

1  
00:00:03,080 --> 00:00:09,059  
good evening everybody wow that's

2  
00:00:06,419 --> 00:00:12,030  
interesting we're gonna let some echo

3  
00:00:09,058 --> 00:00:14,579  
here there we go thank you Thomas okay

4  
00:00:12,029 --> 00:00:16,799  
evening everybody and welcome to the

5  
00:00:14,580 --> 00:00:19,528  
Hubble Space Telescope public lecture

6  
00:00:16,800 --> 00:00:22,589  
series I'm your host dr. Frank summers

7  
00:00:19,528 --> 00:00:24,300  
of the office of public outreach and it

8  
00:00:22,589 --> 00:00:27,390  
is my pleasure to be your host every

9  
00:00:24,300 --> 00:00:30,240  
month and also to give away free

10  
00:00:27,390 --> 00:00:33,000  
pictures we have a brand new lithograph

11  
00:00:30,239 --> 00:00:34,649  
this never been given out before at the

12  
00:00:33,000 --> 00:00:36,179  
public electro series you know those of

13  
00:00:34,649 --> 00:00:38,489  
you who've been here many times say oh

14  
00:00:36,179 --> 00:00:40,140  
it's another one another galaxy picture

15  
00:00:38,488 --> 00:00:42,679  
that I've got well this one is one you

16  
00:00:40,140 --> 00:00:46,859  
haven't got it's a galaxy cluster Abell

17  
00:00:42,679 --> 00:00:50,219  
2744 a very special galaxy cluster

18  
00:00:46,859 --> 00:00:53,429  
because it's the first cluster in the

19  
00:00:50,219 --> 00:00:55,079  
frontier fields project okay and so you

20  
00:00:53,429 --> 00:00:57,359  
get the picture of this galaxy cluster

21  
00:00:55,079 --> 00:01:00,329  
it's special because it is a very very

22  
00:00:57,359 --> 00:01:02,698  
large galaxy cluster it produces

23  
00:01:00,329 --> 00:01:06,000  
gravitational lensing alright which

24  
00:01:02,698 --> 00:01:07,408  
helps us to see very distant galaxies

25  
00:01:06,000 --> 00:01:09,590  
that are magnified by the gravitational

26  
00:01:07,409 --> 00:01:12,359  
lens you want to learn about that idea

27  
00:01:09,590 --> 00:01:14,850  
we've got information on the back that

28  
00:01:12,359 --> 00:01:16,530  
you can read about there's at least a

29

00:01:14,849 --> 00:01:18,868  
couple left if you had did not get one

30  
00:01:16,530 --> 00:01:23,820  
on the way in please pick one up on the

31  
00:01:18,868 --> 00:01:25,530  
way out our talk tonight by Mark

32  
00:01:23,819 --> 00:01:29,158  
kamionkowski which I spelled wrong

33  
00:01:25,530 --> 00:01:35,780  
obviously Kamino Kowski sorry about that

34  
00:01:29,159 --> 00:01:38,850  
mark a telegram from the early universe

35  
00:01:35,780 --> 00:01:41,040  
okay upcoming next month

36  
00:01:38,849 --> 00:01:45,509  
Joshua peak will be talking about outer

37  
00:01:41,040 --> 00:01:47,219  
space basically talking about the

38  
00:01:45,509 --> 00:01:50,280  
emptiness that's out there and what's

39  
00:01:47,219 --> 00:01:52,618  
actually in the space between the stars

40  
00:01:50,280 --> 00:01:57,540  
it's not really as empty as you may

41  
00:01:52,618 --> 00:02:00,090  
think January this auditorium is going

42  
00:01:57,540 --> 00:02:01,950  
to undergo some renovations okay there

43  
00:02:00,090 --> 00:02:05,280

will be some renovations and so the

44

00:02:01,950 --> 00:02:07,228

first week in January I was told I could

45

00:02:05,280 --> 00:02:09,780

not hold the public lecture series so we

46

00:02:07,228 --> 00:02:13,300

are holding it on the second Tuesday in

47

00:02:09,780 --> 00:02:15,550

January so January 13th 2015

48

00:02:13,300 --> 00:02:19,450

and it will be a fascinating topic by

49

00:02:15,550 --> 00:02:21,010

some amazing astronomer basically the

50

00:02:19,449 --> 00:02:24,909

astronomer to be named later

51

00:02:21,009 --> 00:02:26,859

that don't worry I get there okay it's

52

00:02:24,909 --> 00:02:27,759

been a little busy this month but we'll

53

00:02:26,860 --> 00:02:31,270

get there

54

00:02:27,759 --> 00:02:34,239

in February we have hey one of the

55

00:02:31,270 --> 00:02:36,550

longed longer titles of topics that have

56

00:02:34,240 --> 00:02:38,980

been given to me from cosmic birth to

57

00:02:36,550 --> 00:02:42,730

living earth the next great space

58  
00:02:38,979 --> 00:02:44,169  
telescope beyond JWST if you come to

59  
00:02:42,729 --> 00:02:46,149  
these you know we've talked a lot about

60  
00:02:44,169 --> 00:02:48,369  
the next great observatory the James

61  
00:02:46,150 --> 00:02:51,819  
Webb Space Telescope for those who are

62  
00:02:48,370 --> 00:02:54,370  
wondering what's beyond even that Jason

63  
00:02:51,819 --> 00:02:58,689  
Tomlinson will elucidate you in February

64  
00:02:54,370 --> 00:03:02,230  
of next year okay these are listed on

65  
00:02:58,689 --> 00:03:04,359  
our website easiest thing to do is just

66  
00:03:02,229 --> 00:03:06,069  
say Hubble public talks into your

67  
00:03:04,360 --> 00:03:07,870  
favorite search engine this should be

68  
00:03:06,069 --> 00:03:11,349  
come up you can see we've got the

69  
00:03:07,870 --> 00:03:15,430  
upcoming lectures as well as the archive

70  
00:03:11,349 --> 00:03:18,459  
back to 2005 so that's nine years of

71  
00:03:15,430 --> 00:03:20,980  
amazing cosmic knowledge that you can

72  
00:03:18,459 --> 00:03:21,370  
absorb by watching all of our webcasts

73  
00:03:20,979 --> 00:03:23,049  
okay

74  
00:03:21,370 --> 00:03:25,689  
just think how smart you would be

75  
00:03:23,050 --> 00:03:28,840  
watching nine years of cosmic knowledge

76  
00:03:25,689 --> 00:03:32,530  
that'll anyway so that's available for

77  
00:03:28,840 --> 00:03:34,479  
you we have emails I just got one

78  
00:03:32,530 --> 00:03:36,849  
tonight of somebody who was on our email

79  
00:03:34,479 --> 00:03:38,769  
list and some for some reason got off of

80  
00:03:36,849 --> 00:03:43,209  
it so she gave me your email address

81  
00:03:38,770 --> 00:03:45,300  
I'll add her and you won't get any spam

82  
00:03:43,209 --> 00:03:48,400  
from it because it's very very low

83  
00:03:45,300 --> 00:03:51,370  
emails you can contact us public lecture

84  
00:03:48,400 --> 00:03:54,069  
at STScI dot edu asks us comments

85  
00:03:51,370 --> 00:03:55,360  
questions or even sign up for the

86

00:03:54,069 --> 00:03:57,280  
announcements because if you send us an

87  
00:03:55,360 --> 00:04:01,840  
email we'll have your return address to

88  
00:03:57,280 --> 00:04:05,560  
do it social media Facebook Twitter

89  
00:04:01,840 --> 00:04:08,379  
Google+ Pinterest I'm on Facebook

90  
00:04:05,560 --> 00:04:09,670  
Google+ and sometimes I Twitter I don't

91  
00:04:08,379 --> 00:04:13,090  
do as much of the social media as I'm

92  
00:04:09,669 --> 00:04:15,399  
supposed to but it's there if you are so

93  
00:04:13,090 --> 00:04:17,560  
interested in it

94  
00:04:15,400 --> 00:04:19,090  
Observatory I'm not sure that they are

95  
00:04:17,560 --> 00:04:21,040  
doing the observatory tonight because

96  
00:04:19,089 --> 00:04:23,859  
they had it planned scheduled for last

97  
00:04:21,040 --> 00:04:26,080  
week and so there's a big question mark

98  
00:04:23,860 --> 00:04:27,629  
anybody from the spacecraft Sara Torre

99  
00:04:26,079 --> 00:04:29,978  
here

100  
00:04:27,629 --> 00:04:31,598

hearing silence I will assume that they

101

00:04:29,978 --> 00:04:32,800

are not going to do the observatory

102

00:04:31,598 --> 00:04:34,629

tonight

103

00:04:32,800 --> 00:04:36,759

I'll ask them remind me to ask again at

104

00:04:34,629 --> 00:04:38,889

the end of the lecture in case the MS I

105

00:04:36,759 --> 00:04:43,180

mean if Maryland spacecraft or folks do

106

00:04:38,889 --> 00:04:44,918

show up okay so my favorite part of the

107

00:04:43,180 --> 00:04:50,250

evening is the news from the universe

108

00:04:44,918 --> 00:04:55,719

this is for November 2014 to Pluto and

109

00:04:50,250 --> 00:04:57,160

Beyond part two when last we discussed

110

00:04:55,720 --> 00:04:59,470

of course when we're talking about going

111

00:04:57,160 --> 00:05:00,699

to Pluto we are talking about the New

112

00:04:59,470 --> 00:05:06,009

Horizons mission

113

00:05:00,699 --> 00:05:09,250

New Horizons launched back in 2006

114

00:05:06,009 --> 00:05:12,250

it got went past Jupiter in 2007 has



115  
00:05:09,250 --> 00:05:16,449  
been cruising out towards Pluto for the

116  
00:05:12,250 --> 00:05:18,418  
past nine years and will finally get to

117  
00:05:16,449 --> 00:05:22,000  
Pluto next summer

118  
00:05:18,418 --> 00:05:25,750  
so here is the path of the New Horizons

119  
00:05:22,000 --> 00:05:27,819  
full trajectory as it was in July when I

120  
00:05:25,750 --> 00:05:31,899  
first presented part one of this and

121  
00:05:27,819 --> 00:05:34,598  
part one oh and just to mention the the

122  
00:05:31,899 --> 00:05:35,519  
milestones sometime January or shortly

123  
00:05:34,598 --> 00:05:37,990  
thereafter

124  
00:05:35,519 --> 00:05:42,430  
New Horizons will have better resolution

125  
00:05:37,990 --> 00:05:44,168  
than Hubble does okay so all of next

126  
00:05:42,430 --> 00:05:46,090  
year the time for New Horizons is

127  
00:05:44,168 --> 00:05:47,408  
precious because they will have better

128  
00:05:46,089 --> 00:05:49,810  
resolution the Hubble these are some

129  
00:05:47,408 --> 00:05:51,879  
Hubble images of Pluto where you can see

130  
00:05:49,810 --> 00:05:53,889  
the pixelation of it all right and

131  
00:05:51,879 --> 00:05:55,870  
that's the that's that's that's the best

132  
00:05:53,889 --> 00:05:58,110  
Hubble can do in terms of getting

133  
00:05:55,870 --> 00:06:00,788  
individual pictures we can of course

134  
00:05:58,110 --> 00:06:03,580  
interpolate from them to get better maps

135  
00:06:00,788 --> 00:06:07,449  
but next summer for next year we'll be

136  
00:06:03,579 --> 00:06:10,750  
able to get that it'll go past Pluto on

137  
00:06:07,449 --> 00:06:14,169  
July 14th best deal day next summer

138  
00:06:10,750 --> 00:06:16,269  
we'll do a buzz over Pluto it will be

139  
00:06:14,168 --> 00:06:19,299  
moving however really really really fast

140  
00:06:16,269 --> 00:06:21,519  
so this is going to be very carefully

141  
00:06:19,300 --> 00:06:23,500  
and planned encounter of everything and

142  
00:06:21,519 --> 00:06:25,750  
Hubble has been helping by searching

143

00:06:23,500 --> 00:06:30,129  
through the Pluto system discovering the

144  
00:06:25,750 --> 00:06:31,689  
moons Nix Hydra sticks and Kerberos for

145  
00:06:30,129 --> 00:06:34,959  
extra moons of

146  
00:06:31,689 --> 00:06:39,069  
of Pluto that Hubble has been able thing

147  
00:06:34,959 --> 00:06:41,439  
but after it passes by Pluto what next

148  
00:06:39,069 --> 00:06:44,319  
well this is where the Kuiper belt comes

149  
00:06:41,439 --> 00:06:46,239  
in and you can see that what we have

150  
00:06:44,319 --> 00:06:48,158  
here in the interior is the orbits of

151  
00:06:46,238 --> 00:06:50,198  
Jupiter Saturn Uranus and Neptune the

152  
00:06:48,158 --> 00:06:53,348  
giant planets in the solar system all of

153  
00:06:50,199 --> 00:06:54,939  
those white and red objects are new

154  
00:06:53,348 --> 00:06:56,618  
objects that have been discovered in the

155  
00:06:54,939 --> 00:07:00,549  
Kuiper belt below the solar system since

156  
00:06:56,619 --> 00:07:02,519  
1993 well I say all of them but one of

157  
00:07:00,548 --> 00:07:07,628

course Pluto was discovered in 1930

158

00:07:02,519 --> 00:07:10,718

they're 12 1274 as of July this summer

159

00:07:07,629 --> 00:07:13,778

and so the question is we're gonna zoom

160

00:07:10,718 --> 00:07:17,110

past Pluto what do we do afterwards can

161

00:07:13,778 --> 00:07:21,009

we find a suitable Kuiper belt object to

162

00:07:17,110 --> 00:07:23,439

fly past afterwards so Hubble showed

163

00:07:21,009 --> 00:07:25,598

that it could do it and NASA gave us the

164

00:07:23,439 --> 00:07:29,069

go-ahead to do a complete search for

165

00:07:25,598 --> 00:07:31,988

Kuiper belt objects that would be

166

00:07:29,069 --> 00:07:36,879

obtainable with the current orbit of the

167

00:07:31,988 --> 00:07:39,338

mission so they looked at 83 Hubble with

168

00:07:36,879 --> 00:07:42,639

c3 fields okay and this is the tile

169

00:07:39,338 --> 00:07:45,788

mosaic of all these 83 fields that they

170

00:07:42,639 --> 00:07:47,679

looked in and on the lower left-hand

171

00:07:45,788 --> 00:07:49,658

corner is the size of the full moon on

172  
00:07:47,678 --> 00:07:52,448  
the sky and so you can see that they

173  
00:07:49,658 --> 00:07:56,319  
covered an area about half the size of a

174  
00:07:52,449 --> 00:07:58,569  
full moon in total looking for potential

175  
00:07:56,319 --> 00:08:00,908  
Kuiper belt objects that the New

176  
00:07:58,569 --> 00:08:03,989  
Horizons mission could visit they

177  
00:08:00,908 --> 00:08:08,139  
discovered three that were really

178  
00:08:03,988 --> 00:08:10,118  
obtainable potential targets and so if

179  
00:08:08,139 --> 00:08:12,610  
you take those blue as the whipsy three

180  
00:08:10,119 --> 00:08:14,919  
fields and then the purple as a single

181  
00:08:12,610 --> 00:08:16,959  
with c3 field and then you zoom into

182  
00:08:14,918 --> 00:08:19,899  
that red region you can see how just a

183  
00:08:16,959 --> 00:08:22,769  
small piece of that they had to do and

184  
00:08:19,899 --> 00:08:25,269  
you can see the five separate images are

185  
00:08:22,769 --> 00:08:28,718  
different exposures you take multiple

186  
00:08:25,269 --> 00:08:30,610  
exposures separated by time and then the

187  
00:08:28,718 --> 00:08:32,698  
nearby objects the object in our solar

188  
00:08:30,610 --> 00:08:35,620  
system will move across the exposure

189  
00:08:32,698 --> 00:08:38,198  
creating those five separate images so

190  
00:08:35,620 --> 00:08:41,139  
here is what they call PT one potential

191  
00:08:38,198 --> 00:08:44,769  
target one you can see it's real name is

192  
00:08:41,139 --> 00:08:49,570  
one one one zero one one three why

193  
00:08:44,769 --> 00:08:51,189  
which is why we call it PT 1 and this is

194  
00:08:49,570 --> 00:08:54,300  
one of the this this is the favored

195  
00:08:51,190 --> 00:08:57,250  
target for New Horizons to mission

196  
00:08:54,299 --> 00:08:59,259  
mission mission to visit after going

197  
00:08:57,250 --> 00:09:01,269  
past Pluto so as I said there are three

198  
00:08:59,259 --> 00:09:04,830  
potential targets size estimates for

199  
00:09:01,269 --> 00:09:07,958  
these are between 25 and 55 kilometers

200

00:09:04,830 --> 00:09:09,430  
one of them is definitely reachable and

201  
00:09:07,958 --> 00:09:11,919  
when we say definitely reachable the

202  
00:09:09,429 --> 00:09:15,458  
idea is that we need enough propulsion

203  
00:09:11,919 --> 00:09:17,649  
to shift the orbit to shift the the path

204  
00:09:15,458 --> 00:09:20,619  
of New Horizons to go past this object

205  
00:09:17,649 --> 00:09:22,208  
right and so given the constraints of

206  
00:09:20,620 --> 00:09:25,778  
the propellant and stuff we have on

207  
00:09:22,208 --> 00:09:27,429  
board can we shift it and so one is

208  
00:09:25,778 --> 00:09:31,809  
definitely reachable two of them are

209  
00:09:27,429 --> 00:09:33,429  
potentially accessible but just because

210  
00:09:31,809 --> 00:09:35,019  
we found potential targets doesn't mean

211  
00:09:33,429 --> 00:09:38,049  
that New Horizons is actually going to

212  
00:09:35,019 --> 00:09:40,449  
go there nASA has to approve and fund

213  
00:09:38,049 --> 00:09:43,000  
the extension of the mission the mission

214  
00:09:40,450 --> 00:09:45,209

is funded through the Pluto of the Pluto

215

00:09:43,000 --> 00:09:48,370

flyby and all the analysis of that data

216

00:09:45,208 --> 00:09:50,619

NASA must secure must approve the

217

00:09:48,370 --> 00:09:52,328

funding for that so they're going to go

218

00:09:50,620 --> 00:09:55,060

through the entire year next year and

219

00:09:52,328 --> 00:09:57,069

somewhere around in early 2016 the

220

00:09:55,059 --> 00:09:59,500

decision will be made whether or not

221

00:09:57,070 --> 00:10:05,890

they're going to go and look at a second

222

00:09:59,500 --> 00:10:08,379

object no worries of a collision - the

223

00:10:05,889 --> 00:10:10,958

question was no there was no it's pretty

224

00:10:08,379 --> 00:10:16,720

pretty pretty really totally empty out

225

00:10:10,958 --> 00:10:18,909

there I mean it's well you're used to if

226

00:10:16,720 --> 00:10:21,070

you ever if you saw Star Wars you know

227

00:10:18,909 --> 00:10:23,828

how dense the asteroid belt isn't

228

00:10:21,070 --> 00:10:26,079

because as spaceships zooming through



229

00:10:23,828 --> 00:10:28,479

the asteroid belt is pure fiction

230

00:10:26,078 --> 00:10:30,519

okay if you fly through the asteroid

231

00:10:28,480 --> 00:10:32,769

belt you will never ever know that

232

00:10:30,519 --> 00:10:35,199

you're inside the asteroid belt because

233

00:10:32,769 --> 00:10:37,689

it's just incredibly amounts of space in

234

00:10:35,200 --> 00:10:39,278

between the asteroids okay same thing

235

00:10:37,690 --> 00:10:41,470

even more true for the Kuiper belt

236

00:10:39,278 --> 00:10:42,879

objects okay incredible amounts of space

237

00:10:41,470 --> 00:10:45,459

in between them so you have to work

238

00:10:42,879 --> 00:10:50,110

really really really hard in order to

239

00:10:45,458 --> 00:10:53,948

fly past one of these okay here is just

240

00:10:50,110 --> 00:10:55,950

for example the potential target one 30

241

00:10:53,948 --> 00:10:58,829

to 45 kilometers in diameter

242

00:10:55,950 --> 00:11:01,950

compared to asteroid eros that we flew

243  
00:10:58,830 --> 00:11:05,160  
past and rubber ducky also known as

244  
00:11:01,950 --> 00:11:06,660  
comet cherammal of Gerasimenko this is

245  
00:11:05,159 --> 00:11:08,969  
the rosetta target which is only four

246  
00:11:06,659 --> 00:11:12,120  
kilometers in diameter and of course

247  
00:11:08,970 --> 00:11:14,070  
rubber ducky is going to get visited is

248  
00:11:12,120 --> 00:11:16,350  
currently being visited but it'll have a

249  
00:11:14,070 --> 00:11:21,120  
lander tomorrow I'll wait a question

250  
00:11:16,350 --> 00:11:22,409  
there get in there in just a second okay

251  
00:11:21,120 --> 00:11:26,850  
good question

252  
00:11:22,409 --> 00:11:30,029  
how much further away is it well so here

253  
00:11:26,850 --> 00:11:33,330  
is an artist's depiction of it and so

254  
00:11:30,029 --> 00:11:35,159  
this is the idea of what it might look

255  
00:11:33,330 --> 00:11:36,200  
like this Kuiper belt object way out at

256  
00:11:35,159 --> 00:11:39,480  
the edge of space

257

00:11:36,200 --> 00:11:43,500  
and the idea is that it's supposed to be

258  
00:11:39,480 --> 00:11:45,870  
here but this is of course fantasy this

259  
00:11:43,500 --> 00:11:48,629  
is not even scientifically correct it's

260  
00:11:45,870 --> 00:11:50,490  
a nice idea but you recognize when I

261  
00:11:48,629 --> 00:11:52,500  
showed you that path that New Horizons

262  
00:11:50,490 --> 00:11:56,460  
is that has been going straight past

263  
00:11:52,500 --> 00:12:00,899  
Pluto and Pluto is about three billion

264  
00:11:56,460 --> 00:12:03,530  
miles out from the Sun and this new

265  
00:12:00,899 --> 00:12:06,090  
object is about four billion miles out

266  
00:12:03,529 --> 00:12:08,759  
so the problem with this diagram is that

267  
00:12:06,090 --> 00:12:11,370  
that object should be moved over to the

268  
00:12:08,759 --> 00:12:13,110  
end of that green line and actually if

269  
00:12:11,370 --> 00:12:14,639  
you're looking back at the Sun from that

270  
00:12:13,110 --> 00:12:17,070  
object you should be seeing Pluto in a

271  
00:12:14,639 --> 00:12:18,269

direct line with the Sun because New

272

00:12:17,070 --> 00:12:21,260

Horizons is not going to be able to

273

00:12:18,269 --> 00:12:23,309

change its its its path very much so

274

00:12:21,259 --> 00:12:25,259

it's alright it's just an artist

275

00:12:23,309 --> 00:12:27,719

rendition here but the point is is that

276

00:12:25,259 --> 00:12:30,360

it's about four billion miles out so

277

00:12:27,720 --> 00:12:32,759

after traveling three billion miles over

278

00:12:30,360 --> 00:12:34,470

course of ten years it's gonna have to

279

00:12:32,759 --> 00:12:36,000

travel another billion miles to get

280

00:12:34,470 --> 00:12:37,620

there which will take another three

281

00:12:36,000 --> 00:12:39,629

years three or four years to get there

282

00:12:37,620 --> 00:12:44,629

okay which is the question I think you

283

00:12:39,629 --> 00:12:47,850

were really asking right right okay okay

284

00:12:44,629 --> 00:12:50,460

next topic a close encounter of the

285

00:12:47,850 --> 00:12:52,139

fourth planet kind this is another

286  
00:12:50,460 --> 00:12:52,800  
revisit of a story that we've been

287  
00:12:52,139 --> 00:12:56,429  
following

288  
00:12:52,799 --> 00:12:59,149  
of course comet siding spring siding

289  
00:12:56,429 --> 00:13:03,859  
spring which flew past Mars last month

290  
00:12:59,149 --> 00:13:07,139  
this is a Damien peach the guy gets

291  
00:13:03,860 --> 00:13:08,639  
amazingly good comet pictures Danny

292  
00:13:07,139 --> 00:13:09,600  
peach this is a picture of comet siding

293  
00:13:08,639 --> 00:13:14,220  
spring from Fair

294  
00:13:09,600 --> 00:13:18,120  
of last year and of course in October it

295  
00:13:14,220 --> 00:13:20,040  
flew past Mars and this this it's on

296  
00:13:18,120 --> 00:13:22,500  
this giant looping orbit it's got like a

297  
00:13:20,039 --> 00:13:23,939  
million year orbit okay and it's coming

298  
00:13:22,500 --> 00:13:25,590  
down underneath the solar system and

299  
00:13:23,940 --> 00:13:28,170  
back up through it and it just happens

300  
00:13:25,590 --> 00:13:30,450  
to pass by the orbit of Mars and Mars

301  
00:13:28,169 --> 00:13:32,490  
just happened to be there at the same

302  
00:13:30,450 --> 00:13:33,420  
time it was passing by incredible

303  
00:13:32,490 --> 00:13:35,850  
coincidence

304  
00:13:33,419 --> 00:13:38,429  
this doesn't do it justice it actually

305  
00:13:35,850 --> 00:13:42,509  
came within twenty Mars diameters of

306  
00:13:38,429 --> 00:13:45,359  
Mars on there and so of course is

307  
00:13:42,509 --> 00:13:48,389  
there's gonna a on the scale of the

308  
00:13:45,360 --> 00:13:50,129  
solar system that's amazingly close all

309  
00:13:48,389 --> 00:13:52,350  
right so we're wondering was there going

310  
00:13:50,129 --> 00:13:55,039  
to be any problems this is an artist's

311  
00:13:52,350 --> 00:13:57,629  
depiction of the comet flying past Mars

312  
00:13:55,039 --> 00:13:59,849  
and this was to illustrate the idea that

313  
00:13:57,629 --> 00:14:03,929  
NASA was going to do a Duck and Cover

314

00:13:59,850 --> 00:14:06,149  
take the three spacecrafts that we have

315  
00:14:03,929 --> 00:14:07,559  
in orbit around Mars and make sure they

316  
00:14:06,149 --> 00:14:09,149  
were on the far side of the planet at

317  
00:14:07,559 --> 00:14:13,139  
the proper time so that they wouldn't

318  
00:14:09,149 --> 00:14:16,429  
get hit but this was overly optimistic

319  
00:14:13,139 --> 00:14:19,769  
in terms of the size of the coma of the

320  
00:14:16,429 --> 00:14:21,089  
spacecraft of the comet it wasn't nearly

321  
00:14:19,769 --> 00:14:23,429  
any that big

322  
00:14:21,090 --> 00:14:26,310  
there wasn't any huge problems with it

323  
00:14:23,429 --> 00:14:27,870  
and after the flyby they put up this

324  
00:14:26,309 --> 00:14:31,139  
webpage saying everything's in good

325  
00:14:27,870 --> 00:14:33,690  
health MRO maven and Odyssey are all in

326  
00:14:31,139 --> 00:14:34,500  
good health no problems there wasn't

327  
00:14:33,690 --> 00:14:36,720  
really something we were sweating

328  
00:14:34,500 --> 00:14:38,399

amazingly but you know if the coma had

329

00:14:36,720 --> 00:14:40,769

been really really big there could have

330

00:14:38,399 --> 00:14:44,370

been some serious problems what we were

331

00:14:40,769 --> 00:14:47,549

interested also in is the ones on the

332

00:14:44,370 --> 00:14:49,590

surface could they look up and see an

333

00:14:47,549 --> 00:14:51,750

observation of a comet from another

334

00:14:49,590 --> 00:14:57,149

planet first observation of a comet from

335

00:14:51,750 --> 00:15:00,889

another planet and they got it it's not

336

00:14:57,149 --> 00:15:03,929

that impressive but they did get it okay

337

00:15:00,889 --> 00:15:07,639

so that in the center is comet siding

338

00:15:03,929 --> 00:15:11,459

spring as seen from the surface of Mars

339

00:15:07,639 --> 00:15:13,799

so that's a cool image not very detailed

340

00:15:11,460 --> 00:15:16,110

in anything if you want a really good

341

00:15:13,799 --> 00:15:18,149

image unfortunately this the the the

342

00:15:16,110 --> 00:15:19,680

missions at Mars did not get the good



343  
00:15:18,149 --> 00:15:21,720  
image where are we gonna get the good

344  
00:15:19,679 --> 00:15:22,569  
image we're gonna go back to Damian

345  
00:15:21,720 --> 00:15:26,110  
peach because

346  
00:15:22,570 --> 00:15:27,250  
gets the coolest pictures okay so on the

347  
00:15:26,110 --> 00:15:29,350  
right hand side that thing with the

348  
00:15:27,250 --> 00:15:30,669  
spikes that looks like a star it's not a

349  
00:15:29,350 --> 00:15:33,659  
star that's Mars

350  
00:15:30,669 --> 00:15:36,969  
that's how amazingly bright Mars is

351  
00:15:33,659 --> 00:15:37,779  
compared to comet siding spring 's lower

352  
00:15:36,970 --> 00:15:42,070  
left of it

353  
00:15:37,779 --> 00:15:44,439  
okay so again just like for comet Ison

354  
00:15:42,070 --> 00:15:48,040  
the best comp ixr seem to always come

355  
00:15:44,440 --> 00:15:49,270  
from Damian peach he's done I don't know

356  
00:15:48,039 --> 00:15:51,969  
how he does it I've never been an

357  
00:15:49,269 --> 00:15:54,220  
amateur astronomer I've never been a

358  
00:15:51,970 --> 00:15:56,740  
telescopic astronomer or an astro

359  
00:15:54,220 --> 00:15:58,930  
photographer but he gets the gets the

360  
00:15:56,740 --> 00:16:01,060  
cool things all right so this shows you

361  
00:15:58,929 --> 00:16:04,059  
the correct relative brightness of them

362  
00:16:01,059 --> 00:16:08,019  
all right and it also gives you a clue

363  
00:16:04,059 --> 00:16:11,579  
as to what this image is this is a

364  
00:16:08,019 --> 00:16:13,750  
Hubble image but it is a composite okay

365  
00:16:11,580 --> 00:16:15,550  
way too many people on the internet that

366  
00:16:13,750 --> 00:16:18,070  
thought this was a single image all

367  
00:16:15,549 --> 00:16:20,139  
right and if you look at this okay go

368  
00:16:18,070 --> 00:16:21,970  
back to this you can see there's no way

369  
00:16:20,139 --> 00:16:23,740  
you can get Mars in the same exposure

370  
00:16:21,970 --> 00:16:26,590  
anywhere near that you can get the comet

371

00:16:23,740 --> 00:16:30,460  
so what Hubble did here is Hubble took

372  
00:16:26,590 --> 00:16:32,590  
separate images of Mars and of the comet

373  
00:16:30,460 --> 00:16:34,450  
all right so that it could do the

374  
00:16:32,590 --> 00:16:37,450  
exposure level correctly for each and

375  
00:16:34,450 --> 00:16:41,110  
then we mosaic them together to show the

376  
00:16:37,450 --> 00:16:43,210  
correct relative scale okay so you can

377  
00:16:41,110 --> 00:16:45,700  
see this is the 20 Mars diameters across

378  
00:16:43,210 --> 00:16:48,280  
right all right but that's the scale of

379  
00:16:45,700 --> 00:16:50,230  
the coma of the comet and you can see

380  
00:16:48,279 --> 00:16:54,039  
it's not quite big enough to really have

381  
00:16:50,230 --> 00:16:56,950  
caused major havoc at Mars so we had a

382  
00:16:54,039 --> 00:16:59,289  
really really close approach between two

383  
00:16:56,950 --> 00:17:01,540  
objects in the solar system on the

384  
00:16:59,289 --> 00:17:03,549  
scales of billions of miles they were

385  
00:17:01,539 --> 00:17:05,470

coming in you know at just a hundred

386

00:17:03,549 --> 00:17:08,259

thousandth of my hundred thousand a

387

00:17:05,470 --> 00:17:10,650

hundred thousand miles but even then it

388

00:17:08,259 --> 00:17:13,660

wasn't enough to cause any major havoc

389

00:17:10,650 --> 00:17:17,230

so it was it was an interesting event

390

00:17:13,660 --> 00:17:22,990

but nothing nothing Mars shattering how

391

00:17:17,230 --> 00:17:27,400

about that all right finally the coolest

392

00:17:22,990 --> 00:17:28,779

image I have seen in years and I call it

393

00:17:27,400 --> 00:17:30,370

mining the gaps

394

00:17:28,779 --> 00:17:32,049

and those have you been to London

395

00:17:30,369 --> 00:17:36,549

understand what I'm talking about

396

00:17:32,049 --> 00:17:40,059

so we have for many years been seeing

397

00:17:36,549 --> 00:17:43,869

disks of material around newborn stars

398

00:17:40,059 --> 00:17:46,149

okay young stars as we as a as a cloud

399

00:17:43,869 --> 00:17:49,059

of dust material collapses to form a

400  
00:17:46,150 --> 00:17:51,040  
star it forms a disk around it and here

401  
00:17:49,059 --> 00:17:53,470  
you can see on the left au microscopy

402  
00:17:51,039 --> 00:17:56,019  
where we see the edge on of the disk and

403  
00:17:53,470 --> 00:17:59,019  
on the right HD 107 146 where we see the

404  
00:17:56,019 --> 00:18:00,430  
face onto these disks okay and this the

405  
00:17:59,019 --> 00:18:01,960  
star in the centre of course is blocked

406  
00:18:00,430 --> 00:18:04,240  
out by a coronagraph so you can actually

407  
00:18:01,960 --> 00:18:08,890  
see the disk disk of material around it

408  
00:18:04,240 --> 00:18:10,809  
and so we're seeing these disks and they

409  
00:18:08,890 --> 00:18:12,640  
can be sometimes kind of ratty but you

410  
00:18:10,809 --> 00:18:14,169  
know we can see in the top and the

411  
00:18:12,640 --> 00:18:16,000  
bottom here we've got the observation

412  
00:18:14,170 --> 00:18:18,039  
from Hubble and the bottom is the

413  
00:18:16,000 --> 00:18:19,990  
artist's interpretation to help you

414  
00:18:18,039 --> 00:18:22,480  
guide your eye in terms of seeing these

415  
00:18:19,990 --> 00:18:24,700  
disks around these objects and so we're

416  
00:18:22,480 --> 00:18:27,819  
finally seeing lots and lots of these

417  
00:18:24,700 --> 00:18:29,940  
disks we're confirming that star and

418  
00:18:27,819 --> 00:18:33,549  
plant information goes through a disk

419  
00:18:29,940 --> 00:18:35,950  
furthermore in some places such as foam

420  
00:18:33,549 --> 00:18:38,470  
alot we're seeing these rings and you

421  
00:18:35,950 --> 00:18:42,009  
see this thin ring out here and this

422  
00:18:38,470 --> 00:18:45,910  
ring at foam a lot okay was indicative

423  
00:18:42,009 --> 00:18:47,950  
of the idea that planets had formed one

424  
00:18:45,910 --> 00:18:50,200  
because it was a nice thin ring and you

425  
00:18:47,950 --> 00:18:52,450  
need a gravitational body to create that

426  
00:18:50,200 --> 00:18:54,759  
ring and to because that ring was

427  
00:18:52,450 --> 00:18:56,559  
slightly off center and a gravitational

428

00:18:54,759 --> 00:18:59,019  
pull of a planet could have pulled it

429  
00:18:56,559 --> 00:19:03,240  
off center and so info a lot we went in

430  
00:18:59,019 --> 00:19:05,470  
looking and we found a planet okay that

431  
00:19:03,240 --> 00:19:06,940  
potentially could cause it and we

432  
00:19:05,470 --> 00:19:11,200  
believe that that that is the planet

433  
00:19:06,940 --> 00:19:14,019  
that caused the the ring there now

434  
00:19:11,200 --> 00:19:16,360  
Hubble has great resolution okay it does

435  
00:19:14,019 --> 00:19:18,549  
amazing things but there's a new

436  
00:19:16,359 --> 00:19:20,649  
telescope that has just come online oops

437  
00:19:18,549 --> 00:19:21,849  
I'm sorry I forgot about that this other

438  
00:19:20,650 --> 00:19:24,370  
thing there's one other observation I

439  
00:19:21,849 --> 00:19:27,159  
wanted to do in the setup is the Keck

440  
00:19:24,369 --> 00:19:29,559  
Observatory okay this is the star the

441  
00:19:27,160 --> 00:19:31,090  
disk around beta Pictoris the Hubble

442  
00:19:29,559 --> 00:19:32,859

observations on the bottom and the

443

00:19:31,089 --> 00:19:35,679

center of the thing up top you can

444

00:19:32,859 --> 00:19:37,659

actually start to see lumps in the the

445

00:19:35,680 --> 00:19:39,160

disc now this is an edge-on disc and you

446

00:19:37,660 --> 00:19:40,779

can see lumps in it where you think that

447

00:19:39,160 --> 00:19:42,279

planets might start

448

00:19:40,779 --> 00:19:45,160

start forming so we're beginning to see

449

00:19:42,279 --> 00:19:47,529

not just the disks and these rings and

450

00:19:45,160 --> 00:19:49,060

these lumps within the Rings to try and

451

00:19:47,529 --> 00:19:51,670

indicate the possibility of planet

452

00:19:49,059 --> 00:19:54,690

formation within them right but there's

453

00:19:51,670 --> 00:19:58,600

a new telescope on the Atacama Desert at

454

00:19:54,690 --> 00:20:00,880

15,000 feet in Chile and this is a

455

00:19:58,599 --> 00:20:02,919

millimeter wave observatory it's called

456

00:20:00,880 --> 00:20:05,950

the Atacama Large millimeter or array



457  
00:20:02,920 --> 00:20:09,250  
and with it they can separate their

458  
00:20:05,950 --> 00:20:12,009  
dishes by up to 15 kilometres they can

459  
00:20:09,250 --> 00:20:14,710  
synthesize a telescope that's 15

460  
00:20:12,009 --> 00:20:17,049  
kilometers in length and this is the

461  
00:20:14,710 --> 00:20:20,650  
artist's depiction and here is a shot of

462  
00:20:17,049 --> 00:20:23,470  
the partially built atacama Alma up up

463  
00:20:20,650 --> 00:20:27,040  
there and with that they can start

464  
00:20:23,470 --> 00:20:31,539  
looking at the amazing things so they

465  
00:20:27,039 --> 00:20:40,359  
looked at a star named HL Tauri ok HL

466  
00:20:31,539 --> 00:20:41,980  
Tauri I don't have my HL Tauri is

467  
00:20:40,359 --> 00:20:44,289  
somewhere in here this is a Hubble image

468  
00:20:41,980 --> 00:20:47,279  
alright you can see that and these eehh

469  
00:20:44,289 --> 00:20:49,659  
right in there there is a star HL Tauri

470  
00:20:47,279 --> 00:20:53,049  
and they looked at it in millimeter

471  
00:20:49,660 --> 00:20:57,460  
wavelengths and they got an absolutely

472  
00:20:53,049 --> 00:20:59,289  
amazing image ok in that small region

473  
00:20:57,460 --> 00:21:04,150  
they were able to see this let me pull

474  
00:20:59,289 --> 00:21:07,779  
it up full size this is the disc around

475  
00:21:04,150 --> 00:21:11,320  
a 1 million year old star we can see the

476  
00:21:07,779 --> 00:21:13,589  
gaps and the ring structures and the

477  
00:21:11,319 --> 00:21:17,470  
holes in the ring structures which are

478  
00:21:13,589 --> 00:21:20,829  
incredibly indicative of the formation

479  
00:21:17,470 --> 00:21:23,650  
of planets in this disc all right we

480  
00:21:20,829 --> 00:21:26,289  
have never seen a disc in anywhere near

481  
00:21:23,650 --> 00:21:26,860  
this detail this is an amazing image it

482  
00:21:26,289 --> 00:21:29,049  
floored

483  
00:21:26,859 --> 00:21:31,750  
all of us we were passing it around if I

484  
00:21:29,049 --> 00:21:33,549  
email so many astronomers posted it on

485

00:21:31,750 --> 00:21:36,759  
Facebook and Google+ all over the place

486  
00:21:33,549 --> 00:21:40,299  
just a stunning image this is the first

487  
00:21:36,759 --> 00:21:42,910  
high-res image release from Alma when

488  
00:21:40,299 --> 00:21:44,649  
they're out in the 15 kilometer baseline

489  
00:21:42,910 --> 00:21:46,750  
mode where they can get the highest

490  
00:21:44,650 --> 00:21:48,880  
resolution they will actually look in

491  
00:21:46,750 --> 00:21:51,369  
lower frequencies able to get even

492  
00:21:48,880 --> 00:21:53,690  
higher resolution than this it just

493  
00:21:51,369 --> 00:21:56,268  
augers an incredible

494  
00:21:53,690 --> 00:21:58,970  
credible wealth of information in

495  
00:21:56,269 --> 00:22:03,200  
millimeter way of astronomy to come from

496  
00:21:58,970 --> 00:22:05,089  
Alma and this is literally one of the

497  
00:22:03,200 --> 00:22:10,100  
most amazing images I've seen in years

498  
00:22:05,089 --> 00:22:13,128  
so we're seeing details of plant

499  
00:22:10,099 --> 00:22:21,500

formation around other stars really cool

500

00:22:13,128 --> 00:22:22,638

stuff maybe I might be but might may be

501

00:22:21,500 --> 00:22:23,569

flipping that they're gonna look how

502

00:22:22,638 --> 00:22:24,918

about this they look at other

503

00:22:23,569 --> 00:22:27,398

frequencies and get slightly higher

504

00:22:24,919 --> 00:22:29,509

resolution than this how about that I

505

00:22:27,398 --> 00:22:30,949

just think I've been given a teacher

506

00:22:29,509 --> 00:22:35,509

works trough the last two hours I can't

507

00:22:30,950 --> 00:22:37,129

think anymore okay so that's the news

508

00:22:35,509 --> 00:22:40,429

from the universe and it's time to move

509

00:22:37,128 --> 00:22:43,158

over to our featured speaker our speaker

510

00:22:40,429 --> 00:22:45,110

tonight is Mark kamionkowski who comes

511

00:22:43,159 --> 00:22:50,360

to us all the way from across the street

512

00:22:45,109 --> 00:22:52,609

at the Johns Hopkins University mark got

513

00:22:50,359 --> 00:22:55,609

his undergraduate degree at Washington

514  
00:22:52,609 --> 00:22:57,829  
University in st. Louis then went on to

515  
00:22:55,609 --> 00:23:01,579  
get his graduate did his graduate work

516  
00:22:57,829 --> 00:23:05,480  
at the University of Chicago then went

517  
00:23:01,579 --> 00:23:07,519  
on to Columbia University where I oh no

518  
00:23:05,480 --> 00:23:09,048  
I'm sorry he went to Princeton at the

519  
00:23:07,519 --> 00:23:11,679  
Institute for Advanced Study for a

520  
00:23:09,048 --> 00:23:16,009  
postdoc and then went up to Columbia

521  
00:23:11,679 --> 00:23:18,288  
where he gave me half a job after I

522  
00:23:16,009 --> 00:23:20,628  
finished my postdoc at Princeton I got

523  
00:23:18,288 --> 00:23:22,490  
half a postdoc at Columbia with Mark and

524  
00:23:20,628 --> 00:23:25,278  
half a postdoc at the America Museum of

525  
00:23:22,490 --> 00:23:28,339  
Natural History with Neil Tyson so they

526  
00:23:25,278 --> 00:23:31,849  
shared me for a couple years before I

527  
00:23:28,339 --> 00:23:33,980  
moved on to M & H fully so obviously

528  
00:23:31,849 --> 00:23:36,798  
indebted to him for that then he went

529  
00:23:33,980 --> 00:23:40,069  
out to Caltech professor there and

530  
00:23:36,798 --> 00:23:41,960  
finally came here to Johns Hopkins he is

531  
00:23:40,069 --> 00:23:44,058  
definitely one of the world's experts in

532  
00:23:41,960 --> 00:23:45,139  
the cosmic wave background and really

533  
00:23:44,058 --> 00:23:46,819  
looking forward to hearing from him

534  
00:23:45,138 --> 00:23:49,028  
ladies and gentlemen dr. Mark

535  
00:23:46,819 --> 00:23:49,028  
kamionkowski

536  
00:23:54,740 --> 00:24:03,509  
thank you very much so Frank and I

537  
00:24:01,380 --> 00:24:05,790  
overlapped for a few years Columbia and

538  
00:24:03,509 --> 00:24:11,849  
one of the things we did together is try

539  
00:24:05,789 --> 00:24:14,609  
to figure out why galaxies spin we made

540  
00:24:11,849 --> 00:24:15,859  
some progress so today I'm going to tell

541  
00:24:14,609 --> 00:24:19,490  
you about something completely different

542

00:24:15,859 --> 00:24:22,889  
I'm gonna tell you about some new

543  
00:24:19,490 --> 00:24:26,069  
measurements that have been made the

544  
00:24:22,890 --> 00:24:29,130  
results were announced in March and we

545  
00:24:26,069 --> 00:24:30,419  
may be seeing a signal from the first

546  
00:24:29,130 --> 00:24:31,740  
trillionth of a trillionth of a

547  
00:24:30,420 --> 00:24:35,160  
trillionth of a second after the Big

548  
00:24:31,740 --> 00:24:38,039  
Bang whether we are not still remains to

549  
00:24:35,160 --> 00:24:42,660  
be determined and I will try to explain

550  
00:24:38,039 --> 00:24:44,279  
to you the story so just to begin this

551  
00:24:42,660 --> 00:24:45,540  
was a there was a press conference at

552  
00:24:44,279 --> 00:24:49,889  
the harvard-smithsonian Center for

553  
00:24:45,539 --> 00:24:55,409  
Astrophysics where the team which is

554  
00:24:49,890 --> 00:24:57,270  
called I Sept 2 announced discovery of

555  
00:24:55,410 --> 00:25:00,870  
gravitational waves from the Big Bang

556  
00:24:57,269 --> 00:25:03,029

and the harvard-smithsonian Center for

557

00:25:00,869 --> 00:25:05,399

Astrophysics has these types of press

558

00:25:03,029 --> 00:25:07,230

conferences all the time because they're

559

00:25:05,400 --> 00:25:08,310

discovering exoplanets all the time and

560

00:25:07,230 --> 00:25:09,390

this is one of the places where they

561

00:25:08,309 --> 00:25:12,269

announced the discovery of the

562

00:25:09,390 --> 00:25:14,250

exoplanets the response to this

563

00:25:12,269 --> 00:25:15,690

particular news conference though was

564

00:25:14,250 --> 00:25:18,359

unlike anything they had ever seen

565

00:25:15,690 --> 00:25:20,220

before and in fact most people who tried

566

00:25:18,359 --> 00:25:22,199

to log in to the website to watch the

567

00:25:20,220 --> 00:25:24,329

news conference life were unable to do

568

00:25:22,200 --> 00:25:26,730

so because there was such demand to

569

00:25:24,329 --> 00:25:28,740

watch it that the demand actually

570

00:25:26,730 --> 00:25:32,490

brought the Harvard web service to their



571  
00:25:28,740 --> 00:25:34,620  
knees so it was really really huge it

572  
00:25:32,490 --> 00:25:37,230  
was written up in Scientific American it

573  
00:25:34,619 --> 00:25:40,199  
was front page on the New York Times New

574  
00:25:37,230 --> 00:25:42,960  
Scientist every single news source in

575  
00:25:40,200 --> 00:25:46,140  
the world covered the story and in

576  
00:25:42,960 --> 00:25:51,960  
particular through was if I can find it

577  
00:25:46,140 --> 00:25:56,520  
here this Saturday morning afterwards so

578  
00:25:51,960 --> 00:25:57,660  
let me play Danny welcome to the show

579  
00:25:56,519 --> 00:26:00,000  
you're gonna start us off with who's

580  
00:25:57,660 --> 00:26:01,980  
Karl this time Carl Kasell living legend

581  
00:26:00,000 --> 00:26:03,690  
that he is is going to recreate for you

582  
00:26:01,980 --> 00:26:04,720  
three quotations of the week's news your

583  
00:26:03,690 --> 00:26:06,340  
job of course identify

584  
00:26:04,720 --> 00:26:08,140  
I explained just two of them do that

585  
00:26:06,339 --> 00:26:09,609  
you'll win our prize calls voice on your

586  
00:26:08,140 --> 00:26:12,309  
home answering machine you ready to go

587  
00:26:09,609 --> 00:26:14,019  
yeah all right here is your first quote

588  
00:26:12,308 --> 00:26:17,019  
that's pretty damn cool

589  
00:26:14,019 --> 00:26:19,538  
that was a theoretical physicist named

590  
00:26:17,019 --> 00:26:21,879  
Mark chemin outski he's reacting to news

591  
00:26:19,538 --> 00:26:25,298  
that researchers had found evidence of

592  
00:26:21,880 --> 00:26:28,210  
what the big bang indeed yes the big

593  
00:26:25,298 --> 00:26:30,668  
bang or what came right after the Big

594  
00:26:28,210 --> 00:26:32,860  
Bang basically the beginning of the

595  
00:26:30,669 --> 00:26:34,750  
universe physicists all over the world

596  
00:26:32,859 --> 00:26:36,158  
were incredibly excited they said the

597  
00:26:34,750 --> 00:26:38,470  
discoveries that was announced this week

598  
00:26:36,159 --> 00:26:40,840  
was the most revolutionary advance in

599

00:26:38,470 --> 00:26:42,819  
science and decades it's amazingly cool

600  
00:26:40,839 --> 00:26:46,750  
it's deeply important it is impossible

601  
00:26:42,819 --> 00:26:48,700  
to explain in English they tried they

602  
00:26:46,750 --> 00:26:51,099  
compared the universe to a grapefruit to

603  
00:26:48,700 --> 00:26:53,230  
a pot of boiling pasta to bread dough

604  
00:26:51,099 --> 00:26:55,798  
being stretched and then we realized the

605  
00:26:53,230 --> 00:26:58,298  
physicists had just skipped their lunch

606  
00:26:55,798 --> 00:27:01,179  
and what happened this week as they

607  
00:26:58,298 --> 00:27:02,980  
announced an experiment that proved that

608  
00:27:01,179 --> 00:27:04,630  
they were right they predicted this

609  
00:27:02,980 --> 00:27:06,669  
result and they got it and they said

610  
00:27:04,630 --> 00:27:09,909  
this was such an amazing discovery so

611  
00:27:06,669 --> 00:27:12,220  
specific that one person made an analogy

612  
00:27:09,909 --> 00:27:13,570  
to imagine if someone were to create a

613  
00:27:12,220 --> 00:27:16,000

model of the world in which they

614

00:27:13,569 --> 00:27:18,250

predicted that there would be age this

615

00:27:16,000 --> 00:27:20,890

is their example a little troll doll

616

00:27:18,250 --> 00:27:23,859

under a floorboard on the third floor of

617

00:27:20,890 --> 00:27:26,140

Ruth Bader Ginsburg childhood home right

618

00:27:23,859 --> 00:27:27,788

now the example and then this week's

619

00:27:26,140 --> 00:27:29,320

discovery was like somebody going to the

620

00:27:27,788 --> 00:27:30,908

home going to the third floor opening up

621

00:27:29,319 --> 00:27:33,409

a floorboard and finding it that's how

622

00:27:30,909 --> 00:27:36,030

amazing this prediction was that

623

00:27:33,410 --> 00:27:40,650

so that would be exciting like if I

624

00:27:36,029 --> 00:27:43,710

found it anyway so I am actually gonna

625

00:27:40,650 --> 00:27:45,300

try to explain it to you in English and

626

00:27:43,710 --> 00:27:47,509

Frank you're not the only one to screw

627

00:27:45,299 --> 00:27:51,809

up my last name as you can tell here

628  
00:27:47,509 --> 00:27:55,319  
that's okay so that was a March 18th

629  
00:27:51,809 --> 00:27:58,859  
2014 but it's been over half a year

630  
00:27:55,319 --> 00:28:01,559  
since and since then there have been a

631  
00:27:58,859 --> 00:28:03,359  
number of questions raised so these are

632  
00:28:01,559 --> 00:28:05,490  
some of the headlines backlist a Big

633  
00:28:03,359 --> 00:28:07,859  
Bang discovery gathers steam no evidence

634  
00:28:05,490 --> 00:28:09,960  
for against gravitational waves they

635  
00:28:07,859 --> 00:28:13,379  
named discovery comes under fire etc etc

636  
00:28:09,960 --> 00:28:15,450  
so as Carl Sagan said extraordinary

637  
00:28:13,380 --> 00:28:18,600  
result results require extraordinary

638  
00:28:15,450 --> 00:28:21,150  
scrutiny and these results if true are

639  
00:28:18,599 --> 00:28:22,949  
as extraordinary as it gets and they

640  
00:28:21,150 --> 00:28:25,320  
therefore require the most extraordinary

641  
00:28:22,950 --> 00:28:27,809  
scrutiny so I'm going to give you an

642  
00:28:25,319 --> 00:28:29,490  
update to try to tell you what is going

643  
00:28:27,809 --> 00:28:31,859  
on and what you might want to look

644  
00:28:29,490 --> 00:28:34,170  
forward for in the future so here's a

645  
00:28:31,859 --> 00:28:36,659  
brief outline so I'm gonna give you some

646  
00:28:34,170 --> 00:28:38,310  
background in Cosmo about cosmology I'm

647  
00:28:36,660 --> 00:28:41,009  
then gonna tell you about an idea that

648  
00:28:38,309 --> 00:28:42,960  
known as inflation it was postulated by

649  
00:28:41,009 --> 00:28:45,359  
a variety of theoretical physicists

650  
00:28:42,960 --> 00:28:48,840  
about 35 years ago and roughly speaking

651  
00:28:45,359 --> 00:28:51,240  
it's an idea for what set the Big Bang

652  
00:28:48,839 --> 00:28:53,129  
in motion I'm thinking I'm going to tell

653  
00:28:51,240 --> 00:28:55,319  
you how it is that we make measurements

654  
00:28:53,130 --> 00:28:57,870  
of the Cosmic Microwave Background and

655  
00:28:55,319 --> 00:28:59,490  
how it is that we infer all this

656

00:28:57,869 --> 00:29:01,619  
information about the early universe

657  
00:28:59,490 --> 00:29:04,049  
from the measurements that we make and

658  
00:29:01,619 --> 00:29:07,819  
then at the end I'll explain what bicep2

659  
00:29:04,049 --> 00:29:07,819  
has seen these gravitational waves

660  
00:29:19,200 --> 00:29:29,740  
okay so I'll explain to you thank you so

661  
00:29:25,960 --> 00:29:31,090  
I'll explain to you what bicep saw why

662  
00:29:29,740 --> 00:29:32,589  
we believe they may be seeing

663  
00:29:31,089 --> 00:29:34,929  
gravitational waves for inflation but

664  
00:29:32,589 --> 00:29:37,269  
also the possibility that they might be

665  
00:29:34,930 --> 00:29:41,230  
seeing nothing more than interstellar

666  
00:29:37,269 --> 00:29:43,240  
dust so there was a NASA satellite that

667  
00:29:41,230 --> 00:29:45,279  
flew in the early 1990s called

668  
00:29:43,240 --> 00:29:49,140  
the cosmic background Explorer which we

669  
00:29:45,279 --> 00:29:51,819  
abbreviate as Kobe and it made a map of

670  
00:29:49,140 --> 00:29:53,590

this Cosmic Microwave Background and

671

00:29:51,819 --> 00:29:55,240

that map looked like this and I'll tell

672

00:29:53,589 --> 00:29:57,308

you in a few more slides more precisely

673

00:29:55,240 --> 00:30:00,670

what it is that we're looking for but

674

00:29:57,308 --> 00:30:02,769

very very literally this picture is

675

00:30:00,670 --> 00:30:06,100

actually a picture of the afterglow of

676

00:30:02,769 --> 00:30:09,970

the Big Bang this was a very exciting

677

00:30:06,099 --> 00:30:11,889

science result the two principal

678

00:30:09,970 --> 00:30:13,630

investigators for the project I'm George

679

00:30:11,890 --> 00:30:15,160

Smoot and John Mather who's down the

680

00:30:13,630 --> 00:30:17,980

road to counter Space Flight Center and

681

00:30:15,160 --> 00:30:20,470

who's now the chief scientist for JWST

682

00:30:17,980 --> 00:30:22,599

is that right chief scientist yeah so

683

00:30:20,470 --> 00:30:25,240

they were awarded the 2006 Nobel Prize

684

00:30:22,599 --> 00:30:31,000

so this was a big deal in the world of



685  
00:30:25,240 --> 00:30:33,250  
cosmology and physics about a decade

686  
00:30:31,000 --> 00:30:34,990  
later there was another satellite

687  
00:30:33,250 --> 00:30:36,910  
mission flown by NASA called the

688  
00:30:34,990 --> 00:30:39,339  
Wilkinson microwave anisotropy probe

689  
00:30:36,910 --> 00:30:41,470  
named after David Wilkinson a physics

690  
00:30:39,339 --> 00:30:43,629  
professor at Princeton University who

691  
00:30:41,470 --> 00:30:45,279  
passed away shortly after the launch who

692  
00:30:43,630 --> 00:30:47,020  
was responsible for doing a lot of the

693  
00:30:45,279 --> 00:30:49,629  
work that late a lot of the groundwork

694  
00:30:47,019 --> 00:30:53,440  
for this measurement so this is the map

695  
00:30:49,630 --> 00:30:55,720  
that the W Maps satellite made about ten

696  
00:30:53,440 --> 00:30:58,330  
years ago and again this has been

697  
00:30:55,720 --> 00:31:01,210  
extraordinarily scientifically fruitful

698  
00:30:58,329 --> 00:31:04,210  
measurement or experiment and I can tell

699  
00:31:01,210 --> 00:31:05,920  
you that the papers that have come out

700  
00:31:04,210 --> 00:31:08,259  
of the W Mapp collaboration have been

701  
00:31:05,920 --> 00:31:10,630  
the most highly cited science paper most

702  
00:31:08,259 --> 00:31:14,009  
highly cited papers in all of science

703  
00:31:10,630 --> 00:31:16,480  
and inside citations are our currency

704  
00:31:14,009 --> 00:31:18,640  
papers they get lots of citations by

705  
00:31:16,480 --> 00:31:20,470  
other scientists are very very valuable

706  
00:31:18,640 --> 00:31:22,450  
and these papers have received more

707  
00:31:20,470 --> 00:31:26,410  
citations than any other science project

708  
00:31:22,450 --> 00:31:29,470  
over the past decade and I should say

709  
00:31:26,410 --> 00:31:30,759  
that the principal investigator of w map

710  
00:31:29,470 --> 00:31:32,289  
is actually Chuck Bennett

711  
00:31:30,759 --> 00:31:34,058  
who's a professor of physics

712  
00:31:32,289 --> 00:31:38,168  
and astronomy right across the street

713

00:31:34,058 --> 00:31:40,629  
here and then more recently launched in

714  
00:31:38,169 --> 00:31:42,640  
2009 and taking data since then the

715  
00:31:40,630 --> 00:31:44,500  
European Space Agency has developed a

716  
00:31:42,640 --> 00:31:47,350  
subsequent generation experiment called

717  
00:31:44,500 --> 00:31:49,869  
the Planck satellite and this is the

718  
00:31:47,349 --> 00:31:52,089  
image that was first provided by the

719  
00:31:49,869 --> 00:31:54,428  
Planck satellite in March of last year

720  
00:31:52,089 --> 00:31:56,949  
and again this was very exciting science

721  
00:31:54,429 --> 00:31:58,480  
very science exciting science result it

722  
00:31:56,950 --> 00:32:00,720  
was announced again on the front page of

723  
00:31:58,480 --> 00:32:03,970  
the New York Times and other news eight

724  
00:32:00,720 --> 00:32:05,350  
news sources throughout the world so

725  
00:32:03,970 --> 00:32:07,808  
this is a picture of the Cosmic

726  
00:32:05,349 --> 00:32:10,959  
Microwave Background as imaged by Kobe

727  
00:32:07,808 --> 00:32:12,399

from the early 1990s this is an image of

728

00:32:10,960 --> 00:32:16,090

the Cosmic Microwave Background is

729

00:32:12,400 --> 00:32:17,679

imaged by W map and this is the image of

730

00:32:16,089 --> 00:32:19,509

the Cosmic Microwave Background provided

731

00:32:17,679 --> 00:32:21,340

by Planck so you see that every 10 years

732

00:32:19,509 --> 00:32:24,400

we've been able to do much better in

733

00:32:21,339 --> 00:32:27,308

terms of angular resolution and angular

734

00:32:24,400 --> 00:32:31,000

resolution is good as you've seen just

735

00:32:27,308 --> 00:32:33,700

with that picture of that's that the

736

00:32:31,000 --> 00:32:38,230

protoplanetary disk it's nice to have

737

00:32:33,700 --> 00:32:46,600

more information so here's a picture

738

00:32:38,230 --> 00:32:48,849

does anybody know what's here close so

739

00:32:46,599 --> 00:32:51,339

actually I gave this talk I think it

740

00:32:48,849 --> 00:32:53,859

might be the projector quality I gave

741

00:32:51,339 --> 00:32:57,279

this talk in Aspen Colorado and

742  
00:32:53,859 --> 00:32:58,629  
everybody saw what it was I've given the

743  
00:32:57,279 --> 00:33:00,160  
talk several other times and people

744  
00:32:58,630 --> 00:33:04,720  
don't know what it is so here's a

745  
00:33:00,160 --> 00:33:06,220  
high-resolution image okay but still

746  
00:33:04,720 --> 00:33:07,630  
that's a pretty blurry image you know

747  
00:33:06,220 --> 00:33:09,700  
what's going on here that's the Mona

748  
00:33:07,630 --> 00:33:13,059  
Lisa and then here's a much more high

749  
00:33:09,700 --> 00:33:15,519  
much higher resolution image and this is

750  
00:33:13,058 --> 00:33:18,460  
a very pretty picture and we can infer a

751  
00:33:15,519 --> 00:33:20,470  
lot about you know about the picture by

752  
00:33:18,460 --> 00:33:21,819  
looking at this blurred image we know

753  
00:33:20,470 --> 00:33:22,990  
that it's the Mona Lisa we know there's

754  
00:33:21,819 --> 00:33:25,329  
a picture of a woman and she's sitting

755  
00:33:22,990 --> 00:33:26,380  
there and these are her two hands but

756  
00:33:25,329 --> 00:33:28,149  
this is a much more high-resolution

757  
00:33:26,380 --> 00:33:30,490  
image and there's a lot more information

758  
00:33:28,150 --> 00:33:32,019  
in here and if you're an art historian

759  
00:33:30,490 --> 00:33:35,740  
you would actually go look at the

760  
00:33:32,019 --> 00:33:37,418  
detailed brushstrokes and infer not only

761  
00:33:35,740 --> 00:33:38,769  
something about the general you know

762  
00:33:37,419 --> 00:33:40,929  
structure of the painting but you would

763  
00:33:38,769 --> 00:33:42,579  
actually learn a lot about how da Vinci

764  
00:33:40,929 --> 00:33:44,500  
actually went about making this painting

765  
00:33:42,579 --> 00:33:45,148  
so the point is that there's a lot more

766  
00:33:44,500 --> 00:33:47,338  
information

767  
00:33:45,148 --> 00:33:49,199  
available when we make high-resolution

768  
00:33:47,338 --> 00:33:51,479  
images and so now that we have this

769  
00:33:49,200 --> 00:33:52,950  
Planck satellite image of the Cosmic

770

00:33:51,479 --> 00:33:57,179  
Microwave Background we have a huge

771  
00:33:52,950 --> 00:33:57,989  
amount more information than we did 20

772  
00:33:57,179 --> 00:34:01,080  
years ago

773  
00:33:57,989 --> 00:34:02,879  
so what exactly are we looking at so now

774  
00:34:01,079 --> 00:34:04,739  
I'm going to attempt to explain to you

775  
00:34:02,878 --> 00:34:07,019  
what it is that this image is showing us

776  
00:34:04,739 --> 00:34:10,230  
so to do that I'm first going to show

777  
00:34:07,019 --> 00:34:13,349  
you a picture of the night sky so this

778  
00:34:10,230 --> 00:34:15,480  
is a picture of the night sky as it

779  
00:34:13,349 --> 00:34:17,669  
appears when you go outside on a clear

780  
00:34:15,480 --> 00:34:19,559  
night and look at it and you see lots of

781  
00:34:17,668 --> 00:34:21,690  
stars and when you look with a very

782  
00:34:19,559 --> 00:34:23,278  
powerful telescope like the the Hubble

783  
00:34:21,690 --> 00:34:24,990  
telescope if you see pictures of the

784  
00:34:23,278 --> 00:34:27,989

Hubble Deep Field you see lots of

785

00:34:24,989 --> 00:34:29,759

galaxies but the most salient feature of

786

00:34:27,989 --> 00:34:31,739

this is not the stars which are these

787

00:34:29,760 --> 00:34:36,210

tiny little dots but it's actually the

788

00:34:31,739 --> 00:34:39,298

black space in between so most of the

789

00:34:36,210 --> 00:34:40,949

sky is dark when you look at it at

790

00:34:39,298 --> 00:34:42,690

optical frequencies which are the

791

00:34:40,949 --> 00:34:47,519

electromagnetic frequencies at which

792

00:34:42,690 --> 00:34:51,510

your eyes operate but optical lights or

793

00:34:47,519 --> 00:34:53,009

visible light is covers only a very very

794

00:34:51,510 --> 00:34:55,500

narrow range of the entire

795

00:34:53,010 --> 00:34:57,869

electromagnetic frequency spectrum so

796

00:34:55,500 --> 00:34:59,940

visible light extends over a very small

797

00:34:57,869 --> 00:35:01,500

range of frequencies or wavelengths and

798

00:34:59,940 --> 00:35:05,220

as we go to the left we're going to



799  
00:35:01,500 --> 00:35:06,960  
longer wavelengths shorter frequencies

800  
00:35:05,219 --> 00:35:09,959  
as we go to the right we run to higher

801  
00:35:06,960 --> 00:35:12,420  
frequencies and shorter wavelengths so

802  
00:35:09,960 --> 00:35:14,099  
to slightly higher frequencies than

803  
00:35:12,420 --> 00:35:16,170  
visible light there's ultraviolet light

804  
00:35:14,099 --> 00:35:17,970  
which you need to worry about when you

805  
00:35:16,170 --> 00:35:21,088  
go outside when you go out in the beach

806  
00:35:17,969 --> 00:35:22,858  
there's infrared light at slightly lower

807  
00:35:21,088 --> 00:35:24,659  
frequencies which is how these are

808  
00:35:22,858 --> 00:35:27,989  
thermometers the two point that your

809  
00:35:24,659 --> 00:35:29,818  
forhead work there are microwave

810  
00:35:27,989 --> 00:35:31,528  
there's microwave radiation and even

811  
00:35:29,818 --> 00:35:34,380  
longer wavelengths this is how you heat

812  
00:35:31,528 --> 00:35:35,730  
up your leftover soup and the radio

813  
00:35:34,380 --> 00:35:38,130  
waves which is how we listen to the

814  
00:35:35,730 --> 00:35:39,778  
radio or watch TV at higher frequencies

815  
00:35:38,130 --> 00:35:40,950  
they're x-rays you know what x-rays are

816  
00:35:39,778 --> 00:35:43,048  
useful for and then even higher

817  
00:35:40,949 --> 00:35:44,219  
frequencies that are gamma rays so

818  
00:35:43,048 --> 00:35:46,079  
there's a broad spectrum of

819  
00:35:44,219 --> 00:35:48,480  
electromagnetic radiation and when we

820  
00:35:46,079 --> 00:35:50,818  
look at the sky with our eyes we're

821  
00:35:48,480 --> 00:35:53,789  
seeing only a tiny fraction of what is

822  
00:35:50,818 --> 00:35:56,429  
actually out there and in particular if

823  
00:35:53,789 --> 00:35:58,830  
you could look at the sky at microwave

824  
00:35:56,429 --> 00:36:00,899  
frequencies rather than visit

825  
00:35:58,829 --> 00:36:04,739  
frequency's the night sky would look

826  
00:36:00,900 --> 00:36:06,809  
like this this is actually a map of the

827

00:36:04,739 --> 00:36:09,329  
sky as it would appear if your eyes are

828  
00:36:06,809 --> 00:36:11,039  
operated at optical free at microwave

829  
00:36:09,329 --> 00:36:14,759  
frequencies and it's actually

830  
00:36:11,039 --> 00:36:17,429  
superimposed on an image of the launch

831  
00:36:14,760 --> 00:36:19,740  
site for a telescope that was flown in

832  
00:36:17,429 --> 00:36:21,690  
the late 1990s called boomerang a

833  
00:36:19,739 --> 00:36:23,699  
balloon borne telescope that flew around

834  
00:36:21,690 --> 00:36:25,019  
Antarctica so this is actually a

835  
00:36:23,699 --> 00:36:26,789  
mountain in the background this is

836  
00:36:25,019 --> 00:36:28,710  
actually a cloud and this is what the

837  
00:36:26,789 --> 00:36:30,779  
night sky would look like if your eyes

838  
00:36:28,710 --> 00:36:33,150  
operate on microwave frequencies so at

839  
00:36:30,780 --> 00:36:37,740  
microwave frequencies the night sky is

840  
00:36:33,150 --> 00:36:40,200  
not dark it blows this was anticipated

841  
00:36:37,739 --> 00:36:47,250

not only by theoretical physicists but

842

00:36:40,199 --> 00:36:50,159

also by hand go and this is a picture of

843

00:36:47,250 --> 00:36:52,230

a small fraction of the sky this is

844

00:36:50,159 --> 00:36:55,379

actually a current state-of-the-art

845

00:36:52,230 --> 00:36:58,920

image of the microwave sky so this is

846

00:36:55,380 --> 00:37:01,590

actually a map of the entire sky in all

847

00:36:58,920 --> 00:37:04,800

directions and it is called a mala wide

848

00:37:01,590 --> 00:37:06,840

or equal area projection so if we took a

849

00:37:04,800 --> 00:37:09,090

map of the earth the earth is has a

850

00:37:06,840 --> 00:37:11,430

spherical surface if we were to sort of

851

00:37:09,090 --> 00:37:12,690

unwrap it and plot it in this way then

852

00:37:11,429 --> 00:37:14,879

you would see North America over here

853

00:37:12,690 --> 00:37:16,650

South America over here Eurasia Africa

854

00:37:14,880 --> 00:37:19,260

Antarctica at the bottom and Australia

855

00:37:16,650 --> 00:37:21,480

over here so what we look at over here

856  
00:37:19,260 --> 00:37:24,870  
is an image actually of the entire

857  
00:37:21,480 --> 00:37:26,909  
surface of the sky unwrapped so that we

858  
00:37:24,869 --> 00:37:30,089  
can plot it on the Sun in this form over

859  
00:37:26,909 --> 00:37:34,409  
here and what you're seeing with these

860  
00:37:30,090 --> 00:37:37,950  
color contrasts what you're seeing with

861  
00:37:34,409 --> 00:37:40,440  
these color contrasts are regions of hot

862  
00:37:37,949 --> 00:37:42,659  
or brighter or fainter regions regions

863  
00:37:40,440 --> 00:37:45,389  
that are brighter or fainter but only by

864  
00:37:42,659 --> 00:37:47,579  
roughly one part in hundred thousand so

865  
00:37:45,389 --> 00:37:50,309  
to a first approximation this glow is

866  
00:37:47,579 --> 00:37:51,840  
very very uniform but if your eyes

867  
00:37:50,309 --> 00:37:54,389  
operated not only at microwave

868  
00:37:51,840 --> 00:37:55,980  
frequencies but could detect brightness

869  
00:37:54,389 --> 00:37:57,629  
fluctuations of one part one hundred

870  
00:37:55,980 --> 00:37:59,519  
thousand you would see that there are

871  
00:37:57,630 --> 00:38:00,900  
some colder regions and some hotter

872  
00:37:59,519 --> 00:38:05,190  
regions that's what these red and blue

873  
00:38:00,900 --> 00:38:07,920  
spots are so let me tell you a little

874  
00:38:05,190 --> 00:38:10,349  
bit about cosmology so cosmology is the

875  
00:38:07,920 --> 00:38:11,680  
study of the origin and evolution of the

876  
00:38:10,349 --> 00:38:13,779  
universe

877  
00:38:11,679 --> 00:38:15,279  
the first step in this direction is to

878  
00:38:13,780 --> 00:38:17,170  
actually understand something that's a

879  
00:38:15,280 --> 00:38:18,880  
bit smaller and closer to home the solar

880  
00:38:17,170 --> 00:38:20,530  
system and so we just heard a bunch of

881  
00:38:18,880 --> 00:38:22,300  
very interesting things that are going

882  
00:38:20,530 --> 00:38:27,430  
on in our exploration of the solar

883  
00:38:22,300 --> 00:38:32,289  
system we are one of eight or nine

884

00:38:27,429 --> 00:38:36,039  
planets I don't know what the number of

885  
00:38:32,289 --> 00:38:39,130  
planets this week is but all of the

886  
00:38:36,039 --> 00:38:40,989  
planets orbit around the Sun and the

887  
00:38:39,130 --> 00:38:42,640  
reason they orbit around the Sun is that

888  
00:38:40,989 --> 00:38:44,079  
the Sun exerts a very strong

889  
00:38:42,639 --> 00:38:46,449  
gravitational has a very strong

890  
00:38:44,079 --> 00:38:50,019  
gravitational field that keeps all these

891  
00:38:46,449 --> 00:38:52,629  
planets in orbit around the Sun it turns

892  
00:38:50,019 --> 00:38:55,360  
out that our Sun is a star that's very

893  
00:38:52,630 --> 00:38:57,130  
special to us because it is our star but

894  
00:38:55,360 --> 00:38:59,559  
in the bigger picture there's nothing

895  
00:38:57,130 --> 00:39:02,800  
special about the Sun it turns out that

896  
00:38:59,559 --> 00:39:05,429  
it is one of roughly 10 billion such

897  
00:39:02,800 --> 00:39:08,080  
stars all of which are gravitationally

898  
00:39:05,429 --> 00:39:10,569

agglomerate it into this huge structure

899

00:39:08,079 --> 00:39:13,509

that we call a galaxy in the name of our

900

00:39:10,570 --> 00:39:16,420

particular galaxy is the Milky Way so

901

00:39:13,510 --> 00:39:18,880

the Milky Way is a very massive object

902

00:39:16,420 --> 00:39:20,740

and it exerts a gravitational field and

903

00:39:18,880 --> 00:39:23,200

that gravitational key field keeps the

904

00:39:20,739 --> 00:39:25,509

orbit of each of these stars in a rough

905

00:39:23,199 --> 00:39:27,669

keeps each of these stars on a roughly

906

00:39:25,510 --> 00:39:30,550

circular orbit around the center of the

907

00:39:27,670 --> 00:39:31,809

galaxy and it takes our Sun about 200

908

00:39:30,550 --> 00:39:36,310

million years to get all the way around

909

00:39:31,809 --> 00:39:39,099

once so it turns out though that this

910

00:39:36,309 --> 00:39:41,650

Milky Way is a very special galaxy to us

911

00:39:39,099 --> 00:39:43,089

because it is our galaxy but again in

912

00:39:41,650 --> 00:39:45,789

the bigger picture there is nothing



913  
00:39:43,090 --> 00:39:48,579  
special about this galaxy it turns out

914  
00:39:45,789 --> 00:39:52,000  
that it is one of several hundred

915  
00:39:48,579 --> 00:39:55,119  
billion galaxies that we can see in our

916  
00:39:52,000 --> 00:39:57,099  
observable universe so this is not a

917  
00:39:55,119 --> 00:40:01,359  
picture of the universe this is actually

918  
00:39:57,099 --> 00:40:05,139  
a simulation a cosmological simulation

919  
00:40:01,360 --> 00:40:08,860  
actually Frank was one of the pioneers

920  
00:40:05,139 --> 00:40:11,739  
of simulations like this so each of

921  
00:40:08,860 --> 00:40:13,960  
these little dots here is a galaxy and

922  
00:40:11,739 --> 00:40:15,279  
this is a picture of a huge volume in

923  
00:40:13,960 --> 00:40:17,949  
the universe that shows how these

924  
00:40:15,280 --> 00:40:18,580  
galaxies are distributed throughout the

925  
00:40:17,949 --> 00:40:21,519  
universe

926  
00:40:18,579 --> 00:40:23,239  
so the earth spins around the Sun the

927  
00:40:21,519 --> 00:40:25,159  
Sun spins around the Milky Way

928  
00:40:23,239 --> 00:40:26,899  
and then you might imagine that all

929  
00:40:25,159 --> 00:40:29,269  
these galaxies wind up spinning around

930  
00:40:26,900 --> 00:40:31,599  
each other it turns out though that at

931  
00:40:29,269 --> 00:40:34,759  
this stage the hierarchy ends as

932  
00:40:31,599 --> 00:40:37,519  
discovered originally by this pipe

933  
00:40:34,760 --> 00:40:40,220  
smoking gentleman by the name of Edwin

934  
00:40:37,519 --> 00:40:43,009  
Hubble so Edwin Hubble was an astronomer

935  
00:40:40,219 --> 00:40:49,088  
at Carnegie observatories in Pasadena

936  
00:40:43,010 --> 00:40:51,200  
and he made a measurement that

937  
00:40:49,088 --> 00:40:56,599  
revolutionized our understanding of the

938  
00:40:51,199 --> 00:40:59,000  
universe so those of you who are fans of

939  
00:40:56,599 --> 00:41:01,220  
Isaac Asimov might be interested to pick

940  
00:40:59,000 --> 00:41:03,440  
up a big fat book he wrote called

941

00:41:01,219 --> 00:41:05,598  
chronology of the history of science and

942  
00:41:03,440 --> 00:41:07,608  
it's a great book and it starts from

943  
00:41:05,599 --> 00:41:10,460  
ancient times and it goes through every

944  
00:41:07,608 --> 00:41:12,889  
year and lists the most exciting science

945  
00:41:10,460 --> 00:41:16,369  
discoveries of that year a collection of

946  
00:41:12,889 --> 00:41:18,710  
years and he has a very broad an

947  
00:41:16,369 --> 00:41:21,920  
interesting and unique perspective on

948  
00:41:18,710 --> 00:41:24,650  
all of science and in that book he calls

949  
00:41:21,920 --> 00:41:27,889  
this discovery along with the discovery

950  
00:41:24,650 --> 00:41:31,099  
of the double helix structure of the DNA

951  
00:41:27,889 --> 00:41:33,049  
molecule as the two most revolutionary

952  
00:41:31,099 --> 00:41:35,900  
and scientific advances of the 20th

953  
00:41:33,050 --> 00:41:39,950  
century so what Hubble did is he looked

954  
00:41:35,900 --> 00:41:41,900  
at a bunch of nearby galaxies and he

955  
00:41:39,949 --> 00:41:44,779

measured or estimated the distance to

956

00:41:41,900 --> 00:41:47,088

each galaxy and then he also measured he

957

00:41:44,780 --> 00:41:49,339

also saw that every galaxy was moving

958

00:41:47,088 --> 00:41:51,769

away from us and he measured the

959

00:41:49,338 --> 00:41:53,750

velocity with which each galaxy was

960

00:41:51,769 --> 00:41:55,849

moving away from us and what he showed

961

00:41:53,750 --> 00:41:57,889

is that there's a correlation more

962

00:41:55,849 --> 00:42:00,230

distant galaxies are moving away from us

963

00:41:57,889 --> 00:42:02,569

at larger speeds than closer galaxies

964

00:42:00,230 --> 00:42:04,670

the galaxies that are fairly nearby are

965

00:42:02,570 --> 00:42:06,588

moving away from us but not so rapidly

966

00:42:04,670 --> 00:42:09,400

the ones that are more that are further

967

00:42:06,588 --> 00:42:12,199

away are moving away much faster and

968

00:42:09,400 --> 00:42:16,940

from this we infer that the universe is

969

00:42:12,199 --> 00:42:18,679

expanding and I made a movie you have to

970  
00:42:16,940 --> 00:42:21,200  
understand I'm a theoretical physicist

971  
00:42:18,679 --> 00:42:23,809  
this is very very high technology for me

972  
00:42:21,199 --> 00:42:26,689  
so I'm gonna show you a movie of an

973  
00:42:23,809 --> 00:42:29,809  
expanding universe so I want you to look

974  
00:42:26,690 --> 00:42:31,849  
at these two this pair of galaxies so

975  
00:42:29,809 --> 00:42:33,858  
there's this of each of these red lines

976  
00:42:31,849 --> 00:42:36,710  
supposed to be a galaxy or point into a

977  
00:42:33,858 --> 00:42:39,348  
galaxy I want you to look at this pair

978  
00:42:36,710 --> 00:42:42,170  
in this pair so the red pair are closer

979  
00:42:39,349 --> 00:42:44,510  
together and the blue pair are further

980  
00:42:42,170 --> 00:42:47,838  
away and now what I'm going to do is

981  
00:42:44,510 --> 00:42:49,640  
blow up the entire grid and as I blow up

982  
00:42:47,838 --> 00:42:51,769  
the entire grid which you're supposed to

983  
00:42:49,639 --> 00:42:54,739  
notice is that the blue points are

984  
00:42:51,769 --> 00:42:56,630  
moving away faster from moving away from

985  
00:42:54,739 --> 00:43:02,868  
each other faster than are the red

986  
00:42:56,630 --> 00:43:10,730  
points so let me play the movie so there

987  
00:43:02,869 --> 00:43:12,200  
it is you don't get that so the red

988  
00:43:10,730 --> 00:43:14,750  
points are moving away from each other

989  
00:43:12,199 --> 00:43:17,769  
whoops slightly larger it's slightly

990  
00:43:14,750 --> 00:43:22,880  
smaller velocities than the blue points

991  
00:43:17,769 --> 00:43:27,108  
so Edwin Hubble's discovery demonstrated

992  
00:43:22,880 --> 00:43:29,240  
that the universe is expanding if the

993  
00:43:27,108 --> 00:43:30,739  
universe is expanding today if all the

994  
00:43:29,239 --> 00:43:33,889  
galaxies are moving away from each other

995  
00:43:30,739 --> 00:43:35,568  
today that means that earlier times if

996  
00:43:33,889 --> 00:43:37,699  
we run this movie backwards at earlier

997  
00:43:35,568 --> 00:43:39,469  
times every galaxy would be closer

998

00:43:37,699 --> 00:43:41,419  
together all of the galaxies would be

999  
00:43:39,469 --> 00:43:44,029  
much closer together the density of

1000  
00:43:41,420 --> 00:43:46,250  
galaxies would be larger so the density

1001  
00:43:44,030 --> 00:43:48,859  
of the universe the number of galaxies

1002  
00:43:46,250 --> 00:43:52,130  
per some unit volume would have been

1003  
00:43:48,858 --> 00:43:54,529  
larger so if this is what the universe

1004  
00:43:52,130 --> 00:43:59,030  
looks like today each of these dots

1005  
00:43:54,530 --> 00:44:00,319  
being a galaxy then at earlier times the

1006  
00:43:59,030 --> 00:44:01,579  
density would have been higher the

1007  
00:44:00,318 --> 00:44:04,159  
galaxies would have been closer together

1008  
00:44:01,579 --> 00:44:05,150  
and at earlier times the galaxies were

1009  
00:44:04,159 --> 00:44:10,068  
even closer together

1010  
00:44:05,150 --> 00:44:12,650  
etc etc etc so one thing that we can do

1011  
00:44:10,068 --> 00:44:16,460  
from Hubble's measurement is extrapolate

1012  
00:44:12,650 --> 00:44:19,010

back in time if we see any two galaxies

1013

00:44:16,460 --> 00:44:21,409

moving away from each other today if we

1014

00:44:19,010 --> 00:44:24,140

run that movie back in time we can

1015

00:44:21,409 --> 00:44:26,000

figure out that at some finite time in

1016

00:44:24,139 --> 00:44:28,969

the past those galaxies must have been

1017

00:44:26,000 --> 00:44:31,579

on top of each other okay if I see a car

1018

00:44:28,969 --> 00:44:33,919

a mile away and I see that it's driving

1019

00:44:31,579 --> 00:44:36,170

away at 60 miles per hour I know that

1020

00:44:33,920 --> 00:44:38,930

one minute ago it was right here

1021

00:44:36,170 --> 00:44:41,000

so we do the same calculation with the

1022

00:44:38,929 --> 00:44:45,078

expansion rate that Hubble measured and

1023

00:44:41,000 --> 00:44:47,440

we infer that 13.8 billion years ago the

1024

00:44:45,079 --> 00:44:50,000

universe must have been in a state of

1025

00:44:47,440 --> 00:44:53,389

infinite density

1026

00:44:50,000 --> 00:44:55,730

and that is what we refer to as the Big



1027  
00:44:53,389 --> 00:45:03,108  
Bang so this is my picture of the

1028  
00:44:55,730 --> 00:45:04,460  
infinite density so I told someone today

1029  
00:45:03,108 --> 00:45:05,809  
I'm giving a public lecture this evening

1030  
00:45:04,460 --> 00:45:09,250  
they said you got to show them nice

1031  
00:45:05,809 --> 00:45:12,710  
pictures they love to see nice pictures

1032  
00:45:09,250 --> 00:45:16,519  
so here's a slightly nicer picture so

1033  
00:45:12,710 --> 00:45:18,289  
this is a picture that illustrates the

1034  
00:45:16,519 --> 00:45:21,349  
evolution of the universe as we

1035  
00:45:18,289 --> 00:45:24,108  
understand it now and it's made by the W

1036  
00:45:21,349 --> 00:45:25,760  
map collaboration so we live in the

1037  
00:45:24,108 --> 00:45:29,598  
universe that's thirteen point seven

1038  
00:45:25,760 --> 00:45:31,340  
seven billion years old and we observe

1039  
00:45:29,599 --> 00:45:33,950  
it with satellites like the W map

1040  
00:45:31,340 --> 00:45:35,840  
satellite and if we look back in time so

1041  
00:45:33,949 --> 00:45:38,598  
as we go from the right to the left

1042  
00:45:35,840 --> 00:45:41,390  
we're looking further further larger and

1043  
00:45:38,599 --> 00:45:44,300  
larger distances since light travels at

1044  
00:45:41,389 --> 00:45:45,679  
a finite speed when we look at larger

1045  
00:45:44,300 --> 00:45:47,930  
and larger distances we are seeing

1046  
00:45:45,679 --> 00:45:50,539  
objects as they were at earlier in

1047  
00:45:47,929 --> 00:45:52,639  
earlier times so when we look at fairly

1048  
00:45:50,539 --> 00:45:54,588  
nearby objects things like galaxies we

1049  
00:45:52,639 --> 00:45:57,289  
are seeing those galaxies as they were

1050  
00:45:54,588 --> 00:45:58,909  
fairly recently as we go to larger

1051  
00:45:57,289 --> 00:46:00,920  
distances for example with the Hubble

1052  
00:45:58,909 --> 00:46:02,598  
Space Telescope we can see galaxies that

1053  
00:46:00,920 --> 00:46:04,909  
are about ten billion years old ten

1054  
00:46:02,599 --> 00:46:08,630  
billion light years away we're seeing

1055

00:46:04,909 --> 00:46:09,829  
things that are 10 billion years away 10

1056  
00:46:08,630 --> 00:46:11,380  
billion light years away we're seeing

1057  
00:46:09,829 --> 00:46:14,838  
them as they were a few billion years

1058  
00:46:11,380 --> 00:46:16,430  
after the Big Bang but even with our

1059  
00:46:14,838 --> 00:46:18,320  
most powerful telescopes there's only a

1060  
00:46:16,429 --> 00:46:20,868  
finite distance out to which we can see

1061  
00:46:18,320 --> 00:46:22,940  
with the James Webb Space Telescope we

1062  
00:46:20,869 --> 00:46:25,010  
actually hope to image directly the

1063  
00:46:22,940 --> 00:46:27,200  
first stars which we have very good

1064  
00:46:25,010 --> 00:46:29,810  
reason to believe were formed about 400

1065  
00:46:27,199 --> 00:46:32,029  
million years after the Big Bang but if

1066  
00:46:29,809 --> 00:46:32,989  
we look even further back which we can

1067  
00:46:32,030 --> 00:46:35,119  
do with these Cosmic Microwave

1068  
00:46:32,989 --> 00:46:36,169  
Background measurements when we make

1069  
00:46:35,119 --> 00:46:38,000

these Cosmic Microwave Background

1070

00:46:36,170 --> 00:46:41,210

measurements were actually looking at

1071

00:46:38,000 --> 00:46:43,010

the universe as it was three hundred and

1072

00:46:41,210 --> 00:46:45,800

seventy five thousand years after the

1073

00:46:43,010 --> 00:46:49,460

Big Bang and we are looking back a

1074

00:46:45,800 --> 00:46:52,310

distance of about 13.8 eight billion

1075

00:46:49,460 --> 00:46:53,599

light-years now the thing that's so

1076

00:46:52,309 --> 00:46:56,449

exciting about these Cosmic Microwave

1077

00:46:53,599 --> 00:46:58,400

Background measurements is not only that

1078

00:46:56,449 --> 00:46:59,929

we're imaging the universe as it was

1079

00:46:58,400 --> 00:47:02,059

three hundred seventy-five thousand

1080

00:46:59,929 --> 00:47:03,619

years after the Big Bang but we have

1081

00:47:02,059 --> 00:47:05,449

very good reason to believe

1082

00:47:03,619 --> 00:47:08,779

as I will try to explain in the next few

1083

00:47:05,449 --> 00:47:11,659

slides that this image that we have

1084  
00:47:08,780 --> 00:47:14,420  
reflects directly what was happening in

1085  
00:47:11,659 --> 00:47:15,859  
the very first trillionth of a

1086  
00:47:14,420 --> 00:47:17,510  
trillionth of a trillionth of a second

1087  
00:47:15,860 --> 00:47:20,599  
after the Big Bang at the time that this

1088  
00:47:17,510 --> 00:47:21,890  
process which we hypothesize this

1089  
00:47:20,599 --> 00:47:25,059  
process called inflation that we

1090  
00:47:21,889 --> 00:47:28,969  
hypothesize should have been occurring

1091  
00:47:25,059 --> 00:47:30,380  
so one way of looking at how remarkable

1092  
00:47:28,969 --> 00:47:32,239  
this is is that when we look at this

1093  
00:47:30,380 --> 00:47:35,210  
Cosmic Microwave Background image of the

1094  
00:47:32,239 --> 00:47:37,909  
Big Bang the universe was 380,000 years

1095  
00:47:35,210 --> 00:47:41,590  
old it's now 13.8 billion years old if

1096  
00:47:37,909 --> 00:47:44,449  
you look at a human who is 50 years old

1097  
00:47:41,590 --> 00:47:47,390  
and you try to figure out what fraction

1098  
00:47:44,449 --> 00:47:50,719  
of the age must have been would they

1099  
00:47:47,389 --> 00:47:53,449  
have been when they were 375 thousand

1100  
00:47:50,719 --> 00:47:57,079  
years divided by 13.8 billion years this

1101  
00:47:53,449 --> 00:47:59,239  
is analogous to taking a picture of a

1102  
00:47:57,079 --> 00:48:03,860  
human being a few seconds after

1103  
00:47:59,239 --> 00:48:05,539  
conception and from this image we can

1104  
00:48:03,860 --> 00:48:08,930  
infer the initial conditions that gave

1105  
00:48:05,539 --> 00:48:10,309  
rise to everything else later on so

1106  
00:48:08,929 --> 00:48:12,739  
here's another picture of what we're

1107  
00:48:10,309 --> 00:48:16,460  
looking at so this is where we live in

1108  
00:48:12,739 --> 00:48:18,799  
the universe the universe is 13.8

1109  
00:48:16,460 --> 00:48:20,720  
billion years old nothing can travel

1110  
00:48:18,800 --> 00:48:22,580  
faster than the speed of light which

1111  
00:48:20,719 --> 00:48:24,949  
means that there is a finite distance

1112

00:48:22,579 --> 00:48:27,559  
out to which we see which we call the

1113  
00:48:24,949 --> 00:48:29,839  
horizon and that distance is 13.8

1114  
00:48:27,559 --> 00:48:32,570  
billion light years and so when we look

1115  
00:48:29,840 --> 00:48:34,880  
at the universe with whatever telescopes

1116  
00:48:32,570 --> 00:48:36,680  
or whatever observations we can make we

1117  
00:48:34,880 --> 00:48:38,450  
can only look out to this finite

1118  
00:48:36,679 --> 00:48:42,139  
distance and the Cosmic Microwave

1119  
00:48:38,449 --> 00:48:44,269  
Background is actually this surface over

1120  
00:48:42,139 --> 00:48:46,069  
here so when we look at the Cosmic

1121  
00:48:44,269 --> 00:48:46,550  
Microwave Background that W map or

1122  
00:48:46,070 --> 00:48:48,920  
Planck

1123  
00:48:46,550 --> 00:48:51,980  
image is actually a picture of the

1124  
00:48:48,920 --> 00:48:55,700  
universe picture of a spherical surface

1125  
00:48:51,980 --> 00:48:57,469  
in the universe of radius 13.8 billion

1126  
00:48:55,699 --> 00:49:00,529

light years and we're seeing it as it

1127

00:48:57,469 --> 00:49:03,559

was 380,000 years after the Big Bang so

1128

00:49:00,530 --> 00:49:05,480

it's actually a remarkable image we're

1129

00:49:03,559 --> 00:49:07,579

actually looking at the edge of the

1130

00:49:05,480 --> 00:49:11,510

observable universe and we are imaging

1131

00:49:07,579 --> 00:49:13,489

it with an amazing precision and

1132

00:49:11,510 --> 00:49:15,410

resolution so that's what we're looking

1133

00:49:13,489 --> 00:49:17,119

at we're looking at the edge of the

1134

00:49:15,409 --> 00:49:19,440

observable universe

1135

00:49:17,119 --> 00:49:22,500

so what I'm going to try to tell you now

1136

00:49:19,440 --> 00:49:24,510

is that this picture is not only you

1137

00:49:22,500 --> 00:49:26,670

know amazing because it's the edge of

1138

00:49:24,510 --> 00:49:28,470

the observable universe but it's amazing

1139

00:49:26,670 --> 00:49:31,680

because it provides a huge amount of

1140

00:49:28,469 --> 00:49:34,019

detailed and precise information about



1141  
00:49:31,679 --> 00:49:38,669  
the origin of the universe its contents

1142  
00:49:34,019 --> 00:49:40,469  
and its evolution so what I'm going to

1143  
00:49:38,670 --> 00:49:43,769  
tell you about in particular is that

1144  
00:49:40,469 --> 00:49:45,629  
this picture gives us very good reason

1145  
00:49:43,769 --> 00:49:48,300  
to believe that this mechanism that we

1146  
00:49:45,630 --> 00:49:50,190  
call inflation actually occurred that it

1147  
00:49:48,300 --> 00:49:53,269  
actually is what set the Big Bang in

1148  
00:49:50,190 --> 00:49:55,679  
motion so as I said inflation is an idea

1149  
00:49:53,269 --> 00:49:58,019  
more or less for what to set the Big

1150  
00:49:55,679 --> 00:49:59,849  
Bang in motion what is it that actually

1151  
00:49:58,019 --> 00:50:01,559  
made the thing bang in the first place

1152  
00:49:59,849 --> 00:50:02,699  
it's something that would have happened

1153  
00:50:01,559 --> 00:50:04,110  
during the first trillionth of a

1154  
00:50:02,699 --> 00:50:06,210  
trillionth of a trillionth of a second

1155  
00:50:04,110 --> 00:50:07,769  
of the universe and one of the things

1156  
00:50:06,210 --> 00:50:09,659  
that's most exciting not only to

1157  
00:50:07,769 --> 00:50:13,619  
cosmologists and astronomers but to

1158  
00:50:09,659 --> 00:50:16,500  
physicists is that the mechanism behind

1159  
00:50:13,619 --> 00:50:18,480  
inflation is actually based on ideas

1160  
00:50:16,500 --> 00:50:21,000  
that come from elementary particle

1161  
00:50:18,480 --> 00:50:23,039  
theory so this is a talk about cosmology

1162  
00:50:21,000 --> 00:50:24,690  
it's at the Space Telescope Science

1163  
00:50:23,039 --> 00:50:26,070  
Institute we're talking about the

1164  
00:50:24,690 --> 00:50:29,490  
biggest things in the universe that we

1165  
00:50:26,070 --> 00:50:31,050  
see very very far away but it turns out

1166  
00:50:29,489 --> 00:50:35,279  
that this is actually also talked about

1167  
00:50:31,050 --> 00:50:39,810  
elementary particle theory so we have a

1168  
00:50:35,280 --> 00:50:42,690  
beautiful theory for the physics of

1169

00:50:39,809 --> 00:50:46,889  
sumit subatomic particles we now know

1170  
00:50:42,690 --> 00:50:48,720  
that atomic nuclei are made out of

1171  
00:50:46,889 --> 00:50:53,639  
protons and neutrons we've known this

1172  
00:50:48,719 --> 00:50:55,529  
for 80-plus years we know more moreover

1173  
00:50:53,639 --> 00:50:57,509  
that those protons neutrons are made out

1174  
00:50:55,530 --> 00:50:59,910  
of smaller particles that we call up and

1175  
00:50:57,510 --> 00:51:01,890  
down quarks we also know that those up

1176  
00:50:59,909 --> 00:51:04,379  
and down quarks are two of the lightest

1177  
00:51:01,889 --> 00:51:07,759  
of six quarks the other four of the

1178  
00:51:04,380 --> 00:51:11,610  
charm strange top and bottom all of the

1179  
00:51:07,760 --> 00:51:14,220  
chemistry that's responsible for just

1180  
00:51:11,610 --> 00:51:16,980  
about everything involved in life and

1181  
00:51:14,219 --> 00:51:18,869  
plan to earth all the chemistry is due

1182  
00:51:16,980 --> 00:51:22,230  
to the behavior of the electrons in

1183  
00:51:18,869 --> 00:51:24,269

atoms that spin around the nuclei it

1184

00:51:22,230 --> 00:51:27,719

turns out that the electron is again

1185

00:51:24,269 --> 00:51:29,400

only one of three similar particles that

1186

00:51:27,719 --> 00:51:30,629

we call leptons it's the lightest and

1187

00:51:29,400 --> 00:51:33,269

there are two other particles

1188

00:51:30,630 --> 00:51:34,739

lepton in the tile left on and then it

1189

00:51:33,268 --> 00:51:37,858

associated with each of these three

1190

00:51:34,739 --> 00:51:39,509

leptons are three very weakly

1191

00:51:37,858 --> 00:51:42,748

interacting and very light particles

1192

00:51:39,509 --> 00:51:44,219

called neutrinos and we have a theory

1193

00:51:42,748 --> 00:51:45,988

that explains how these particles

1194

00:51:44,219 --> 00:51:48,149

interact these particles interact

1195

00:51:45,989 --> 00:51:50,519

through the exchange of photons which is

1196

00:51:48,150 --> 00:51:52,410

light but there are also other particles

1197

00:51:50,518 --> 00:51:55,798

analogous to the photon called gluons

1198  
00:51:52,409 --> 00:51:57,778  
and Z and W bosons that also describe

1199  
00:51:55,798 --> 00:51:59,608  
the behavior of these particles and the

1200  
00:51:57,778 --> 00:52:03,478  
last piece of this puzzle was discovered

1201  
00:51:59,608 --> 00:52:05,728  
just two years ago at the Large Hadron

1202  
00:52:03,478 --> 00:52:08,189  
Collider the Higgs boson and there was a

1203  
00:52:05,728 --> 00:52:09,899  
nobel prize awarded last year to Higgs

1204  
00:52:08,190 --> 00:52:11,579  
and two other gentlemen who first

1205  
00:52:09,900 --> 00:52:18,539  
predicted the existence of this particle

1206  
00:52:11,579 --> 00:52:19,920  
back in the 1960s so I am going to try

1207  
00:52:18,539 --> 00:52:21,329  
to explain to you why it is that we

1208  
00:52:19,920 --> 00:52:24,329  
believe that something like inflation

1209  
00:52:21,329 --> 00:52:26,700  
occurred so why do we believe that

1210  
00:52:24,329 --> 00:52:29,970  
something like inflation occur at the

1211  
00:52:26,699 --> 00:52:35,960  
birth of the universe it's because this

1212  
00:52:29,969 --> 00:52:35,959  
map this map tells us it doesn't say

1213  
00:52:36,048 --> 00:52:43,349  
inflation there's no I there's no end

1214  
00:52:39,690 --> 00:52:45,690  
there's no F no other letters at some

1215  
00:52:43,349 --> 00:52:49,289  
point some people thought they saw an SH

1216  
00:52:45,690 --> 00:52:52,259  
which stands for Stephen Hawking I can't

1217  
00:52:49,289 --> 00:52:55,079  
see it in here right now but that has

1218  
00:52:52,259 --> 00:52:58,079  
been debunked by the W math

1219  
00:52:55,079 --> 00:52:59,880  
collaboration but still what I'm going

1220  
00:52:58,079 --> 00:53:02,039  
to try to explain is that there is a

1221  
00:52:59,880 --> 00:53:06,358  
huge amount of information in this map

1222  
00:53:02,039 --> 00:53:07,739  
and it is does all but say inflation so

1223  
00:53:06,358 --> 00:53:12,509  
to explain how this works

1224  
00:53:07,739 --> 00:53:16,920  
I took a piece of paper and I drew 100

1225  
00:53:12,509 --> 00:53:23,039  
dots on there so there are 150 dots 50

1226

00:53:16,920 --> 00:53:25,229  
dots and I put them at random so you can

1227  
00:53:23,039 --> 00:53:30,180  
look at this and you are not supposed to

1228  
00:53:25,228 --> 00:53:32,788  
see any pattern okay I just 50 dots down

1229  
00:53:30,179 --> 00:53:36,318  
if you see a pattern in there it's

1230  
00:53:32,789 --> 00:53:36,319  
probably just Rorschach

1231  
00:53:39,210 --> 00:53:46,690  
exactly so so fifty dots at random so

1232  
00:53:43,469 --> 00:53:50,199  
here is another picture another piece of

1233  
00:53:46,690 --> 00:53:52,900  
paper I put fifty down for fifty fifty

1234  
00:53:50,199 --> 00:53:56,679  
dots on this piece of paper but there is

1235  
00:53:52,900 --> 00:53:58,690  
some structure and your eye and your

1236  
00:53:56,679 --> 00:54:00,248  
brain your brain can process the image

1237  
00:53:58,690 --> 00:54:03,989  
that your eye makes and you can figure

1238  
00:54:00,248 --> 00:54:07,659  
it out so you all see that there are now

1239  
00:54:03,989 --> 00:54:11,199  
ten I'm sorry five agglomerations each

1240  
00:54:07,659 --> 00:54:12,940

that has ten dots okay so your brain

1241

00:54:11,199 --> 00:54:15,538

does this calculation your brain can

1242

00:54:12,940 --> 00:54:18,940

process this and see structure in there

1243

00:54:15,539 --> 00:54:20,619

here's another picture so now there's an

1244

00:54:18,940 --> 00:54:22,778

additional layer of structure there

1245

00:54:20,619 --> 00:54:26,140

again five agglomerations of ten dots

1246

00:54:22,778 --> 00:54:29,639

but each of these glom racing's is no

1247

00:54:26,139 --> 00:54:33,960

longer just random dots thrown out

1248

00:54:29,639 --> 00:54:37,288

they're actually more or less circles

1249

00:54:33,960 --> 00:54:39,400

here's another layer of structure

1250

00:54:37,289 --> 00:54:43,890

everyone can see what's different

1251

00:54:39,400 --> 00:54:49,180

between these two the other circles

1252

00:54:43,889 --> 00:54:51,818

these are squares so your brain is doing

1253

00:54:49,179 --> 00:54:53,949

an image processing algorithm you don't

1254

00:54:51,818 --> 00:54:57,219

think about it but your brain is an



1255  
00:54:53,949 --> 00:54:59,469  
extremely powerful computer and then

1256  
00:54:57,219 --> 00:55:01,808  
here's another you know image another

1257  
00:54:59,469 --> 00:55:03,098  
another pattern so again this is

1258  
00:55:01,809 --> 00:55:05,499  
different and you can see there are

1259  
00:55:03,099 --> 00:55:07,269  
fifty dots they're not randomly thrown

1260  
00:55:05,498 --> 00:55:12,159  
out on the piece of paper but they're

1261  
00:55:07,268 --> 00:55:17,018  
actually arranged in a lattice so there

1262  
00:55:12,159 --> 00:55:20,498  
is information that can be distinguished

1263  
00:55:17,018 --> 00:55:23,169  
from seemingly random patterns and your

1264  
00:55:20,498 --> 00:55:25,469  
brain knows how to do that not only your

1265  
00:55:23,170 --> 00:55:28,720  
brain knows how to do this but your

1266  
00:55:25,469 --> 00:55:33,909  
computer also knows how to do this so

1267  
00:55:28,719 --> 00:55:36,219  
any of you have an apple and you zom use

1268  
00:55:33,909 --> 00:55:39,298  
a I fo toe there's this new feature that

1269  
00:55:36,219 --> 00:55:41,588  
came out a few years called um faces and

1270  
00:55:39,298 --> 00:55:43,989  
the computer will actually go through

1271  
00:55:41,588 --> 00:55:47,828  
all of your pictures and guess with

1272  
00:55:43,989 --> 00:55:49,139  
pretty good accuracy who the people in

1273  
00:55:47,829 --> 00:55:53,860  
those pictures are

1274  
00:55:49,139 --> 00:55:56,379  
okay so computer scientists have

1275  
00:55:53,860 --> 00:55:58,030  
actually developed in recent years very

1276  
00:55:56,380 --> 00:56:01,140  
powerful algorithms for facial

1277  
00:55:58,030 --> 00:56:04,030  
recognition software fascial recognition

1278  
00:56:01,139 --> 00:56:05,679  
so again the computer can now do

1279  
00:56:04,030 --> 00:56:08,950  
something like what you do you know you

1280  
00:56:05,679 --> 00:56:10,599  
look at two people no two people look

1281  
00:56:08,949 --> 00:56:12,669  
alike you can always tell any two people

1282  
00:56:10,599 --> 00:56:13,989  
apart then the computer we've now been

1283

00:56:12,670 --> 00:56:18,840  
able to train the computer to do the

1284  
00:56:13,989 --> 00:56:23,500  
same thing so this looks like gibberish

1285  
00:56:18,840 --> 00:56:28,960  
if you don't know how to look at it this

1286  
00:56:23,500 --> 00:56:32,079  
is another some more gibberish so can

1287  
00:56:28,960 --> 00:56:38,500  
anybody read this this actually says

1288  
00:56:32,079 --> 00:56:40,779  
something so interestingly enough I gave

1289  
00:56:38,500 --> 00:56:42,550  
a talk to high school physics teachers

1290  
00:56:40,780 --> 00:56:44,980  
from the area over the summer and

1291  
00:56:42,550 --> 00:56:48,460  
several of them actually were able to

1292  
00:56:44,980 --> 00:56:50,829  
read this so this is the simplest

1293  
00:56:48,460 --> 00:56:54,150  
possible code this is I think called the

1294  
00:56:50,829 --> 00:56:57,069  
one letter swap so if I take this

1295  
00:56:54,150 --> 00:56:58,539  
sentence and I replace every letter by

1296  
00:56:57,070 --> 00:57:00,670  
the preceding letter in the alphabet

1297  
00:56:58,539 --> 00:57:05,500

sort of replace every B by an a every C

1298

00:57:00,670 --> 00:57:07,000

by a B every D by a C then this winds up

1299

00:57:05,500 --> 00:57:08,829

saying the true sign of intelligence is

1300

00:57:07,000 --> 00:57:11,619

not knowledge but imagination which is

1301

00:57:08,829 --> 00:57:16,059

something Albert Einstein said so the

1302

00:57:11,619 --> 00:57:18,819

point is that what you see and what

1303

00:57:16,059 --> 00:57:20,349

initially appears as gibberish can

1304

00:57:18,820 --> 00:57:23,620

actually have meaning if you know how to

1305

00:57:20,349 --> 00:57:26,710

crack the code and this is actually what

1306

00:57:23,619 --> 00:57:29,679

we do in science the point of science is

1307

00:57:26,710 --> 00:57:30,490

to find hidden patterns in nature here's

1308

00:57:29,679 --> 00:57:32,500

another example

1309

00:57:30,489 --> 00:57:34,899

not from code breaking but from science

1310

00:57:32,500 --> 00:57:39,699

and paleontology you find a bunch of

1311

00:57:34,900 --> 00:57:41,470

rocks or fossils and then if you know

1312  
00:57:39,699 --> 00:57:43,000  
what you're doing you can assemble them

1313  
00:57:41,469 --> 00:57:45,669  
it's a puzzle you put it together and

1314  
00:57:43,000 --> 00:57:50,590  
this bunch of random rocks actually

1315  
00:57:45,670 --> 00:57:53,079  
turns out to be a dinosaur so this is

1316  
00:57:50,590 --> 00:57:54,760  
not gibberish and the way that we

1317  
00:57:53,079 --> 00:57:59,829  
actually crack the code the way we

1318  
00:57:54,760 --> 00:58:02,080  
actually interpret this image is to

1319  
00:57:59,829 --> 00:58:03,940  
employ mathematical technique

1320  
00:58:02,079 --> 00:58:07,019  
that were developed by joseph fourier in

1321  
00:58:03,940 --> 00:58:10,240  
the early 1800s and what Fourier showed

1322  
00:58:07,019 --> 00:58:13,079  
mathematically is that any pattern can

1323  
00:58:10,239 --> 00:58:15,279  
be represented as a bunch of waves

1324  
00:58:13,079 --> 00:58:17,769  
anything can be represented as a bunch

1325  
00:58:15,280 --> 00:58:20,019  
of waves those of you read about on the

1326  
00:58:17,769 --> 00:58:22,630  
the particle wave duality in quantum

1327  
00:58:20,019 --> 00:58:24,789  
mechanics the particle wave duality is

1328  
00:58:22,630 --> 00:58:27,340  
nothing more than the observation that

1329  
00:58:24,789 --> 00:58:29,349  
Fourier made in the early 1800s that

1330  
00:58:27,340 --> 00:58:32,110  
anything can be represented as a bunch

1331  
00:58:29,349 --> 00:58:34,869  
of waves this laser pointer can be

1332  
00:58:32,110 --> 00:58:37,150  
represented as a bunch of waves and when

1333  
00:58:34,869 --> 00:58:39,730  
you learn about Fourier analysis in

1334  
00:58:37,150 --> 00:58:41,950  
mathematics classes it's very very

1335  
00:58:39,730 --> 00:58:44,380  
straightforward so it turns out that you

1336  
00:58:41,949 --> 00:58:47,109  
can just apply what we call a Fourier

1337  
00:58:44,380 --> 00:58:49,599  
transform or a wave transform to this

1338  
00:58:47,110 --> 00:58:51,579  
map and when you apply a wave transform

1339  
00:58:49,599 --> 00:58:58,239  
to this map it winds up looking like

1340

00:58:51,579 --> 00:59:00,789  
this and this has structure that you can

1341  
00:58:58,239 --> 00:59:02,829  
see and to the trained eye it's not just

1342  
00:59:00,789 --> 00:59:04,119  
structure but it's actually beautiful

1343  
00:59:02,829 --> 00:59:07,960  
and has a huge amount of information

1344  
00:59:04,119 --> 00:59:12,579  
this which is mathematically equivalent

1345  
00:59:07,960 --> 00:59:15,849  
to this this is the fingerprint of

1346  
00:59:12,579 --> 00:59:17,529  
inflation so turns out that what's

1347  
00:59:15,849 --> 00:59:19,179  
particularly interesting is not just

1348  
00:59:17,530 --> 00:59:21,280  
that we can make the image so seeing

1349  
00:59:19,179 --> 00:59:22,599  
this image tells us that something like

1350  
00:59:21,280 --> 00:59:25,210  
inflation must have occurred in the

1351  
00:59:22,599 --> 00:59:28,059  
early universe but moreover there's a

1352  
00:59:25,210 --> 00:59:29,619  
lot of information so there's the radii

1353  
00:59:28,059 --> 00:59:31,150  
of the wings there's the width of the

1354  
00:59:29,619 --> 00:59:33,549

Rings for example that there's the

1355

00:59:31,150 --> 00:59:35,740

brightness of the Rings so this ring

1356

00:59:33,550 --> 00:59:37,180

this dots is a lot brighter than this

1357

00:59:35,739 --> 00:59:38,799

ring here this ring is brighter than

1358

00:59:37,179 --> 00:59:41,500

this one over here there are also these

1359

00:59:38,800 --> 00:59:43,300

troughs they're dark but not necessarily

1360

00:59:41,500 --> 00:59:44,949

completely dark and then there's the

1361

00:59:43,300 --> 00:59:47,560

width of the Rings how wide is this how

1362

00:59:44,949 --> 00:59:49,750

wide is this one etc etc so there's a

1363

00:59:47,559 --> 00:59:51,369

lot of information in here there are a

1364

00:59:49,750 --> 00:59:55,750

lot of numbers that I would need to

1365

00:59:51,369 --> 00:59:58,839

fully describe this pattern and if we

1366

00:59:55,750 --> 01:00:00,849

process this information a bit further

1367

00:59:58,840 --> 01:00:03,670

what we infer from this processing is

1368

01:00:00,849 --> 01:00:05,199

that the atoms of which we are composed



1369  
01:00:03,670 --> 01:00:07,869  
of which everything in the solar system

1370  
01:00:05,199 --> 01:00:11,309  
is composed constitute only 4.6 percent

1371  
01:00:07,869 --> 01:00:13,539  
of the energy density of the universe

1372  
01:00:11,309 --> 01:00:15,369  
there is something called dark matter

1373  
01:00:13,539 --> 01:00:15,849  
which holds galaxies together which

1374  
01:00:15,369 --> 01:00:18,338  
makes up

1375  
01:00:15,849 --> 01:00:20,710  
23% of the universe and then there's

1376  
01:00:18,338 --> 01:00:22,119  
dark energy which makes up the other 72%

1377  
01:00:20,710 --> 01:00:25,449  
of the universe and this was discovered

1378  
01:00:22,119 --> 01:00:27,130  
in 1998 and Nobel Prize was given to

1379  
01:00:25,449 --> 01:00:28,960  
three gentlemen including Adam riess

1380  
01:00:27,130 --> 01:00:33,430  
across the street for this discovery

1381  
01:00:28,960 --> 01:00:36,220  
back in 2011 the other thing that's this

1382  
01:00:33,429 --> 01:00:37,690  
image tells us as I told you is that

1383  
01:00:36,219 --> 01:00:39,879  
something like inflation must have

1384  
01:00:37,690 --> 01:00:42,700  
occurred so we live in you universe

1385  
01:00:39,880 --> 01:00:44,858  
that's 13.8 billion years old the first

1386  
01:00:42,699 --> 01:00:46,659  
stars were formed to 400 million years

1387  
01:00:44,858 --> 01:00:48,130  
after the Big Bang we have this very

1388  
01:00:46,659 --> 01:00:49,568  
nice image of the universe as it was

1389  
01:00:48,130 --> 01:00:50,009  
three hundred thousand years after the

1390  
01:00:49,568 --> 01:00:52,838  
Big Bang

1391  
01:00:50,009 --> 01:00:55,389  
but that processing of that image that

1392  
01:00:52,838 --> 01:00:56,798  
wave transform that fingerprint tells us

1393  
01:00:55,389 --> 01:00:58,900  
that something like inflation occurred

1394  
01:00:56,798 --> 01:01:01,349  
in the first fraction of a fraction of a

1395  
01:00:58,900 --> 01:01:05,910  
fraction of a second after the Big Bang

1396  
01:01:01,349 --> 01:01:08,650  
so we can feel very proud of ourselves

1397

01:01:05,909 --> 01:01:10,328  
because now we have a very elegant model

1398  
01:01:08,650 --> 01:01:14,528  
for what happened what's that the Big

1399  
01:01:10,329 --> 01:01:16,599  
Bang in motion but that's never enough

1400  
01:01:14,528 --> 01:01:19,059  
for scientists and we all want to know

1401  
01:01:16,599 --> 01:01:20,680  
what else can we learn can we

1402  
01:01:19,059 --> 01:01:24,579  
characterize this period of inflation

1403  
01:01:20,679 --> 01:01:26,649  
any better and the answer is yes so it

1404  
01:01:24,579 --> 01:01:28,210  
turns out that inflation makes a number

1405  
01:01:26,650 --> 01:01:29,858  
of predictions some of which were

1406  
01:01:28,210 --> 01:01:31,588  
verified with this fingerprint that we

1407  
01:01:29,858 --> 01:01:34,058  
saw in the Cosmic Microwave Background

1408  
01:01:31,588 --> 01:01:37,150  
but inflation also predicts that the

1409  
01:01:34,059 --> 01:01:41,859  
universe should be filled with a gas of

1410  
01:01:37,150 --> 01:01:44,019  
gravitational waves so electromagnetic

1411  
01:01:41,858 --> 01:01:45,969

waves are light and the way

1412

01:01:44,018 --> 01:01:47,919

electromagnetic waves work is as follows

1413

01:01:45,969 --> 01:01:50,650

so think about a radio transmitter and a

1414

01:01:47,920 --> 01:01:52,180

radio receiver there is an antenna at

1415

01:01:50,650 --> 01:01:54,278

the Trant for the transmitter you can

1416

01:01:52,179 --> 01:01:57,368

see those antenna towers on antenna Hill

1417

01:01:54,278 --> 01:02:01,150

across the highway so those antennas

1418

01:01:57,369 --> 01:02:03,369

have metal and what happens is they set

1419

01:02:01,150 --> 01:02:05,950

up electronics so that the electrons in

1420

01:02:03,369 --> 01:02:08,259

that metal shake up and down those

1421

01:02:05,949 --> 01:02:09,968

electrons have an electric field and

1422

01:02:08,259 --> 01:02:13,028

when those electrons wiggle up and down

1423

01:02:09,969 --> 01:02:14,858

they send out a propagating disturbance

1424

01:02:13,028 --> 01:02:17,559

in the electromagnetic fields and that

1425

01:02:14,858 --> 01:02:19,449

wave travels to the antenna in your car

1426  
01:02:17,559 --> 01:02:21,759  
and the antenna of your car has a bunch

1427  
01:02:19,449 --> 01:02:23,528  
of free electrons and what happens is

1428  
01:02:21,759 --> 01:02:25,599  
this wave comes along it hits these

1429  
01:02:23,528 --> 01:02:27,639  
electrons and it sets those electrons in

1430  
01:02:25,599 --> 01:02:29,200  
motion and then your radio processes

1431  
01:02:27,639 --> 01:02:34,150  
that signal and play

1432  
01:02:29,199 --> 01:02:37,598  
top 40 hits or whatever else so that's

1433  
01:02:34,150 --> 01:02:40,420  
how electromagnetic waves work if I set

1434  
01:02:37,599 --> 01:02:42,519  
electric charges in motion it sends out

1435  
01:02:40,420 --> 01:02:44,260  
waves and then those waves set other

1436  
01:02:42,519 --> 01:02:47,320  
electric charges in motion and that's

1437  
01:02:44,260 --> 01:02:50,920  
how we use these for communication it

1438  
01:02:47,320 --> 01:02:53,410  
turns out that in gravity there is

1439  
01:02:50,920 --> 01:02:55,088  
something similar if I take a massive

1440  
01:02:53,409 --> 01:02:57,039  
object that has a gravitational field

1441  
01:02:55,088 --> 01:03:00,099  
like the Sun has a gravitational field

1442  
01:02:57,039 --> 01:03:01,929  
if I were to say shake the Sun up and

1443  
01:03:00,099 --> 01:03:03,338  
down that would give rise to a

1444  
01:03:01,929 --> 01:03:05,529  
propagating disturbance in the

1445  
01:03:03,338 --> 01:03:07,690  
gravitational field and then if there

1446  
01:03:05,530 --> 01:03:10,210  
was some other test mass like a planet

1447  
01:03:07,690 --> 01:03:14,858  
far away that planet would get set in

1448  
01:03:10,210 --> 01:03:16,980  
motion so this is a picture of what

1449  
01:03:14,858 --> 01:03:20,380  
would happen if a gravitational wave

1450  
01:03:16,980 --> 01:03:22,240  
hits a spherical object what a

1451  
01:03:20,380 --> 01:03:24,760  
gravitational wave actually does is not

1452  
01:03:22,239 --> 01:03:26,439  
shake the object up and down as it does

1453  
01:03:24,760 --> 01:03:29,380  
with an electron but it actually gives

1454

01:03:26,440 --> 01:03:31,869  
rise to distortions in the shape of this

1455  
01:03:29,380 --> 01:03:33,880  
spherical object that elongates it in

1456  
01:03:31,869 --> 01:03:35,230  
this direction and then elongates in

1457  
01:03:33,880 --> 01:03:37,539  
this direction in this direction this

1458  
01:03:35,230 --> 01:03:40,030  
direction etc so it would take an object

1459  
01:03:37,539 --> 01:03:42,849  
and sort of make it wobble around that

1460  
01:03:40,030 --> 01:03:44,200  
shape wobble around so inflation

1461  
01:03:42,849 --> 01:03:45,940  
predicts that the universe would be

1462  
01:03:44,199 --> 01:03:48,189  
filled with these gravitational waves

1463  
01:03:45,940 --> 01:03:53,500  
and in particular those gravitational

1464  
01:03:48,190 --> 01:03:57,429  
waves would hits the Cosmic Microwave

1465  
01:03:53,500 --> 01:03:58,900  
Background surface of last scattering at

1466  
01:03:57,429 --> 01:04:00,549  
the Cosmic Microwave Background we're

1467  
01:03:58,900 --> 01:04:02,170  
looking at a spherical surface at the

1468  
01:04:00,550 --> 01:04:05,440

edge of the universe at the edge of the

1469

01:04:02,170 --> 01:04:06,940

observable universe in the absence of a

1470

01:04:05,440 --> 01:04:08,650

gravitational wave that surface is

1471

01:04:06,940 --> 01:04:10,960

perfectly spherical but if these

1472

01:04:08,650 --> 01:04:13,510

inflationary gravitational waves exist

1473

01:04:10,960 --> 01:04:15,639

they would distort the shape of that

1474

01:04:13,510 --> 01:04:20,230

surface of last scattering some

1475

01:04:15,639 --> 01:04:26,379

particular way so what my colleagues and

1476

01:04:20,230 --> 01:04:29,920

I and another group realized in 1996 is

1477

01:04:26,380 --> 01:04:32,619

that the gravitational waves produced by

1478

01:04:29,920 --> 01:04:34,568

inflation give rise to a signature in

1479

01:04:32,619 --> 01:04:38,170

the polarization of the Cosmic Microwave

1480

01:04:34,568 --> 01:04:40,059

Background so it turns out that light

1481

01:04:38,170 --> 01:04:43,349

has properties that are apparent to all

1482

01:04:40,059 --> 01:04:45,608

of us light can be brighter or faint



1483  
01:04:43,349 --> 01:04:47,650  
some things are very bright and some

1484  
01:04:45,608 --> 01:04:51,880  
things are very faint light also has

1485  
01:04:47,650 --> 01:04:53,440  
color it can be red green blue etc it

1486  
01:04:51,880 --> 01:04:55,269  
turns out that there's another property

1487  
01:04:53,440 --> 01:04:58,510  
the light has that we generally that our

1488  
01:04:55,269 --> 01:05:01,599  
eyes are not really tuned to detect and

1489  
01:04:58,510 --> 01:05:04,150  
that is polarization so remember an

1490  
01:05:01,599 --> 01:05:05,949  
electromagnetic wave is a wave so if I

1491  
01:05:04,150 --> 01:05:07,539  
shake an electron up and down the

1492  
01:05:05,949 --> 01:05:10,269  
electromagnetic wave is gonna go like

1493  
01:05:07,539 --> 01:05:11,469  
this run into you and if you have an

1494  
01:05:10,269 --> 01:05:13,210  
antenna that's pointed in this direction

1495  
01:05:11,469 --> 01:05:15,429  
then the electrons will shake up and

1496  
01:05:13,210 --> 01:05:17,320  
down but if I have an intent of its

1497  
01:05:15,429 --> 01:05:18,759  
point in this direction the electrons

1498  
01:05:17,320 --> 01:05:21,850  
can't shake up and down there's nowhere

1499  
01:05:18,760 --> 01:05:24,130  
for them to go so if I have an antenna

1500  
01:05:21,849 --> 01:05:25,420  
that's oriented this way I can tell

1501  
01:05:24,130 --> 01:05:27,550  
whether the doctor magnetic wave is

1502  
01:05:25,420 --> 01:05:29,230  
coming this way and if I have an antenna

1503  
01:05:27,550 --> 01:05:30,700  
oriented this way I can detect

1504  
01:05:29,230 --> 01:05:33,010  
electromagnetic waves where they are

1505  
01:05:30,699 --> 01:05:35,858  
shaking is in the horizontal direction

1506  
01:05:33,010 --> 01:05:38,020  
and you can actually detect this if you

1507  
01:05:35,858 --> 01:05:40,719  
have polarized sunglasses next time you

1508  
01:05:38,019 --> 01:05:43,358  
go to the ATM machine most ATM machines

1509  
01:05:40,719 --> 01:05:45,309  
are LCD screens most out most LCD

1510  
01:05:43,358 --> 01:05:47,500  
screens are polarized if you take your

1511

01:05:45,309 --> 01:05:51,099  
polarized sunglasses and rotate them by

1512  
01:05:47,500 --> 01:05:53,440  
45 degrees the screen will disappear so

1513  
01:05:51,099 --> 01:05:56,319  
light is polarized and you can measure

1514  
01:05:53,440 --> 01:05:57,519  
it it's easy to detect polarization so

1515  
01:05:56,320 --> 01:06:00,630  
here's actually a picture of what I told

1516  
01:05:57,519 --> 01:06:05,230  
you before electromagnetic waves are

1517  
01:06:00,630 --> 01:06:07,390  
oops electromagnetic waves are what we

1518  
01:06:05,230 --> 01:06:10,329  
call transverse waves they shake up and

1519  
01:06:07,389 --> 01:06:12,759  
down or side to side and this isn't

1520  
01:06:10,329 --> 01:06:15,730  
distinction two longitudinal waves like

1521  
01:06:12,760 --> 01:06:17,800  
sound waves so when I talk there's a

1522  
01:06:15,730 --> 01:06:21,000  
sound wave that propagates it actually

1523  
01:06:17,800 --> 01:06:22,990  
has a wave that profited compresses

1524  
01:06:21,000 --> 01:06:26,440  
along the direction of which it's

1525  
01:06:22,989 --> 01:06:28,149

propagating anyway electromagnetic waves

1526

01:06:26,440 --> 01:06:30,039

are transverse waves and so they can

1527

01:06:28,150 --> 01:06:33,970

have this linear polarization that's

1528

01:06:30,039 --> 01:06:35,800

either up and down or side to side so

1529

01:06:33,969 --> 01:06:37,299

now suppose I look at an image there's a

1530

01:06:35,800 --> 01:06:39,130

polarization over here there's a

1531

01:06:37,300 --> 01:06:40,510

polarization over here polarization over

1532

01:06:39,130 --> 01:06:45,180

here there could be a polarization and

1533

01:06:40,510 --> 01:06:48,100

every point so here is an image a

1534

01:06:45,179 --> 01:06:50,169

polarized pattern that I can draw on the

1535

01:06:48,099 --> 01:06:51,849

surface of the board and here's another

1536

01:06:50,170 --> 01:06:53,950

polarization pattern in the neck and

1537

01:06:51,849 --> 01:06:55,449

draw and here's another polarization

1538

01:06:53,949 --> 01:06:56,078

pattern here's another polarization

1539

01:06:55,449 --> 01:06:58,178

pattern

1540  
01:06:56,079 --> 01:06:59,829  
the difference between the ones on the

1541  
01:06:58,179 --> 01:07:01,869  
left and the ones on the right is that

1542  
01:06:59,829 --> 01:07:04,179  
the ones on the right have a handedness

1543  
01:07:01,869 --> 01:07:06,278  
this one swirls around in a

1544  
01:07:04,179 --> 01:07:08,439  
counterclockwise direction and this

1545  
01:07:06,278 --> 01:07:10,150  
rolls around in a clockwise direction if

1546  
01:07:08,438 --> 01:07:12,938  
I look at this in a mirror it would look

1547  
01:07:10,150 --> 01:07:15,130  
like this and vice versa if I were to

1548  
01:07:12,938 --> 01:07:16,719  
look at this in a mirror would look the

1549  
01:07:15,130 --> 01:07:19,239  
same if I look at this in the mirror it

1550  
01:07:16,719 --> 01:07:22,088  
would look the same so these we call in

1551  
01:07:19,239 --> 01:07:24,670  
technical jargon emotes in these we call

1552  
01:07:22,088 --> 01:07:27,159  
in technical jargon be modes so the B

1553  
01:07:24,670 --> 01:07:29,979  
modes have the swirling pattern and what

1554  
01:07:27,159 --> 01:07:32,618  
we realized back in 1996 is that

1555  
01:07:29,978 --> 01:07:35,068  
gravitational waves give rise to the

1556  
01:07:32,619 --> 01:07:38,249  
swirling pattern in the CMB polarization

1557  
01:07:35,068 --> 01:07:42,969  
so this is something that we pointed out

1558  
01:07:38,248 --> 01:07:44,768  
in 1996 and various other theoretical

1559  
01:07:42,969 --> 01:07:47,739  
physicists studied it and found it

1560  
01:07:44,768 --> 01:07:48,818  
interesting and experimental physicists

1561  
01:07:47,739 --> 01:07:50,978  
also thought that it might be

1562  
01:07:48,818 --> 01:07:53,349  
interesting to try to measure look for a

1563  
01:07:50,978 --> 01:07:55,989  
swirling pattern in the polarization of

1564  
01:07:53,349 --> 01:07:58,170  
the Cosmic Microwave Background so since

1565  
01:07:55,989 --> 01:08:00,309  
then there have been a huge number of

1566  
01:07:58,170 --> 01:08:03,459  
independent experimental groups that

1567  
01:08:00,309 --> 01:08:05,229  
have been looking for this so this ABS

1568

01:08:03,458 --> 01:08:07,058  
stands for a B mode search this is a

1569  
01:08:05,228 --> 01:08:08,858  
Princeton led collaboration light bird

1570  
01:08:07,059 --> 01:08:09,699  
is a Japanese project that's on the

1571  
01:08:08,858 --> 01:08:11,889  
drawing board

1572  
01:08:09,699 --> 01:08:13,809  
he Beck's was a University of Minnesota

1573  
01:08:11,889 --> 01:08:17,198  
LEDs balloon experiment that flew

1574  
01:08:13,809 --> 01:08:21,039  
recently the atacama cosmology telescope

1575  
01:08:17,198 --> 01:08:24,278  
is a Princeton led collaboration at in

1576  
01:08:21,039 --> 01:08:26,559  
Chile the Polar Bear Simon's array is I

1577  
01:08:24,279 --> 01:08:27,849  
believe also in actually I don't know

1578  
01:08:26,559 --> 01:08:33,579  
where it is I forget I think it's also

1579  
01:08:27,849 --> 01:08:36,099  
in Chile this is a UCSD UC Berkeley LED

1580  
01:08:33,578 --> 01:08:37,328  
collaboration the Planck satellite was

1581  
01:08:36,099 --> 01:08:40,389  
not designed to make these measurements

1582  
01:08:37,328 --> 01:08:43,149

but they did a last-minute change to the

1583

01:08:40,389 --> 01:08:45,298

design to measure polarization Pipers in

1584

01:08:43,149 --> 01:08:48,608

NASA Goddard Space Flight Center effort

1585

01:08:45,298 --> 01:08:51,269

LSP is a Rome a project of an Italian

1586

01:08:48,609 --> 01:08:53,949

project spider is a project led by

1587

01:08:51,270 --> 01:08:56,469

Princeton University SP T poses huge

1588

01:08:53,948 --> 01:08:58,238

collaboration led by University of

1589

01:08:56,469 --> 01:08:59,859

Chicago and then there's also a project

1590

01:08:58,238 --> 01:09:01,658

right across the street called the class

1591

01:08:59,859 --> 01:09:02,230

telescope led by Chuck Bennett so V

1592

01:09:01,658 --> 01:09:05,198

marriage

1593

01:09:02,229 --> 01:09:07,328

um that's also looking for the signal so

1594

01:09:05,198 --> 01:09:09,338

this is a big deal and a lot of

1595

01:09:07,328 --> 01:09:09,880

experimental groups have been racing to

1596

01:09:09,338 --> 01:09:11,619

detect



1597  
01:09:09,880 --> 01:09:14,800  
the swirling pattern and the CMB

1598  
01:09:11,619 --> 01:09:17,170  
polarization so that's why there was a

1599  
01:09:14,800 --> 01:09:19,890  
lot of attention given to this

1600  
01:09:17,170 --> 01:09:24,340  
announcement on the 17th of March 2014

1601  
01:09:19,890 --> 01:09:26,170  
of detection of the swirling pattern so

1602  
01:09:24,340 --> 01:09:27,699  
this is actually the map of the Cosmic

1603  
01:09:26,170 --> 01:09:29,350  
Microwave Background polarization that

1604  
01:09:27,699 --> 01:09:31,569  
this collaboration made that the sky

1605  
01:09:29,350 --> 01:09:33,370  
telescope made and you can see the

1606  
01:09:31,569 --> 01:09:35,559  
swirling pattern so around this red spot

1607  
01:09:33,369 --> 01:09:38,140  
the polarization swirling in this

1608  
01:09:35,560 --> 01:09:40,180  
direction and around this blue spot over

1609  
01:09:38,140 --> 01:09:44,980  
here it's sort of swirling in the other

1610  
01:09:40,180 --> 01:09:47,079  
direction so this if it is what they

1611  
01:09:44,979 --> 01:09:50,549  
believe it they if it's what they claim

1612  
01:09:47,079 --> 01:09:54,670  
it is what they think it is is amazing

1613  
01:09:50,550 --> 01:09:57,940  
so the question now is whether they are

1614  
01:09:54,670 --> 01:10:00,430  
really seeing a V mode signal from

1615  
01:09:57,939 --> 01:10:02,979  
gravitational waves from inflation or

1616  
01:10:00,430 --> 01:10:06,250  
possibly just some contamination from

1617  
01:10:02,979 --> 01:10:07,989  
dust in the Milky Way so when we look at

1618  
01:10:06,250 --> 01:10:10,720  
this Cosmic Microwave Background we have

1619  
01:10:07,989 --> 01:10:13,059  
to look through our own galaxy and it

1620  
01:10:10,720 --> 01:10:15,520  
turns out that our own galaxy has a lot

1621  
01:10:13,060 --> 01:10:18,610  
of interstellar dust and this

1622  
01:10:15,520 --> 01:10:21,640  
interstellar dust can emit light that

1623  
01:10:18,609 --> 01:10:24,339  
can be polarized and so we're not really

1624  
01:10:21,640 --> 01:10:27,280  
sure whether what they're seeing is

1625

01:10:24,340 --> 01:10:29,829  
gravitational waves or dust so back in

1626  
01:10:27,279 --> 01:10:32,619  
march bicep2 actually provided several

1627  
01:10:29,829 --> 01:10:34,119  
fairly persuasive arguments that their

1628  
01:10:32,619 --> 01:10:37,479  
data does not look like what we would

1629  
01:10:34,119 --> 01:10:38,979  
expect dust to look like but other

1630  
01:10:37,479 --> 01:10:40,329  
people since then have said well we

1631  
01:10:38,979 --> 01:10:41,979  
don't really know what the slips like

1632  
01:10:40,329 --> 01:10:43,920  
interstellar dust is very complicated

1633  
01:10:41,979 --> 01:10:46,839  
anybody's trying to sweep up a floor

1634  
01:10:43,920 --> 01:10:50,890  
knows that dust can be very very

1635  
01:10:46,840 --> 01:10:52,930  
complicated and more recently back in

1636  
01:10:50,890 --> 01:10:57,850  
September the Planck satellite released

1637  
01:10:52,930 --> 01:10:59,860  
new data on dust that actually seems to

1638  
01:10:57,850 --> 01:11:02,020  
indicate the dust does not look like

1639  
01:10:59,859 --> 01:11:05,649

what bicep2 thought it should look like

1640

01:11:02,020 --> 01:11:08,410

back in March so we don't really know

1641

01:11:05,649 --> 01:11:09,789

now whether that signal that b-mode

1642

01:11:08,409 --> 01:11:12,819

signals that they detected is

1643

01:11:09,789 --> 01:11:14,829

gravitational waves or dust so what

1644

01:11:12,819 --> 01:11:16,420

we're trying to do now is figure it out

1645

01:11:14,829 --> 01:11:18,039

and one way that we're hoping to figure

1646

01:11:16,420 --> 01:11:21,220

it out is through this frequency

1647

01:11:18,039 --> 01:11:23,050

dependence so I told you that light has

1648

01:11:21,220 --> 01:11:23,640

a electromagnetic frequency less

1649

01:11:23,050 --> 01:11:25,800

terminated

1650

01:11:23,640 --> 01:11:28,770

sequence II and there are broad range of

1651

01:11:25,800 --> 01:11:30,690

electromagnetic frequencies it turns out

1652

01:11:28,770 --> 01:11:33,480

that the B mode signal that they are

1653

01:11:30,689 --> 01:11:36,539

looking for would be very large at

1654  
01:11:33,479 --> 01:11:38,099  
roughly 150 gigahertz the

1655  
01:11:36,539 --> 01:11:40,289  
electromagnetic frequency at which the

1656  
01:11:38,100 --> 01:11:41,970  
bicep2 measurements are made but smaller

1657  
01:11:40,289 --> 01:11:44,939  
at higher frequencies and smaller at

1658  
01:11:41,970 --> 01:11:47,909  
lower frequencies dust on the other hand

1659  
01:11:44,939 --> 01:11:50,879  
would be much larger at higher

1660  
01:11:47,909 --> 01:11:53,519  
frequencies than at lower frequencies so

1661  
01:11:50,880 --> 01:11:55,319  
what bicep did in order to try to

1662  
01:11:53,520 --> 01:11:57,750  
distinguish whether they were looking at

1663  
01:11:55,319 --> 01:12:00,899  
the Cosmic Microwave Background or dust

1664  
01:11:57,750 --> 01:12:03,810  
was used data from 150 gigahertz and

1665  
01:12:00,899 --> 01:12:07,250  
weaker data less lower signal-to-noise

1666  
01:12:03,810 --> 01:12:10,530  
data from 100 gigahertz complemented by

1667  
01:12:07,250 --> 01:12:12,390  
not very precise information from W map

1668  
01:12:10,529 --> 01:12:14,219  
at low frequencies and not very precise

1669  
01:12:12,390 --> 01:12:20,190  
information from Planck at higher

1670  
01:12:14,220 --> 01:12:21,930  
frequencies so the idea that they the

1671  
01:12:20,189 --> 01:12:24,149  
algorithms they used were good

1672  
01:12:21,930 --> 01:12:28,230  
algorithms but the data available were

1673  
01:12:24,149 --> 01:12:29,909  
not very very good so what my colleagues

1674  
01:12:28,229 --> 01:12:31,439  
across the street Chuck Bennett and Toby

1675  
01:12:29,909 --> 01:12:33,809  
marrieds are trying to do with this some

1676  
01:12:31,439 --> 01:12:36,329  
class telescope cosmology large angular

1677  
01:12:33,810 --> 01:12:37,890  
scale surveyor is to try to do this

1678  
01:12:36,329 --> 01:12:40,380  
multi frequency measurement more

1679  
01:12:37,890 --> 01:12:43,110  
precisely so here's another picture of

1680  
01:12:40,380 --> 01:12:45,840  
this that I along lines I showed you so

1681  
01:12:43,109 --> 01:12:47,939  
the signal strength for the for a

1682

01:12:45,840 --> 01:12:49,440  
gravitational waves from the Cosman the

1683  
01:12:47,939 --> 01:12:51,960  
Cosmic Microwave Background looks like

1684  
01:12:49,439 --> 01:12:55,349  
this whereas the signal from the galaxy

1685  
01:12:51,960 --> 01:12:58,140  
goes down and then back up and they

1686  
01:12:55,350 --> 01:13:00,960  
actually have hope to image the sky in

1687  
01:12:58,140 --> 01:13:02,910  
four frequencies 40 90 150 and 200 20

1688  
01:13:00,960 --> 01:13:05,340  
gigahertz and if they can measure the

1689  
01:13:02,909 --> 01:13:07,260  
relative strength of the signals in

1690  
01:13:05,340 --> 01:13:09,060  
these four different frequencies they

1691  
01:13:07,260 --> 01:13:11,369  
can distinguish the contribution from

1692  
01:13:09,060 --> 01:13:13,950  
the Milky Way from the cosmic signal

1693  
01:13:11,369 --> 01:13:16,739  
that we're really interested in the

1694  
01:13:13,949 --> 01:13:20,159  
other thing that we hope to do is try to

1695  
01:13:16,739 --> 01:13:21,739  
use a spatial the spatial dependence of

1696  
01:13:20,159 --> 01:13:25,409

the signal roughly a cross correlation

1697

01:13:21,739 --> 01:13:28,109

so Planck provides a map of the dust it

1698

01:13:25,409 --> 01:13:29,849

tells us where the dust is and then we

1699

01:13:28,109 --> 01:13:31,349

can look at the bicep2 signal and see

1700

01:13:29,850 --> 01:13:31,740

whether there be mode amplitude is

1701

01:13:31,350 --> 01:13:34,590

bigger

1702

01:13:31,739 --> 01:13:36,578

we're playing causes of dust is and it

1703

01:13:34,590 --> 01:13:39,489

is very very literally like trying to

1704

01:13:36,578 --> 01:13:42,549

fingerprints so we have a fingerprint of

1705

01:13:39,488 --> 01:13:44,049

dust from Planck and this is what bicep2

1706

01:13:42,550 --> 01:13:45,969

might look like and they want to know

1707

01:13:44,050 --> 01:13:49,929

whether this fingerprint looks the same

1708

01:13:45,969 --> 01:13:52,779

as this fingerprint so the question is

1709

01:13:49,929 --> 01:13:54,219

when we actually image the dust map

1710

01:13:52,779 --> 01:13:58,269

which is being provided by the Planck



1711  
01:13:54,219 --> 01:14:01,960  
satellite will it look more like this or

1712  
01:13:58,270 --> 01:14:04,389  
like this and the answer is we don't

1713  
01:14:01,960 --> 01:14:07,599  
know the measurements have not been made

1714  
01:14:04,389 --> 01:14:09,730  
yet with a sufficient precision but we

1715  
01:14:07,599 --> 01:14:12,760  
hope that they will in the next few

1716  
01:14:09,729 --> 01:14:14,649  
years so the next steps are to overlay

1717  
01:14:12,760 --> 01:14:16,480  
the Planck and the bicep2 maps to see

1718  
01:14:14,649 --> 01:14:17,948  
whether they look the same or not if

1719  
01:14:16,479 --> 01:14:19,750  
they look completely different that

1720  
01:14:17,948 --> 01:14:22,359  
provides some reasonable evidence that

1721  
01:14:19,750 --> 01:14:23,920  
bicep2 is seen gravitational waves if

1722  
01:14:22,359 --> 01:14:27,609  
they look the same then Planck the

1723  
01:14:23,920 --> 01:14:29,469  
bicep2 is probably just seeing dust in

1724  
01:14:27,609 --> 01:14:31,630  
science things are not true because

1725  
01:14:29,469 --> 01:14:33,250  
somebody or some collaboration says

1726  
01:14:31,630 --> 01:14:35,699  
they're true they're true because many

1727  
01:14:33,250 --> 01:14:37,809  
different scientists make independent

1728  
01:14:35,698 --> 01:14:39,638  
observations and come to the same

1729  
01:14:37,809 --> 01:14:43,090  
conclusions and so there are all these

1730  
01:14:39,639 --> 01:14:45,219  
other competing telescopes which are you

1731  
01:14:43,090 --> 01:14:47,289  
know catching up to bicep2 in terms of

1732  
01:14:45,219 --> 01:14:48,880  
sensitivity and if bicep2 is seen

1733  
01:14:47,289 --> 01:14:50,679  
gravitational waves these other guys

1734  
01:14:48,880 --> 01:14:52,239  
should be seeing them too there's the

1735  
01:14:50,679 --> 01:14:54,670  
frequency dependence that I talked

1736  
01:14:52,238 --> 01:14:56,738  
talked about and then if there is a

1737  
01:14:54,670 --> 01:14:58,270  
gravitational wave signal it should be

1738  
01:14:56,738 --> 01:15:00,368  
the same all over the sky

1739

01:14:58,270 --> 01:15:02,349  
whereas the dust signal is brighter in

1740  
01:15:00,368 --> 01:15:05,529  
certain region of the sky than in other

1741  
01:15:02,349 --> 01:15:07,869  
regions of the sky so I am a theoretical

1742  
01:15:05,529 --> 01:15:10,439  
physicist my job is to make predictions

1743  
01:15:07,868 --> 01:15:14,170  
and so I am going to make a prediction

1744  
01:15:10,439 --> 01:15:16,259  
my prediction is that we will figure it

1745  
01:15:14,170 --> 01:15:16,260  
out

1746  
01:15:18,889 --> 01:15:24,690  
but this is a very exciting so you know

1747  
01:15:21,960 --> 01:15:26,039  
back in early summer when I agreed to

1748  
01:15:24,689 --> 01:15:27,899  
give this talk I thought you know this

1749  
01:15:26,039 --> 01:15:29,600  
is gonna be the victory tour talk you

1750  
01:15:27,899 --> 01:15:31,920  
know we discover gravitational waves

1751  
01:15:29,600 --> 01:15:32,699  
someone's gonna get a Nobel Prize and

1752  
01:15:31,920 --> 01:15:34,380  
this is great

1753  
01:15:32,698 --> 01:15:37,379

and we've you know talking about this

1754

01:15:34,380 --> 01:15:39,359

decades from now but I don't know so I

1755

01:15:37,380 --> 01:15:41,279

have to say that the arguments the

1756

01:15:39,359 --> 01:15:43,529

bicep2 gave that it's not dust we're

1757

01:15:41,279 --> 01:15:45,658

very very convincing at the time and

1758

01:15:43,529 --> 01:15:47,519

there's still many intriguing things

1759

01:15:45,658 --> 01:15:50,698

about the data that suggests that it's

1760

01:15:47,520 --> 01:15:53,280

not obviously dust but it is true that

1761

01:15:50,698 --> 01:15:54,928

since then we've realized that dust is

1762

01:15:53,279 --> 01:15:57,899

more complicated than we thought back in

1763

01:15:54,929 --> 01:15:59,789

March so we really don't know I do think

1764

01:15:57,899 --> 01:16:02,429

there's some good reason to believe that

1765

01:15:59,789 --> 01:16:04,649

we may at the end of the day be seeing

1766

01:16:02,429 --> 01:16:06,960

gravitational waves but I don't know yet

1767

01:16:04,649 --> 01:16:08,609

if these are indeed gravitational waves

1768  
01:16:06,960 --> 01:16:11,489  
it's as exciting as it gets

1769  
01:16:08,609 --> 01:16:13,289  
we're seeing some possible consequences

1770  
01:16:11,488 --> 01:16:15,899  
of the unification of the fundamental

1771  
01:16:13,289 --> 01:16:17,670  
forces at energy scales much greater

1772  
01:16:15,899 --> 01:16:19,920  
than those accessible with laboratory

1773  
01:16:17,670 --> 01:16:22,050  
experiments this would constitute the

1774  
01:16:19,920 --> 01:16:23,969  
first detection of gravitational waves I

1775  
01:16:22,050 --> 01:16:25,770  
did not mention this but these

1776  
01:16:23,969 --> 01:16:28,889  
gravitational waves are produced by a

1777  
01:16:25,770 --> 01:16:30,360  
Hawking like process in the early

1778  
01:16:28,889 --> 01:16:34,949  
universe so it would actually be

1779  
01:16:30,359 --> 01:16:37,289  
discovery of Hawking radiation the

1780  
01:16:34,948 --> 01:16:39,839  
physics that produces this in some sense

1781  
01:16:37,289 --> 01:16:41,429  
merges gravity and quantum mechanics or

1782  
01:16:39,840 --> 01:16:43,050  
at least scratches the surface of a

1783  
01:16:41,429 --> 01:16:45,090  
merger of gravity and quantum mechanics

1784  
01:16:43,050 --> 01:16:46,619  
and the biggest thing that theoretical

1785  
01:16:45,090 --> 01:16:49,199  
physicists have been trying to do in

1786  
01:16:46,619 --> 01:16:51,269  
20th century in 21st century science is

1787  
01:16:49,198 --> 01:16:53,219  
merged general relativity Einstein's

1788  
01:16:51,270 --> 01:16:56,159  
general relativity with the laws of

1789  
01:16:53,219 --> 01:16:58,679  
quantum mechanics and if this is what we

1790  
01:16:56,158 --> 01:17:01,019  
think it is this is actually scratching

1791  
01:16:58,679 --> 01:17:02,520  
the surface of what may ultimately prove

1792  
01:17:01,020 --> 01:17:04,440  
to be a merger between gravity and

1793  
01:17:02,520 --> 01:17:06,150  
quantum mechanics and perhaps most

1794  
01:17:04,439 --> 01:17:07,888  
exciting is that if this is what we

1795  
01:17:06,149 --> 01:17:10,229  
think it is if it turns out to really be

1796

01:17:07,889 --> 01:17:12,449  
inflationary gravitational waves and we

1797  
01:17:10,229 --> 01:17:14,158  
are actually seeing a brand-new signal

1798  
01:17:12,448 --> 01:17:15,329  
from a trillionth of a trillionth of a

1799  
01:17:14,158 --> 01:17:18,149  
trillionth of a second after the Big

1800  
01:17:15,329 --> 01:17:20,609  
Bang and if they've detected are these B

1801  
01:17:18,149 --> 01:17:22,500  
modes from inflate from inflation then

1802  
01:17:20,609 --> 01:17:24,988  
what we've only discovered so far is a

1803  
01:17:22,500 --> 01:17:26,550  
Rosetta stone and you know it took many

1804  
01:17:24,988 --> 01:17:28,869  
years after the discovery of the Rosetta

1805  
01:17:26,550 --> 01:17:31,360  
Stone to actually craft the code

1806  
01:17:28,869 --> 01:17:33,250  
figure out what's written there and over

1807  
01:17:31,359 --> 01:17:35,139  
the next few decades if these measures

1808  
01:17:33,250 --> 01:17:36,850  
if this is these are be modes we can

1809  
01:17:35,140 --> 01:17:39,130  
measure these be modes more precisely

1810  
01:17:36,850 --> 01:17:40,000

through the same types of analyses that

1811

01:17:39,130 --> 01:17:42,400

we've done in the Cosmic Microwave

1812

01:17:40,000 --> 01:17:44,289

Background maps we have so far and we

1813

01:17:42,399 --> 01:17:47,649

have an entirely new avenue to study

1814

01:17:44,289 --> 01:17:51,010

what happened very first microsecond

1815

01:17:47,649 --> 01:17:53,909

after the Big Bang so I will close by

1816

01:17:51,010 --> 01:17:53,909

saying stay tuned

1817

01:18:05,470 --> 01:18:14,810

okay so y'all get all that complex feel

1818

01:18:12,260 --> 01:18:28,670

lots of cool things I'm sure there are a

1819

01:18:14,810 --> 01:18:30,410

few questions how about you should you

1820

01:18:28,670 --> 01:18:33,529

repeat the question for the webcasting

1821

01:18:30,409 --> 01:18:35,599

audience so the question is whether the

1822

01:18:33,529 --> 01:18:36,949

Cosmic Microwave Background is affected

1823

01:18:35,600 --> 01:18:38,180

by gravitational lensing

1824

01:18:36,949 --> 01:18:40,909

so this Cosmic Microwave Background



1825  
01:18:38,180 --> 01:18:42,800  
comes from a very large distance so this

1826  
01:18:40,909 --> 01:18:44,149  
light you know it's emitted from the

1827  
01:18:42,800 --> 01:18:46,520  
cosmic microwave background surface of

1828  
01:18:44,149 --> 01:18:48,199  
mascara it goes a very very long way

1829  
01:18:46,520 --> 01:18:50,720  
before you know we see it in our

1830  
01:18:48,199 --> 01:18:52,220  
telescope and it passes by a lot of

1831  
01:18:50,720 --> 01:18:54,110  
things a lot of galaxies and clusters of

1832  
01:18:52,220 --> 01:18:55,760  
galaxies and we know that general

1833  
01:18:54,109 --> 01:18:58,159  
relativity bends the trajectories of

1834  
01:18:55,760 --> 01:18:59,900  
light rays so you might ask whether that

1835  
01:18:58,159 --> 01:19:01,760  
Cosmic Microwave Background image is

1836  
01:18:59,899 --> 01:19:06,349  
distorted by this gravitational lensing

1837  
01:19:01,760 --> 01:19:08,030  
and it turns out that it is and this was

1838  
01:19:06,350 --> 01:19:12,020  
one of the big results of the Planck

1839  
01:19:08,029 --> 01:19:13,460  
satellite last March March of 2013 now I

1840  
01:19:12,020 --> 01:19:16,010  
don't have the image with me they

1841  
01:19:13,460 --> 01:19:18,859  
actually have measured the distribution

1842  
01:19:16,010 --> 01:19:20,060  
of mass in the universe by the effects

1843  
01:19:18,859 --> 01:19:22,069  
of gravitational and by the

1844  
01:19:20,060 --> 01:19:24,080  
gravitational lensing distortions of the

1845  
01:19:22,069 --> 01:19:26,689  
Cosmic Microwave Background so the

1846  
01:19:24,079 --> 01:19:29,350  
answer is yes and it's one of the the

1847  
01:19:26,689 --> 01:19:42,049  
major triumphs of the Planck satellite

1848  
01:19:29,350 --> 01:19:44,870  
okay other questions so there are

1849  
01:19:42,050 --> 01:19:47,090  
different ideas about what it is and

1850  
01:19:44,869 --> 01:19:50,029  
most of it is probably silicates and

1851  
01:19:47,090 --> 01:19:54,800  
these dust particles have a wide variety

1852  
01:19:50,029 --> 01:19:57,319  
of sizes but a micron is a typical size

1853

01:19:54,800 --> 01:20:01,100  
so like they're they're much smaller

1854  
01:19:57,319 --> 01:20:03,319  
than sand particles I think you know if

1855  
01:20:01,100 --> 01:20:05,539  
you take a to talk to erasers filled

1856  
01:20:03,319 --> 01:20:06,979  
with talk and bang them I think that

1857  
01:20:05,539 --> 01:20:11,649  
those chalk dust particles are

1858  
01:20:06,979 --> 01:20:11,649  
comparable in size so it is

1859  
01:20:12,679 --> 01:20:19,429  
it's you know tens of grams per

1860  
01:20:14,899 --> 01:20:22,609  
centimeter cubed it's like sand so very

1861  
01:20:19,429 --> 01:20:24,859  
small we don't know what it is in detail

1862  
01:20:22,609 --> 01:20:28,639  
there are various ideas and then it also

1863  
01:20:24,859 --> 01:20:31,639  
merges into things called PAH molecules

1864  
01:20:28,639 --> 01:20:34,940  
so a very small dust particle finds up

1865  
01:20:31,639 --> 01:20:37,010  
looking like a very big molecule but

1866  
01:20:34,939 --> 01:20:44,269  
basically it's you know dust like you

1867  
01:20:37,010 --> 01:20:47,360

know a chalkboard dust gravitational

1868

01:20:44,270 --> 01:20:58,280

waves turn out to be some source of

1869

01:20:47,359 --> 01:21:00,348

humongous amounts of energy is whether

1870

01:20:58,279 --> 01:21:02,269

the gravitational waves might turn out

1871

01:21:00,349 --> 01:21:05,179

to be a huge source of energy that we

1872

01:21:02,270 --> 01:21:07,219

could tap into so the answer is no so

1873

01:21:05,179 --> 01:21:08,840

the there are upper limits to the energy

1874

01:21:07,219 --> 01:21:11,179

density of these gravitational waves and

1875

01:21:08,840 --> 01:21:12,770

the the best upper limit is that it's

1876

01:21:11,179 --> 01:21:14,270

one tenth of the energy density in the

1877

01:21:12,770 --> 01:21:17,320

Cosmic Microwave Background

1878

01:21:14,270 --> 01:21:22,760

and that's a very small energy density

1879

01:21:17,319 --> 01:21:25,939

so the roughly 400 sir roughly 400

1880

01:21:22,760 --> 01:21:28,880

photons per cubic centimeter and there

1881

01:21:25,939 --> 01:21:31,638

are very long wavelengths are very low

1882  
01:21:28,880 --> 01:21:34,429  
energy photons more difficult part is

1883  
01:21:31,639 --> 01:21:36,500  
the tap into question detecting the

1884  
01:21:34,429 --> 01:21:38,569  
gravitational wave is extremely

1885  
01:21:36,500 --> 01:21:40,158  
difficult the motions that these

1886  
01:21:38,569 --> 01:21:45,558  
gravitational waves would induce and

1887  
01:21:40,158 --> 01:21:48,229  
test masses is extremely feeble and just

1888  
01:21:45,559 --> 01:21:51,980  
the idea of getting energy from waves is

1889  
01:21:48,229 --> 01:21:54,379  
tricky so Tesla had this idea so Tesla

1890  
01:21:51,979 --> 01:21:55,939  
was a genius but he's also a semi not he

1891  
01:21:54,380 --> 01:21:58,340  
had this idea that we could do energy

1892  
01:21:55,939 --> 01:22:01,609  
transmission not by laying cables but by

1893  
01:21:58,340 --> 01:22:03,619  
a propagating radio waves and it didn't

1894  
01:22:01,609 --> 01:22:06,158  
work and he blew up several things

1895  
01:22:03,618 --> 01:22:06,158  
trying to

1896  
01:22:06,929 --> 01:22:12,788  
forty orders of magnitude longer than

1897  
01:22:10,328 --> 01:22:15,189  
gravitational waves so if we can't do

1898  
01:22:12,788 --> 01:22:21,729  
with electromagnetic waves it's not hey

1899  
01:22:15,189 --> 01:22:24,638  
40 orders just a bit over here this sort

1900  
01:22:21,729 --> 01:22:27,359  
of follow-up to the first question how

1901  
01:22:24,639 --> 01:22:31,389  
do we know that sort of the image of the

1902  
01:22:27,359 --> 01:22:33,519  
microwave pattern mentioned by Coby and

1903  
01:22:31,389 --> 01:22:36,010  
the subsequent satellites has not been

1904  
01:22:33,520 --> 01:22:40,980  
distorted by other intervening sources

1905  
01:22:36,010 --> 01:22:43,659  
of microwave or so it turns out that the

1906  
01:22:40,979 --> 01:22:46,118  
predictions of inflation for the Cosmic

1907  
01:22:43,658 --> 01:22:51,538  
Microwave Background pattern are very

1908  
01:22:46,118 --> 01:22:54,788  
very precise and the prediction is that

1909  
01:22:51,538 --> 01:22:57,939  
the image should be a what we call the

1910

01:22:54,788 --> 01:23:00,189  
Gaussian random map so it's a very very

1911  
01:22:57,939 --> 01:23:03,098  
specific prediction so you know what a

1912  
01:23:00,189 --> 01:23:04,629  
bell curve is right bell curve goes up

1913  
01:23:03,099 --> 01:23:07,860  
and it goes down has a very precise

1914  
01:23:04,630 --> 01:23:11,440  
mathematical description anything else

1915  
01:23:07,859 --> 01:23:13,000  
is not a bell curve so if I draw a curve

1916  
01:23:11,439 --> 01:23:14,319  
that goes like that that's not a bell

1917  
01:23:13,000 --> 01:23:16,090  
curve if I draw a triangle it's not a

1918  
01:23:14,319 --> 01:23:18,368  
bell curve a square is not a bell curve

1919  
01:23:16,090 --> 01:23:20,559  
anything that's not a bell curve is not

1920  
01:23:18,368 --> 01:23:23,019  
a bell curve and anything that's not a

1921  
01:23:20,559 --> 01:23:26,010  
Gaussian random map is not a Gaussian

1922  
01:23:23,020 --> 01:23:30,010  
random map and it turns out that the the

1923  
01:23:26,010 --> 01:23:33,670  
images are Gaussian to one part in

1924  
01:23:30,010 --> 01:23:36,039

10,000 so we know that the distortions

1925

01:23:33,670 --> 01:23:38,050  
are extremely small but we now can't

1926

01:23:36,038 --> 01:23:41,529  
detect these very tiniest or seems very

1927

01:23:38,050 --> 01:23:43,570  
tiny distortions we can attribute very

1928

01:23:41,529 --> 01:23:47,578  
precisely to the effects of

1929

01:23:43,569 --> 01:23:50,859  
gravitational lensing in the back there

1930

01:23:47,578 --> 01:23:53,229  
just a simple question but the on the B

1931

01:23:50,859 --> 01:23:54,639  
modes but that create bumps on the

1932

01:23:53,229 --> 01:23:56,709  
outside edges

1933

01:23:54,639 --> 01:24:00,788  
maybe I'm saying it simply but the

1934

01:23:56,710 --> 01:24:03,250  
outside edges of where you have

1935

01:24:00,788 --> 01:24:05,019  
inflation if you had one picture where

1936

01:24:03,250 --> 01:24:07,868  
there was like kind of a a ball with

1937

01:24:05,020 --> 01:24:11,079  
spirals well those B modes actually

1938

01:24:07,868 --> 01:24:13,389  
rotate and create like dimples on the



1939  
01:24:11,078 --> 01:24:15,069  
outside edge or how does that work it's

1940  
01:24:13,389 --> 01:24:17,730  
the other way around so what happens is

1941  
01:24:15,069 --> 01:24:20,649  
that there's surface of last scattering

1942  
01:24:17,729 --> 01:24:23,078  
the light that we see from in the Cosmic

1943  
01:24:20,649 --> 01:24:26,618  
Microwave Background is actually emitted

1944  
01:24:23,078 --> 01:24:28,808  
from the surface of last scattering it

1945  
01:24:26,618 --> 01:24:31,448  
comes in it starts jiggling starts

1946  
01:24:28,809 --> 01:24:33,070  
moving it around and those motions are

1947  
01:24:31,448 --> 01:24:37,149  
what gives rise to the polarization

1948  
01:24:33,069 --> 01:24:38,380  
pattern so it's those motions induced by

1949  
01:24:37,149 --> 01:24:41,529  
the gravitational waves give rise to

1950  
01:24:38,380 --> 01:24:47,349  
that polarization pattern not vice versa

1951  
01:24:41,529 --> 01:24:48,939  
I was just asking well that is their

1952  
01:24:47,349 --> 01:24:51,670  
varying density or something that's

1953  
01:24:48,939 --> 01:24:53,138  
creating that and and is it a flat wall

1954  
01:24:51,670 --> 01:24:55,059  
on the outside edge of that or is it

1955  
01:24:53,139 --> 01:24:56,800  
something that that that energy goes

1956  
01:24:55,059 --> 01:25:01,059  
both directions or is it only coming one

1957  
01:24:56,800 --> 01:25:02,650  
way oh it's going in all directions but

1958  
01:25:01,059 --> 01:25:10,269  
we only the see the stuff that's coming

1959  
01:25:02,649 --> 01:25:14,078  
towards us okay yeah question here Hey

1960  
01:25:10,269 --> 01:25:16,480  
in this the COBE and w map actin and

1961  
01:25:14,078 --> 01:25:20,288  
puck background radiation

1962  
01:25:16,479 --> 01:25:22,988  
you mentioned hotter and colder

1963  
01:25:20,288 --> 01:25:27,250  
is that a spectral or an intensity or is

1964  
01:25:22,988 --> 01:25:29,018  
it the same difference so hotter and

1965  
01:25:27,250 --> 01:25:33,038  
colder means brighter what I should have

1966  
01:25:29,019 --> 01:25:34,420  
said is brighter and fainter that's an

1967

01:25:33,038 --> 01:25:36,000  
intensity measurement or is it a

1968  
01:25:34,420 --> 01:25:37,269  
specular the difference in frequency

1969  
01:25:36,000 --> 01:25:42,279  
wavelength

1970  
01:25:37,269 --> 01:25:43,570  
it's an intensity measurement and I can

1971  
01:25:42,279 --> 01:25:45,880  
tell you more if you want more detailed

1972  
01:25:43,569 --> 01:25:47,380  
information about how what precise

1973  
01:25:45,880 --> 01:25:55,118  
they're measuring but it's an intensity

1974  
01:25:47,380 --> 01:25:57,368  
measurement okay lights because the

1975  
01:25:55,118 --> 01:25:59,859  
speed of light is what is faster than

1976  
01:25:57,368 --> 01:26:01,719  
the rate of that car and you just said

1977  
01:25:59,859 --> 01:26:03,130  
we can't see things going away from us

1978  
01:26:01,719 --> 01:26:05,288  
so you've said all the galaxies are

1979  
01:26:03,130 --> 01:26:07,118  
moving faster than the speed of light so

1980  
01:26:05,288 --> 01:26:13,090  
we can't see things moving away from us

1981  
01:26:07,118 --> 01:26:14,920

oh we're moving in this direction and

1982

01:26:13,090 --> 01:26:16,929

everything's expanding we should be

1983

01:26:14,920 --> 01:26:19,480

looking this way and not see anything

1984

01:26:16,929 --> 01:26:21,788

but if we look back the other way we

1985

01:26:19,479 --> 01:26:24,698

should see you know things coming

1986

01:26:21,788 --> 01:26:25,840

towards us unless they should be a

1987

01:26:24,698 --> 01:26:28,419

little bit more dense

1988

01:26:25,840 --> 01:26:30,880

so now that you've told me about the Big

1989

01:26:28,420 --> 01:26:33,310

Bang it makes me think that whatever

1990

01:26:30,880 --> 01:26:35,109

that source is over here there's not one

1991

01:26:33,310 --> 01:26:37,320

Big Bang it makes it seem like this a

1992

01:26:35,109 --> 01:26:39,489

series of things so that additional

1993

01:26:37,319 --> 01:26:42,250

matter would be released from that

1994

01:26:39,489 --> 01:26:44,109

source like you know peeling an onion

1995

01:26:42,250 --> 01:26:47,170

and now you've has layers of one layer

1996  
01:26:44,109 --> 01:26:49,089  
bangs the next layer bangs the next

1997  
01:26:47,170 --> 01:26:51,039  
layer so that when we look that way

1998  
01:26:49,090 --> 01:26:53,890  
we don't see anything but when we look

1999  
01:26:51,039 --> 01:26:58,439  
back we can still see matters upcoming

2000  
01:26:53,890 --> 01:27:02,310  
tours okay so this is so the

2001  
01:26:58,439 --> 01:27:05,109  
understanding the Big Bang

2002  
01:27:02,310 --> 01:27:08,590  
it's probably the it's the hardest thing

2003  
01:27:05,109 --> 01:27:11,049  
to explain and to understand and I had

2004  
01:27:08,590 --> 01:27:18,329  
to take general relativity and cosmology

2005  
01:27:11,050 --> 01:27:18,329  
several times before I really I think so

2006  
01:27:19,380 --> 01:27:24,460  
explosions so the Big Bang is all often

2007  
01:27:22,119 --> 01:27:25,930  
described as an explosion but it's kind

2008  
01:27:24,460 --> 01:27:27,970  
of a misnomer because when we think of

2009  
01:27:25,930 --> 01:27:30,520  
explosions you know we think of

2010  
01:27:27,970 --> 01:27:34,590  
something over there blowing up and then

2011  
01:27:30,520 --> 01:27:36,970  
we see it but that's not the big bang

2012  
01:27:34,590 --> 01:27:40,659  
what we observe is that the entire

2013  
01:27:36,970 --> 01:27:45,070  
universe is expanding imagine that I had

2014  
01:27:40,659 --> 01:27:48,039  
a balloon that was very small and I were

2015  
01:27:45,069 --> 01:27:49,960  
to I blew it up slowly and think about

2016  
01:27:48,039 --> 01:27:55,899  
the surface which is a two-dimensional

2017  
01:27:49,960 --> 01:27:57,970  
universe every point on that universe is

2018  
01:27:55,899 --> 01:27:59,529  
moving away from every other point every

2019  
01:27:57,970 --> 01:28:01,600  
point on the surface the balloon is

2020  
01:27:59,529 --> 01:28:05,500  
moving away from every other points as I

2021  
01:28:01,600 --> 01:28:06,850  
blow it up but there is no place on the

2022  
01:28:05,500 --> 01:28:11,260  
balloon that's different than any other

2023  
01:28:06,850 --> 01:28:13,780  
place and the expanding universe is a

2024

01:28:11,260 --> 01:28:17,070  
three dimensional analog of the surface

2025  
01:28:13,779 --> 01:28:17,069  
of a balloon that's being blown up

2026  
01:28:31,199 --> 01:28:34,559  
the circuits have another bubble and

2027  
01:28:33,029 --> 01:28:37,109  
they started a balloon and they're all

2028  
01:28:34,560 --> 01:28:38,610  
expanding yeah we can't do that so so so

2029  
01:28:37,109 --> 01:28:41,729  
the problem with this analogy is that

2030  
01:28:38,609 --> 01:28:44,369  
when we look at the the balloon it's a

2031  
01:28:41,729 --> 01:28:46,229  
two-dimensional surface that we can see

2032  
01:28:44,369 --> 01:28:49,050  
because we're in three dimensions and

2033  
01:28:46,229 --> 01:28:50,609  
for this analogy to work really well we

2034  
01:28:49,050 --> 01:28:51,420  
would have to live in four dimensions

2035  
01:28:50,609 --> 01:28:53,789  
and be able to look at our

2036  
01:28:51,420 --> 01:28:56,220  
three-dimensional universe from outside

2037  
01:28:53,789 --> 01:28:59,250  
it we can talk afterwards I can try to

2038  
01:28:56,220 --> 01:29:02,789

explain the expansion of expansion

2039

01:28:59,250 --> 01:29:05,520

spaces be the stretching of space and

2040

01:29:02,789 --> 01:29:08,430

not really moving through space is one

2041

01:29:05,520 --> 01:29:10,260

of the fundamental pieces that you have

2042

01:29:08,430 --> 01:29:11,880

to grasp in order for a lot of this to

2043

01:29:10,260 --> 01:29:20,280

some of this to make sense all right

2044

01:29:11,880 --> 01:29:23,520

we've hit at a good amount of time next

2045

01:29:20,279 --> 01:29:28,769

month December we will have Joshua peak

2046

01:29:23,520 --> 01:29:31,770

on outer space the landing on the

2047

01:29:28,770 --> 01:29:35,280

Rosetta on comet rubber ducky cheerio

2048

01:29:31,770 --> 01:29:36,780

mom Gerasimenko is like what did we

2049

01:29:35,279 --> 01:29:37,469

figure out was 11 a.m. tomorrow or

2050

01:29:36,779 --> 01:29:41,789

something like that

2051

01:29:37,470 --> 01:29:43,710

Eastern Time and somebody put up here

2052

01:29:41,789 --> 01:29:48,180

that Adam riess is getting yet another



2053  
01:29:43,710 --> 01:29:50,039  
prize and it's going to be simulcast on

2054  
01:29:48,180 --> 01:29:52,829  
the Discovery Channel and Science

2055  
01:29:50,039 --> 01:29:54,539  
Channel 6 p.m. Saturday with hosted by

2056  
01:29:52,829 --> 01:29:57,449  
Seth MacFarlane and other things like

2057  
01:29:54,539 --> 01:29:58,979  
that so you want to see yet another

2058  
01:29:57,449 --> 01:30:00,539  
thing for Adam riess go ahead alright

2059  
01:29:58,979 --> 01:30:03,259  
thank you all for coming let's give Marc

2060  
01:30:00,539 --> 01:30:03,260  
another hand