 00:20:53,109  
though it's a dead star it still has a

481  
00:20:50,230 --> 00:20:58,420  
beating heart and that was our Halloween

482  
00:20:53,109 --> 00:21:01,569  
release for this year now to our

483  
00:20:58,420 --> 00:21:04,930  
featured speaker our speaker tonight is

484  
00:21:01,569 --> 00:21:06,819  
Toby marriage he is from the across the

485

00:21:04,930 --> 00:21:10,120  
street the Johns Hopkins University where

486  
00:21:06,819 --> 00:21:13,629  
he is an assistant professor he has been

487  
00:21:10,119 --> 00:21:16,629  
there for seven years after having come

488  
00:21:13,630 --> 00:21:18,400  
to us from Princeton University and he

489  
00:21:16,630 --> 00:21:21,190  
was kind of unusual that he was at

490  
00:21:18,400 --> 00:21:24,550  
Princeton for 14 years he just couldn't

491  
00:21:21,190 --> 00:21:26,350  
graduate no he did his undergraduate

492  
00:21:24,549 --> 00:21:28,149  
work at Princeton and then he did his

493  
00:21:26,349 --> 00:21:30,219  
graduate work at Princeton with a

494  
00:21:28,150 --> 00:21:32,500  
one-year hiatus at Cambridge in England

495  
00:21:30,220 --> 00:21:34,839  
right okay so you had to get out of

496  
00:21:32,500 --> 00:21:36,430  
Princeton for just one year but that's

497  
00:21:34,839 --> 00:21:39,730  
kind of unusual to be able to spend that

498  
00:21:36,430 --> 00:21:41,259  
long at one institution and obviously we

499  
00:21:39,730 --> 00:21:43,329

are very fortunate to have him here in

500

00:21:41,259 --> 00:21:45,629

Baltimore ladies and gentlemen Toby

501

00:21:43,329 --> 00:21:45,629

marriage

502

00:21:58,440 --> 00:22:04,900

you can hear me okay

503

00:22:00,480 --> 00:22:08,710

all right good back there all right I'll

504

00:22:04,900 --> 00:22:11,830

soon so okay great well it's a real

505

00:22:08,710 --> 00:22:14,880

pleasure to be here tonight this is a

506

00:22:11,829 --> 00:22:17,769

really excellent forum I mean I try to

507

00:22:14,880 --> 00:22:21,278

encourage my students to you know learn

508

00:22:17,769 --> 00:22:23,168

for the joy of learning as sort of for

509

00:22:21,278 --> 00:22:25,509

grades and I think this is a good

510

00:22:23,169 --> 00:22:30,549

example of people learning for the for

511

00:22:25,509 --> 00:22:32,710

the joy of learning so tonight I'm going

512

00:22:30,548 --> 00:22:35,019

to tell you about a project we have

513

00:22:32,710 --> 00:22:37,558

across the street at the department of

514  
00:22:35,019 --> 00:22:40,389  
physics and astronomy at johns hopkins

515  
00:22:37,558 --> 00:22:43,230  
called the cosmology large angular scale

516  
00:22:40,390 --> 00:22:47,380  
surveyor and i'm going to keep the talk

517  
00:22:43,230 --> 00:22:50,110  
relatively short and with the hope that

518  
00:22:47,380 --> 00:22:53,710  
some of you will join me for a tour of

519  
00:22:50,109 --> 00:22:57,819  
our telescope building facility across

520  
00:22:53,710 --> 00:23:00,909  
the street so i'm going to begin with

521  
00:22:57,819 --> 00:23:04,148  
the scientific goals of the of the of

522  
00:23:00,909 --> 00:23:06,399  
the cosmology large angular scale say a

523  
00:23:04,148 --> 00:23:10,000  
surveyor which from now on i'll referred

524  
00:23:06,398 --> 00:23:11,979  
to as his class so with class we're

525  
00:23:10,000 --> 00:23:13,679  
trying to end our primary the primary

526  
00:23:11,980 --> 00:23:18,220  
question we're trying to answer is this

527  
00:23:13,679 --> 00:23:23,710  
how did this happen so that is how did

528  
00:23:18,220 --> 00:23:25,000  
the universe happen and you know in

529  
00:23:23,710 --> 00:23:26,829  
order to answer that we need to

530  
00:23:25,000 --> 00:23:29,380  
essentially look back in time we need to

531  
00:23:26,829 --> 00:23:32,379  
but go back we need to be able to probe

532  
00:23:29,380 --> 00:23:36,730  
the earliest moments of the universe to

533  
00:23:32,380 --> 00:23:40,690  
say how did this all get started and the

534  
00:23:36,730 --> 00:23:43,899  
tool we astronomers have for that is is

535  
00:23:40,690 --> 00:23:46,090  
life of course so the light that we see

536  
00:23:43,898 --> 00:23:48,158  
on the sky is essentially a cosmic

537  
00:23:46,089 --> 00:23:50,949  
fossil record and this comes from the

538  
00:23:48,159 --> 00:23:53,679  
fact that it takes light time to travel

539  
00:23:50,950 --> 00:23:56,009  
to us from distant objects so if you

540  
00:23:53,679 --> 00:23:59,130  
consider for instance the Sun

541  
00:23:56,009 --> 00:24:01,319  
that takes it takes light eight minutes

542

00:23:59,130 --> 00:24:04,590  
to reach us from the Sun so we're seeing

543  
00:24:01,319 --> 00:24:07,829  
the Sun as it was eight minutes ago if

544  
00:24:04,589 --> 00:24:09,689  
God forgive bid the Sun went out we

545  
00:24:07,829 --> 00:24:13,710  
wouldn't know to a pleasant eight

546  
00:24:09,690 --> 00:24:16,140  
minutes if you look further out of

547  
00:24:13,710 --> 00:24:18,750  
course you see stars those stars we're

548  
00:24:16,140 --> 00:24:22,560  
seeing as they were tens of years ago

549  
00:24:18,750 --> 00:24:24,690  
and look further out you get two nearby

550  
00:24:22,559 --> 00:24:26,599  
galaxies now you're now you're looking

551  
00:24:24,690 --> 00:24:29,940  
back in the past a million years

552  
00:24:26,599 --> 00:24:32,189  
millions of years look even further out

553  
00:24:29,940 --> 00:24:34,350  
you see the earlier galaxies in their

554  
00:24:32,190 --> 00:24:38,519  
universe you're looking back billions of

555  
00:24:34,349 --> 00:24:40,500  
years and if you look all the way back

556  
00:24:38,519 --> 00:24:43,319

all the way back to before these

557

00:24:40,500 --> 00:24:45,420

galaxies formed you see a wall of light

558

00:24:43,319 --> 00:24:47,849

and that wall of light is called the

559

00:24:45,420 --> 00:24:49,470

Cosmic Microwave Background what's

560

00:24:47,849 --> 00:24:51,719

happened at this point is you've looked

561

00:24:49,470 --> 00:24:54,420

all the way back to the very earliest

562

00:24:51,720 --> 00:24:58,950

moments of the universe some 13.7

563

00:24:54,420 --> 00:25:03,240

billion years ago and at that point the

564

00:24:58,950 --> 00:25:07,230

universe was so dense that hydrogen

565

00:25:03,240 --> 00:25:10,259

which makes up most of the gas or normal

566

00:25:07,230 --> 00:25:12,950

particles in the universe was ionized

567

00:25:10,259 --> 00:25:16,200

and you just see this opaque plasma of

568

00:25:12,950 --> 00:25:18,150

photons and electrons and protons ooming

569

00:25:16,200 --> 00:25:21,210

around and so it just looks like a

570

00:25:18,150 --> 00:25:24,330

cosmic soup and if you look very closely



571  
00:25:21,210 --> 00:25:27,539  
with the contrast of better than one and

572  
00:25:24,329 --> 00:25:29,429  
a hundred thousand you'll see bumps in

573  
00:25:27,539 --> 00:25:32,430  
the brightness brightness and dark spots

574  
00:25:29,430 --> 00:25:33,840  
and this in this bright wall and that is

575  
00:25:32,430 --> 00:25:37,970  
what we study with the Cosmic Microwave

576  
00:25:33,839 --> 00:25:42,839  
Background this is how it all began and

577  
00:25:37,970 --> 00:25:44,940  
from this all of this formed so we have

578  
00:25:42,839 --> 00:25:47,819  
an answer we can look back in time we

579  
00:25:44,940 --> 00:25:51,390  
can use our time machine looking out is

580  
00:25:47,819 --> 00:25:54,809  
looking back and we can say that these

581  
00:25:51,390 --> 00:25:59,930  
came from this or to put it in pictures

582  
00:25:54,809 --> 00:25:59,929  
this evolved from this

583  
00:26:01,240 --> 00:26:06,250  
there's layers to everything so of

584  
00:26:04,119 --> 00:26:08,069  
course the next question is well how did

585  
00:26:06,250 --> 00:26:10,269  
this happen

586  
00:26:08,069 --> 00:26:13,720  
unfortunately you can't look past this

587  
00:26:10,269 --> 00:26:15,849  
wall in light and so we have to infer

588  
00:26:13,720 --> 00:26:19,600  
from our physics what happened before

589  
00:26:15,849 --> 00:26:22,538  
this what put this in place and one of

590  
00:26:19,599 --> 00:26:25,648  
the best theories we have for how this

591  
00:26:22,538 --> 00:26:29,379  
got there is called inflation theory and

592  
00:26:25,648 --> 00:26:31,979  
inflation theory posits that all of this

593  
00:26:29,380 --> 00:26:36,278  
structure in the very early universe

594  
00:26:31,980 --> 00:26:40,329  
grew from quantum fluctuations these are

595  
00:26:36,278 --> 00:26:43,599  
subatomic fluctuations that quantum

596  
00:26:40,329 --> 00:26:47,019  
physics says have to be there and the

597  
00:26:43,599 --> 00:26:49,209  
inflation theory posits that the early

598  
00:26:47,019 --> 00:26:52,389  
universe grew out of these random

599

00:26:49,210 --> 00:26:57,069  
quantum fluctuations I know it sounds

600  
00:26:52,390 --> 00:27:00,700  
crazy but it explains a lot in addition

601  
00:26:57,069 --> 00:27:03,339  
to the bumps in the early universe that

602  
00:27:00,700 --> 00:27:07,210  
grew into galaxies inflation theory

603  
00:27:03,339 --> 00:27:11,470  
predicts that not only are there quantum

604  
00:27:07,210 --> 00:27:14,470  
fluctuations in this energy density that

605  
00:27:11,470 --> 00:27:17,890  
gives rise to gravitational wells that

606  
00:27:14,470 --> 00:27:21,669  
into which pool are matter and into

607  
00:27:17,890 --> 00:27:24,929  
which grow our galaxy's there are also

608  
00:27:21,669 --> 00:27:28,090  
cosmic fluctuations in space-time itself

609  
00:27:24,929 --> 00:27:31,059  
so space-time is rippling stretching

610  
00:27:28,089 --> 00:27:33,879  
squishing squashing in the early

611  
00:27:31,058 --> 00:27:37,798  
universe and these get blown up to

612  
00:27:33,880 --> 00:27:40,960  
cosmic scales as well and these become

613  
00:27:37,798 --> 00:27:42,700

universe sized gravitational waves

614

00:27:40,960 --> 00:27:45,788

so the squishing and squashing of

615

00:27:42,700 --> 00:27:48,330

space-time writ large across the entire

616

00:27:45,788 --> 00:27:48,329

universe

617

00:27:50,339 --> 00:27:56,648

so speaking of squishing and squashing

618

00:27:54,038 --> 00:27:59,140

so this is a picture of a gravitational

619

00:27:56,648 --> 00:28:02,019

wave and what a gravitational wave does

620

00:27:59,140 --> 00:28:05,049

is it squashes space in one direction

621

00:28:02,019 --> 00:28:08,798

and it stretches it in the other so this

622

00:28:05,048 --> 00:28:12,158

is a little animation see if it works

623

00:28:08,798 --> 00:28:14,349

there we go so squish squash squish

624

00:28:12,159 --> 00:28:18,549

stretch squash etc

625

00:28:14,349 --> 00:28:20,648

so as you can see when it pulls in this

626

00:28:18,548 --> 00:28:23,528

direction it pushes in that direction

627

00:28:20,648 --> 00:28:26,678

and when it pushes in this direction it

628  
00:28:23,528 --> 00:28:28,419  
pulls in that direction so this is going

629  
00:28:26,679 --> 00:28:32,259  
to affect the light in the early

630  
00:28:28,419 --> 00:28:34,480  
universe and in particular what's going

631  
00:28:32,259 --> 00:28:36,778  
to happen is when you squish the Y when

632  
00:28:34,480 --> 00:28:40,599  
you squish space like this you're gonna

633  
00:28:36,778 --> 00:28:42,369  
you basically boost the CMB the Cosmic

634  
00:28:40,599 --> 00:28:44,109  
Microwave Background the light in the

635  
00:28:42,369 --> 00:28:46,178  
early universe you boost the light in

636  
00:28:44,109 --> 00:28:49,628  
that direction so you basically have you

637  
00:28:46,179 --> 00:28:53,190  
know light beams travelling in like this

638  
00:28:49,628 --> 00:28:57,788  
in the middle of a gravitational wave

639  
00:28:53,190 --> 00:28:59,769  
and what this does is it produces what

640  
00:28:57,788 --> 00:29:01,690  
happens is these light beams come in and

641  
00:28:59,769 --> 00:29:03,878  
they scatter they scatter off of that

642  
00:29:01,690 --> 00:29:08,259  
plasma in the early universe and then

643  
00:29:03,878 --> 00:29:10,178  
they come to us polarized so you're so

644  
00:29:08,259 --> 00:29:12,849  
you may be familiar with the

645  
00:29:10,179 --> 00:29:16,059  
polarization of light from say if you're

646  
00:29:12,849 --> 00:29:18,189  
a fishing and sunlight comes off it

647  
00:29:16,058 --> 00:29:19,418  
comes off the comes off the water and

648  
00:29:18,190 --> 00:29:23,019  
it's bright and you can put on your

649  
00:29:19,419 --> 00:29:25,778  
polarized sunglasses and and and and

650  
00:29:23,019 --> 00:29:29,679  
brought and block the glare from from

651  
00:29:25,778 --> 00:29:31,509  
the lake but and this this is exactly

652  
00:29:29,679 --> 00:29:35,860  
the same kind of thing there's another

653  
00:29:31,509 --> 00:29:39,669  
analogy again with sunlight in the sky

654  
00:29:35,859 --> 00:29:42,459  
so as sunlight passes through the

655  
00:29:39,669 --> 00:29:44,049  
atmosphere and it scatters it's actually

656

00:29:42,460 --> 00:29:48,220  
ends up being polarized so you're

657  
00:29:44,048 --> 00:29:51,009  
outside on a nice day and especially as

658  
00:29:48,220 --> 00:29:53,139  
the sun's going going down towards the

659  
00:29:51,009 --> 00:29:56,639  
horizon you'll have a you'll have a

660  
00:29:53,138 --> 00:29:59,729  
clearer polarized pattern on the sky in

661  
00:29:56,638 --> 00:30:05,168  
particular here is is sort of

662  
00:29:59,730 --> 00:30:07,990  
schematically depicted the polarization

663  
00:30:05,169 --> 00:30:09,669  
here of the light is mostly vertical so

664  
00:30:07,990 --> 00:30:12,250  
the light oscillates in this direction

665  
00:30:09,669 --> 00:30:13,778  
and out here the scattered light

666  
00:30:12,250 --> 00:30:16,509  
oscillates in this direction and out

667  
00:30:13,778 --> 00:30:19,808  
here the light is relatively on

668  
00:30:16,509 --> 00:30:23,950  
polarized so if we apply a polarizing

669  
00:30:19,808 --> 00:30:26,710  
filter to this image such that we block

670  
00:30:23,950 --> 00:30:28,150

that vertical polarization where we have

671

00:30:26,710 --> 00:30:32,049

vertically polarized light

672

00:30:28,150 --> 00:30:34,450

it's going to go dark and that's what

673

00:30:32,049 --> 00:30:36,819

you see so if you walked outside with a

674

00:30:34,450 --> 00:30:39,069

polarized filter on your eyes at this

675

00:30:36,819 --> 00:30:40,929

time you would actually see a dark band

676

00:30:39,069 --> 00:30:43,869

on the sky so you can go out in an

677

00:30:40,930 --> 00:30:47,549

experiment with this the skies actually

678

00:30:43,869 --> 00:30:49,989

ends up being polarized in this way and

679

00:30:47,549 --> 00:30:50,619

we're not the only ones that know about

680

00:30:49,990 --> 00:30:53,559

this

681

00:30:50,619 --> 00:30:57,609

in fact bees know about this they

682

00:30:53,559 --> 00:31:00,339

actually use this to navigate they have

683

00:30:57,609 --> 00:31:02,740

polarization sensitive photoreceptors in

684

00:31:00,339 --> 00:31:05,319

their eyes and they can use this



685  
00:31:02,740 --> 00:31:09,190  
polarization effect to tell the other

686  
00:31:05,319 --> 00:31:12,639  
bees where to get palling they can tell

687  
00:31:09,190 --> 00:31:14,529  
east from north from west using the fact

688  
00:31:12,640 --> 00:31:17,170  
that the sky is polarized here towards

689  
00:31:14,529 --> 00:31:19,450  
the north and not towards the east so

690  
00:31:17,170 --> 00:31:21,130  
again the point here is that when you

691  
00:31:19,450 --> 00:31:28,059  
get scattering of light you get this

692  
00:31:21,130 --> 00:31:31,450  
polarization okay so just to realize so

693  
00:31:28,059 --> 00:31:35,500  
an analogy with scattered sunlight the

694  
00:31:31,450 --> 00:31:37,210  
CMB is scattered through polarization

695  
00:31:35,500 --> 00:31:41,920  
due to this gravitational wave

696  
00:31:37,210 --> 00:31:46,000  
enhancement good news for bees in the

697  
00:31:41,920 --> 00:31:47,370  
early universe no there weren't any bees

698  
00:31:46,000 --> 00:31:51,390  
in the earlier

699  
00:31:47,369 --> 00:31:56,250  
okay all right so but the point here is

700  
00:31:51,390 --> 00:31:58,620  
that gravitational waves produce this

701  
00:31:56,250 --> 00:32:01,140  
polarization in the CMB and we can go

702  
00:31:58,619 --> 00:32:02,929  
out and look for that in order to find

703  
00:32:01,140 --> 00:32:07,650  
evidence for these gravitational waves

704  
00:32:02,930 --> 00:32:10,769  
so to completely stretch my analogy to

705  
00:32:07,650 --> 00:32:13,070  
it's breaking strength the bees use the

706  
00:32:10,769 --> 00:32:16,259  
polarization of the Sun to find Paul and

707  
00:32:13,069 --> 00:32:18,329  
we use the polarization of the CMB to

708  
00:32:16,259 --> 00:32:23,369  
find the primordial gravitational waves

709  
00:32:18,329 --> 00:32:24,869  
from inflation all right so here we go

710  
00:32:23,369 --> 00:32:27,449  
so how do we do that we don't have

711  
00:32:24,869 --> 00:32:29,729  
photoreceptors that our polarization

712  
00:32:27,450 --> 00:32:31,559  
sensitive in our eyes to see the CMB we

713

00:32:29,730 --> 00:32:35,160  
have to build telescopes and so that's

714  
00:32:31,559 --> 00:32:38,450  
what we're doing so this is class so

715  
00:32:35,160 --> 00:32:41,820  
this is a artist's rendition of class

716  
00:32:38,450 --> 00:32:43,019  
it's an array of four telescopes what

717  
00:32:41,819 --> 00:32:45,779  
you're looking at here are two

718  
00:32:43,019 --> 00:32:48,420  
structures two pedestals and on each

719  
00:32:45,779 --> 00:32:50,609  
pedestal there are two telescopes with

720  
00:32:48,420 --> 00:32:53,550  
beams looking at the sky through beams

721  
00:32:50,609 --> 00:32:59,429  
represented by these four these four

722  
00:32:53,549 --> 00:33:02,159  
green columns and in particular these

723  
00:32:59,430 --> 00:33:03,810  
telescopes operate at four different

724  
00:33:02,160 --> 00:33:06,570  
wavelengths or four different

725  
00:33:03,809 --> 00:33:08,700  
frequencies going from here at about a

726  
00:33:06,569 --> 00:33:10,919  
millimeter wavelength so these are very

727  
00:33:08,700 --> 00:33:13,830

long frequencies compared to say optical

728

00:33:10,920 --> 00:33:15,900

light which is a micron so we're looking

729

00:33:13,829 --> 00:33:18,509

at millimeter wavelengths so this is a

730

00:33:15,900 --> 00:33:20,130

the this telescope here looks at a

731

00:33:18,509 --> 00:33:22,379

millimeter and two millimeter light

732

00:33:20,130 --> 00:33:24,180

these two telescopes look at light

733

00:33:22,380 --> 00:33:26,790

that's about three millimeters long and

734

00:33:24,180 --> 00:33:29,220

wavelength and this telescope looks like

735

00:33:26,789 --> 00:33:30,899

it looks at an even longer wavelength in

736

00:33:29,220 --> 00:33:36,870

this sort of six to seven millimeter

737

00:33:30,900 --> 00:33:39,810

range so so so for telescopes for

738

00:33:36,869 --> 00:33:42,869

frequencies in the middle of the Atacama

739

00:33:39,809 --> 00:33:45,269

Desert of northern Chile at 5200 meters

740

00:33:42,869 --> 00:33:47,819

and we'll have more on that on the site

741

00:33:45,269 --> 00:33:49,680

in a little bit but let's let's let's

742  
00:33:47,819 --> 00:33:53,250  
dig in a little bit to the design of the

743  
00:33:49,680 --> 00:33:57,029  
telescope so one first question is you

744  
00:33:53,250 --> 00:33:59,179  
know why for frequencies right and you

745  
00:33:57,029 --> 00:34:02,428  
know it's all about fruit

746  
00:33:59,179 --> 00:34:05,700  
but it's a good analogy so basically

747  
00:34:02,429 --> 00:34:07,940  
these frequencies of in the microwave

748  
00:34:05,700 --> 00:34:10,318  
the frequencies were looking at

749  
00:34:07,940 --> 00:34:11,789  
correspond to colors now if you're

750  
00:34:10,318 --> 00:34:13,858  
looking at the sky

751  
00:34:11,789 --> 00:34:15,568  
or any other picture without color if

752  
00:34:13,858 --> 00:34:18,358  
you're looking at stuff that looks

753  
00:34:15,568 --> 00:34:23,398  
similar say an orange a lime and a lemon

754  
00:34:18,358 --> 00:34:26,519  
or is it a lime and orange and well I

755  
00:34:23,398 --> 00:34:28,918  
can't tell because there's not color but

756  
00:34:26,519 --> 00:34:31,409  
but yeah so so the point here is that

757  
00:34:28,918 --> 00:34:33,529  
without colors it's hard to tell things

758  
00:34:31,409 --> 00:34:37,079  
apart both on the sky and in real life

759  
00:34:33,530 --> 00:34:39,300  
so you add colors and you can tell your

760  
00:34:37,079 --> 00:34:41,159  
oranges from your lemons or in our game

761  
00:34:39,300 --> 00:34:42,990  
you can tell the Cosmic Microwave

762  
00:34:41,159 --> 00:34:46,200  
Background from other sources of

763  
00:34:42,989 --> 00:34:48,449  
microwave radiation mainly from our

764  
00:34:46,199 --> 00:34:53,878  
galaxy you're talking about a mission

765  
00:34:48,449 --> 00:34:58,169  
from hot from warm dust and/or a mission

766  
00:34:53,878 --> 00:35:00,809  
from light via mission you saw from the

767  
00:34:58,170 --> 00:35:03,930  
Crab Nebula from accelerated electrons

768  
00:35:00,809 --> 00:35:06,599  
in any case you want to be able to you

769  
00:35:03,929 --> 00:35:09,809  
basically what we you know just like you

770

00:35:06,599 --> 00:35:12,088  
need red blue and green in this picture

771  
00:35:09,809 --> 00:35:17,250  
to tell these fruit apart

772  
00:35:12,088 --> 00:35:19,469  
we need 40 gigahertz 90 gigahertz 150

773  
00:35:17,250 --> 00:35:23,250  
gigahertz and 220 gigahertz in order to

774  
00:35:19,469 --> 00:35:26,219  
tell the dust apart from the cosmic

775  
00:35:23,250 --> 00:35:27,900  
microwave background so that's why we

776  
00:35:26,219 --> 00:35:29,969  
have the four frequencies is basically

777  
00:35:27,900 --> 00:35:32,519  
to make a color picture of the sky to

778  
00:35:29,969 --> 00:35:34,409  
know that what we're looking at is

779  
00:35:32,519 --> 00:35:36,588  
actually the is actually this

780  
00:35:34,409 --> 00:35:42,029  
polarization signature from primordial

781  
00:35:36,588 --> 00:35:44,099  
gravitational waves all right so let's

782  
00:35:42,030 --> 00:35:45,900  
look under the hood all right so this is

783  
00:35:44,099 --> 00:35:48,869  
one of the telescopes and all the

784  
00:35:45,900 --> 00:35:50,130

telescopes look look similar but Optima

785

00:35:48,869 --> 00:35:52,980  
but operate at these different

786

00:35:50,130 --> 00:35:56,000  
frequencies so let's follow the light so

787

00:35:52,980 --> 00:35:58,650  
the light enters the telescope here and

788

00:35:56,000 --> 00:36:00,269  
the light comes in and it reflects off

789

00:35:58,650 --> 00:36:02,460  
of this thing color that I've got

790

00:36:00,269 --> 00:36:04,858  
labeled here as the BPM the stands for

791

00:36:02,460 --> 00:36:06,420  
variable delay polarization modulator

792

00:36:04,858 --> 00:36:07,650  
and let's just leave that for now I'm

793

00:36:06,420 --> 00:36:10,798  
going to talk a lot about that later

794

00:36:07,650 --> 00:36:12,200  
because this is really really what makes

795

00:36:10,798 --> 00:36:15,150  
class special

796

00:36:12,199 --> 00:36:18,000  
but let's just let the light reflect off

797

00:36:15,150 --> 00:36:21,210  
of that now it bounces off of the it

798

00:36:18,000 --> 00:36:24,269  
reflects off these mirrors primary



799  
00:36:21,210 --> 00:36:27,869  
secondary and the light travels into

800  
00:36:24,269 --> 00:36:29,789  
this into this what we call a cryogenic

801  
00:36:27,869 --> 00:36:32,250  
receiver which in the sense that it

802  
00:36:29,789 --> 00:36:36,059  
receives the light cryogenic in the

803  
00:36:32,250 --> 00:36:39,300  
sense that it's cold and it goes through

804  
00:36:36,059 --> 00:36:42,659  
these cryogenic lenses this lens sits at

805  
00:36:39,300 --> 00:36:43,560  
4 Kelvin so for 4 degrees above absolute

806  
00:36:42,659 --> 00:36:46,170  
zero

807  
00:36:43,559 --> 00:36:49,049  
this lens sits at 1 Kelvin and it

808  
00:36:46,170 --> 00:36:50,820  
finally reaches our detectors that's it

809  
00:36:49,050 --> 00:36:53,130  
in the focal plane of the telescope and

810  
00:36:50,820 --> 00:36:55,380  
these are only one tenth of a Kelvin

811  
00:36:53,130 --> 00:36:58,769  
above absolute zero we need them to be

812  
00:36:55,380 --> 00:37:01,590  
that cold because the signal that we're

813  
00:36:58,769 --> 00:37:03,659  
looking at is exceptionally faint and if

814  
00:37:01,590 --> 00:37:06,660  
we have thermal fluctuations that are

815  
00:37:03,659 --> 00:37:08,730  
say the level of thermal fluctuations in

816  
00:37:06,659 --> 00:37:10,739  
this room then the noise from those

817  
00:37:08,730 --> 00:37:12,690  
thermal fluctuations completely swamp

818  
00:37:10,739 --> 00:37:15,049  
our signal so that's why we need to cool

819  
00:37:12,690 --> 00:37:17,550  
our detectors so cold

820  
00:37:15,050 --> 00:37:21,320  
zooming into the detectors here they are

821  
00:37:17,550 --> 00:37:23,730  
these are actually microfabricated

822  
00:37:21,320 --> 00:37:25,380  
detectors that are made just down the

823  
00:37:23,730 --> 00:37:27,690  
street at NASA Goddard Space Flight

824  
00:37:25,380 --> 00:37:29,550  
Center and we collaborate with the

825  
00:37:27,690 --> 00:37:35,369  
scientists there to build these

826  
00:37:29,550 --> 00:37:38,100  
detectors all right so I promise I

827

00:37:35,369 --> 00:37:41,969  
talked about this BPM or this variable

828  
00:37:38,099 --> 00:37:44,190  
delay polarization modulator so the BPM

829  
00:37:41,969 --> 00:37:46,619  
is it shown here it's about 60

830  
00:37:44,190 --> 00:37:48,210  
centimeters across and what you're

831  
00:37:46,619 --> 00:37:51,329  
looking at here you can sort of see a

832  
00:37:48,210 --> 00:37:54,389  
haze in front of the circular circular

833  
00:37:51,329 --> 00:37:56,699  
mirror that haze is about a few

834  
00:37:54,389 --> 00:37:58,859  
kilometers worth of a hundred micron

835  
00:37:56,699 --> 00:38:03,119  
wire stretched to its breaking strength

836  
00:37:58,860 --> 00:38:04,650  
and separated by about as much space so

837  
00:38:03,119 --> 00:38:07,109  
you know the few kilometers of wire

838  
00:38:04,650 --> 00:38:11,400  
stretched in the 60 cent is centimeter

839  
00:38:07,110 --> 00:38:15,570  
aperture and supported by this frame and

840  
00:38:11,400 --> 00:38:19,579  
if you add a few tons of force in it so

841  
00:38:15,570 --> 00:38:22,380

the idea here is that this wire grid

842

00:38:19,579 --> 00:38:23,569

reflects one polarization because the

843

00:38:22,380 --> 00:38:28,240

grids in one direction

844

00:38:23,570 --> 00:38:28,240

and transmits another to this mirror and

845

00:38:29,710 --> 00:38:34,369

that's the group that's that's the VP

846

00:38:32,869 --> 00:38:36,710

I'm deployed in the field with its

847

00:38:34,369 --> 00:38:39,380

creator Katie she's a she's a graduate

848

00:38:36,710 --> 00:38:41,480

student over and in our labs but this is

849

00:38:39,380 --> 00:38:43,550

she spent about three months up in the

850

00:38:41,480 --> 00:38:52,070

desert and this was this is a good

851

00:38:43,550 --> 00:38:53,570

moment for her okay so okay so to say

852

00:38:52,070 --> 00:38:56,059

what's going on with this polarization

853

00:38:53,570 --> 00:38:58,460

modulator a little bit more

854

00:38:56,059 --> 00:39:01,789

schematically here's that wire grid that

855

00:38:58,460 --> 00:39:05,179

kilometer worth of wires stretched in a

856  
00:39:01,789 --> 00:39:07,250  
comb like this and we have the mirror

857  
00:39:05,179 --> 00:39:10,159  
right up against the wires and what

858  
00:39:07,250 --> 00:39:12,349  
we're going to do is we're going to move

859  
00:39:10,159 --> 00:39:17,719  
that mirror and this is what the VPM

860  
00:39:12,349 --> 00:39:20,420  
does it has a very tense wire grid in

861  
00:39:17,719 --> 00:39:22,399  
front and it has a mirror that sits

862  
00:39:20,420 --> 00:39:24,889  
behind it and moves back and forth and

863  
00:39:22,400 --> 00:39:27,079  
so what you can see is happening here is

864  
00:39:24,889 --> 00:39:29,900  
that one polarization state the

865  
00:39:27,079 --> 00:39:32,569  
polarization state that's like this is

866  
00:39:29,900 --> 00:39:34,610  
transmitting through the wire grid going

867  
00:39:32,570 --> 00:39:38,030  
to the mirror and the other polarization

868  
00:39:34,610 --> 00:39:41,440  
state is is is reflecting off the grid

869  
00:39:38,030 --> 00:39:44,060  
and so in this way we separate in phase

870  
00:39:41,440 --> 00:39:49,309  
one polarization state from the other

871  
00:39:44,059 --> 00:39:51,940  
and we move this mirror at about ten ten

872  
00:39:49,309 --> 00:39:55,369  
Hertz so up and down ten times a second

873  
00:39:51,940 --> 00:39:59,750  
and in this way we modulate this

874  
00:39:55,369 --> 00:40:03,170  
polarization signal so the picture is

875  
00:39:59,750 --> 00:40:04,639  
this we have this we have the signal

876  
00:40:03,170 --> 00:40:06,710  
coming in from the CMB

877  
00:40:04,639 --> 00:40:09,170  
and we run it through this variable

878  
00:40:06,710 --> 00:40:11,150  
delay polarization modulator and we move

879  
00:40:09,170 --> 00:40:13,519  
that mirror up and down and so the

880  
00:40:11,150 --> 00:40:15,800  
signal gets encoded at this ten Hertz

881  
00:40:13,519 --> 00:40:19,519  
frequency at this high frequency and

882  
00:40:15,800 --> 00:40:21,610  
then you have this noise from from the

883  
00:40:19,519 --> 00:40:25,099  
telescope and from say the atmosphere

884

00:40:21,610 --> 00:40:26,930  
that on which this this frequency rides

885  
00:40:25,099 --> 00:40:29,210  
so this is a little bit like your car

886  
00:40:26,929 --> 00:40:31,730  
radius you can tune in to a station and

887  
00:40:29,210 --> 00:40:33,050  
hear a signal you turn it tune a little

888  
00:40:31,730 --> 00:40:35,510  
bit to the right from that station all

889  
00:40:33,050 --> 00:40:36,590  
you hear is fuzz and so this is what

890  
00:40:35,510 --> 00:40:39,440  
we're doing we're two

891  
00:40:36,590 --> 00:40:41,570  
we're basically putting our using this

892  
00:40:39,440 --> 00:40:44,059  
variable delay polarization modulator

893  
00:40:41,570 --> 00:40:46,550  
where we're putting our cosmic microwave

894  
00:40:44,059 --> 00:40:50,239  
background signal at a specific

895  
00:40:46,550 --> 00:40:54,220  
frequency that's away from our noise so

896  
00:40:50,239 --> 00:40:56,329  
I've designed a look at we we've we've

897  
00:40:54,219 --> 00:41:00,139  
we've created a little audio

898  
00:40:56,329 --> 00:41:02,389

demonstration of this soso which will

899

00:41:00,139 --> 00:41:03,710

sort of demonstrate how this how this

900

00:41:02,389 --> 00:41:06,739

techniques work and it techniques

901

00:41:03,710 --> 00:41:10,490

technique works so the cosmic microwave

902

00:41:06,739 --> 00:41:13,129

background polarization is going to be

903

00:41:10,489 --> 00:41:15,109

represented by a voice here and we're

904

00:41:13,130 --> 00:41:16,910

going to show how that can get drowned

905

00:41:15,110 --> 00:41:18,920

out but then when you move it to a

906

00:41:16,909 --> 00:41:21,079

higher frequency you'll be able to hear

907

00:41:18,920 --> 00:41:24,619

it despite the noise so let's let's see

908

00:41:21,079 --> 00:41:27,860

how this goes so here's the signal the

909

00:41:24,619 --> 00:41:40,460

cosmic microwave background polarization

910

00:41:27,860 --> 00:41:43,039

okay and here's the noise now we put

911

00:41:40,460 --> 00:41:51,260

them together and it's gonna be hard to

912

00:41:43,039 --> 00:41:52,789

hear this signal hard to hear the signal



913  
00:41:51,260 --> 00:42:00,590  
now we're going to boost the signal a

914  
00:41:52,789 --> 00:42:03,190  
higher frequency okay now we're gonna

915  
00:42:00,590 --> 00:42:03,190  
add the noise

916  
00:42:11,570 --> 00:42:17,030  
that's exactly our class works so we

917  
00:42:14,960 --> 00:42:18,530  
take that we take the we we take this

918  
00:42:17,030 --> 00:42:20,840  
this signal that what other bye

919  
00:42:18,530 --> 00:42:23,720  
otherwise be you know a low frequency

920  
00:42:20,840 --> 00:42:25,910  
like my voice and drowned in this low

921  
00:42:23,719 --> 00:42:28,669  
frequency noise and we boost it to this

922  
00:42:25,909 --> 00:42:30,259  
higher frequency using that BPM and then

923  
00:42:28,670 --> 00:42:32,119  
we can disentangle that from the noise

924  
00:42:30,260 --> 00:42:35,300  
just like your ear could disentangle the

925  
00:42:32,119 --> 00:42:38,119  
higher frequency signal from the low

926  
00:42:35,300 --> 00:42:43,100  
frequency noise this is very good

927  
00:42:38,119 --> 00:42:46,279  
analogy okay so we build this thing and

928  
00:42:43,099 --> 00:42:47,960  
then what do we do so the first step is

929  
00:42:46,280 --> 00:42:50,540  
you know we bring this all together we

930  
00:42:47,960 --> 00:42:57,380  
put the vpm on the telescope over in in

931  
00:42:50,539 --> 00:43:02,210  
in in the physics department that's step

932  
00:42:57,380 --> 00:43:04,869  
one step two we tear it down and put it

933  
00:43:02,210 --> 00:43:07,820  
into containers shipping containers and

934  
00:43:04,869 --> 00:43:11,179  
then we put it on a boat in Baltimore

935  
00:43:07,820 --> 00:43:14,000  
Harbor and that boat goes down goes

936  
00:43:11,179 --> 00:43:15,440  
through the Panama Canal and to a port

937  
00:43:14,000 --> 00:43:20,119  
in northern Chile

938  
00:43:15,440 --> 00:43:22,250  
and then the put it on trucks and then

939  
00:43:20,119 --> 00:43:27,380  
we truck it up to the site at 5200

940  
00:43:22,250 --> 00:43:31,190  
meters here and install it so and to

941

00:43:27,380 --> 00:43:33,680  
zoom into the site so here's our site so

942  
00:43:31,190 --> 00:43:35,840  
this is this is basically completely

943  
00:43:33,679 --> 00:43:38,929  
isolated we have to have our own

944  
00:43:35,840 --> 00:43:41,890  
generators have our fuel delivered this

945  
00:43:38,929 --> 00:43:44,239  
was installed by you know you know

946  
00:43:41,889 --> 00:43:47,949  
postdocs graduate students and the

947  
00:43:44,239 --> 00:43:50,599  
occasional professor this is we

948  
00:43:47,949 --> 00:43:52,669  
contracted a company to put in these and

949  
00:43:50,599 --> 00:43:56,299  
put in these and putting these slabs and

950  
00:43:52,670 --> 00:43:57,889  
put in some put in some conduit but it

951  
00:43:56,300 --> 00:43:59,480  
was the students pulling the power

952  
00:43:57,889 --> 00:44:01,539  
cables through these conduit and

953  
00:43:59,480 --> 00:44:04,460  
connecting these these these these

954  
00:44:01,539 --> 00:44:07,699  
telescopes so this is the first

955  
00:44:04,460 --> 00:44:10,490

telescope that 40 gigahertz telescope in

956

00:44:07,699 --> 00:44:12,289

the in the desert and you can see what

957

00:44:10,489 --> 00:44:13,759

we've done is we've retrofitted some of

958

00:44:12,289 --> 00:44:15,559

these shipping containers to be our

959

00:44:13,760 --> 00:44:20,590

control room our machine shop or

960

00:44:15,559 --> 00:44:20,590

laboratory etc and

961

00:44:20,780 --> 00:44:27,710

again I yeah and hey and and it's very

962

00:44:25,190 --> 00:44:30,019

excited back in May to get our our first

963

00:44:27,710 --> 00:44:31,490

light this is when the telescope first

964

00:44:30,019 --> 00:44:34,039

sees something in our case it was the

965

00:44:31,489 --> 00:44:38,119

moon which you know we confirmed it was

966

00:44:34,039 --> 00:44:40,369

there it's good but we were mainly just

967

00:44:38,119 --> 00:44:42,019

excited to see the detectors light up of

968

00:44:40,369 --> 00:44:46,029

course and and we've been we've been

969

00:44:42,019 --> 00:44:48,650

making cosmological observations sense

970  
00:44:46,030 --> 00:44:50,680  
and and one thing I really want to

971  
00:44:48,650 --> 00:44:56,420  
emphasize here is that it really is a

972  
00:44:50,679 --> 00:44:59,809  
student and young scientist training

973  
00:44:56,420 --> 00:45:05,090  
training ground these guys do so much

974  
00:44:59,809 --> 00:45:08,480  
and you they really are the engine for

975  
00:45:05,090 --> 00:45:13,880  
this project and a lot of these folks

976  
00:45:08,480 --> 00:45:17,090  
are over here across the street and so I

977  
00:45:13,880 --> 00:45:20,390  
wanted to leave you with a little bit of

978  
00:45:17,090 --> 00:45:24,050  
a so I said a few things about the site

979  
00:45:20,389 --> 00:45:26,449  
but I wanted to play something for you

980  
00:45:24,050 --> 00:45:28,100  
that we made this summer that gives you

981  
00:45:26,449 --> 00:45:30,649  
an even better idea of our of our

982  
00:45:28,099 --> 00:45:33,259  
operations of our operations out there

983  
00:45:30,650 --> 00:45:41,480  
so this is about a few couple minute

984  
00:45:33,260 --> 00:45:43,760  
video and then we'll wrap up welcome to

985  
00:45:41,480 --> 00:45:46,849  
the class low altitude headquarters in

986  
00:45:43,760 --> 00:45:49,790  
san pedro de atacama chile at 2,400

987  
00:45:46,849 --> 00:45:52,849  
meters or 8000 feet this is where the

988  
00:45:49,789 --> 00:45:55,369  
class team eats and sleeps above me you

989  
00:45:52,849 --> 00:45:57,670  
can see the radio link that the class

990  
00:45:55,369 --> 00:46:00,500  
team uses to talk to the mountain site

991  
00:45:57,670 --> 00:46:03,619  
they use this link to beam down data and

992  
00:46:00,500 --> 00:46:06,920  
also to control the telescope's san

993  
00:46:03,619 --> 00:46:09,079  
pedro de atacama chile the rural oasis

994  
00:46:06,920 --> 00:46:11,539  
town in the middle of the Atacama Desert

995  
00:46:09,079 --> 00:46:14,360  
it has striking geological features such

996  
00:46:11,539 --> 00:46:16,670  
as that which you see behind me this is

997  
00:46:14,360 --> 00:46:19,420  
the landscape on the drive up to the

998

00:46:16,670 --> 00:46:19,420  
class site

999  
00:46:21,150 --> 00:46:29,880  
this is Sarah toko this is the mountain

1000  
00:46:24,760 --> 00:46:29,880  
on which class is sighted

1001  
00:46:31,829 --> 00:46:38,639  
Sara toko is an extinct volcano there

1002  
00:46:35,519 --> 00:46:41,250  
used to be a sulfur mine on saratoga but

1003  
00:46:38,639 --> 00:46:44,579  
now it's dedicated to observations of

1004  
00:46:41,250 --> 00:46:47,239  
the Cosmic Microwave Background or C and

1005  
00:46:44,579 --> 00:46:47,239  
B

1006  
00:46:48,489 --> 00:46:55,358  
welcome to the class high-altitude

1007  
00:46:50,550 --> 00:46:58,060  
mountain site at 5200 meters this is the

1008  
00:46:55,358 --> 00:47:00,730  
first of four class telescopes which was

1009  
00:46:58,059 --> 00:47:03,250  
installed in the spring of 2016

1010  
00:47:00,730 --> 00:47:07,059  
this telescope scans the sky as you can

1011  
00:47:03,250 --> 00:47:09,190  
see here as the telescope scans the

1012  
00:47:07,059 --> 00:47:11,739

light from the CMB enters the cone at

1013

00:47:09,190 --> 00:47:13,990

the top of the telescope reflects off of

1014

00:47:11,739 --> 00:47:16,929

mirrors and is focused onto cryogenic

1015

00:47:13,989 --> 00:47:18,009

detectors operating in near absolute

1016

00:47:16,929 --> 00:47:21,669

zero temperature

1017

00:47:18,010 --> 00:47:24,820

this telescope scans the sky night and

1018

00:47:21,670 --> 00:47:27,700

day in order to make a map we search

1019

00:47:24,820 --> 00:47:29,410

this map for the faint signal in the

1020

00:47:27,699 --> 00:47:32,529

polarization of the Cosmic Microwave

1021

00:47:29,409 --> 00:47:36,039

Background from gravitational radiation

1022

00:47:32,530 --> 00:47:39,519

in the early universe which can tell us

1023

00:47:36,039 --> 00:47:42,279

how the universe began from this

1024

00:47:39,519 --> 00:47:45,009

perspective you can see the entire last

1025

00:47:42,280 --> 00:47:46,510

sight to my right is the telescope

1026

00:47:45,010 --> 00:47:49,210

scanning the CMB



1027  
00:47:46,510 --> 00:47:50,890  
you can see into the cone at the top of

1028  
00:47:49,210 --> 00:47:54,190  
the telescope into which the light

1029  
00:47:50,889 --> 00:47:56,529  
enters to the right of the telescope you

1030  
00:47:54,190 --> 00:47:59,740  
see our control room our laboratory

1031  
00:47:56,530 --> 00:48:02,619  
container machine-shop container where

1032  
00:47:59,739 --> 00:48:06,309  
we put together the telescope so this is

1033  
00:48:02,619 --> 00:48:08,588  
Denise paya and manwich and they're the

1034  
00:48:06,309 --> 00:48:11,769  
engineers that operate the class

1035  
00:48:08,588 --> 00:48:14,289  
telescope they're here year-round Denise

1036  
00:48:11,769 --> 00:48:18,449  
just graduated from the federal

1037  
00:48:14,289 --> 00:48:21,789  
University of ouro preto in Brazil and

1038  
00:48:18,449 --> 00:48:24,960  
man way just graduated from Johns

1039  
00:48:21,789 --> 00:48:24,960  
Hopkins University

1040  
00:48:25,048 --> 00:48:30,630  
Denise how the cryogenic temperatures

1041  
00:48:27,059 --> 00:48:35,459  
good 30 meter Kelvin what are their

1042  
00:48:30,630 --> 00:48:37,409  
colors ready 30 degrees all right

1043  
00:48:35,458 --> 00:48:41,118  
another good day at the site let's go

1044  
00:48:37,409 --> 00:48:41,119  
down the mountain yeah yeah sounds good

1045  
00:48:55,449 --> 00:49:03,769  
all right so this is just starting we

1046  
00:49:02,119 --> 00:49:06,079  
just moved that first telescope out we

1047  
00:49:03,769 --> 00:49:08,269  
got another three telescopes to deploy

1048  
00:49:06,079 --> 00:49:11,509  
over the next couple years the survey

1049  
00:49:08,269 --> 00:49:16,750  
goes for five years so you can follow us

1050  
00:49:11,510 --> 00:49:16,750  
at this address and stay tuned thank you

1051  
00:49:42,210 --> 00:49:50,170  
no no it's a pretty compact site so so

1052  
00:49:45,489 --> 00:49:51,909  
it's within that fenced area so so the

1053  
00:49:50,170 --> 00:49:53,769  
the second telescope actually goes on

1054  
00:49:51,909 --> 00:49:55,659  
the same pedestal as the one you saw

1055

00:49:53,769 --> 00:50:04,030  
there and we'll be shipping out the

1056  
00:49:55,659 --> 00:50:09,098  
other pedestal next year well this look

1057  
00:50:04,030 --> 00:50:13,000  
like Nova didn't it no no we've had

1058  
00:50:09,099 --> 00:50:15,640  
we've we've enjoyed some work with the

1059  
00:50:13,000 --> 00:50:18,250  
Sun and and and other and other media

1060  
00:50:15,639 --> 00:50:21,940  
outlets but not over yet we're working

1061  
00:50:18,250 --> 00:50:25,630  
on yeah yeah there's there's a lot of

1062  
00:50:21,940 --> 00:50:27,970  
great stuff going on so yeah okay so

1063  
00:50:25,630 --> 00:50:29,349  
that may have been right next door it's

1064  
00:50:27,969 --> 00:50:33,699  
the most expensive ground-based

1065  
00:50:29,349 --> 00:50:35,980  
telescope in the in in the world it's

1066  
00:50:33,699 --> 00:50:38,710  
called the Atacama Large millimeter

1067  
00:50:35,980 --> 00:50:42,670  
Array or Alma and it's a six it's sixty

1068  
00:50:38,710 --> 00:50:44,740  
dishes not four and the yeah they do

1069  
00:50:42,670 --> 00:50:48,880

they do wonderful stuff all the way from

1070

00:50:44,739 --> 00:50:52,838

study hi high-redshift galaxies to look

1071

00:50:48,880 --> 00:50:56,260

for you know you know the discs out from

1072

00:50:52,838 --> 00:50:59,019

which out of which planets form so it's

1073

00:50:56,260 --> 00:51:01,119

there's a lot going on out there so I

1074

00:50:59,019 --> 00:51:03,159

said the site is isolated and it is

1075

00:51:01,119 --> 00:51:07,019

quite isolated but we do have other a

1076

00:51:03,159 --> 00:51:07,019

strong astronomical facilities

1077

00:51:18,840 --> 00:51:24,010

exactly we need to I always forget we

1078

00:51:22,780 --> 00:51:26,260

need to repeat the questions for the

1079

00:51:24,010 --> 00:51:27,790

folks on the website la webcast can hear

1080

00:51:26,260 --> 00:51:29,770

the questions okay sounds good sounds

1081

00:51:27,789 --> 00:51:31,300

good is it oh that's great so the

1082

00:51:29,769 --> 00:51:34,389

question is given the four frequencies

1083

00:51:31,300 --> 00:51:37,869

will we be pointing the telescope at the

1084  
00:51:34,389 --> 00:51:40,059  
same sky in order to make this yeah

1085  
00:51:37,869 --> 00:51:42,910  
color image basically of the early

1086  
00:51:40,059 --> 00:51:46,989  
universe and and absolutely will we'll

1087  
00:51:42,909 --> 00:51:49,690  
be doing that the but it's helped by the

1088  
00:51:46,989 --> 00:51:52,599  
fact that we're mapping 70% of the sky

1089  
00:51:49,690 --> 00:51:55,150  
so it's hard not to point it the the sky

1090  
00:51:52,599 --> 00:51:57,639  
that we're looking at and we don't have

1091  
00:51:55,150 --> 00:52:00,849  
to point it exactly the same time so so

1092  
00:51:57,639 --> 00:52:02,710  
basically just you know the universe

1093  
00:52:00,849 --> 00:52:04,868  
isn't going anywhere so just like if you

1094  
00:52:02,710 --> 00:52:07,300  
had a family standing for a portrait you

1095  
00:52:04,869 --> 00:52:10,809  
could come by and take RGB pictures of

1096  
00:52:07,300 --> 00:52:12,190  
them and to sing subsequent times and

1097  
00:52:10,809 --> 00:52:14,500  
put them together that's sort of what

1098  
00:52:12,190 --> 00:52:18,760  
we're doing we're imaging the universe

1099  
00:52:14,500 --> 00:52:21,449  
with with the different frequencies the

1100  
00:52:18,760 --> 00:52:23,650  
same the same part of the universe and

1101  
00:52:21,449 --> 00:52:25,529  
and putting them together but we don't

1102  
00:52:23,650 --> 00:52:30,660  
necessarily have to have them pointed

1103  
00:52:25,530 --> 00:52:30,660  
simultaneously at the same spot back

1104  
00:52:40,079 --> 00:52:44,380  
that's a great question yeah absolutely

1105  
00:52:42,070 --> 00:52:47,700  
there are other so the question is

1106  
00:52:44,380 --> 00:52:54,849  
thanks are there are there other are

1107  
00:52:47,699 --> 00:52:58,480  
there I'm going to learn are there other

1108  
00:52:54,849 --> 00:53:00,009  
species on planet earth which which can

1109  
00:52:58,480 --> 00:53:04,090  
see this polarization with their eyes

1110  
00:53:00,010 --> 00:53:07,030  
and yeah and in it turns out to be sort

1111  
00:53:04,090 --> 00:53:08,769  
of other insects for some reason this

1112

00:53:07,030 --> 00:53:14,160  
seems to be the particular domain of

1113  
00:53:08,769 --> 00:53:18,309  
these animals these creatures although I

1114  
00:53:14,159 --> 00:53:19,719  
yeah and and yeah I I learned about this

1115  
00:53:18,309 --> 00:53:24,130  
through this magical place called

1116  
00:53:19,719 --> 00:53:25,059  
Wikipedia and so so so you can read

1117  
00:53:24,130 --> 00:53:28,410  
about it there too

1118  
00:53:25,059 --> 00:53:28,409  
and I think there's probably more

1119  
00:54:07,108 --> 00:54:19,598  
sure so the question is is going back to

1120  
00:54:14,289 --> 00:54:22,210  
the point about modulation and yeah

1121  
00:54:19,599 --> 00:54:24,220  
correctly describing how in the example

1122  
00:54:22,210 --> 00:54:27,250  
a voice which was a signal was was

1123  
00:54:24,219 --> 00:54:30,819  
brought to higher frequency such that

1124  
00:54:27,250 --> 00:54:32,530  
you could hear it despite the low the

1125  
00:54:30,820 --> 00:54:37,119  
low frequency noise in which it was

1126  
00:54:32,530 --> 00:54:41,980

otherwise drowned out so and and then

1127

00:54:37,119 --> 00:54:45,099

the question is is there a particular

1128

00:54:41,980 --> 00:54:48,250

aspect of our signal say at 40 gigahertz

1129

00:54:45,099 --> 00:54:53,740

that's that makes it possible to

1130

00:54:48,250 --> 00:55:00,849

modulate it up on the noise spectral

1131

00:54:53,739 --> 00:55:02,709

density yeah sure sure yeah so the noise

1132

00:55:00,849 --> 00:55:05,380

in our the noise that we get in our

1133

00:55:02,710 --> 00:55:07,630

telescope you can classify noise by

1134

00:55:05,380 --> 00:55:11,588

colors so the noise that we see in our

1135

00:55:07,630 --> 00:55:13,720

telescope is usually it can be referred

1136

00:55:11,588 --> 00:55:15,940

to as brown noise so this is this is

1137

00:55:13,719 --> 00:55:20,618

noise that is higher at lower

1138

00:55:15,940 --> 00:55:24,970

frequencies and and and and lower at

1139

00:55:20,619 --> 00:55:28,030

higher higher frequencies and and so so

1140

00:55:24,969 --> 00:55:30,399

and essentially what happens here is



1141  
00:55:28,030 --> 00:55:34,210  
it's it's important to just a it's a

1142  
00:55:30,400 --> 00:55:36,519  
there's a a essentially what we're doing

1143  
00:55:34,210 --> 00:55:39,369  
with the with what the telescope is

1144  
00:55:36,519 --> 00:55:42,940  
we're removing the basically we're

1145  
00:55:39,369 --> 00:55:46,030  
observing the sky and looking at the CMB

1146  
00:55:42,940 --> 00:55:48,579  
polarization and it's coming in at 40

1147  
00:55:46,030 --> 00:55:51,190  
gigahertz right but what we're doing is

1148  
00:55:48,579 --> 00:55:53,230  
we're just just like you know when you

1149  
00:55:51,190 --> 00:55:57,670  
see blue light you don't see you know

1150  
00:55:53,230 --> 00:55:59,230  
the electromagnetic signal from that

1151  
00:55:57,670 --> 00:56:01,119  
blue light going up and down you just

1152  
00:55:59,230 --> 00:56:02,530  
see some blue intensity so we're just

1153  
00:56:01,119 --> 00:56:06,039  
imaging the intensity or the

1154  
00:56:02,530 --> 00:56:08,290  
polarization magnitude of the light at

1155  
00:56:06,039 --> 00:56:10,269  
40 gigahertz and then what we're doing

1156  
00:56:08,289 --> 00:56:12,699  
is taking that signal and we're putting

1157  
00:56:10,269 --> 00:56:17,769  
it at just 10 Hertz so something quite

1158  
00:56:12,699 --> 00:56:19,929  
you know quite manageable and the point

1159  
00:56:17,769 --> 00:56:22,570  
here is that if you take it

1160  
00:56:19,929 --> 00:56:24,969  
for the way you saw the telescope

1161  
00:56:22,570 --> 00:56:26,740  
scanning on the sky and in the

1162  
00:56:24,969 --> 00:56:29,769  
atmosphere is blowing by so that

1163  
00:56:26,739 --> 00:56:32,739  
atmosphere is is a significant source of

1164  
00:56:29,769 --> 00:56:34,900  
noise it has it has structure in it and

1165  
00:56:32,739 --> 00:56:38,079  
different it's bright and dark and it

1166  
00:56:34,900 --> 00:56:39,880  
blows across what happens is that we see

1167  
00:56:38,079 --> 00:56:42,039  
that in the telescope the brightness of

1168  
00:56:39,880 --> 00:56:43,180  
the atmosphere and it's much much

1169

00:56:42,039 --> 00:56:46,960  
brighter than the CMB

1170  
00:56:43,179 --> 00:56:49,269  
and and and basically the the spectrum

1171  
00:56:46,960 --> 00:56:52,929  
of that of that signal from or the noise

1172  
00:56:49,269 --> 00:56:55,599  
if you will of that atmosphere has this

1173  
00:56:52,929 --> 00:56:58,389  
brown noise spectrum and so we modulate

1174  
00:56:55,599 --> 00:57:00,400  
up above that it basically goes away by

1175  
00:56:58,389 --> 00:57:03,069  
about it hurts so we get to 10 Hertz

1176  
00:57:00,400 --> 00:57:04,869  
above that noise actually a really cool

1177  
00:57:03,070 --> 00:57:07,300  
thing to do is you can again it goes

1178  
00:57:04,869 --> 00:57:09,969  
back to what Coupee do you can if you

1179  
00:57:07,300 --> 00:57:11,500  
look up the color of noise this is

1180  
00:57:09,969 --> 00:57:14,559  
another this is actually what gave me

1181  
00:57:11,500 --> 00:57:17,980  
the idea for this for this demo is on

1182  
00:57:14,559 --> 00:57:19,570  
Wikipedia you have they actually have

1183  
00:57:17,980 --> 00:57:21,250

the sound of different noise

1184

00:57:19,570 --> 00:57:23,440

so there's you've probably heard of

1185

00:57:21,250 --> 00:57:26,320

white noise so you're the brown noise

1186

00:57:23,440 --> 00:57:29,380

sort of sounded like the ocean but but

1187

00:57:26,320 --> 00:57:31,390

but white noise you know it sounds it

1188

00:57:29,380 --> 00:57:33,789

sounds like here so that sounds like HBO

1189

00:57:31,389 --> 00:57:37,779

use white noise and one of their promo

1190

00:57:33,789 --> 00:57:39,820

yeah yeah but but you can hear there's

1191

00:57:37,780 --> 00:57:41,140

pink noise there's red noise there's you

1192

00:57:39,820 --> 00:57:44,470

know there's all kinds of not gray noise

1193

00:57:41,139 --> 00:57:45,969

and what color is your noise yeah that's

1194

00:57:44,469 --> 00:58:04,299

right that's great so you can go find

1195

00:57:45,969 --> 00:58:07,299

your color more questions that's a great

1196

00:58:04,300 --> 00:58:09,460

question so um yeah so so repeat the

1197

00:58:07,300 --> 00:58:11,500

quiz so sorry

1198  
00:58:09,460 --> 00:58:14,199  
the I said the question is how do we

1199  
00:58:11,500 --> 00:58:19,269  
maintain the cold temperatures of our of

1200  
00:58:14,199 --> 00:58:22,659  
our of our telescope for Kelvin all the

1201  
00:58:19,269 --> 00:58:27,670  
way down to a fraction of a Kelvin in

1202  
00:58:22,659 --> 00:58:29,619  
the field and basically it's it's it's

1203  
00:58:27,670 --> 00:58:31,269  
it's it's not too different from your

1204  
00:58:29,619 --> 00:58:32,348  
refrigerator at home except we're really

1205  
00:58:31,269 --> 00:58:35,469  
souped up

1206  
00:58:32,349 --> 00:58:38,920  
you have a really high electric bill if

1207  
00:58:35,469 --> 00:58:41,768  
you had our refrigerators so but and we

1208  
00:58:38,920 --> 00:58:43,838  
use helium so we use we compress helium

1209  
00:58:41,768 --> 00:58:47,078  
and then we expand helium and when you

1210  
00:58:43,838 --> 00:58:49,088  
when you expand the gas it cools alright

1211  
00:58:47,079 --> 00:58:52,420  
and so that's that's basically how we

1212  
00:58:49,088 --> 00:58:55,659  
get down to 4 Kelvin and it's a closed

1213  
00:58:52,420 --> 00:58:58,509  
cycle just like the fridge where the

1214  
00:58:55,659 --> 00:59:01,899  
where the material comes in you expand

1215  
00:58:58,509 --> 00:59:03,940  
it and and it cools down and then you

1216  
00:59:01,900 --> 00:59:06,999  
can then then you basically use that

1217  
00:59:03,940 --> 00:59:08,889  
cold material to cool your food in this

1218  
00:59:06,998 --> 00:59:12,969  
case we're cooling our cryogenic

1219  
00:59:08,889 --> 00:59:14,469  
detectors and then that gives us 2 4

1220  
00:59:12,969 --> 00:59:16,389  
Kelvin and then we want to get even

1221  
00:59:14,469 --> 00:59:18,818  
colder we want to get to a fraction of a

1222  
00:59:16,389 --> 00:59:20,768  
Kelvin and we use another closed system

1223  
00:59:18,818 --> 00:59:24,788  
but now we use and which still uses

1224  
00:59:20,768 --> 00:59:28,149  
helium helium but it uses an exotic

1225  
00:59:24,789 --> 00:59:32,650  
isotope of helium helium 3 so uses a

1226

00:59:28,150 --> 00:59:34,599  
mixture of regular helium helium 4 and

1227  
00:59:32,650 --> 00:59:37,088  
helium 3 and it's essentially

1228  
00:59:34,599 --> 00:59:41,229  
evaporating helium 3 through a mixture

1229  
00:59:37,088 --> 00:59:43,210  
of through a helium 3 deprived mixture

1230  
00:59:41,228 --> 00:59:45,608  
of helium three and four and so it's

1231  
00:59:43,210 --> 00:59:49,239  
it's fancy kind of evaporative cooling

1232  
00:59:45,608 --> 00:59:50,650  
that gets us down to down to the coldest

1233  
00:59:49,239 --> 00:59:52,059  
temperatures a little bit like the

1234  
00:59:50,650 --> 01:00:01,088  
evaporative cooling on your skin but

1235  
00:59:52,059 --> 01:00:02,619  
more so absolutely yeah yeah for

1236  
01:00:01,088 --> 01:00:05,440  
instance our detectors are

1237  
01:00:02,619 --> 01:00:08,499  
superconductors so they are detected or

1238  
01:00:05,440 --> 01:00:10,900  
we actually operate our detectors right

1239  
01:00:08,498 --> 01:00:12,728  
at the transition between being a normal

1240  
01:00:10,900 --> 01:00:15,670

metal and a metal without any resistance

1241

01:00:12,728 --> 01:00:17,828

so we use a lot of fancy tricks in there

1242

01:00:15,670 --> 01:00:19,298

we used we use quantum interference to

1243

01:00:17,829 --> 01:00:23,039

read out our detectors it just gets

1244

01:00:19,298 --> 01:00:23,038

cooler I could go up

1245

01:00:28,190 --> 01:00:31,889

that's a great question okay so the

1246

01:00:30,449 --> 01:00:35,579

question is what is the resolution of

1247

01:00:31,889 --> 01:00:38,719

the telescope so the the this signal

1248

01:00:35,579 --> 01:00:42,779

like I said it we're going for these

1249

01:00:38,719 --> 01:00:45,329

universe sized gravitational waves and

1250

01:00:42,780 --> 01:00:48,330

even even if you put it even if you put

1251

01:00:45,329 --> 01:00:50,069

these waves at a very far distance as

1252

01:00:48,329 --> 01:00:55,469

far out as we're looking at they're

1253

01:00:50,070 --> 01:00:57,570

still really big so so our telescopes

1254

01:00:55,469 --> 01:00:59,639

are essentially have degree scale



1255  
01:00:57,570 --> 01:01:02,160  
resolution so you saw them you saw the

1256  
01:00:59,639 --> 01:01:05,489  
moon right at the at the beginning

1257  
01:01:02,159 --> 01:01:09,179  
comparing the Hubble Deep Field our you

1258  
01:01:05,489 --> 01:01:12,539  
know our our beams are twice that big so

1259  
01:01:09,179 --> 01:01:15,210  
it's our resolution which the moon looks

1260  
01:01:12,539 --> 01:01:17,699  
like a point tell us okay so let me just

1261  
01:01:15,210 --> 01:01:20,190  
get for that into perspective Hubble's

1262  
01:01:17,699 --> 01:01:24,059  
resolution is a 20th of an arc second

1263  
01:01:20,190 --> 01:01:29,369  
and an arc second is one 3600 of a

1264  
01:01:24,059 --> 01:01:32,730  
degree so that makes about what seventy

1265  
01:01:29,369 --> 01:01:34,380  
thousand his resolution is 70 house

1266  
01:01:32,730 --> 01:01:36,900  
resolution is seventy thousand times

1267  
01:01:34,380 --> 01:01:38,400  
better than his resolution okay but

1268  
01:01:36,900 --> 01:01:40,139  
Hubble is looking at really tiny things

1269  
01:01:38,400 --> 01:01:41,519  
in the sky he's looking at really big

1270  
01:01:40,139 --> 01:01:50,069  
big things in the sky

1271  
01:01:41,519 --> 01:01:53,400  
okay different tool different job it

1272  
01:01:50,070 --> 01:01:54,930  
yeah yeah I mean I think there's so many

1273  
01:01:53,400 --> 01:01:56,760  
bells and whistles with this thing that

1274  
01:01:54,929 --> 01:01:59,759  
it's it's almost more like an apparatus

1275  
01:01:56,760 --> 01:02:01,590  
yeah but it is a telescope forty

1276  
01:01:59,760 --> 01:02:03,570  
thousand square degrees in the sky so

1277  
01:02:01,590 --> 01:02:05,190  
he's still got a good number of pixels

1278  
01:02:03,570 --> 01:02:06,930  
to look at ya know ya know we're

1279  
01:02:05,190 --> 01:02:09,750  
definitely still doing what one would

1280  
01:02:06,929 --> 01:02:11,519  
would eventually call imaging but like

1281  
01:02:09,750 --> 01:02:13,889  
in the 40 gigahertz receiver we only

1282  
01:02:11,519 --> 01:02:19,280  
have what would be called you know you

1283

01:02:13,889 --> 01:02:21,269  
know 30 32 32 pixels in our camera so

1284  
01:02:19,280 --> 01:02:25,580  
it's a different it's a different game

1285  
01:02:21,269 --> 01:02:25,579  
but but it's analogous yeah

1286  
01:02:31,699 --> 01:02:36,179  
that's a great that's a great question

1287  
01:02:34,318 --> 01:02:39,538  
is are we going to build more cameras in

1288  
01:02:36,179 --> 01:02:41,669  
order to get to the whole sky and from

1289  
01:02:39,539 --> 01:02:43,799  
the Atacama Desert there so that's

1290  
01:02:41,670 --> 01:02:44,250  
that's that's in the tropics you can

1291  
01:02:43,798 --> 01:02:46,139  
believe it

1292  
01:02:44,250 --> 01:02:49,048  
actually most of the deserts in the

1293  
01:02:46,139 --> 01:02:52,500  
world are sir presently any case the the

1294  
01:02:49,048 --> 01:02:54,449  
it's a subtopic so so so but in any case

1295  
01:02:52,500 --> 01:02:57,809  
the point is it's not far from the

1296  
01:02:54,449 --> 01:03:00,538  
equator so so from that location we can

1297  
01:02:57,809 --> 01:03:04,170

actually image most of the sky but yeah

1298

01:03:00,539 --> 01:03:07,230

there are there are there are you know

1299

01:03:04,170 --> 01:03:10,079

thinking more than five years out and

1300

01:03:07,230 --> 01:03:12,809

north northern hemisphere excite there

1301

01:03:10,079 --> 01:03:14,700

there there there there are reasonably

1302

01:03:12,809 --> 01:03:16,589

good sites and in the in the northern

1303

01:03:14,699 --> 01:03:18,980

hemisphere that are being explored the

1304

01:03:16,588 --> 01:03:21,929

two main places people look for the CMB

1305

01:03:18,980 --> 01:03:24,000

are well bit here in the auto common

1306

01:03:21,929 --> 01:03:29,989

desert and the other one is the South

1307

01:03:24,000 --> 01:03:29,989

Pole so exotic spots

1308

01:03:51,329 --> 01:03:57,730

everything no the question is and

1309

01:03:55,900 --> 01:03:59,769

actually that's the Chantal she was

1310

01:03:57,730 --> 01:04:03,570

helpful she's she's helped make this

1311

01:03:59,769 --> 01:04:06,159

earlier issues there at the beginning

1312  
01:04:03,570 --> 01:04:10,390  
it's it's a so the question is what

1313  
01:04:06,159 --> 01:04:13,769  
what's been the most challenging what's

1314  
01:04:10,389 --> 01:04:16,929  
been the most challenging part of class

1315  
01:04:13,769 --> 01:04:19,800  
and I think I you know I think for a lot

1316  
01:04:16,929 --> 01:04:23,079  
of us I mean we're all most of us having

1317  
01:04:19,800 --> 01:04:25,300  
are pretty young I mean the in in the

1318  
01:04:23,079 --> 01:04:27,009  
context in class and I and I think I

1319  
01:04:25,300 --> 01:04:29,560  
think probably the biggest challenge is

1320  
01:04:27,010 --> 01:04:31,900  
just realizing we could do it and you

1321  
01:04:29,559 --> 01:04:33,849  
know and just sort of overcoming this

1322  
01:04:31,900 --> 01:04:38,260  
sort of perception of like wow this is a

1323  
01:04:33,849 --> 01:04:40,660  
huge project and and and and and and

1324  
01:04:38,260 --> 01:04:43,420  
sort of yeah and you know now we got it

1325  
01:04:40,659 --> 01:04:46,239  
in the field so this is related to that

1326  
01:04:43,420 --> 01:04:47,050  
I mean when starting the James Webb

1327  
01:04:46,239 --> 01:04:49,118  
Space Telescope

1328  
01:04:47,050 --> 01:04:51,310  
you know they had several new

1329  
01:04:49,119 --> 01:04:53,289  
technologies they had to invent while

1330  
01:04:51,309 --> 01:04:55,570  
building the new series fair and you're

1331  
01:04:53,289 --> 01:04:57,969  
talking about using quantum interference

1332  
01:04:55,570 --> 01:05:01,359  
to read out your detectors right and

1333  
01:04:57,969 --> 01:05:04,118  
working with you know the liquid helium

1334  
01:05:01,358 --> 01:05:06,519  
the helium cooling and tritium cooling

1335  
01:05:04,119 --> 01:05:08,740  
and such how much of that was already

1336  
01:05:06,519 --> 01:05:10,599  
known versus how much did you have any

1337  
01:05:08,739 --> 01:05:12,459  
major technologies you had to invent to

1338  
01:05:10,599 --> 01:05:16,330  
try and get some of this working

1339  
01:05:12,460 --> 01:05:18,338  
yeah those detectors that that are made

1340

01:05:16,329 --> 01:05:20,799  
at NASA Goddard we've been working with

1341  
01:05:18,338 --> 01:05:23,559  
them to develop them over the last the

1342  
01:05:20,800 --> 01:05:26,890  
last six years they're they're they're

1343  
01:05:23,559 --> 01:05:29,440  
unique in the field of CMB observations

1344  
01:05:26,889 --> 01:05:34,179  
so that was that's that's required a lot

1345  
01:05:29,440 --> 01:05:36,338  
of development and for instance that 40

1346  
01:05:34,179 --> 01:05:39,000  
gigahertz telescope and the array of

1347  
01:05:36,338 --> 01:05:44,650  
detectors there there's that's the first

1348  
01:05:39,000 --> 01:05:52,239  
ever camera like that the those those be

1349  
01:05:44,650 --> 01:05:54,220  
PM's you saw the KT built those those

1350  
01:05:52,239 --> 01:05:57,899  
are yeah those have never been built

1351  
01:05:54,219 --> 01:06:00,368  
before so so it's or used in this way I

1352  
01:05:57,900 --> 01:06:02,019  
find that the public likes to hear about

1353  
01:06:00,369 --> 01:06:04,150  
you know what's the

1354  
01:06:02,019 --> 01:06:06,610

you know highlight the real R&D aspect

1355

01:06:04,150 --> 01:06:07,869

of science I mean sometimes people think

1356

01:06:06,610 --> 01:06:10,210

that oh well we'll just build another

1357

01:06:07,869 --> 01:06:12,190

telescope and it's just the same old

1358

01:06:10,210 --> 01:06:14,079

telescope but really there's so many of

1359

01:06:12,190 --> 01:06:15,429

these science experiments that you know

1360

01:06:14,079 --> 01:06:16,929

are pushing the edge boundaries of

1361

01:06:15,429 --> 01:06:18,969

science but they're also pushing the

1362

01:06:16,929 --> 01:06:20,859

boundaries of technology you know in

1363

01:06:18,969 --> 01:06:23,079

order to enable new science and yeah

1364

01:06:20,860 --> 01:06:25,599

yeah I mean there's basically three main

1365

01:06:23,079 --> 01:06:27,279

parts to class one is the the first one

1366

01:06:25,599 --> 01:06:30,400

is of course the science that we're

1367

01:06:27,280 --> 01:06:32,680

going after and then the second one is

1368

01:06:30,400 --> 01:06:34,780

training scientists and and then the



1369  
01:06:32,679 --> 01:06:43,899  
third is this technology development so

1370  
01:06:34,780 --> 01:06:46,330  
so yeah absolutely yeah okay the

1371  
01:06:43,900 --> 01:06:53,559  
question is who is funding us so why you

1372  
01:06:46,329 --> 01:06:57,369  
of course no of course that's the truth

1373  
01:06:53,559 --> 01:07:01,389  
right so we're primarily funded to the

1374  
01:06:57,369 --> 01:07:03,190  
National Science Foundation and they've

1375  
01:07:01,389 --> 01:07:06,909  
supported that both the developments of

1376  
01:07:03,190 --> 01:07:11,108  
the instrument and now they've just

1377  
01:07:06,909 --> 01:07:15,219  
recently funded us to execute the the

1378  
01:07:11,108 --> 01:07:19,779  
five-year survey we also have helped

1379  
01:07:15,219 --> 01:07:22,358  
from from a lot of other sources the

1380  
01:07:19,780 --> 01:07:25,540  
detector development is like I said it's

1381  
01:07:22,358 --> 01:07:26,889  
done at NASA so NASA supports the

1382  
01:07:25,539 --> 01:07:28,599  
technology development of those

1383  
01:07:26,889 --> 01:07:30,659  
detectors looking ahead towards the

1384  
01:07:28,599 --> 01:07:35,049  
space mission to do this type of thing

1385  
01:07:30,659 --> 01:07:38,879  
and we also have we also have private

1386  
01:07:35,050 --> 01:07:41,080  
contributions through through through

1387  
01:07:38,880 --> 01:07:46,300  
through folks who are just excited about

1388  
01:07:41,079 --> 01:07:50,679  
the about the telescope the total amount

1389  
01:07:46,300 --> 01:07:52,090  
this is the sum it's it's in the twenty

1390  
01:07:50,679 --> 01:07:55,319  
thousand it's use hype twenty thousand

1391  
01:07:52,090 --> 01:07:55,320  
twenty million dollar ballpark

1392  
01:07:58,889 --> 01:08:06,210  
so this what I'm showing you here is

1393  
01:08:01,588 --> 01:08:10,559  
sort of roughly seven years in the

1394  
01:08:06,210 --> 01:08:12,510  
making from from sort of serious

1395  
01:08:10,559 --> 01:08:15,269  
building and then it's going to be

1396  
01:08:12,510 --> 01:08:18,088  
another five years to the science so

1397

01:08:15,269 --> 01:08:20,548  
these projects end up being on this sort

1398  
01:08:18,088 --> 01:08:22,289  
of this sort of medium scale project is

1399  
01:08:20,548 --> 01:08:33,028  
on the is on the sort of ten year

1400  
01:08:22,289 --> 01:08:35,698  
timescale the question is are we on the

1401  
01:08:33,029 --> 01:08:38,750  
right track and yes there's there's

1402  
01:08:35,698 --> 01:08:43,379  
we're still the data is just coming in

1403  
01:08:38,750 --> 01:08:46,409  
and and I can't say much about it until

1404  
01:08:43,380 --> 01:08:50,210  
we fully tease these things out but yes

1405  
01:08:46,409 --> 01:08:50,210  
every every things are looking good

1406  
01:09:03,260 --> 01:09:10,020  
the question is yeah how much power does

1407  
01:09:06,689 --> 01:09:13,979  
it take to to to to run these telescopes

1408  
01:09:10,020 --> 01:09:17,430  
and yes so those the generators that

1409  
01:09:13,979 --> 01:09:21,298  
were in the in the site picture those

1410  
01:09:17,430 --> 01:09:23,490  
are sort of D rated for it so where it

1411  
01:09:21,298 --> 01:09:25,710

said we're at 17,000 feet it's half an

1412

01:09:23,489 --> 01:09:29,460

atmosphere so those generators are about

1413

01:09:25,710 --> 01:09:33,630

200 kilowatt generators and UD rate them

1414

01:09:29,460 --> 01:09:35,789

by you know roughly half and and so and

1415

01:09:33,630 --> 01:09:40,859

and that's roughly the power consumption

1416

01:09:35,789 --> 01:09:42,539

of the folds or Observatory and so so

1417

01:09:40,859 --> 01:09:45,600

yeah so each one of the like for each

1418

01:09:42,539 --> 01:09:48,269

each one of those helium refrigerators

1419

01:09:45,600 --> 01:09:50,370

takes about ten kilowatts and then

1420

01:09:48,270 --> 01:09:51,839

you've got to move the telescopes you

1421

01:09:50,369 --> 01:09:53,809

got to keep people from freezing when

1422

01:09:51,838 --> 01:09:57,359

they're at the site you know run heaters

1423

01:09:53,810 --> 01:10:00,930

we we have oxygen we have we have oxygen

1424

01:09:57,359 --> 01:10:05,369

oxygen concentrators for folks to be

1425

01:10:00,930 --> 01:10:09,110

smarter at the site and those take each

1426  
01:10:05,369 --> 01:10:11,069  
take four kilowatts and you have -

1427  
01:10:09,109 --> 01:10:15,509  
nothing nothing not that much for the

1428  
01:10:11,069 --> 01:10:17,009  
Yankees Yankees yeah a lot of power okay

1429  
01:10:15,510 --> 01:10:18,659  
yeah just a couple more because you want

1430  
01:10:17,010 --> 01:10:19,440  
to take people across the street yeah be

1431  
01:10:18,659 --> 01:10:21,979  
great Hank Tilly

1432  
01:10:19,439 --> 01:10:21,979  
so here

1433  
01:10:26,260 --> 01:10:36,730  
oh yeah okay I mean I think the there's

1434  
01:10:34,809 --> 01:10:38,980  
two there's two different aspects right

1435  
01:10:36,729 --> 01:10:40,959  
there's the there's the science aspect

1436  
01:10:38,979 --> 01:10:43,178  
and that one's just looking way out

1437  
01:10:40,960 --> 01:10:46,179  
right so that's you know you know what

1438  
01:10:43,179 --> 01:10:49,510  
it was you know how does understanding

1439  
01:10:46,179 --> 01:10:51,969  
the how the universe was created you

1440  
01:10:49,510 --> 01:10:55,420  
know you know how is that going to

1441  
01:10:51,969 --> 01:10:58,139  
enable us to you know advance humanity

1442  
01:10:55,420 --> 01:11:01,328  
and you know we don't know that yet but

1443  
01:10:58,139 --> 01:11:03,460  
certainly would be good to know to make

1444  
01:11:01,328 --> 01:11:05,439  
progress so that's the big play that

1445  
01:11:03,460 --> 01:11:08,139  
sets the one side and then the other

1446  
01:11:05,439 --> 01:11:10,029  
side is is this technology development

1447  
01:11:08,139 --> 01:11:13,179  
like for instance these cold detectors

1448  
01:11:10,029 --> 01:11:15,550  
or that are so sensitive to find faint

1449  
01:11:13,179 --> 01:11:18,929  
ripples of polarization in the early

1450  
01:11:15,550 --> 01:11:21,400  
universe can be used for remote sensing

1451  
01:11:18,929 --> 01:11:23,408  
and other applications you can use them

1452  
01:11:21,399 --> 01:11:26,738  
in different wave fans look for

1453  
01:11:23,408 --> 01:11:28,348  
radiation this type of thing so that

1454

01:11:26,738 --> 01:11:30,698  
that's that's that's one example

1455  
01:11:28,349 --> 01:11:33,010  
polarization modulation polarizations

1456  
01:11:30,698 --> 01:11:35,948  
everywhere if bees got a hold of that

1457  
01:11:33,010 --> 01:11:38,369  
modulate now honey all over the place

1458  
01:11:35,948 --> 01:11:42,549  
we'd like to have super bees yeah

1459  
01:11:38,368 --> 01:11:45,038  
controlling the universe yeah but no but

1460  
01:11:42,550 --> 01:11:47,860  
but yeah that's seriously um the the

1461  
01:11:45,038 --> 01:11:50,340  
benefits of the the researcher to this

1462  
01:11:47,859 --> 01:11:53,558  
you know sort of big picture science

1463  
01:11:50,340 --> 01:11:56,920  
where where is that going to take us you

1464  
01:11:53,559 --> 01:11:59,710  
know you have to you have to you have to

1465  
01:11:56,920 --> 01:12:04,239  
think far out and but the technology

1466  
01:11:59,710 --> 01:12:05,828  
transfer okay Peter I have to cut you

1467  
01:12:04,238 --> 01:12:07,149  
off as though there was a gentleman in

1468  
01:12:05,828 --> 01:12:09,158

the back there and this gentleman over

1469

01:12:07,149 --> 01:12:11,578

there I have to have done it last two

1470

01:12:09,158 --> 01:12:11,578

questions

1471

01:12:19,189 --> 01:12:25,710

sure sure yeah so the question is where

1472

01:12:22,979 --> 01:12:28,638

does the spectral selectivity of the of

1473

01:12:25,710 --> 01:12:32,519

the telescope come in and it's actually

1474

01:12:28,639 --> 01:12:37,078

built right on to those built right on

1475

01:12:32,519 --> 01:12:40,369

to those chips so so what happens is the

1476

01:12:37,078 --> 01:12:42,599

light comes into the detector from the

1477

01:12:40,368 --> 01:12:45,149

telescope focuses the light onto the

1478

01:12:42,599 --> 01:12:48,480

detector and the detector actually picks

1479

01:12:45,149 --> 01:12:50,638

up the electromagnetic waves and sends

1480

01:12:48,479 --> 01:12:52,500

it sends it through code sends it

1481

01:12:50,639 --> 01:12:54,118

through circuitry it's a microwave

1482

01:12:52,500 --> 01:12:56,309

surgical history so high-speed



1483  
01:12:54,118 --> 01:13:00,479  
electronic circuitry and we actually

1484  
01:12:56,309 --> 01:13:03,090  
implement filters on on the silicon

1485  
01:13:00,479 --> 01:13:04,709  
there to define to define the bands

1486  
01:13:03,090 --> 01:13:07,110  
there are other places where we can

1487  
01:13:04,710 --> 01:13:09,300  
choke down and and and limit long

1488  
01:13:07,109 --> 01:13:11,549  
wavelengths and things like that and we

1489  
01:13:09,300 --> 01:13:14,099  
we play a lot of games to make sure that

1490  
01:13:11,550 --> 01:13:16,170  
we don't see that that pesky high

1491  
01:13:14,099 --> 01:13:18,000  
frequencies short wavelength light

1492  
01:13:16,170 --> 01:13:19,649  
doesn't get in and that's that's one of

1493  
01:13:18,000 --> 01:13:20,849  
the innovations with this detector so

1494  
01:13:19,649 --> 01:13:23,308  
there's a bunch of different ways which

1495  
01:13:20,849 --> 01:13:25,769  
we we sort of select out our specific

1496  
01:13:23,309 --> 01:13:28,288  
band so we don't look at something we

1497  
01:13:25,769 --> 01:13:30,679  
don't want to see okay and you have last

1498  
01:13:28,288 --> 01:13:30,679  
question

1499  
01:13:43,988 --> 01:13:50,468  
no no I probably just said it okay so

1500  
01:13:48,099 --> 01:13:54,460  
the question is in what way does the the

1501  
01:13:50,469 --> 01:13:56,920  
CMB help us understand the early

1502  
01:13:54,460 --> 01:13:58,630  
universe sir okay great now that's a

1503  
01:13:56,920 --> 01:14:00,309  
great question to end on

1504  
01:13:58,630 --> 01:14:02,469  
so basically basically this is a

1505  
01:14:00,309 --> 01:14:05,559  
snapshot of the early universe so the

1506  
01:14:02,469 --> 01:14:10,149  
first answer is simply like it is the

1507  
01:14:05,559 --> 01:14:12,400  
early Earth so so it you know it in the

1508  
01:14:10,149 --> 01:14:14,439  
same way as Hubble can can image you

1509  
01:14:12,399 --> 01:14:17,098  
know what the galaxies look like you

1510  
01:14:14,439 --> 01:14:19,748  
know 11 billion years ago or whatever

1511

01:14:17,099 --> 01:14:22,869  
we're saying what does the universe look

1512  
01:14:19,748 --> 01:14:24,939  
like when it was 13.7 billion years old

1513  
01:14:22,868 --> 01:14:27,448  
before all the galaxies were around so

1514  
01:14:24,939 --> 01:14:30,308  
you so there's a literal image you know

1515  
01:14:27,448 --> 01:14:33,998  
it's basically a thermal soup it's like

1516  
01:14:30,309 --> 01:14:35,559  
looking into a kiln and it's hot and so

1517  
01:14:33,998 --> 01:14:38,590  
that's what we're seeing we're imaging

1518  
01:14:35,559 --> 01:14:41,498  
that heat from the early universe so so

1519  
01:14:38,590 --> 01:14:45,279  
that's that's sort of the the basic

1520  
01:14:41,498 --> 01:14:47,078  
level and then what the the really

1521  
01:14:45,279 --> 01:14:49,420  
awesome thing about the early universe

1522  
01:14:47,078 --> 01:14:52,090  
is it's a lot simpler than the late

1523  
01:14:49,420 --> 01:14:53,980  
universe so you look around and you see

1524  
01:14:52,090 --> 01:14:57,038  
all these different types of galaxies

1525  
01:14:53,979 --> 01:14:59,319

red blue some of them with jets shooting

1526

01:14:57,038 --> 01:15:01,689

out of them stuff like that this is hard

1527

01:14:59,319 --> 01:15:03,099

to understand this has very complicated

1528

01:15:01,689 --> 01:15:05,109

these things have very complicated

1529

01:15:03,099 --> 01:15:08,710

physics and very complicated histories

1530

01:15:05,109 --> 01:15:12,908

the early universe is it does not have a

1531

01:15:08,710 --> 01:15:15,609

long long history and because it's just

1532

01:15:12,908 --> 01:15:17,679

this soup right our physics actually

1533

01:15:15,609 --> 01:15:19,868

describe it pretty well so what we can

1534

01:15:17,679 --> 01:15:21,819

do is we can take that picture and use

1535

01:15:19,868 --> 01:15:24,368

pretty basic physics you know modern

1536

01:15:21,819 --> 01:15:26,399

physics but not you know not too much

1537

01:15:24,368 --> 01:15:28,808

more than you know electromagnetism

1538

01:15:26,399 --> 01:15:30,848

thermodynamics throw in some nuclear

1539

01:15:28,809 --> 01:15:32,260

physics but you know some stuff we know

1540  
01:15:30,849 --> 01:15:33,940  
pretty well and we've constrained from

1541  
01:15:32,260 --> 01:15:35,860  
the laboratory and you can take that

1542  
01:15:33,939 --> 01:15:39,129  
picture and you can go backwards and you

1543  
01:15:35,859 --> 01:15:42,788  
can go forwards with it and so and so so

1544  
01:15:39,130 --> 01:15:44,260  
we can we so the so the so the basic

1545  
01:15:42,788 --> 01:15:48,908  
answer is that physics of the early

1546  
01:15:44,260 --> 01:15:51,070  
universe is actually relatively you know

1547  
01:15:48,908 --> 01:15:53,379  
it's sort of fundamental in some sort of

1548  
01:15:51,069 --> 01:15:55,599  
sense that our laws can

1549  
01:15:53,380 --> 01:15:58,210  
and and simple in the way that our law

1550  
01:15:55,600 --> 01:15:59,770  
in the sense that it's not doesn't have

1551  
01:15:58,210 --> 01:16:01,720  
all this complexity like these

1552  
01:15:59,770 --> 01:16:03,520  
life-forms in this room are so complex

1553  
01:16:01,720 --> 01:16:05,350  
we can't describe them but we can't

1554  
01:16:03,520 --> 01:16:14,890  
describe the early universe with our

1555  
01:16:05,350 --> 01:16:15,070  
laws okay so give a hand give a hand all

1556  
01:16:14,890 --> 01:16:17,500  
right

1557  
01:16:15,069 --> 01:16:19,119  
Toby's gonna pack up his stuff and then

1558  
01:16:17,500 --> 01:16:20,350  
you'll be able to take whoever wants to

1559  
01:16:19,119 --> 01:16:22,659  
go across the street

1560  
01:16:20,350 --> 01:16:25,930  
next month we have Christine Chen

1561  
01:16:22,659 --> 01:16:27,760  
talking about debris disks and you won't

1562  
01:16:25,930 --> 01:16:29,619  
want to miss it but I will miss it

1563  
01:16:27,760 --> 01:16:31,840  
because I will be in San Francisco next

1564  
01:16:29,619 --> 01:16:35,380  
month giving a talk at the Morrison

1565  
01:16:31,840 --> 01:16:37,390  
planetarium and in the day at night

1566  
01:16:35,380 --> 01:16:39,730  
before this I won't be back in time so

1567  
01:16:37,390 --> 01:16:42,400  
I'll have a great Thanksgiving all have

1568

01:16:39,729 --> 01:16:44,529  
a great holiday season else I won't see

1569  
01:16:42,399 --> 01:16:46,869  
you till 2017 but I'll have a guest host

1570  
01:16:44,529 --> 01:16:49,000  
here to help Christine Chen give you an

1571  
01:16:46,869 --> 01:16:53,729  
amazing talk next month thank you all

1572  
01:16:49,000 --> 01:16:53,729  
for coming and we'll see you next time