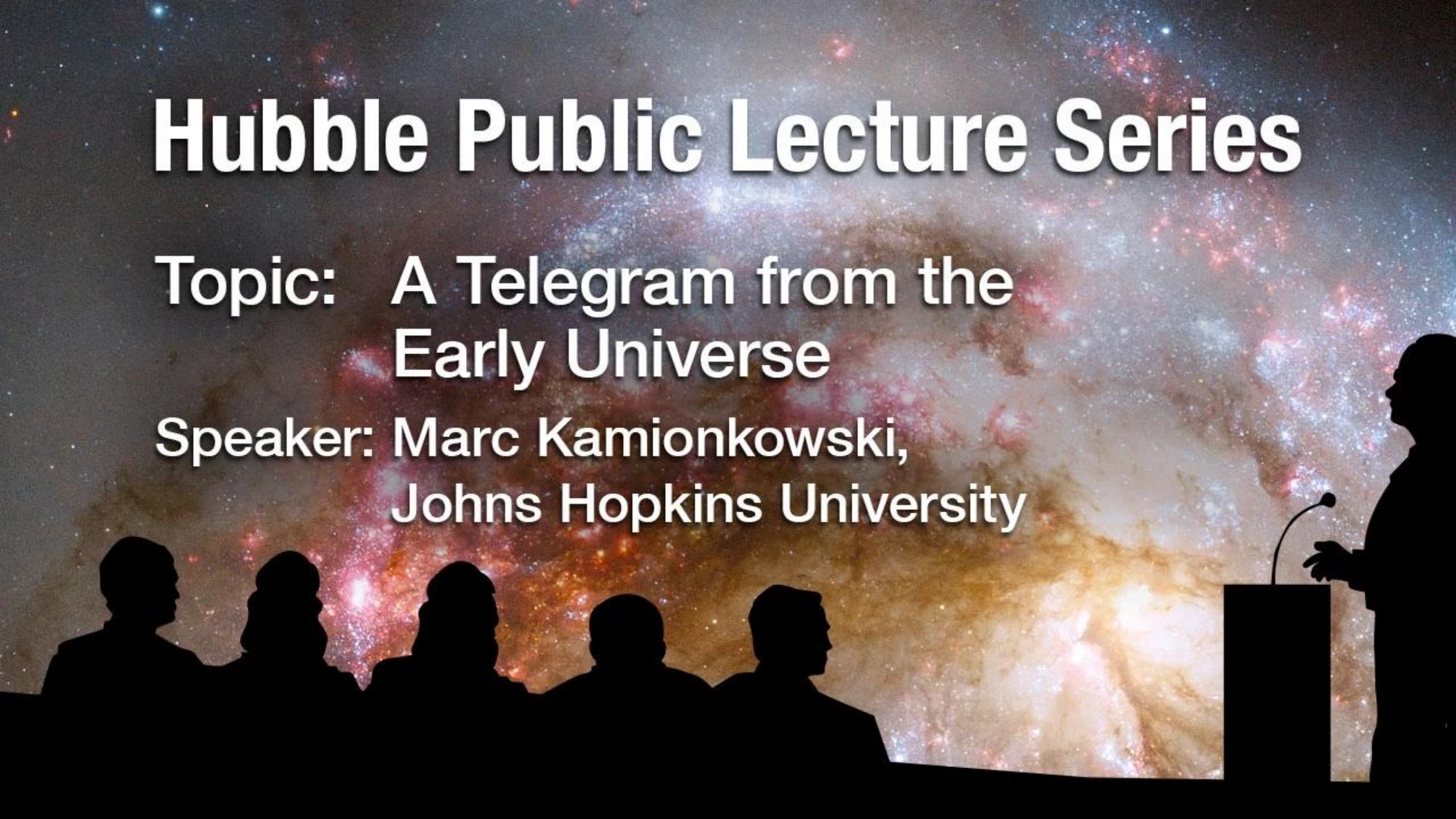
Hubble Public Lecture Series

Topic: A Telegram from the Early Universe

Speaker: Marc Kamionkowski, Johns Hopkins University



1
00:00:09,049 --> 00:00:06,410
good evening everybody wow that's

2
00:00:12,020 --> 00:00:09,059
interesting we're gonna let some echo

3
00:00:14,570 --> 00:00:12,030
here there we go thank you Thomas okay

4
00:00:16,790 --> 00:00:14,580
evening everybody and welcome to the

5
00:00:19,519 --> 00:00:16,800
Hubble Space Telescope public lecture

6
00:00:22,580 --> 00:00:19,529
series I'm your host dr. Frank summers

7
00:00:24,290 --> 00:00:22,590
of the office of public outreach and it

8
00:00:27,380 --> 00:00:24,300
is my pleasure to be your host every

9
00:00:30,230 --> 00:00:27,390
month and also to give away free

10
00:00:32,990 --> 00:00:30,240
pictures we have a brand new lithograph

11
00:00:34,639 --> 00:00:33,000
this never been given out before at the

12
00:00:36,170 --> 00:00:34,649
public electro series you know those of

13
00:00:38,479 --> 00:00:36,180

you who've been here many times say oh

14
00:00:40,130 --> 00:00:38,489
it's another one another galaxy picture

15
00:00:42,670 --> 00:00:40,140
that I've got well this one is one you

16
00:00:46,850 --> 00:00:42,680
haven't got it's a galaxy cluster Abell

17
00:00:50,209 --> 00:00:46,860
2744 a very special galaxy cluster

18
00:00:53,420 --> 00:00:50,219
because it's the first cluster in the

19
00:00:55,069 --> 00:00:53,430
frontier fields project okay and so you

20
00:00:57,350 --> 00:00:55,079
get the picture of this galaxy cluster

21
00:01:00,319 --> 00:00:57,360
it's special because it is a very very

22
00:01:02,689 --> 00:01:00,329
large galaxy cluster it produces

23
00:01:05,990 --> 00:01:02,699
gravitational lensing alright which

24
00:01:07,399 --> 00:01:06,000
helps us to see very distant galaxies

25
00:01:09,580 --> 00:01:07,409
that are magnified by the gravitational

26
00:01:12,350 --> 00:01:09,590
lens you want to learn about that idea

27
00:01:14,840 --> 00:01:12,360
we've got information on the back that

28
00:01:16,520 --> 00:01:14,850
you can read about there's at least a

29
00:01:18,859 --> 00:01:16,530
couple left if you had did not get one

30
00:01:23,810 --> 00:01:18,869
on the way in please pick one up on the

31
00:01:25,520 --> 00:01:23,820
way out our talk tonight by Mark

32
00:01:29,149 --> 00:01:25,530
kamionkowski which I spelled wrong

33
00:01:35,770 --> 00:01:29,159
obviously Kamino Kowski sorry about that

34
00:01:38,840 --> 00:01:35,780
mark a telegram from the early universe

35
00:01:41,030 --> 00:01:38,850
okay upcoming next month

36
00:01:45,499 --> 00:01:41,040
Joshua peak will be talking about outer

37
00:01:47,210 --> 00:01:45,509
space basically talking about the

38
00:01:50,270 --> 00:01:47,220

emptiness that's out there and what's

39
00:01:52,609 --> 00:01:50,280
actually in the space between the stars

40
00:01:57,530 --> 00:01:52,619
it's not really as empty as you may

41
00:02:00,080 --> 00:01:57,540
think January this auditorium is going

42
00:02:01,940 --> 00:02:00,090
to undergo some renovations okay there

43
00:02:05,270 --> 00:02:01,950
will be some renovations and so the

44
00:02:07,219 --> 00:02:05,280
first week in January I was told I could

45
00:02:09,770 --> 00:02:07,229
not hold the public lecture series so we

46
00:02:13,290 --> 00:02:09,780
are holding it on the second Tuesday in

47
00:02:15,540 --> 00:02:13,300
January so January 13th 2015

48
00:02:19,440 --> 00:02:15,550
and it will be a fascinating topic by

49
00:02:21,000 --> 00:02:19,450
some amazing astronomer basically the

50
00:02:24,900 --> 00:02:21,010
astronomer to be named later

51
00:02:26,850 --> 00:02:24,910
that don't worry I get there okay it's

52
00:02:27,750 --> 00:02:26,860
been a little busy this month but we'll

53
00:02:31,260 --> 00:02:27,760
get there

54
00:02:34,230 --> 00:02:31,270
in February we have hey one of the

55
00:02:36,540 --> 00:02:34,240
longed longer titles of topics that have

56
00:02:38,970 --> 00:02:36,550
been given to me from cosmic birth to

57
00:02:42,720 --> 00:02:38,980
living earth the next great space

58
00:02:44,160 --> 00:02:42,730
telescope beyond JWST if you come to

59
00:02:46,140 --> 00:02:44,170
these you know we've talked a lot about

60
00:02:48,360 --> 00:02:46,150
the next great observatory the James

61
00:02:51,810 --> 00:02:48,370
Webb Space Telescope for those who are

62
00:02:54,360 --> 00:02:51,820
wondering what's beyond even that Jason

63
00:02:58,680 --> 00:02:54,370

Tomlinson will elucidate you in February

64
00:03:02,220 --> 00:02:58,690
of next year okay these are listed on

65
00:03:04,350 --> 00:03:02,230
our website easiest thing to do is just

66
00:03:06,060 --> 00:03:04,360
say Hubble public talks into your

67
00:03:07,860 --> 00:03:06,070
favorite search engine this should be

68
00:03:11,340 --> 00:03:07,870
come up you can see we've got the

69
00:03:15,420 --> 00:03:11,350
upcoming lectures as well as the archive

70
00:03:18,449 --> 00:03:15,430
back to 2005 so that's nine years of

71
00:03:20,970 --> 00:03:18,459
amazing cosmic knowledge that you can

72
00:03:21,360 --> 00:03:20,980
absorb by watching all of our webcasts

73
00:03:23,040 --> 00:03:21,370
okay

74
00:03:25,680 --> 00:03:23,050
just think how smart you would be

75
00:03:28,830 --> 00:03:25,690
watching nine years of cosmic knowledge

76
00:03:32,520 --> 00:03:28,840
that'll anyway so that's available for

77
00:03:34,470 --> 00:03:32,530
you we have emails I just got one

78
00:03:36,840 --> 00:03:34,480
tonight of somebody who was on our email

79
00:03:38,760 --> 00:03:36,850
list and some for some reason got off of

80
00:03:43,199 --> 00:03:38,770
it so she gave me your email address

81
00:03:45,290 --> 00:03:43,209
I'll add her and you won't get any spam

82
00:03:48,390 --> 00:03:45,300
from it because it's very very low

83
00:03:51,360 --> 00:03:48,400
emails you can contact us public lecture

84
00:03:54,060 --> 00:03:51,370
at STScI dot edu asks us comments

85
00:03:55,350 --> 00:03:54,070
questions or even sign up for the

86
00:03:57,270 --> 00:03:55,360
announcements because if you send us an

87
00:04:01,830 --> 00:03:57,280
email we'll have your return address to

88
00:04:05,550 --> 00:04:01,840

do it social media Facebook Twitter

89
00:04:08,370 --> 00:04:05,560
Google+ Pinterest I'm on Facebook

90
00:04:09,660 --> 00:04:08,380
Google+ and sometimes I Twitter I don't

91
00:04:13,080 --> 00:04:09,670
do as much of the social media as I'm

92
00:04:15,390 --> 00:04:13,090
supposed to but it's there if you are so

93
00:04:17,550 --> 00:04:15,400
interested in it

94
00:04:19,080 --> 00:04:17,560
Observatory I'm not sure that they are

95
00:04:21,030 --> 00:04:19,090
doing the observatory tonight because

96
00:04:23,850 --> 00:04:21,040
they had it planned scheduled for last

97
00:04:26,070 --> 00:04:23,860
week and so there's a big question mark

98
00:04:27,620 --> 00:04:26,080
anybody from the spacecraft Sara Torre

99
00:04:29,969 --> 00:04:27,630
here

100
00:04:31,589 --> 00:04:29,979
hearing silence I will assume that they

101
00:04:32,790 --> 00:04:31,599
are not going to do the observatory

102
00:04:34,620 --> 00:04:32,800
tonight

103
00:04:36,749 --> 00:04:34,630
I'll ask them remind me to ask again at

104
00:04:38,879 --> 00:04:36,759
the end of the lecture in case the MS I

105
00:04:43,170 --> 00:04:38,889
mean if Maryland spacecraft or folks do

106
00:04:44,909 --> 00:04:43,180
show up okay so my favorite part of the

107
00:04:50,240 --> 00:04:44,919
evening is the news from the universe

108
00:04:55,710 --> 00:04:50,250
this is for November 2014 to Pluto and

109
00:04:57,150 --> 00:04:55,720
Beyond part two when last we discussed

110
00:04:59,460 --> 00:04:57,160
of course when we're talking about going

111
00:05:00,689 --> 00:04:59,470
to Pluto we are talking about the New

112
00:05:05,999 --> 00:05:00,699
Horizons mission

113
00:05:09,240 --> 00:05:06,009

New Horizons launched back in 2006

114
00:05:12,240 --> 00:05:09,250
it got went past Jupiter in 2007 has

115
00:05:16,439 --> 00:05:12,250
been cruising out towards Pluto for the

116
00:05:18,409 --> 00:05:16,449
past nine years and will finally get to

117
00:05:21,990 --> 00:05:18,419
Pluto next summer

118
00:05:25,740 --> 00:05:22,000
so here is the path of the New Horizons

119
00:05:27,809 --> 00:05:25,750
full trajectory as it was in July when I

120
00:05:31,890 --> 00:05:27,819
first presented part one of this and

121
00:05:34,589 --> 00:05:31,900
part one oh and just to mention the the

122
00:05:35,510 --> 00:05:34,599
milestones sometime January or shortly

123
00:05:37,980 --> 00:05:35,520
thereafter

124
00:05:42,420 --> 00:05:37,990
New Horizons will have better resolution

125
00:05:44,159 --> 00:05:42,430
than Hubble does okay so all of next

126
00:05:46,080 --> 00:05:44,169
year the time for New Horizons is

127
00:05:47,399 --> 00:05:46,090
precious because they will have better

128
00:05:49,800 --> 00:05:47,409
resolution the Hubble these are some

129
00:05:51,870 --> 00:05:49,810
Hubble images of Pluto where you can see

130
00:05:53,879 --> 00:05:51,880
the pixelation of it all right and

131
00:05:55,860 --> 00:05:53,889
that's the that's that's that's the best

132
00:05:58,100 --> 00:05:55,870
Hubble can do in terms of getting

133
00:06:00,779 --> 00:05:58,110
individual pictures we can of course

134
00:06:03,570 --> 00:06:00,789
interpolate from them to get better maps

135
00:06:07,439 --> 00:06:03,580
but next summer for next year we'll be

136
00:06:10,740 --> 00:06:07,449
able to get that it'll go past Pluto on

137
00:06:14,159 --> 00:06:10,750
July 14th best deal day next summer

138
00:06:16,260 --> 00:06:14,169

we'll do a buzz over Pluto it will be

139
00:06:19,290 --> 00:06:16,270
moving however really really really fast

140
00:06:21,510 --> 00:06:19,300
so this is going to be very carefully

141
00:06:23,490 --> 00:06:21,520
and planned encounter of everything and

142
00:06:25,740 --> 00:06:23,500
Hubble has been helping by searching

143
00:06:30,120 --> 00:06:25,750
through the Pluto system discovering the

144
00:06:31,679 --> 00:06:30,130
moons Nix Hydra sticks and Kerberos for

145
00:06:34,949 --> 00:06:31,689
extra moons of

146
00:06:39,059 --> 00:06:34,959
of Pluto that Hubble has been able thing

147
00:06:41,429 --> 00:06:39,069
but after it passes by Pluto what next

148
00:06:44,309 --> 00:06:41,439
well this is where the Kuiper belt comes

149
00:06:46,229 --> 00:06:44,319
in and you can see that what we have

150
00:06:48,149 --> 00:06:46,239
here in the interior is the orbits of

151
00:06:50,189 --> 00:06:48,159
Jupiter Saturn Uranus and Neptune the

152
00:06:53,339 --> 00:06:50,199
giant planets in the solar system all of

153
00:06:54,929 --> 00:06:53,349
those white and red objects are new

154
00:06:56,609 --> 00:06:54,939
objects that have been discovered in the

155
00:07:00,539 --> 00:06:56,619
Kuiper belt below the solar system since

156
00:07:02,509 --> 00:07:00,549
1993 well I say all of them but one of

157
00:07:07,619 --> 00:07:02,519
course Pluto was discovered in 1930

158
00:07:10,709 --> 00:07:07,629
they're 12 1274 as of July this summer

159
00:07:13,769 --> 00:07:10,719
and so the question is we're gonna zoom

160
00:07:17,100 --> 00:07:13,779
past Pluto what do we do afterwards can

161
00:07:20,999 --> 00:07:17,110
we find a suitable Kuiper belt object to

162
00:07:23,429 --> 00:07:21,009
fly past afterwards so Hubble showed

163
00:07:25,589 --> 00:07:23,439

that it could do it and NASA gave us the

164
00:07:29,059 --> 00:07:25,599
go-ahead to do a complete search for

165
00:07:31,979 --> 00:07:29,069
Kuiper belt objects that would be

166
00:07:36,869 --> 00:07:31,989
obtainable with the current orbit of the

167
00:07:39,329 --> 00:07:36,879
mission so they looked at 83 Hubble with

168
00:07:42,629 --> 00:07:39,339
c3 fields okay and this is the tile

169
00:07:45,779 --> 00:07:42,639
mosaic of all these 83 fields that they

170
00:07:47,669 --> 00:07:45,789
looked in and on the lower left-hand

171
00:07:49,649 --> 00:07:47,679
corner is the size of the full moon on

172
00:07:52,439 --> 00:07:49,659
the sky and so you can see that they

173
00:07:56,309 --> 00:07:52,449
covered an area about half the size of a

174
00:07:58,559 --> 00:07:56,319
full moon in total looking for potential

175
00:08:00,899 --> 00:07:58,569
Kuiper belt objects that the New

176
00:08:03,979 --> 00:08:00,909
Horizons mission could visit they

177
00:08:08,129 --> 00:08:03,989
discovered three that were really

178
00:08:10,109 --> 00:08:08,139
obtainable potential targets and so if

179
00:08:12,600 --> 00:08:10,119
you take those blue as the whipsey three

180
00:08:14,909 --> 00:08:12,610
fields and then the purple as a single

181
00:08:16,949 --> 00:08:14,919
with c3 field and then you zoom into

182
00:08:19,889 --> 00:08:16,959
that red region you can see how just a

183
00:08:22,759 --> 00:08:19,899
small piece of that they had to do and

184
00:08:25,259 --> 00:08:22,769
you can see the five separate images are

185
00:08:28,709 --> 00:08:25,269
different exposures you take multiple

186
00:08:30,600 --> 00:08:28,719
exposures separated by time and then the

187
00:08:32,689 --> 00:08:30,610
nearby objects the object in our solar

188
00:08:35,610 --> 00:08:32,699

system will move across the exposure

189
00:08:38,189 --> 00:08:35,620
creating those five separate images so

190
00:08:41,129 --> 00:08:38,199
here is what they call PT one potential

191
00:08:44,760 --> 00:08:41,139
target one you can see it's real name is

192
00:08:49,560 --> 00:08:44,770
one one one zero one one three why

193
00:08:51,180 --> 00:08:49,570
which is why we call it PT 1 and this is

194
00:08:54,290 --> 00:08:51,190
one of the this this is the favored

195
00:08:57,240 --> 00:08:54,300
target for New Horizons to mission

196
00:08:59,250 --> 00:08:57,250
mission mission to visit after going

197
00:09:01,260 --> 00:08:59,260
past Pluto so as I said there are three

198
00:09:04,820 --> 00:09:01,270
potential targets size estimates for

199
00:09:07,949 --> 00:09:04,830
these are between 25 and 55 kilometers

200
00:09:09,420 --> 00:09:07,959
one of them is definitely reachable and

201
00:09:11,910 --> 00:09:09,430
when we say definitely reachable the

202
00:09:15,449 --> 00:09:11,920
idea is that we need enough propulsion

203
00:09:17,639 --> 00:09:15,459
to shift the orbit to shift the the path

204
00:09:20,610 --> 00:09:17,649
of New Horizons to go past this object

205
00:09:22,199 --> 00:09:20,620
right and so given the constraints of

206
00:09:25,769 --> 00:09:22,209
the propellant and stuff we have on

207
00:09:27,420 --> 00:09:25,779
board can we shift it and so one is

208
00:09:31,800 --> 00:09:27,430
definitely reachable two of them are

209
00:09:33,420 --> 00:09:31,810
potentially accessible but just because

210
00:09:35,010 --> 00:09:33,430
we found potential targets doesn't mean

211
00:09:38,040 --> 00:09:35,020
that New Horizons is actually going to

212
00:09:40,440 --> 00:09:38,050
go there nASA has to approve and fund

213
00:09:42,990 --> 00:09:40,450

the extension of the mission the mission

214
00:09:45,199 --> 00:09:43,000
is funded through the Pluto of the Pluto

215
00:09:48,360 --> 00:09:45,209
flyby and all the analysis of that data

216
00:09:50,610 --> 00:09:48,370
NASA must secure must approve the

217
00:09:52,319 --> 00:09:50,620
funding for that so they're going to go

218
00:09:55,050 --> 00:09:52,329
through the entire year next year and

219
00:09:57,060 --> 00:09:55,060
somewhere around in early 2016 the

220
00:09:59,490 --> 00:09:57,070
decision will be made whether or not

221
00:10:05,880 --> 00:09:59,500
they're going to go and look at a second

222
00:10:08,370 --> 00:10:05,890
object no worries of a collision - the

223
00:10:10,949 --> 00:10:08,380
question was no there was no it's pretty

224
00:10:16,710 --> 00:10:10,959
pretty pretty really totally empty out

225
00:10:18,900 --> 00:10:16,720
there I mean it's well you're used to if

226
00:10:21,060 --> 00:10:18,910
you ever if you saw Star Wars you know

227
00:10:23,819 --> 00:10:21,070
how dense the asteroid belt isn't

228
00:10:26,069 --> 00:10:23,829
because as spaceships zooming through

229
00:10:28,470 --> 00:10:26,079
the asteroid belt is pure fiction

230
00:10:30,510 --> 00:10:28,480
okay if you fly through the asteroid

231
00:10:32,760 --> 00:10:30,520
belt you will never ever know that

232
00:10:35,190 --> 00:10:32,770
you're inside the asteroid belt because

233
00:10:37,680 --> 00:10:35,200
it's just incredibly amounts of space in

234
00:10:39,269 --> 00:10:37,690
between the asteroids okay same thing

235
00:10:41,460 --> 00:10:39,279
even more true for the Kuiper belt

236
00:10:42,870 --> 00:10:41,470
objects okay incredible amounts of space

237
00:10:45,449 --> 00:10:42,880
in between them so you have to work

238
00:10:50,100 --> 00:10:45,459

really really really hard in order to

239
00:10:53,939 --> 00:10:50,110
fly past one of these okay here is just

240
00:10:55,940 --> 00:10:53,949
for example the potential target one 30

241
00:10:58,820 --> 00:10:55,950
to 45 kilometers in diameter

242
00:11:01,940 --> 00:10:58,830
compared to asteroid eros that we flew

243
00:11:05,150 --> 00:11:01,950
past and rubber ducky also known as

244
00:11:06,650 --> 00:11:05,160
comet cherammal of Gerasimenko this is

245
00:11:08,960 --> 00:11:06,660
the rosetta target which is only four

246
00:11:12,110 --> 00:11:08,970
kilometers in diameter and of course

247
00:11:14,060 --> 00:11:12,120
rubber ducky is going to get visited is

248
00:11:16,340 --> 00:11:14,070
currently being visited but it'll have a

249
00:11:21,110 --> 00:11:16,350
lander tomorrow I'll wait a question

250
00:11:22,400 --> 00:11:21,120
there get in there in just a second okay

251
00:11:26,840 --> 00:11:22,410
good question

252
00:11:30,020 --> 00:11:26,850
how much further away is it well so here

253
00:11:33,320 --> 00:11:30,030
is an artist's depiction of it and so

254
00:11:35,150 --> 00:11:33,330
this is the idea of what it might look

255
00:11:36,190 --> 00:11:35,160
like this Kuiper belt object way out at

256
00:11:39,470 --> 00:11:36,200
the edge of space

257
00:11:43,490 --> 00:11:39,480
and the idea is that it's supposed to be

258
00:11:45,860 --> 00:11:43,500
here but this is of course fantasy this

259
00:11:48,620 --> 00:11:45,870
is not even scientifically correct it's

260
00:11:50,480 --> 00:11:48,630
a nice idea but you recognize when I

261
00:11:52,490 --> 00:11:50,490
showed you that path that New Horizons

262
00:11:56,450 --> 00:11:52,500
is that has been going straight past

263
00:12:00,890 --> 00:11:56,460

Pluto and Pluto is about three billion

264
00:12:03,520 --> 00:12:00,900
miles out from the Sun and this new

265
00:12:06,080 --> 00:12:03,530
object is about four billion miles out

266
00:12:08,750 --> 00:12:06,090
so the problem with this diagram is that

267
00:12:11,360 --> 00:12:08,760
that object should be moved over to the

268
00:12:13,100 --> 00:12:11,370
end of that green line and actually if

269
00:12:14,630 --> 00:12:13,110
you're looking back at the Sun from that

270
00:12:17,060 --> 00:12:14,640
object you should be seeing Pluto in a

271
00:12:18,260 --> 00:12:17,070
direct line with the Sun because New

272
00:12:21,250 --> 00:12:18,270
Horizons is not going to be able to

273
00:12:23,300 --> 00:12:21,260
change its its its path very much so

274
00:12:25,250 --> 00:12:23,310
it's alright it's just an artist

275
00:12:27,710 --> 00:12:25,260
rendition here but the point is is that

276
00:12:30,350 --> 00:12:27,720
it's about four billion miles out so

277
00:12:32,750 --> 00:12:30,360
after traveling three billion miles over

278
00:12:34,460 --> 00:12:32,760
course of ten years it's gonna have to

279
00:12:35,990 --> 00:12:34,470
travel another billion miles to get

280
00:12:37,610 --> 00:12:36,000
there which will take another three

281
00:12:39,620 --> 00:12:37,620
years three or four years to get there

282
00:12:44,620 --> 00:12:39,630
okay which is the question I think you

283
00:12:47,840 --> 00:12:44,630
were really asking right right okay okay

284
00:12:50,450 --> 00:12:47,850
next topic a close encounter of the

285
00:12:52,130 --> 00:12:50,460
fourth planet kind this is another

286
00:12:52,790 --> 00:12:52,140
revisit of a story that we've been

287
00:12:56,420 --> 00:12:52,800
following

288
00:12:59,140 --> 00:12:56,430

of course comet siding spring siding

289
00:13:03,850 --> 00:12:59,150
spring which flew past Mars last month

290
00:13:07,130 --> 00:13:03,860
this is a Damien peach the guy gets

291
00:13:08,630 --> 00:13:07,140
amazingly good comet pictures Danny

292
00:13:09,590 --> 00:13:08,640
peach this is a picture of comet siding

293
00:13:14,210 --> 00:13:09,600
spring from Fair

294
00:13:18,110 --> 00:13:14,220
of last year and of course in October it

295
00:13:20,030 --> 00:13:18,120
flew past Mars and this this it's on

296
00:13:22,490 --> 00:13:20,040
this giant looping orbit it's got like a

297
00:13:23,930 --> 00:13:22,500
million year orbit okay and it's coming

298
00:13:25,580 --> 00:13:23,940
down underneath the solar system and

299
00:13:28,160 --> 00:13:25,590
back up through it and it just happens

300
00:13:30,440 --> 00:13:28,170
to pass by the orbit of Mars and Mars

301
00:13:32,480 --> 00:13:30,450
just happened to be there at the same

302
00:13:33,410 --> 00:13:32,490
time it was passing by incredible

303
00:13:35,840 --> 00:13:33,420
coincidence

304
00:13:38,420 --> 00:13:35,850
this doesn't do it justice it actually

305
00:13:42,500 --> 00:13:38,430
came within twenty Mars diameters of

306
00:13:45,350 --> 00:13:42,510
Mars on there and so of course is

307
00:13:48,380 --> 00:13:45,360
there's gonna a on the scale of the

308
00:13:50,120 --> 00:13:48,390
solar system that's amazingly close all

309
00:13:52,340 --> 00:13:50,130
right so we're wondering was there going

310
00:13:55,030 --> 00:13:52,350
to be any problems this is an artist's

311
00:13:57,620 --> 00:13:55,040
depiction of the comet flying past Mars

312
00:13:59,840 --> 00:13:57,630
and this was to illustrate the idea that

313
00:14:03,920 --> 00:13:59,850

NASA was going to do a Duck and Cover

314
00:14:06,140 --> 00:14:03,930
take the three spacecrafts that we have

315
00:14:07,550 --> 00:14:06,150
in orbit around Mars and make sure they

316
00:14:09,140 --> 00:14:07,560
were on the far side of the planet at

317
00:14:13,130 --> 00:14:09,150
the proper time so that they wouldn't

318
00:14:16,420 --> 00:14:13,140
get hit but this was overly optimistic

319
00:14:19,760 --> 00:14:16,430
in terms of the size of the coma of the

320
00:14:21,080 --> 00:14:19,770
spacecraft of the comet it wasn't nearly

321
00:14:23,420 --> 00:14:21,090
any that big

322
00:14:26,300 --> 00:14:23,430
there wasn't any huge problems with it

323
00:14:27,860 --> 00:14:26,310
and after the flyby they put up this

324
00:14:31,130 --> 00:14:27,870
webpage saying everything's in good

325
00:14:33,680 --> 00:14:31,140
health MRO maven and Odyssey are all in

326
00:14:34,490 --> 00:14:33,690
good health no problems there wasn't

327
00:14:36,710 --> 00:14:34,500
really something we were sweating

328
00:14:38,390 --> 00:14:36,720
amazingly but you know if the coma had

329
00:14:40,760 --> 00:14:38,400
been really really big there could have

330
00:14:44,360 --> 00:14:40,770
been some serious problems what we were

331
00:14:47,540 --> 00:14:44,370
interested also in is the ones on the

332
00:14:49,580 --> 00:14:47,550
surface could they look up and see an

333
00:14:51,740 --> 00:14:49,590
observation of a comet from another

334
00:14:57,140 --> 00:14:51,750
planet first observation of a comet from

335
00:15:00,880 --> 00:14:57,150
another planet and they got it it's not

336
00:15:03,920 --> 00:15:00,890
that impressive but they did get it okay

337
00:15:07,630 --> 00:15:03,930
so that in the center is comet siding

338
00:15:11,450 --> 00:15:07,640

spring as seen from the surface of Mars

339
00:15:13,790 --> 00:15:11,460
so that's a cool image not very detailed

340
00:15:16,100 --> 00:15:13,800
in anything if you want a really good

341
00:15:18,140 --> 00:15:16,110
image unfortunately this the the the

342
00:15:19,670 --> 00:15:18,150
missions at Mars did not get the good

343
00:15:21,710 --> 00:15:19,680
image where are we gonna get the good

344
00:15:22,560 --> 00:15:21,720
image we're gonna go back to Damian

345
00:15:26,100 --> 00:15:22,570
peach because

346
00:15:27,240 --> 00:15:26,110
gets the coolest pictures okay so on the

347
00:15:29,340 --> 00:15:27,250
right hand side that thing with the

348
00:15:30,660 --> 00:15:29,350
spikes that looks like a star it's not a

349
00:15:33,650 --> 00:15:30,670
star that's Mars

350
00:15:36,960 --> 00:15:33,660
that's how amazingly bright Mars is

351
00:15:37,770 --> 00:15:36,970
compared to comet siding spring 's lower

352
00:15:42,060 --> 00:15:37,780
left of it

353
00:15:44,430 --> 00:15:42,070
okay so again just like for comet Ison

354
00:15:48,030 --> 00:15:44,440
the best comp ixr seem to always come

355
00:15:49,260 --> 00:15:48,040
from Damian peach he's done I don't know

356
00:15:51,960 --> 00:15:49,270
how he does it I've never been an

357
00:15:54,210 --> 00:15:51,970
amateur astronomer I've never been a

358
00:15:56,730 --> 00:15:54,220
telescopic astronomer or an astro

359
00:15:58,920 --> 00:15:56,740
photographer but he gets the gets the

360
00:16:01,050 --> 00:15:58,930
cool things all right so this shows you

361
00:16:04,050 --> 00:16:01,060
the correct relative brightness of them

362
00:16:08,010 --> 00:16:04,060
all right and it also gives you a clue

363
00:16:11,570 --> 00:16:08,020

as to what this image is this is a

364
00:16:13,740 --> 00:16:11,580
Hubble image but it is a composite okay

365
00:16:15,540 --> 00:16:13,750
way too many people on the internet that

366
00:16:18,060 --> 00:16:15,550
thought this was a single image all

367
00:16:20,130 --> 00:16:18,070
right and if you look at this okay go

368
00:16:21,960 --> 00:16:20,140
back to this you can see there's no way

369
00:16:23,730 --> 00:16:21,970
you can get Mars in the same exposure

370
00:16:26,580 --> 00:16:23,740
anywhere near that you can get the comet

371
00:16:30,450 --> 00:16:26,590
so what Hubble did here is Hubble took

372
00:16:32,580 --> 00:16:30,460
separate images of Mars and of the comet

373
00:16:34,440 --> 00:16:32,590
all right so that it could do the

374
00:16:37,440 --> 00:16:34,450
exposure level correctly for each and

375
00:16:41,100 --> 00:16:37,450
then we mosaic them together to show the

376
00:16:43,200 --> 00:16:41,110
correct relative scale okay so you can

377
00:16:45,690 --> 00:16:43,210
see this is the 20 Mars diameters across

378
00:16:48,270 --> 00:16:45,700
right all right but that's the scale of

379
00:16:50,220 --> 00:16:48,280
the coma of the comet and you can see

380
00:16:54,030 --> 00:16:50,230
it's not quite big enough to really have

381
00:16:56,940 --> 00:16:54,040
caused major havoc at Mars so we had a

382
00:16:59,280 --> 00:16:56,950
really really close approach between two

383
00:17:01,530 --> 00:16:59,290
objects in the solar system on the

384
00:17:03,540 --> 00:17:01,540
scales of billions of miles they were

385
00:17:05,460 --> 00:17:03,550
coming in you know at just a hundred

386
00:17:08,250 --> 00:17:05,470
thousandth of my hundred thousand a

387
00:17:10,640 --> 00:17:08,260
hundred thousand miles but even then it

388
00:17:13,650 --> 00:17:10,650

wasn't enough to cause any major havoc

389
00:17:17,220 --> 00:17:13,660
so it was it was an interesting event

390
00:17:22,980 --> 00:17:17,230
but nothing nothing Mars shattering how

391
00:17:27,390 --> 00:17:22,990
about that all right finally the coolest

392
00:17:28,770 --> 00:17:27,400
image I have seen in years and I call it

393
00:17:30,360 --> 00:17:28,780
mining the gaps

394
00:17:32,040 --> 00:17:30,370
and those have you been to London

395
00:17:36,540 --> 00:17:32,050
understand what I'm talking about

396
00:17:40,050 --> 00:17:36,550
so we have for many years been seeing

397
00:17:43,860 --> 00:17:40,060
disks of material around newborn stars

398
00:17:46,140 --> 00:17:43,870
okay young stars as we as a as a cloud

399
00:17:49,050 --> 00:17:46,150
of dust material collapses to form a

400
00:17:51,030 --> 00:17:49,060
star it forms a disk around it and here

401
00:17:53,460 --> 00:17:51,040
you can see on the left au microscopy

402
00:17:56,010 --> 00:17:53,470
where we see the edge on of the disk and

403
00:17:59,010 --> 00:17:56,020
on the right HD 107 146 where we see the

404
00:18:00,420 --> 00:17:59,020
face onto these disks okay and this the

405
00:18:01,950 --> 00:18:00,430
star in the centre of course is blocked

406
00:18:04,230 --> 00:18:01,960
out by a coronagraph so you can actually

407
00:18:08,880 --> 00:18:04,240
see the disk disk of material around it

408
00:18:10,800 --> 00:18:08,890
and so we're seeing these disks and they

409
00:18:12,630 --> 00:18:10,810
can be sometimes kind of ratty but you

410
00:18:14,160 --> 00:18:12,640
know we can see in the top and the

411
00:18:15,990 --> 00:18:14,170
bottom here we've got the observation

412
00:18:18,030 --> 00:18:16,000
from Hubble and the bottom is the

413
00:18:19,980 --> 00:18:18,040

artist's interpretation to help you

414
00:18:22,470 --> 00:18:19,990
guide your eye in terms of seeing these

415
00:18:24,690 --> 00:18:22,480
disks around these objects and so we're

416
00:18:27,810 --> 00:18:24,700
finally seeing lots and lots of these

417
00:18:29,930 --> 00:18:27,820
disks we're confirming that star and

418
00:18:33,540 --> 00:18:29,940
plant information goes through a disk

419
00:18:35,940 --> 00:18:33,550
furthermore in some places such as foam

420
00:18:38,460 --> 00:18:35,950
alot we're seeing these rings and you

421
00:18:42,000 --> 00:18:38,470
see this thin ring out here and this

422
00:18:45,900 --> 00:18:42,010
ring at foam a lot okay was indicative

423
00:18:47,940 --> 00:18:45,910
of the idea that planets had formed one

424
00:18:50,190 --> 00:18:47,950
because it was a nice thin ring and you

425
00:18:52,440 --> 00:18:50,200
need a gravitational body to create that

426
00:18:54,750 --> 00:18:52,450
ring and to because that ring was

427
00:18:56,550 --> 00:18:54,760
slightly off center and a gravitational

428
00:18:59,010 --> 00:18:56,560
pull of a planet could have pulled it

429
00:19:03,230 --> 00:18:59,020
off center and so info a lot we went in

430
00:19:05,460 --> 00:19:03,240
looking and we found a planet okay that

431
00:19:06,930 --> 00:19:05,470
potentially could cause it and we

432
00:19:11,190 --> 00:19:06,940
believe that that that is the planet

433
00:19:14,010 --> 00:19:11,200
that caused the the ring there now

434
00:19:16,350 --> 00:19:14,020
Hubble has great resolution okay it does

435
00:19:18,540 --> 00:19:16,360
amazing things but there's a new

436
00:19:20,640 --> 00:19:18,550
telescope that has just come online oops

437
00:19:21,840 --> 00:19:20,650
I'm sorry I forgot about that this other

438
00:19:24,360 --> 00:19:21,850

thing there's one other observation I

439
00:19:27,150 --> 00:19:24,370
wanted to do in the setup is the Keck

440
00:19:29,550 --> 00:19:27,160
Observatory okay this is the star the

441
00:19:31,080 --> 00:19:29,560
disk around beta Pictoris the Hubble

442
00:19:32,850 --> 00:19:31,090
observations on the bottom and the

443
00:19:35,670 --> 00:19:32,860
center of the thing up top you can

444
00:19:37,650 --> 00:19:35,680
actually start to see lumps in the the

445
00:19:39,150 --> 00:19:37,660
disc now this is an edge-on disc and you

446
00:19:40,770 --> 00:19:39,160
can see lumps in it where you think that

447
00:19:42,270 --> 00:19:40,780
planets might start

448
00:19:45,150 --> 00:19:42,280
start forming so we're beginning to see

449
00:19:47,520 --> 00:19:45,160
not just the disks and these rings and

450
00:19:49,050 --> 00:19:47,530
these lumps within the Rings to try and

451
00:19:51,660 --> 00:19:49,060
indicate the possibility of planet

452
00:19:54,680 --> 00:19:51,670
formation within them right but there's

453
00:19:58,590 --> 00:19:54,690
a new telescope on the Atacama Desert at

454
00:20:00,870 --> 00:19:58,600
15,000 feet in Chile and this is a

455
00:20:02,910 --> 00:20:00,880
millimeter wave observatory it's called

456
00:20:05,940 --> 00:20:02,920
the Atacama Large millimeter or array

457
00:20:09,240 --> 00:20:05,950
and with it they can separate their

458
00:20:12,000 --> 00:20:09,250
dishes by up to 15 kilometres they can

459
00:20:14,700 --> 00:20:12,010
synthesize a telescope that's 15

460
00:20:17,040 --> 00:20:14,710
kilometers in length and this is the

461
00:20:20,640 --> 00:20:17,050
artist's depiction and here is a shot of

462
00:20:23,460 --> 00:20:20,650
the partially built atacama Alma up up

463
00:20:27,030 --> 00:20:23,470

there and with that they can start

464
00:20:31,530 --> 00:20:27,040
looking at the amazing things so they

465
00:20:40,350 --> 00:20:31,540
looked at a star named HL Tauri ok HL

466
00:20:41,970 --> 00:20:40,360
Tauri I don't have my HL Tauri is

467
00:20:44,280 --> 00:20:41,980
somewhere in here this is a Hubble image

468
00:20:47,270 --> 00:20:44,290
alright you can see that and these eeeh

469
00:20:49,650 --> 00:20:47,280
right in there there is a star HL Tauri

470
00:20:53,040 --> 00:20:49,660
and they looked at it in millimeter

471
00:20:57,450 --> 00:20:53,050
wavelengths and they got an absolutely

472
00:20:59,280 --> 00:20:57,460
amazing image ok in that small region

473
00:21:04,140 --> 00:20:59,290
they were able to see this let me pull

474
00:21:07,770 --> 00:21:04,150
it up full size this is the disc around

475
00:21:11,310 --> 00:21:07,780
a 1 million year old star we can see the

476
00:21:13,580 --> 00:21:11,320
gaps and the ring structures and the

477
00:21:17,460 --> 00:21:13,590
holes in the ring structures which are

478
00:21:20,820 --> 00:21:17,470
incredibly indicative of the formation

479
00:21:23,640 --> 00:21:20,830
of planets in this disc all right we

480
00:21:26,280 --> 00:21:23,650
have never seen a disc in anywhere near

481
00:21:26,850 --> 00:21:26,290
this detail this is an amazing image it

482
00:21:29,040 --> 00:21:26,860
floored

483
00:21:31,740 --> 00:21:29,050
all of us we were passing it around if I

484
00:21:33,540 --> 00:21:31,750
email so many astronomers posted it on

485
00:21:36,750 --> 00:21:33,550
Facebook and Google+ all over the place

486
00:21:40,290 --> 00:21:36,760
just a stunning image this is the first

487
00:21:42,900 --> 00:21:40,300
high-res image release from Alma when

488
00:21:44,640 --> 00:21:42,910

they're out in the 15 kilometer baseline

489
00:21:46,740 --> 00:21:44,650
mode where they can get the highest

490
00:21:48,870 --> 00:21:46,750
resolution they will actually look in

491
00:21:51,360 --> 00:21:48,880
lower frequencies able to get even

492
00:21:53,680 --> 00:21:51,370
higher resolution than this it just

493
00:21:56,259 --> 00:21:53,690
augers an incredible

494
00:21:58,960 --> 00:21:56,269
credible wealth of information in

495
00:22:03,190 --> 00:21:58,970
millimeter way of astronomy to come from

496
00:22:05,080 --> 00:22:03,200
Alma and this is literally one of the

497
00:22:10,090 --> 00:22:05,090
most amazing images I've seen in years

498
00:22:13,119 --> 00:22:10,100
so we're seeing details of plant

499
00:22:21,490 --> 00:22:13,129
formation around other stars really cool

500
00:22:22,629 --> 00:22:21,500
stuff maybe I might be but might may be

501
00:22:23,560 --> 00:22:22,639
flipping that they're gonna look how

502
00:22:24,909 --> 00:22:23,570
about this they look at other

503
00:22:27,389 --> 00:22:24,919
frequencies and get slightly higher

504
00:22:29,499 --> 00:22:27,399
resolution than this how about that I

505
00:22:30,940 --> 00:22:29,509
just think I've been given a teacher

506
00:22:35,499 --> 00:22:30,950
works trough the last two hours I can't

507
00:22:37,119 --> 00:22:35,509
think anymore okay so that's the news

508
00:22:40,419 --> 00:22:37,129
from the universe and it's time to move

509
00:22:43,149 --> 00:22:40,429
over to our featured speaker our speaker

510
00:22:45,100 --> 00:22:43,159
tonight is Mark kamionkowski who comes

511
00:22:50,350 --> 00:22:45,110
to us all the way from across the street

512
00:22:52,600 --> 00:22:50,360
at the Johns Hopkins University mark got

513
00:22:55,600 --> 00:22:52,610

his undergraduate degree at Washington

514
00:22:57,820 --> 00:22:55,610
University in st. Louis then went on to

515
00:23:01,570 --> 00:22:57,830
get his graduate did his graduate work

516
00:23:05,470 --> 00:23:01,580
at the University of Chicago then went

517
00:23:07,509 --> 00:23:05,480
on to Columbia University where I oh no

518
00:23:09,039 --> 00:23:07,519
I'm sorry he went to Princeton at the

519
00:23:11,669 --> 00:23:09,049
Institute for Advanced Study for a

520
00:23:15,999 --> 00:23:11,679
postdoc and then went up to Columbia

521
00:23:18,279 --> 00:23:16,009
where he gave me half a job after I

522
00:23:20,619 --> 00:23:18,289
finished my postdoc at Princeton I got

523
00:23:22,480 --> 00:23:20,629
half a postdoc at Columbia with Mark and

524
00:23:25,269 --> 00:23:22,490
half a postdoc at the America Museum of

525
00:23:28,330 --> 00:23:25,279
Natural History with Neil Tyson so they

526
00:23:31,840 --> 00:23:28,340
shared me for a couple years before I

527
00:23:33,970 --> 00:23:31,850
moved on to M & H fully so obviously

528
00:23:36,789 --> 00:23:33,980
indebted to him for that then he went

529
00:23:40,060 --> 00:23:36,799
out to Caltech professor there and

530
00:23:41,950 --> 00:23:40,070
finally came here to Johns Hopkins he is

531
00:23:44,049 --> 00:23:41,960
definitely one of the world's experts in

532
00:23:45,129 --> 00:23:44,059
the cosmic wave background and really

533
00:23:46,810 --> 00:23:45,139
looking forward to hearing from him

534
00:23:54,730 --> 00:23:46,820
ladies and gentlemen dr. Mark

535
00:24:03,500 --> 00:24:01,370
thank you very much so Frank and I

536
00:24:05,780 --> 00:24:03,510
overlapped for a few years Columbia and

537
00:24:11,840 --> 00:24:05,790
one of the things we did together is try

538
00:24:14,600 --> 00:24:11,850

to figure out why galaxies spin we made

539
00:24:15,850 --> 00:24:14,610
some progress so today I'm going to tell

540
00:24:19,480 --> 00:24:15,860
you about something completely different

541
00:24:22,880 --> 00:24:19,490
I'm gonna tell you about some new

542
00:24:26,060 --> 00:24:22,890
measurements that have been made the

543
00:24:29,120 --> 00:24:26,070
results were announced in March and we

544
00:24:30,410 --> 00:24:29,130
may be seeing a signal from the first

545
00:24:31,730 --> 00:24:30,420
trillionth of a trillionth of a

546
00:24:35,150 --> 00:24:31,740
trillionth of a second after the Big

547
00:24:38,030 --> 00:24:35,160
Bang whether we are not still remains to

548
00:24:42,650 --> 00:24:38,040
be determined and I will try to explain

549
00:24:44,270 --> 00:24:42,660
to you the story so just to begin this

550
00:24:45,530 --> 00:24:44,280
was a there was a press conference at

551
00:24:49,880 --> 00:24:45,540
the harvard-smithsonian Center for

552
00:24:55,400 --> 00:24:49,890
Astrophysics where the team which is

553
00:24:57,260 --> 00:24:55,410
called I Sept 2 announced discovery of

554
00:25:00,860 --> 00:24:57,270
gravitational waves from the Big Bang

555
00:25:03,020 --> 00:25:00,870
and the harvard-smithsonian Center for

556
00:25:05,390 --> 00:25:03,030
Astrophysics has these types of press

557
00:25:07,220 --> 00:25:05,400
conferences all the time because they're

558
00:25:08,300 --> 00:25:07,230
discovering exoplanets all the time and

559
00:25:09,380 --> 00:25:08,310
this is one of the places where they

560
00:25:12,260 --> 00:25:09,390
announced the discovery of the

561
00:25:14,240 --> 00:25:12,270
exoplanets the response to this

562
00:25:15,680 --> 00:25:14,250
particular news conference though was

563
00:25:18,350 --> 00:25:15,690

unlike anything they had ever seen

564
00:25:20,210 --> 00:25:18,360
before and in fact most people who tried

565
00:25:22,190 --> 00:25:20,220
to log in to the website to watch the

566
00:25:24,320 --> 00:25:22,200
news conference life were unable to do

567
00:25:26,720 --> 00:25:24,330
so because there was such demand to

568
00:25:28,730 --> 00:25:26,730
watch it that the demand actually

569
00:25:32,480 --> 00:25:28,740
brought the Harvard web service to their

570
00:25:34,610 --> 00:25:32,490
knees so it was really really huge it

571
00:25:37,220 --> 00:25:34,620
was written up in Scientific American it

572
00:25:40,190 --> 00:25:37,230
was front page on the New York Times New

573
00:25:42,950 --> 00:25:40,200
Scientist every single news source in

574
00:25:46,130 --> 00:25:42,960
the world covered the story and in

575
00:25:51,950 --> 00:25:46,140
particular through was if I can find it

576
00:25:56,510 --> 00:25:51,960
here this Saturday morning afterwards so

577
00:25:57,650 --> 00:25:56,520
let me play Danny welcome to the show

578
00:25:59,990 --> 00:25:57,660
you're gonna start us off with who's

579
00:26:01,970 --> 00:26:00,000
Karl this time Carl kasell living legend

580
00:26:03,680 --> 00:26:01,980
that he is is going to recreate for you

581
00:26:04,710 --> 00:26:03,690
three quotations of the week's news your

582
00:26:06,330 --> 00:26:04,720
job of course identify

583
00:26:08,130 --> 00:26:06,340
I explained just two of them do that

584
00:26:09,600 --> 00:26:08,140
you'll win our prize calls voice on your

585
00:26:12,299 --> 00:26:09,610
home answering machine you ready to go

586
00:26:14,010 --> 00:26:12,309
yeah all right here is your first quote

587
00:26:17,010 --> 00:26:14,020
that's pretty damn cool

588
00:26:19,529 --> 00:26:17,020

that was a theoretical physicist named

589
00:26:21,870 --> 00:26:19,539
Mark chemin outski he's reacting to news

590
00:26:25,289 --> 00:26:21,880
that researchers had found evidence of

591
00:26:28,200 --> 00:26:25,299
what the big bang indeed yes the big

592
00:26:30,659 --> 00:26:28,210
bang or what came right after the Big

593
00:26:32,850 --> 00:26:30,669
Bang basically the beginning of the

594
00:26:34,740 --> 00:26:32,860
universe physicists all over the world

595
00:26:36,149 --> 00:26:34,750
were incredibly excited they said the

596
00:26:38,460 --> 00:26:36,159
discoveries that was announced this week

597
00:26:40,830 --> 00:26:38,470
was the most revolutionary advance in

598
00:26:42,810 --> 00:26:40,840
science and decades it's amazingly cool

599
00:26:46,740 --> 00:26:42,820
it's deeply important it is impossible

600
00:26:48,690 --> 00:26:46,750
to explain in English they tried they

601
00:26:51,090 --> 00:26:48,700
compared the universe to a grapefruit to

602
00:26:53,220 --> 00:26:51,100
a pot of boiling pasta to bread dough

603
00:26:55,789 --> 00:26:53,230
being stretched and then we realized the

604
00:26:58,289 --> 00:26:55,799
physicists had just skipped their lunch

605
00:27:01,169 --> 00:26:58,299
and what happened this week as they

606
00:27:02,970 --> 00:27:01,179
announced an experiment that proved that

607
00:27:04,620 --> 00:27:02,980
they were right they predicted this

608
00:27:06,659 --> 00:27:04,630
result and they got it and they said

609
00:27:09,899 --> 00:27:06,669
this was such an amazing discovery so

610
00:27:12,210 --> 00:27:09,909
specific that one person made an analogy

611
00:27:13,560 --> 00:27:12,220
to imagine if someone were to create a

612
00:27:15,990 --> 00:27:13,570
model of the world in which they

613
00:27:18,240 --> 00:27:16,000

predicted that there would be age this

614
00:27:20,880 --> 00:27:18,250
is their example a little troll doll

615
00:27:23,850 --> 00:27:20,890
under a floorboard on the third floor of

616
00:27:26,130 --> 00:27:23,860
Ruth Bader Ginsburg childhood home right

617
00:27:27,779 --> 00:27:26,140
now the example and then this week's

618
00:27:29,310 --> 00:27:27,789
discovery was like somebody going to the

619
00:27:30,899 --> 00:27:29,320
home going to the third floor opening up

620
00:27:33,400 --> 00:27:30,909
a floorboard and finding it that's how

621
00:27:36,020 --> 00:27:33,410
amazing this prediction was that

622
00:27:40,640 --> 00:27:36,030
so that would be exciting like if I

623
00:27:43,700 --> 00:27:40,650
found it anyway so I am actually gonna

624
00:27:45,290 --> 00:27:43,710
try to explain it to you in English and

625
00:27:47,500 --> 00:27:45,300
Frank you're not the only one to screw

626
00:27:51,800 --> 00:27:47,510
up my last name as you can tell here

627
00:27:55,310 --> 00:27:51,810
that's okay so that was a March 18th

628
00:27:58,850 --> 00:27:55,320
2014 but it's been over half a year

629
00:28:01,550 --> 00:27:58,860
since and since then there have been a

630
00:28:03,350 --> 00:28:01,560
number of questions raised so these are

631
00:28:05,480 --> 00:28:03,360
some of the headlines backlist a Big

632
00:28:07,850 --> 00:28:05,490
Bang discovery gathers steam no evidence

633
00:28:09,950 --> 00:28:07,860
for against gravitational waves they

634
00:28:13,370 --> 00:28:09,960
named discovery comes under fire etc etc

635
00:28:15,440 --> 00:28:13,380
so as Carl Sagan said extraordinary

636
00:28:18,590 --> 00:28:15,450
result results require extraordinary

637
00:28:21,140 --> 00:28:18,600
scrutiny and these results if true are

638
00:28:22,940 --> 00:28:21,150

as extraordinary as it gets and they

639
00:28:25,310 --> 00:28:22,950
therefore require the most extraordinary

640
00:28:27,800 --> 00:28:25,320
scrutiny so I'm going to give you an

641
00:28:29,480 --> 00:28:27,810
update to try to tell you what is going

642
00:28:31,850 --> 00:28:29,490
on and what you might want to look

643
00:28:34,160 --> 00:28:31,860
forward for in the future so here's a

644
00:28:36,650 --> 00:28:34,170
brief outline so I'm gonna give you some

645
00:28:38,300 --> 00:28:36,660
background in Cosmo about cosmology I'm

646
00:28:41,000 --> 00:28:38,310
then gonna tell you about an idea that

647
00:28:42,950 --> 00:28:41,010
known as inflation it was postulated by

648
00:28:45,350 --> 00:28:42,960
a variety of theoretical physicists

649
00:28:48,830 --> 00:28:45,360
about 35 years ago and roughly speaking

650
00:28:51,230 --> 00:28:48,840
it's an idea for what set the Big Bang

651
00:28:53,120 --> 00:28:51,240
in motion I'm thinking I'm going to tell

652
00:28:55,310 --> 00:28:53,130
you how it is that we make measurements

653
00:28:57,860 --> 00:28:55,320
of the Cosmic Microwave Background and

654
00:28:59,480 --> 00:28:57,870
how it is that we infer all this

655
00:29:01,610 --> 00:28:59,490
information about the early universe

656
00:29:04,040 --> 00:29:01,620
from the measurements that we make and

657
00:29:19,190 --> 00:29:04,050
then at the end I'll explain what bicep2

658
00:29:29,730 --> 00:29:25,950
okay so I'll explain to you thank you so

659
00:29:31,080 --> 00:29:29,740
I'll explain to you what bicep saw why

660
00:29:32,580 --> 00:29:31,090
we believe they may be seeing

661
00:29:34,920 --> 00:29:32,590
gravitational waves for inflation but

662
00:29:37,260 --> 00:29:34,930
also the possibility that they might be

663
00:29:41,220 --> 00:29:37,270

seeing nothing more than interstellar

664
00:29:43,230 --> 00:29:41,230
dust so there was a NASA satellite that

665
00:29:45,270 --> 00:29:43,240
flew in the early 1990s called

666
00:29:49,130 --> 00:29:45,280
the cosmic background Explorer which we

667
00:29:51,810 --> 00:29:49,140
abbreviate as Kobe and it made a map of

668
00:29:53,580 --> 00:29:51,820
this Cosmic Microwave Background and

669
00:29:55,230 --> 00:29:53,590
that map looked like this and I'll tell

670
00:29:57,299 --> 00:29:55,240
you in a few more slides more precisely

671
00:30:00,660 --> 00:29:57,309
what it is that we're looking for but

672
00:30:02,760 --> 00:30:00,670
very very literally this picture is

673
00:30:06,090 --> 00:30:02,770
actually a picture of the afterglow of

674
00:30:09,960 --> 00:30:06,100
the Big Bang this was a very exciting

675
00:30:11,880 --> 00:30:09,970
science result the two principal

676
00:30:13,620 --> 00:30:11,890
investigators for the project I'm George

677
00:30:15,150 --> 00:30:13,630
Smoot and John Mather who's down the

678
00:30:17,970 --> 00:30:15,160
road to counter Space Flight Center and

679
00:30:20,460 --> 00:30:17,980
who's now the chief scientist for JWST

680
00:30:22,590 --> 00:30:20,470
is that right chief scientist yeah so

681
00:30:25,230 --> 00:30:22,600
they were awarded the 2006 Nobel Prize

682
00:30:30,990 --> 00:30:25,240
so this was a big deal in the world of

683
00:30:33,240 --> 00:30:31,000
cosmology and physics about a decade

684
00:30:34,980 --> 00:30:33,250
later there was another satellite

685
00:30:36,900 --> 00:30:34,990
mission flown by NASA called the

686
00:30:39,330 --> 00:30:36,910
Wilkinson microwave anisotropy probe

687
00:30:41,460 --> 00:30:39,340
named after David Wilkinson a physics

688
00:30:43,620 --> 00:30:41,470

professor at Princeton University who

689
00:30:45,270 --> 00:30:43,630
passed away shortly after the launch who

690
00:30:47,010 --> 00:30:45,280
was responsible for doing a lot of the

691
00:30:49,620 --> 00:30:47,020
work that late a lot of the groundwork

692
00:30:53,430 --> 00:30:49,630
for this measurement so this is the map

693
00:30:55,710 --> 00:30:53,440
that the W Maps satellite made about ten

694
00:30:58,320 --> 00:30:55,720
years ago and again this has been

695
00:31:01,200 --> 00:30:58,330
extraordinarily scientifically fruitful

696
00:31:04,200 --> 00:31:01,210
measurement or experiment and I can tell

697
00:31:05,910 --> 00:31:04,210
you that the papers that have come out

698
00:31:08,250 --> 00:31:05,920
of the W Mapp collaboration have been

699
00:31:10,620 --> 00:31:08,260
the most highly cited science paper most

700
00:31:14,000 --> 00:31:10,630
highly cited papers in all of science

701
00:31:16,470 --> 00:31:14,010
and inside citations are our currency

702
00:31:18,630 --> 00:31:16,480
papers they get lots of citations by

703
00:31:20,460 --> 00:31:18,640
other scientists are very very valuable

704
00:31:22,440 --> 00:31:20,470
and these papers have received more

705
00:31:26,400 --> 00:31:22,450
citations than any other science project

706
00:31:29,460 --> 00:31:26,410
over the past decade and I should say

707
00:31:30,750 --> 00:31:29,470
that the principal investigator of w map

708
00:31:32,280 --> 00:31:30,760
is actually Chuck Bennett

709
00:31:34,049 --> 00:31:32,290
who's a professor of physics

710
00:31:38,159 --> 00:31:34,059
and astronomy right across the street

711
00:31:40,620 --> 00:31:38,169
here and then more recently launched in

712
00:31:42,630 --> 00:31:40,630
2009 and taking data since then the

713
00:31:44,490 --> 00:31:42,640

European Space Agency has developed a

714
00:31:47,340 --> 00:31:44,500
subsequent generation experiment called

715
00:31:49,860 --> 00:31:47,350
the Planck satellite and this is the

716
00:31:52,080 --> 00:31:49,870
image that was first provided by the

717
00:31:54,419 --> 00:31:52,090
Planck satellite in March of last year

718
00:31:56,940 --> 00:31:54,429
and again this was very exciting science

719
00:31:58,470 --> 00:31:56,950
very science exciting science result it

720
00:32:00,710 --> 00:31:58,480
was announced again on the front page of

721
00:32:03,960 --> 00:32:00,720
the New York Times and other news eight

722
00:32:05,340 --> 00:32:03,970
news sources throughout the world so

723
00:32:07,799 --> 00:32:05,350
this is a picture of the Cosmic

724
00:32:10,950 --> 00:32:07,809
Microwave Background as imaged by Kobe

725
00:32:12,390 --> 00:32:10,960
from the early 1990s this is an image of

726
00:32:16,080 --> 00:32:12,400
the Cosmic Microwave Background is

727
00:32:17,669 --> 00:32:16,090
imaged by W map and this is the image of

728
00:32:19,500 --> 00:32:17,679
the Cosmic Microwave Background provided

729
00:32:21,330 --> 00:32:19,510
by Planck so you see that every 10 years

730
00:32:24,390 --> 00:32:21,340
we've been able to do much better in

731
00:32:27,299 --> 00:32:24,400
terms of angular resolution and angular

732
00:32:30,990 --> 00:32:27,309
resolution is good as you've seen just

733
00:32:33,690 --> 00:32:31,000
with that picture of that's that the

734
00:32:38,220 --> 00:32:33,700
protoplanetary disk it's nice to have

735
00:32:46,590 --> 00:32:38,230
more information so here's a picture

736
00:32:48,840 --> 00:32:46,600
does anybody know what's here close so

737
00:32:51,330 --> 00:32:48,850
actually I gave this talk I think it

738
00:32:53,850 --> 00:32:51,340

might be the projector quality I gave

739
00:32:57,270 --> 00:32:53,860
this talk in Aspen Colorado and

740
00:32:58,620 --> 00:32:57,280
everybody saw what it was I've given the

741
00:33:00,150 --> 00:32:58,630
talk several other times and people

742
00:33:04,710 --> 00:33:00,160
don't know what it is so here's a

743
00:33:06,210 --> 00:33:04,720
high-resolution image okay but still

744
00:33:07,620 --> 00:33:06,220
that's a pretty blurry image you know

745
00:33:09,690 --> 00:33:07,630
what's going on here that's the Mona

746
00:33:13,049 --> 00:33:09,700
Lisa and then here's a much more high

747
00:33:15,510 --> 00:33:13,059
much higher resolution image and this is

748
00:33:18,450 --> 00:33:15,520
a very pretty picture and we can infer a

749
00:33:20,460 --> 00:33:18,460
lot about you know about the picture by

750
00:33:21,810 --> 00:33:20,470
looking at this blurred image we know

751
00:33:22,980 --> 00:33:21,820
that it's the Mona Lisa we know there's

752
00:33:25,320 --> 00:33:22,990
a picture of a woman and she's sitting

753
00:33:26,370 --> 00:33:25,330
there and these are her two hands but

754
00:33:28,140 --> 00:33:26,380
this is a much more high-resolution

755
00:33:30,480 --> 00:33:28,150
image and there's a lot more information

756
00:33:32,010 --> 00:33:30,490
in here and if you're an art historian

757
00:33:35,730 --> 00:33:32,020
you would actually go look at the

758
00:33:37,409 --> 00:33:35,740
detailed brushstrokes and infer not only

759
00:33:38,760 --> 00:33:37,419
something about the general you know

760
00:33:40,919 --> 00:33:38,770
structure of the painting but you would

761
00:33:42,570 --> 00:33:40,929
actually learn a lot about how da Vinci

762
00:33:44,490 --> 00:33:42,580
actually went about making this painting

763
00:33:45,139 --> 00:33:44,500

so the point is that there's a lot more

764
00:33:47,329 --> 00:33:45,149
information

765
00:33:49,190 --> 00:33:47,339
available when we make high-resolution

766
00:33:51,469 --> 00:33:49,200
images and so now that we have this

767
00:33:52,940 --> 00:33:51,479
Planck satellite image of the Cosmic

768
00:33:57,169 --> 00:33:52,950
Microwave Background we have a huge

769
00:33:57,979 --> 00:33:57,179
amount more information than we did 20

770
00:34:01,070 --> 00:33:57,989
years ago

771
00:34:02,869 --> 00:34:01,080
so what exactly are we looking at so now

772
00:34:04,729 --> 00:34:02,879
I'm going to attempt to explain to you

773
00:34:07,009 --> 00:34:04,739
what it is that this image is showing us

774
00:34:10,220 --> 00:34:07,019
so to do that I'm first going to show

775
00:34:13,339 --> 00:34:10,230
you a picture of the night sky so this

776
00:34:15,470 --> 00:34:13,349
is a picture of the night sky as it

777
00:34:17,659 --> 00:34:15,480
appears when you go outside on a clear

778
00:34:19,549 --> 00:34:17,669
night and look at it and you see lots of

779
00:34:21,680 --> 00:34:19,559
stars and when you look with a very

780
00:34:23,269 --> 00:34:21,690
powerful telescope like the the Hubble

781
00:34:24,980 --> 00:34:23,279
telescope if you see pictures of the

782
00:34:27,980 --> 00:34:24,990
Hubble Deep Field you see lots of

783
00:34:29,750 --> 00:34:27,990
galaxies but the most salient feature of

784
00:34:31,730 --> 00:34:29,760
this is not the stars which are these

785
00:34:36,200 --> 00:34:31,740
tiny little dots but it's actually the

786
00:34:39,289 --> 00:34:36,210
black space in between so most of the

787
00:34:40,940 --> 00:34:39,299
sky is dark when you look at it at

788
00:34:42,680 --> 00:34:40,950

optical frequencies which are the

789
00:34:47,510 --> 00:34:42,690
electromagnetic frequencies at which

790
00:34:51,500 --> 00:34:47,520
your eyes operate but optical lights or

791
00:34:53,000 --> 00:34:51,510
visible light is covers only a very very

792
00:34:55,490 --> 00:34:53,010
narrow range of the entire

793
00:34:57,859 --> 00:34:55,500
electromagnetic frequency spectrum so

794
00:34:59,930 --> 00:34:57,869
visible light extends over a very small

795
00:35:01,490 --> 00:34:59,940
range of frequencies or wavelengths and

796
00:35:05,210 --> 00:35:01,500
as we go to the left we're going to

797
00:35:06,950 --> 00:35:05,220
longer wavelengths shorter frequencies

798
00:35:09,950 --> 00:35:06,960
as we go to the right we run to higher

799
00:35:12,410 --> 00:35:09,960
frequencies and shorter wavelengths so

800
00:35:14,089 --> 00:35:12,420
to slightly higher frequencies than

801
00:35:16,160 --> 00:35:14,099
visible light there's ultraviolet light

802
00:35:17,960 --> 00:35:16,170
which you need to worry about when you

803
00:35:21,079 --> 00:35:17,970
go outside when you go out in the beach

804
00:35:22,849 --> 00:35:21,089
there's infrared light at slightly lower

805
00:35:24,650 --> 00:35:22,859
frequencies which is how these are

806
00:35:27,980 --> 00:35:24,660
thermometers the two point that your

807
00:35:29,809 --> 00:35:27,990
forhead work there are microwave

808
00:35:31,519 --> 00:35:29,819
there's microwave radiation and even

809
00:35:34,370 --> 00:35:31,529
longer wavelengths this is how you heat

810
00:35:35,720 --> 00:35:34,380
up your leftover soup and the radio

811
00:35:38,120 --> 00:35:35,730
waves which is how we listen to the

812
00:35:39,769 --> 00:35:38,130
radio or watch TV at higher frequencies

813
00:35:40,940 --> 00:35:39,779

they're x-rays you know what x-rays are

814
00:35:43,039 --> 00:35:40,950
useful for and then even higher

815
00:35:44,210 --> 00:35:43,049
frequencies that are gamma rays so

816
00:35:46,069 --> 00:35:44,220
there's a broad spectrum of

817
00:35:48,470 --> 00:35:46,079
electromagnetic radiation and when we

818
00:35:50,809 --> 00:35:48,480
look at the sky with our eyes we're

819
00:35:53,779 --> 00:35:50,819
seeing only a tiny fraction of what is

820
00:35:56,420 --> 00:35:53,789
actually out there and in particular if

821
00:35:58,820 --> 00:35:56,430
you could look at the sky at microwave

822
00:36:00,890 --> 00:35:58,830
frequencies rather than visit

823
00:36:04,730 --> 00:36:00,900
frequency's the night sky would look

824
00:36:06,800 --> 00:36:04,740
like this this is actually a map of the

825
00:36:09,320 --> 00:36:06,810
sky as it would appear if your eyes are

826
00:36:11,030 --> 00:36:09,330
operated at optical free at microwave

827
00:36:14,750 --> 00:36:11,040
frequencies and it's actually

828
00:36:17,420 --> 00:36:14,760
superimposed on an image of the launch

829
00:36:19,730 --> 00:36:17,430
site for a telescope that was flown in

830
00:36:21,680 --> 00:36:19,740
the late 1990s called boomerang a

831
00:36:23,690 --> 00:36:21,690
balloon borne telescope that flew around

832
00:36:25,010 --> 00:36:23,700
Antarctica so this is actually a

833
00:36:26,780 --> 00:36:25,020
mountain in the background this is

834
00:36:28,700 --> 00:36:26,790
actually a cloud and this is what the

835
00:36:30,770 --> 00:36:28,710
night sky would look like if your eyes

836
00:36:33,140 --> 00:36:30,780
operate on microwave frequencies so at

837
00:36:37,730 --> 00:36:33,150
microwave frequencies the night sky is

838
00:36:40,190 --> 00:36:37,740

not dark it blows this was anticipated

839
00:36:47,240 --> 00:36:40,200
not only by theoretical physicists but

840
00:36:50,150 --> 00:36:47,250
also by hand go and this is a picture of

841
00:36:52,220 --> 00:36:50,160
a small fraction of the sky this is

842
00:36:55,370 --> 00:36:52,230
actually a current state-of-the-art

843
00:36:58,910 --> 00:36:55,380
image of the microwave sky so this is

844
00:37:01,580 --> 00:36:58,920
actually a map of the entire sky in all

845
00:37:04,790 --> 00:37:01,590
directions and it is called a mala wide

846
00:37:06,830 --> 00:37:04,800
or equal area projection so if we took a

847
00:37:09,080 --> 00:37:06,840
map of the earth the earth is has a

848
00:37:11,420 --> 00:37:09,090
spherical surface if we were to sort of

849
00:37:12,680 --> 00:37:11,430
unwrap it and plot it in this way then

850
00:37:14,870 --> 00:37:12,690
you would see North America over here

851
00:37:16,640 --> 00:37:14,880
South America over here Eurasia Africa

852
00:37:19,250 --> 00:37:16,650
Antarctica at the bottom and Australia

853
00:37:21,470 --> 00:37:19,260
over here so what we look at over here

854
00:37:24,860 --> 00:37:21,480
is an image actually of the entire

855
00:37:26,900 --> 00:37:24,870
surface of the sky unwrapped so that we

856
00:37:30,080 --> 00:37:26,910
can plot it on the Sun in this form over

857
00:37:34,400 --> 00:37:30,090
here and what you're seeing with these

858
00:37:37,940 --> 00:37:34,410
color contrasts what you're seeing with

859
00:37:40,430 --> 00:37:37,950
these color contrasts are regions of hot

860
00:37:42,650 --> 00:37:40,440
or brighter or fainter regions regions

861
00:37:45,380 --> 00:37:42,660
that are brighter or fainter but only by

862
00:37:47,570 --> 00:37:45,390
roughly one part in hundred thousand so

863
00:37:50,300 --> 00:37:47,580

to a first approximation this glow is

864
00:37:51,830 --> 00:37:50,310
very very uniform but if your eyes

865
00:37:54,380 --> 00:37:51,840
operated not only at microwave

866
00:37:55,970 --> 00:37:54,390
frequencies but could detect brightness

867
00:37:57,620 --> 00:37:55,980
fluctuations of one part one hundred

868
00:37:59,510 --> 00:37:57,630
thousand you would see that there are

869
00:38:00,890 --> 00:37:59,520
some colder regions and some hotter

870
00:38:05,180 --> 00:38:00,900
regions that's what these red and blue

871
00:38:07,910 --> 00:38:05,190
spots are so let me tell you a little

872
00:38:10,340 --> 00:38:07,920
bit about cosmology so cosmology is the

873
00:38:11,670 --> 00:38:10,350
study of the origin and evolution of the

874
00:38:13,770 --> 00:38:11,680
universe

875
00:38:15,270 --> 00:38:13,780
the first step in this direction is to

876
00:38:17,160 --> 00:38:15,280
actually understand something that's a

877
00:38:18,870 --> 00:38:17,170
bit smaller and closer to home the solar

878
00:38:20,520 --> 00:38:18,880
system and so we just heard a bunch of

879
00:38:22,290 --> 00:38:20,530
very interesting things that are going

880
00:38:27,420 --> 00:38:22,300
on in our exploration of the solar

881
00:38:32,280 --> 00:38:27,430
system we are one of eight or nine

882
00:38:36,030 --> 00:38:32,290
planets I don't know what the number of

883
00:38:39,120 --> 00:38:36,040
planets this week is but all of the

884
00:38:40,980 --> 00:38:39,130
planets orbit around the Sun and the

885
00:38:42,630 --> 00:38:40,990
reason they orbit around the Sun is that

886
00:38:44,070 --> 00:38:42,640
the Sun exerts a very strong

887
00:38:46,440 --> 00:38:44,080
gravitational has a very strong

888
00:38:50,010 --> 00:38:46,450

gravitational field that keeps all these

889
00:38:52,620 --> 00:38:50,020
planets in orbit around the Sun it turns

890
00:38:55,350 --> 00:38:52,630
out that our Sun is a star that's very

891
00:38:57,120 --> 00:38:55,360
special to us because it is our star but

892
00:38:59,550 --> 00:38:57,130
in the bigger picture there's nothing

893
00:39:02,790 --> 00:38:59,560
special about the Sun it turns out that

894
00:39:05,420 --> 00:39:02,800
it is one of roughly 10 billion such

895
00:39:08,070 --> 00:39:05,430
stars all of which are gravitationally

896
00:39:10,560 --> 00:39:08,080
agglomerate it into this huge structure

897
00:39:13,500 --> 00:39:10,570
that we call a galaxy in the name of our

898
00:39:16,410 --> 00:39:13,510
particular galaxy is the Milky Way so

899
00:39:18,870 --> 00:39:16,420
the Milky Way is a very massive object

900
00:39:20,730 --> 00:39:18,880
and it exerts a gravitational field and

901
00:39:23,190 --> 00:39:20,740
that gravitational key field keeps the

902
00:39:25,500 --> 00:39:23,200
orbit of each of these stars in a rough

903
00:39:27,660 --> 00:39:25,510
keeps each of these stars on a roughly

904
00:39:30,540 --> 00:39:27,670
circular orbit around the center of the

905
00:39:31,800 --> 00:39:30,550
galaxy and it takes our Sun about 200

906
00:39:36,300 --> 00:39:31,810
million years to get all the way around

907
00:39:39,090 --> 00:39:36,310
once so it turns out though that this

908
00:39:41,640 --> 00:39:39,100
Milky Way is a very special galaxy to us

909
00:39:43,080 --> 00:39:41,650
because it is our galaxy but again in

910
00:39:45,780 --> 00:39:43,090
the bigger picture there is nothing

911
00:39:48,570 --> 00:39:45,790
special about this galaxy it turns out

912
00:39:51,990 --> 00:39:48,580
that it is one of several hundred

913
00:39:55,110 --> 00:39:52,000

billion galaxies that we can see in our

914
00:39:57,090 --> 00:39:55,120
observable universe so this is not a

915
00:40:01,350 --> 00:39:57,100
picture of the universe this is actually

916
00:40:05,130 --> 00:40:01,360
a simulation a cosmological simulation

917
00:40:08,850 --> 00:40:05,140
actually Frank was one of the pioneers

918
00:40:11,730 --> 00:40:08,860
of simulations like this so each of

919
00:40:13,950 --> 00:40:11,740
these little dots here is a galaxy and

920
00:40:15,270 --> 00:40:13,960
this is a picture of a huge volume in

921
00:40:17,940 --> 00:40:15,280
the universe that shows how these

922
00:40:18,570 --> 00:40:17,950
galaxies are distributed throughout the

923
00:40:21,510 --> 00:40:18,580
universe

924
00:40:23,230 --> 00:40:21,520
so the earth spins around the Sun the

925
00:40:25,150 --> 00:40:23,240
Sun spins around the Milky Way

926
00:40:26,890 --> 00:40:25,160
and then you might imagine that all

927
00:40:29,260 --> 00:40:26,900
these galaxies wind up spinning around

928
00:40:31,589 --> 00:40:29,270
each other it turns out though that at

929
00:40:34,750 --> 00:40:31,599
this stage the hierarchy ends as

930
00:40:37,510 --> 00:40:34,760
discovered originally by this pipe

931
00:40:40,210 --> 00:40:37,520
smoking gentleman by the name of Edwin

932
00:40:43,000 --> 00:40:40,220
Hubble so Edwin Hubble was an astronomer

933
00:40:49,079 --> 00:40:43,010
at Carnegie observatories in Pasadena

934
00:40:51,190 --> 00:40:49,089
and he made a measurement that

935
00:40:56,589 --> 00:40:51,200
revolutionized our understanding of the

936
00:40:58,990 --> 00:40:56,599
universe so those of you who are fans of

937
00:41:01,210 --> 00:40:59,000
Isaac Asimov might be interested to pick

938
00:41:03,430 --> 00:41:01,220

up a big fat book he wrote called

939
00:41:05,589 --> 00:41:03,440
chronology of the history of science and

940
00:41:07,599 --> 00:41:05,599
it's a great book and it starts from

941
00:41:10,450 --> 00:41:07,609
ancient times and it goes through every

942
00:41:12,880 --> 00:41:10,460
year and lists the most exciting science

943
00:41:16,359 --> 00:41:12,890
discoveries of that year a collection of

944
00:41:18,700 --> 00:41:16,369
years and he has a very broad an

945
00:41:21,910 --> 00:41:18,710
interesting and unique perspective on

946
00:41:24,640 --> 00:41:21,920
all of science and in that book he calls

947
00:41:27,880 --> 00:41:24,650
this discovery along with the discovery

948
00:41:31,089 --> 00:41:27,890
of the double helix structure of the DNA

949
00:41:33,040 --> 00:41:31,099
molecule as the two most revolutionary

950
00:41:35,890 --> 00:41:33,050
and scientific advances of the 20th

951
00:41:39,940 --> 00:41:35,900
century so what Hubble did is he looked

952
00:41:41,890 --> 00:41:39,950
at a bunch of nearby galaxies and he

953
00:41:44,770 --> 00:41:41,900
measured or estimated the distance to

954
00:41:47,079 --> 00:41:44,780
each galaxy and then he also measured he

955
00:41:49,329 --> 00:41:47,089
also saw that every galaxy was moving

956
00:41:51,760 --> 00:41:49,339
away from us and he measured the

957
00:41:53,740 --> 00:41:51,770
velocity with which each galaxy was

958
00:41:55,839 --> 00:41:53,750
moving away from us and what he showed

959
00:41:57,880 --> 00:41:55,849
is that there's a correlation more

960
00:42:00,220 --> 00:41:57,890
distant galaxies are moving away from us

961
00:42:02,560 --> 00:42:00,230
at larger speeds than closer galaxies

962
00:42:04,660 --> 00:42:02,570
the galaxies that are fairly nearby are

963
00:42:06,579 --> 00:42:04,670

moving away from us but not so rapidly

964
00:42:09,390 --> 00:42:06,589
the ones that are more that are further

965
00:42:12,190 --> 00:42:09,400
away are moving away much faster and

966
00:42:16,930 --> 00:42:12,200
from this we infer that the universe is

967
00:42:18,670 --> 00:42:16,940
expanding and I made a movie you have to

968
00:42:21,190 --> 00:42:18,680
understand I'm a theoretical physicist

969
00:42:23,800 --> 00:42:21,200
this is very very high technology for me

970
00:42:26,680 --> 00:42:23,810
so I'm gonna show you a movie of an

971
00:42:29,800 --> 00:42:26,690
expanding universe so I want you to look

972
00:42:31,839 --> 00:42:29,810
at these two this pair of galaxies so

973
00:42:33,849 --> 00:42:31,849
there's this of each of these red lines

974
00:42:36,700 --> 00:42:33,859
supposed to be a galaxy or point into a

975
00:42:39,339 --> 00:42:36,710
galaxy I want you to look at this pair

976
00:42:42,160 --> 00:42:39,349
in this pair so the red pair are closer

977
00:42:44,500 --> 00:42:42,170
together and the blue pair are further

978
00:42:47,829 --> 00:42:44,510
away and now what I'm going to do is

979
00:42:49,630 --> 00:42:47,839
blow up the entire grid and as I blow up

980
00:42:51,760 --> 00:42:49,640
the entire grid which you're supposed to

981
00:42:54,730 --> 00:42:51,770
notice is that the blue points are

982
00:42:56,620 --> 00:42:54,740
moving away faster from moving away from

983
00:43:02,859 --> 00:42:56,630
each other faster than are the red

984
00:43:10,720 --> 00:43:02,869
points so let me play the movie so there

985
00:43:12,190 --> 00:43:10,730
it is you don't get that so the red

986
00:43:14,740 --> 00:43:12,200
points are moving away from each other

987
00:43:17,760 --> 00:43:14,750
whoops slightly larger it's slightly

988
00:43:22,870 --> 00:43:17,770

smaller velocities than the blue points

989
00:43:27,099 --> 00:43:22,880
so Edwin Hubble's discovery demonstrated

990
00:43:29,230 --> 00:43:27,109
that the universe is expanding if the

991
00:43:30,730 --> 00:43:29,240
universe is expanding today if all the

992
00:43:33,880 --> 00:43:30,740
galaxies are moving away from each other

993
00:43:35,559 --> 00:43:33,890
today that means that earlier times if

994
00:43:37,690 --> 00:43:35,569
we run this movie backwards at earlier

995
00:43:39,460 --> 00:43:37,700
times every galaxy would be closer

996
00:43:41,410 --> 00:43:39,470
together all of the galaxies would be

997
00:43:44,020 --> 00:43:41,420
much closer together the density of

998
00:43:46,240 --> 00:43:44,030
galaxies would be larger so the density

999
00:43:48,849 --> 00:43:46,250
of the universe the number of galaxies

1000
00:43:52,120 --> 00:43:48,859
per some unit volume would have been

1001
00:43:54,520 --> 00:43:52,130
larger so if this is what the universe

1002
00:43:59,020 --> 00:43:54,530
looks like today each of these dots

1003
00:44:00,309 --> 00:43:59,030
being a galaxy then at earlier times the

1004
00:44:01,569 --> 00:44:00,319
density would have been higher the

1005
00:44:04,150 --> 00:44:01,579
galaxies would have been closer together

1006
00:44:05,140 --> 00:44:04,160
and at earlier times the galaxies were

1007
00:44:10,059 --> 00:44:05,150
even closer together

1008
00:44:12,640 --> 00:44:10,069
etc etc etc so one thing that we can do

1009
00:44:16,450 --> 00:44:12,650
from Hubble's measurement is extrapolate

1010
00:44:19,000 --> 00:44:16,460
back in time if we see any two galaxies

1011
00:44:21,400 --> 00:44:19,010
moving away from each other today if we

1012
00:44:24,130 --> 00:44:21,410
run that movie back in time we can

1013
00:44:25,990 --> 00:44:24,140

figure out that at some finite time in

1014
00:44:28,960 --> 00:44:26,000
the past those galaxies must have been

1015
00:44:31,569 --> 00:44:28,970
on top of each other okay if I see a car

1016
00:44:33,910 --> 00:44:31,579
a mile away and I see that it's driving

1017
00:44:36,160 --> 00:44:33,920
away at 60 miles per hour I know that

1018
00:44:38,920 --> 00:44:36,170
one minute ago it was right here

1019
00:44:40,990 --> 00:44:38,930
so we do the same calculation with the

1020
00:44:45,069 --> 00:44:41,000
expansion rate that Hubble measured and

1021
00:44:47,430 --> 00:44:45,079
we infer that 13.8 billion years ago the

1022
00:44:49,990 --> 00:44:47,440
universe must have been in a state of

1023
00:44:53,380 --> 00:44:50,000
infinite density

1024
00:44:55,720 --> 00:44:53,390
and that is what we refer to as the Big

1025
00:45:03,099 --> 00:44:55,730
Bang so this is my picture of the

1026
00:45:04,450 --> 00:45:03,109
infinite density so I told someone today

1027
00:45:05,800 --> 00:45:04,460
I'm giving a public lecture this evening

1028
00:45:09,240 --> 00:45:05,810
they said you got to show them nice

1029
00:45:12,700 --> 00:45:09,250
pictures they love to see nice pictures

1030
00:45:16,510 --> 00:45:12,710
so here's a slightly nicer picture so

1031
00:45:18,280 --> 00:45:16,520
this is a picture that illustrates the

1032
00:45:21,339 --> 00:45:18,290
evolution of the universe as we

1033
00:45:24,099 --> 00:45:21,349
understand it now and it's made by the W

1034
00:45:25,750 --> 00:45:24,109
map collaboration so we live in the

1035
00:45:29,589 --> 00:45:25,760
universe that's thirteen point seven

1036
00:45:31,330 --> 00:45:29,599
seven billion years old and we observe

1037
00:45:33,940 --> 00:45:31,340
it with satellites like the W map

1038
00:45:35,830 --> 00:45:33,950

satellite and if we look back in time so

1039
00:45:38,589 --> 00:45:35,840
as we go from the right to the left

1040
00:45:41,380 --> 00:45:38,599
we're looking further further larger and

1041
00:45:44,290 --> 00:45:41,390
larger distances since light travels at

1042
00:45:45,670 --> 00:45:44,300
a finite speed when we look at larger

1043
00:45:47,920 --> 00:45:45,680
and larger distances we are seeing

1044
00:45:50,530 --> 00:45:47,930
objects as they were at earlier in

1045
00:45:52,630 --> 00:45:50,540
earlier times so when we look at fairly

1046
00:45:54,579 --> 00:45:52,640
nearby objects things like galaxies we

1047
00:45:57,280 --> 00:45:54,589
are seeing those galaxies as they were

1048
00:45:58,900 --> 00:45:57,290
fairly recently as we go to larger

1049
00:46:00,910 --> 00:45:58,910
distances for example with the Hubble

1050
00:46:02,589 --> 00:46:00,920
Space Telescope we can see galaxies that

1051
00:46:04,900 --> 00:46:02,599
are about ten billion years old ten

1052
00:46:08,620 --> 00:46:04,910
billion light years away we're seeing

1053
00:46:09,820 --> 00:46:08,630
things that are 10 billion years away 10

1054
00:46:11,370 --> 00:46:09,830
billion light years away we're seeing

1055
00:46:14,829 --> 00:46:11,380
them as they were a few billion years

1056
00:46:16,420 --> 00:46:14,839
after the Big Bang but even with our

1057
00:46:18,310 --> 00:46:16,430
most powerful telescopes there's only a

1058
00:46:20,859 --> 00:46:18,320
finite distance out to which we can see

1059
00:46:22,930 --> 00:46:20,869
with the James Webb Space Telescope we

1060
00:46:25,000 --> 00:46:22,940
actually hope to image directly the

1061
00:46:27,190 --> 00:46:25,010
first stars which we have very good

1062
00:46:29,800 --> 00:46:27,200
reason to believe were formed about 400

1063
00:46:32,020 --> 00:46:29,810

million years after the Big Bang but if

1064
00:46:32,980 --> 00:46:32,030
we look even further back which we can

1065
00:46:35,109 --> 00:46:32,990
do with these Cosmic Microwave

1066
00:46:36,160 --> 00:46:35,119
Background measurements when we make

1067
00:46:37,990 --> 00:46:36,170
these Cosmic Microwave Background

1068
00:46:41,200 --> 00:46:38,000
measurements were actually looking at

1069
00:46:43,000 --> 00:46:41,210
the universe as it was three hundred and

1070
00:46:45,790 --> 00:46:43,010
seventy five thousand years after the

1071
00:46:49,450 --> 00:46:45,800
Big Bang and we are looking back a

1072
00:46:52,300 --> 00:46:49,460
distance of about 13.8 eight billion

1073
00:46:53,589 --> 00:46:52,310
light-years now the thing that's so

1074
00:46:56,440 --> 00:46:53,599
exciting about these Cosmic Microwave

1075
00:46:58,390 --> 00:46:56,450
Background measurements is not only that

1076
00:46:59,920 --> 00:46:58,400
we're imaging the universe as it was

1077
00:47:02,050 --> 00:46:59,930
three hundred seventy-five thousand

1078
00:47:03,610 --> 00:47:02,060
years after the Big Bang but we have

1079
00:47:05,440 --> 00:47:03,620
very good reason to believe

1080
00:47:08,770 --> 00:47:05,450
as I will try to explain in the next few

1081
00:47:11,650 --> 00:47:08,780
slides that this image that we have

1082
00:47:14,410 --> 00:47:11,660
reflects directly what was happening in

1083
00:47:15,850 --> 00:47:14,420
the very first trillionth of a

1084
00:47:17,500 --> 00:47:15,860
trillionth of a trillionth of a second

1085
00:47:20,590 --> 00:47:17,510
after the Big Bang at the time that this

1086
00:47:21,880 --> 00:47:20,600
process which we hypothesize this

1087
00:47:25,050 --> 00:47:21,890
process called inflation that we

1088
00:47:28,960 --> 00:47:25,060

hypothesize should have been occurring

1089
00:47:30,370 --> 00:47:28,970
so one way of looking at how remarkable

1090
00:47:32,230 --> 00:47:30,380
this is is that when we look at this

1091
00:47:35,200 --> 00:47:32,240
Cosmic Microwave Background image of the

1092
00:47:37,900 --> 00:47:35,210
Big Bang the universe was 380,000 years

1093
00:47:41,580 --> 00:47:37,910
old it's now 13.8 billion years old if

1094
00:47:44,440 --> 00:47:41,590
you look at a human who is 50 years old

1095
00:47:47,380 --> 00:47:44,450
and you try to figure out what fraction

1096
00:47:50,710 --> 00:47:47,390
of the age must have been would they

1097
00:47:53,440 --> 00:47:50,720
have been when they were 375 thousand

1098
00:47:57,070 --> 00:47:53,450
years divided by 13.8 billion years this

1099
00:47:59,230 --> 00:47:57,080
is analogous to taking a picture of a

1100
00:48:03,850 --> 00:47:59,240
human being a few seconds after

1101
00:48:05,530 --> 00:48:03,860
conception and from this image we can

1102
00:48:08,920 --> 00:48:05,540
infer the initial conditions that gave

1103
00:48:10,300 --> 00:48:08,930
rise to everything else later on so

1104
00:48:12,730 --> 00:48:10,310
here's another picture of what we're

1105
00:48:16,450 --> 00:48:12,740
looking at so this is where we live in

1106
00:48:18,790 --> 00:48:16,460
the universe the universe is 13.8

1107
00:48:20,710 --> 00:48:18,800
billion years old nothing can travel

1108
00:48:22,570 --> 00:48:20,720
faster than the speed of light which

1109
00:48:24,940 --> 00:48:22,580
means that there is a finite distance

1110
00:48:27,550 --> 00:48:24,950
out to which we see which we call the

1111
00:48:29,830 --> 00:48:27,560
horizon and that distance is 13.8

1112
00:48:32,560 --> 00:48:29,840
billion light years and so when we look

1113
00:48:34,870 --> 00:48:32,570

at the universe with whatever telescopes

1114
00:48:36,670 --> 00:48:34,880
or whatever observations we can make we

1115
00:48:38,440 --> 00:48:36,680
can only look out to this finite

1116
00:48:42,130 --> 00:48:38,450
distance and the Cosmic Microwave

1117
00:48:44,260 --> 00:48:42,140
Background is actually this surface over

1118
00:48:46,060 --> 00:48:44,270
here so when we look at the Cosmic

1119
00:48:46,540 --> 00:48:46,070
Microwave Background that W map or

1120
00:48:48,910 --> 00:48:46,550
Planck

1121
00:48:51,970 --> 00:48:48,920
image is actually a picture of the

1122
00:48:55,690 --> 00:48:51,980
universe picture of a spherical surface

1123
00:48:57,460 --> 00:48:55,700
in the universe of radius 13.8 billion

1124
00:49:00,520 --> 00:48:57,470
light years and we're seeing it as it

1125
00:49:03,550 --> 00:49:00,530
was 380,000 years after the Big Bang so

1126
00:49:05,470 --> 00:49:03,560
it's actually a remarkable image we're

1127
00:49:07,570 --> 00:49:05,480
actually looking at the edge of the

1128
00:49:11,500 --> 00:49:07,580
observable universe and we are imaging

1129
00:49:13,480 --> 00:49:11,510
it with an amazing precision and

1130
00:49:15,400 --> 00:49:13,490
resolution so that's what we're looking

1131
00:49:17,110 --> 00:49:15,410
at we're looking at the edge of the

1132
00:49:19,430 --> 00:49:17,120
observable universe

1133
00:49:22,490 --> 00:49:19,440
so what I'm going to try to tell you now

1134
00:49:24,500 --> 00:49:22,500
is that this picture is not only you

1135
00:49:26,660 --> 00:49:24,510
know amazing because it's the edge of

1136
00:49:28,460 --> 00:49:26,670
the observable universe but it's amazing

1137
00:49:31,670 --> 00:49:28,470
because it provides a huge amount of

1138
00:49:34,010 --> 00:49:31,680

detailed and precise information about

1139
00:49:38,660 --> 00:49:34,020
the origin of the universe its contents

1140
00:49:40,460 --> 00:49:38,670
and its evolution so what I'm going to

1141
00:49:43,760 --> 00:49:40,470
tell you about in particular is that

1142
00:49:45,620 --> 00:49:43,770
this picture gives us very good reason

1143
00:49:48,290 --> 00:49:45,630
to believe that this mechanism that we

1144
00:49:50,180 --> 00:49:48,300
call inflation actually occurred that it

1145
00:49:53,260 --> 00:49:50,190
actually is what set the Big Bang in

1146
00:49:55,670 --> 00:49:53,270
motion so as I said inflation is an idea

1147
00:49:58,010 --> 00:49:55,680
more or less for what to set the Big

1148
00:49:59,840 --> 00:49:58,020
Bang in motion what is it that actually

1149
00:50:01,550 --> 00:49:59,850
made the thing bang in the first place

1150
00:50:02,690 --> 00:50:01,560
it's something that would have happened

1151
00:50:04,100 --> 00:50:02,700
during the first trillionth of a

1152
00:50:06,200 --> 00:50:04,110
trillionth of a trillionth of a second

1153
00:50:07,760 --> 00:50:06,210
of the universe and one of the things

1154
00:50:09,650 --> 00:50:07,770
that's most exciting not only to

1155
00:50:13,610 --> 00:50:09,660
cosmologists and astronomers but to

1156
00:50:16,490 --> 00:50:13,620
physicists is that the mechanism behind

1157
00:50:18,470 --> 00:50:16,500
inflation is actually based on ideas

1158
00:50:20,990 --> 00:50:18,480
that come from elementary particle

1159
00:50:23,030 --> 00:50:21,000
theory so this is a talk about cosmology

1160
00:50:24,680 --> 00:50:23,040
it's at the Space Telescope Science

1161
00:50:26,060 --> 00:50:24,690
Institute we're talking about the

1162
00:50:29,480 --> 00:50:26,070
biggest things in the universe that we

1163
00:50:31,040 --> 00:50:29,490

see very very far away but it turns out

1164
00:50:35,270 --> 00:50:31,050
that this is actually also talked about

1165
00:50:39,800 --> 00:50:35,280
elementary particle theory so we have a

1166
00:50:42,680 --> 00:50:39,810
beautiful theory for the physics of

1167
00:50:46,880 --> 00:50:42,690
sumit subatomic particles we now know

1168
00:50:48,710 --> 00:50:46,890
that atomic nuclei are made out of

1169
00:50:53,630 --> 00:50:48,720
protons and neutrons we've known this

1170
00:50:55,520 --> 00:50:53,640
for 80-plus years we know more moreover

1171
00:50:57,500 --> 00:50:55,530
that those protons neutrons are made out

1172
00:50:59,900 --> 00:50:57,510
of smaller particles that we call up and

1173
00:51:01,880 --> 00:50:59,910
down quarks we also know that those up

1174
00:51:04,370 --> 00:51:01,890
and down quarks are two of the lightest

1175
00:51:07,750 --> 00:51:04,380
of six quarks the other four of the

1176
00:51:11,600 --> 00:51:07,760
charm strange top and bottom all of the

1177
00:51:14,210 --> 00:51:11,610
chemistry that's responsible for just

1178
00:51:16,970 --> 00:51:14,220
about everything involved in life and

1179
00:51:18,860 --> 00:51:16,980
plan to earth all the chemistry is due

1180
00:51:22,220 --> 00:51:18,870
to the behavior of the electrons in

1181
00:51:24,260 --> 00:51:22,230
atoms that spin around the nuclei it

1182
00:51:27,710 --> 00:51:24,270
turns out that the electron is again

1183
00:51:29,390 --> 00:51:27,720
only one of three similar particles that

1184
00:51:30,620 --> 00:51:29,400
we call leptons it's the lightest and

1185
00:51:33,259 --> 00:51:30,630
there are two other particles

1186
00:51:34,729 --> 00:51:33,269
lepton in the tile left on and then it

1187
00:51:37,849 --> 00:51:34,739
associated with each of these three

1188
00:51:39,499 --> 00:51:37,859

leptons are three very weakly

1189
00:51:42,739 --> 00:51:39,509
interacting and very light particles

1190
00:51:44,210 --> 00:51:42,749
called neutrinos and we have a theory

1191
00:51:45,979 --> 00:51:44,220
that explains how these particles

1192
00:51:48,140 --> 00:51:45,989
interact these particles interact

1193
00:51:50,509 --> 00:51:48,150
through the exchange of photons which is

1194
00:51:52,400 --> 00:51:50,519
light but there are also other particles

1195
00:51:55,789 --> 00:51:52,410
analogous to the photon called gluons

1196
00:51:57,769 --> 00:51:55,799
and Z and W bosons that also describe

1197
00:51:59,599 --> 00:51:57,779
the behavior of these particles and the

1198
00:52:03,469 --> 00:51:59,609
last piece of this puzzle was discovered

1199
00:52:05,719 --> 00:52:03,479
just two years ago at the Large Hadron

1200
00:52:08,180 --> 00:52:05,729
Collider the Higgs boson and there was a

1201
00:52:09,890 --> 00:52:08,190
nobel prize awarded last year to Higgs

1202
00:52:11,569 --> 00:52:09,900
and two other gentlemen who first

1203
00:52:18,529 --> 00:52:11,579
predicted the existence of this particle

1204
00:52:19,910 --> 00:52:18,539
back in the 1960s so I am going to try

1205
00:52:21,319 --> 00:52:19,920
to explain to you why it is that we

1206
00:52:24,319 --> 00:52:21,329
believe that something like inflation

1207
00:52:26,690 --> 00:52:24,329
occurred so why do we believe that

1208
00:52:29,960 --> 00:52:26,700
something like inflation occur at the

1209
00:52:36,039 --> 00:52:29,970
birth of the universe it's because this

1210
00:52:43,339 --> 00:52:39,680
inflation there's no I there's no end

1211
00:52:45,680 --> 00:52:43,349
there's no F no other letters at some

1212
00:52:49,279 --> 00:52:45,690
point some people thought they saw an SH

1213
00:52:52,249 --> 00:52:49,289

which stands for Stephen Hawking I can't

1214
00:52:55,069 --> 00:52:52,259
see it in here right now but that has

1215
00:52:58,069 --> 00:52:55,079
been debunked by the W math

1216
00:52:59,870 --> 00:52:58,079
collaboration but still what I'm going

1217
00:53:02,029 --> 00:52:59,880
to try to explain is that there is a

1218
00:53:06,349 --> 00:53:02,039
huge amount of information in this map

1219
00:53:07,729 --> 00:53:06,359
and it is does all but say inflation so

1220
00:53:12,499 --> 00:53:07,739
to explain how this works

1221
00:53:16,910 --> 00:53:12,509
I took a piece of paper and I drew 100

1222
00:53:23,029 --> 00:53:16,920
dots on there so there are 150 dots 50

1223
00:53:25,219 --> 00:53:23,039
dots and I put them at random so you can

1224
00:53:30,170 --> 00:53:25,229
look at this and you are not supposed to

1225
00:53:32,779 --> 00:53:30,180
see any pattern okay I just 50 dots down

1226
00:53:39,200 --> 00:53:32,789
if you see a pattern in there it's

1227
00:53:46,680 --> 00:53:43,460
exactly so so fifty dots at random so

1228
00:53:50,190 --> 00:53:46,690
here is another picture another piece of

1229
00:53:52,890 --> 00:53:50,200
paper I put fifty down for fifty fifty

1230
00:53:56,670 --> 00:53:52,900
dots on this piece of paper but there is

1231
00:53:58,680 --> 00:53:56,680
some structure and your eye and your

1232
00:54:00,239 --> 00:53:58,690
brain your brain can process the image

1233
00:54:03,979 --> 00:54:00,249
that your eye makes and you can figure

1234
00:54:07,650 --> 00:54:03,989
it out so you all see that there are now

1235
00:54:11,190 --> 00:54:07,660
ten I'm sorry five agglomerations each

1236
00:54:12,930 --> 00:54:11,200
that has ten dots okay so your brain

1237
00:54:15,529 --> 00:54:12,940
does this calculation your brain can

1238
00:54:18,930 --> 00:54:15,539

process this and see structure in there

1239
00:54:20,609 --> 00:54:18,940
here's another picture so now there's an

1240
00:54:22,769 --> 00:54:20,619
additional layer of structure there

1241
00:54:26,130 --> 00:54:22,779
again five agglomerations of ten dots

1242
00:54:29,630 --> 00:54:26,140
but each of these glom racing's is no

1243
00:54:33,950 --> 00:54:29,640
longer just random dots thrown out

1244
00:54:37,279 --> 00:54:33,960
they're actually more or less circles

1245
00:54:39,390 --> 00:54:37,289
here's another layer of structure

1246
00:54:43,880 --> 00:54:39,400
everyone can see what's different

1247
00:54:49,170 --> 00:54:43,890
between these two the other circles

1248
00:54:51,809 --> 00:54:49,180
these are squares so your brain is doing

1249
00:54:53,940 --> 00:54:51,819
an image processing algorithm you don't

1250
00:54:57,210 --> 00:54:53,950
think about it but your brain is an

1251
00:54:59,460 --> 00:54:57,220
extremely powerful computer and then

1252
00:55:01,799 --> 00:54:59,470
here's another you know image another

1253
00:55:03,089 --> 00:55:01,809
another pattern so again this is

1254
00:55:05,489 --> 00:55:03,099
different and you can see there are

1255
00:55:07,259 --> 00:55:05,499
fifty dots they're not randomly thrown

1256
00:55:12,150 --> 00:55:07,269
out on the piece of paper but they're

1257
00:55:17,009 --> 00:55:12,160
actually arranged in a lattice so there

1258
00:55:20,489 --> 00:55:17,019
is information that can be distinguished

1259
00:55:23,160 --> 00:55:20,499
from seemingly random patterns and your

1260
00:55:25,460 --> 00:55:23,170
brain knows how to do that not only your

1261
00:55:28,710 --> 00:55:25,470
brain knows how to do this but your

1262
00:55:33,900 --> 00:55:28,720
computer also knows how to do this so

1263
00:55:36,210 --> 00:55:33,910

any of you have an apple and you zom use

1264
00:55:39,289 --> 00:55:36,220
a I fo toe there's this new feature that

1265
00:55:41,579 --> 00:55:39,299
came out a few years called um faces and

1266
00:55:43,979 --> 00:55:41,589
the computer will actually go through

1267
00:55:47,819 --> 00:55:43,989
all of your pictures and guess with

1268
00:55:49,130 --> 00:55:47,829
pretty good accuracy who the people in

1269
00:55:53,850 --> 00:55:49,140
those pictures are

1270
00:55:56,370 --> 00:55:53,860
okay so computer scientists have

1271
00:55:58,020 --> 00:55:56,380
actually developed in recent years very

1272
00:56:01,130 --> 00:55:58,030
powerful algorithms for facial

1273
00:56:04,020 --> 00:56:01,140
recognition software fascial recognition

1274
00:56:05,670 --> 00:56:04,030
so again the computer can now do

1275
00:56:08,940 --> 00:56:05,680
something like what you do you know you

1276
00:56:10,590 --> 00:56:08,950
look at two people no two people look

1277
00:56:12,660 --> 00:56:10,600
alike you can always tell any two people

1278
00:56:13,980 --> 00:56:12,670
apart then the computer we've now been

1279
00:56:18,830 --> 00:56:13,990
able to train the computer to do the

1280
00:56:23,490 --> 00:56:18,840
same thing so this looks like gibberish

1281
00:56:28,950 --> 00:56:23,500
if you don't know how to look at it this

1282
00:56:32,070 --> 00:56:28,960
is another some more gibberish so can

1283
00:56:38,490 --> 00:56:32,080
anybody read this this actually says

1284
00:56:40,770 --> 00:56:38,500
something so interestingly enough I gave

1285
00:56:42,540 --> 00:56:40,780
a talk to high school physics teachers

1286
00:56:44,970 --> 00:56:42,550
from the area over the summer and

1287
00:56:48,450 --> 00:56:44,980
several of them actually were able to

1288
00:56:50,820 --> 00:56:48,460

read this so this is the simplest

1289
00:56:54,140 --> 00:56:50,830
possible code this is I think called the

1290
00:56:57,060 --> 00:56:54,150
one letter swap so if I take this

1291
00:56:58,530 --> 00:56:57,070
sentence and I replace every letter by

1292
00:57:00,660 --> 00:56:58,540
the preceding letter in the alphabet

1293
00:57:05,490 --> 00:57:00,670
sort of replace every B by an a every C

1294
00:57:06,990 --> 00:57:05,500
by a B every D by a C then this winds up

1295
00:57:08,820 --> 00:57:07,000
saying the true sign of intelligence is

1296
00:57:11,610 --> 00:57:08,830
not knowledge but imagination which is

1297
00:57:16,050 --> 00:57:11,620
something Albert Einstein said so the

1298
00:57:18,810 --> 00:57:16,060
point is that what you see and what

1299
00:57:20,340 --> 00:57:18,820
initially appears as gibberish can

1300
00:57:23,610 --> 00:57:20,350
actually have meaning if you know how to

1301
00:57:26,700 --> 00:57:23,620
crack the code and this is actually what

1302
00:57:29,670 --> 00:57:26,710
we do in science the point of science is

1303
00:57:30,480 --> 00:57:29,680
to find hidden patterns in nature here's

1304
00:57:32,490 --> 00:57:30,490
another example

1305
00:57:34,890 --> 00:57:32,500
not from code breaking but from science

1306
00:57:39,690 --> 00:57:34,900
and paleontology you find a bunch of

1307
00:57:41,460 --> 00:57:39,700
rocks or fossils and then if you know

1308
00:57:42,990 --> 00:57:41,470
what you're doing you can assemble them

1309
00:57:45,660 --> 00:57:43,000
it's a puzzle you put it together and

1310
00:57:50,580 --> 00:57:45,670
this bunch of random rocks actually

1311
00:57:53,070 --> 00:57:50,590
turns out to be a dinosaur so this is

1312
00:57:54,750 --> 00:57:53,080
not gibberish and the way that we

1313
00:57:59,820 --> 00:57:54,760

actually crack the code the way we

1314
00:58:02,070 --> 00:57:59,830
actually interpret this image is to

1315
00:58:03,930 --> 00:58:02,080
employ mathematical technique

1316
00:58:07,010 --> 00:58:03,940
that were developed by joseph fourier in

1317
00:58:10,230 --> 00:58:07,020
the early 1800s and what Fourier showed

1318
00:58:13,070 --> 00:58:10,240
mathematically is that any pattern can

1319
00:58:15,270 --> 00:58:13,080
be represented as a bunch of waves

1320
00:58:17,760 --> 00:58:15,280
anything can be represented as a bunch

1321
00:58:20,010 --> 00:58:17,770
of waves those of you read about on the

1322
00:58:22,620 --> 00:58:20,020
the particle wave duality in quantum

1323
00:58:24,780 --> 00:58:22,630
mechanics the particle wave duality is

1324
00:58:27,330 --> 00:58:24,790
nothing more than the observation that

1325
00:58:29,340 --> 00:58:27,340
Fourier made in the early 1800s that

1326
00:58:32,100 --> 00:58:29,350
anything can be represented as a bunch

1327
00:58:34,860 --> 00:58:32,110
of waves this laser pointer can be

1328
00:58:37,140 --> 00:58:34,870
represented as a bunch of waves and when

1329
00:58:39,720 --> 00:58:37,150
you learn about Fourier analysis in

1330
00:58:41,940 --> 00:58:39,730
mathematics classes it's very very

1331
00:58:44,370 --> 00:58:41,950
straightforward so it turns out that you

1332
00:58:47,100 --> 00:58:44,380
can just apply what we call a Fourier

1333
00:58:49,590 --> 00:58:47,110
transform or a wave transform to this

1334
00:58:51,570 --> 00:58:49,600
map and when you apply a wave transform

1335
00:58:58,230 --> 00:58:51,580
to this map it winds up looking like

1336
00:59:00,780 --> 00:58:58,240
this and this has structure that you can

1337
00:59:02,820 --> 00:59:00,790
see and to the trained eye it's not just

1338
00:59:04,110 --> 00:59:02,830

structure but it's actually beautiful

1339
00:59:07,950 --> 00:59:04,120
and has a huge amount of information

1340
00:59:12,570 --> 00:59:07,960
this which is mathematically equivalent

1341
00:59:15,840 --> 00:59:12,580
to this this is the fingerprint of

1342
00:59:17,520 --> 00:59:15,850
inflation so turns out that what's

1343
00:59:19,170 --> 00:59:17,530
particularly interesting is not just

1344
00:59:21,270 --> 00:59:19,180
that we can make the image so seeing

1345
00:59:22,590 --> 00:59:21,280
this image tells us that something like

1346
00:59:25,200 --> 00:59:22,600
inflation must have occurred in the

1347
00:59:28,050 --> 00:59:25,210
early universe but moreover there's a

1348
00:59:29,610 --> 00:59:28,060
lot of information so there's the radii

1349
00:59:31,140 --> 00:59:29,620
of the wings there's the width of the

1350
00:59:33,540 --> 00:59:31,150
Rings for example that there's the

1351
00:59:35,730 --> 00:59:33,550
brightness of the Rings so this ring

1352
00:59:37,170 --> 00:59:35,740
this dots is a lot brighter than this

1353
00:59:38,790 --> 00:59:37,180
ring here this ring is brighter than

1354
00:59:41,490 --> 00:59:38,800
this one over here there are also these

1355
00:59:43,290 --> 00:59:41,500
troughs they're dark but not necessarily

1356
00:59:44,940 --> 00:59:43,300
completely dark and then there's the

1357
00:59:47,550 --> 00:59:44,950
width of the Rings how wide is this how

1358
00:59:49,740 --> 00:59:47,560
wide is this one etc etc so there's a

1359
00:59:51,360 --> 00:59:49,750
lot of information in here there are a

1360
00:59:55,740 --> 00:59:51,370
lot of numbers that I would need to

1361
00:59:58,830 --> 00:59:55,750
fully describe this pattern and if we

1362
01:00:00,840 --> 00:59:58,840
process this information a bit further

1363
01:00:03,660 --> 01:00:00,850

what we infer from this processing is

1364
01:00:05,190 --> 01:00:03,670
that the atoms of which we are composed

1365
01:00:07,860 --> 01:00:05,200
of which everything in the solar system

1366
01:00:11,300 --> 01:00:07,870
is composed constitute only 4.6 percent

1367
01:00:13,530 --> 01:00:11,310
of the energy density of the universe

1368
01:00:15,360 --> 01:00:13,540
there is something called dark matter

1369
01:00:15,839 --> 01:00:15,370
which holds galaxies together which

1370
01:00:18,329 --> 01:00:15,849
makes up

1371
01:00:20,700 --> 01:00:18,339
23% of the universe and then there's

1372
01:00:22,109 --> 01:00:20,710
dark energy which makes up the other 72%

1373
01:00:25,440 --> 01:00:22,119
of the universe and this was discovered

1374
01:00:27,120 --> 01:00:25,450
in 1998 and Nobel Prize was given to

1375
01:00:28,950 --> 01:00:27,130
three gentlemen including Adam riess

1376
01:00:33,420 --> 01:00:28,960
across the street for this discovery

1377
01:00:36,210 --> 01:00:33,430
back in 2011 the other thing that's this

1378
01:00:37,680 --> 01:00:36,220
image tells us as I told you is that

1379
01:00:39,870 --> 01:00:37,690
something like inflation must have

1380
01:00:42,690 --> 01:00:39,880
occurred so we live in you universe

1381
01:00:44,849 --> 01:00:42,700
that's 13.8 billion years old the first

1382
01:00:46,650 --> 01:00:44,859
stars were formed to 400 million years

1383
01:00:48,120 --> 01:00:46,660
after the Big Bang we have this very

1384
01:00:49,559 --> 01:00:48,130
nice image of the universe as it was

1385
01:00:49,999 --> 01:00:49,569
three hundred thousand years after the

1386
01:00:52,829 --> 01:00:50,009
Big Bang

1387
01:00:55,380 --> 01:00:52,839
but that processing of that image that

1388
01:00:56,789 --> 01:00:55,390

wave transform that fingerprint tells us

1389
01:00:58,890 --> 01:00:56,799
that something like inflation occurred

1390
01:01:01,339 --> 01:00:58,900
in the first fraction of a fraction of a

1391
01:01:05,900 --> 01:01:01,349
fraction of a second after the Big Bang

1392
01:01:08,640 --> 01:01:05,910
so we can feel very proud of ourselves

1393
01:01:10,319 --> 01:01:08,650
because now we have a very elegant model

1394
01:01:14,519 --> 01:01:10,329
for what happened what's that the Big

1395
01:01:16,589 --> 01:01:14,529
Bang in motion but that's never enough

1396
01:01:19,049 --> 01:01:16,599
for scientists and we all want to know

1397
01:01:20,670 --> 01:01:19,059
what else can we learn can we

1398
01:01:24,569 --> 01:01:20,680
characterize this period of inflation

1399
01:01:26,640 --> 01:01:24,579
any better and the answer is yes so it

1400
01:01:28,200 --> 01:01:26,650
turns out that inflation makes a number

1401
01:01:29,849 --> 01:01:28,210
of predictions some of which were

1402
01:01:31,579 --> 01:01:29,859
verified with this fingerprint that we

1403
01:01:34,049 --> 01:01:31,589
saw in the Cosmic Microwave Background

1404
01:01:37,140 --> 01:01:34,059
but inflation also predicts that the

1405
01:01:41,849 --> 01:01:37,150
universe should be filled with a gas of

1406
01:01:44,009 --> 01:01:41,859
gravitational waves so electromagnetic

1407
01:01:45,959 --> 01:01:44,019
waves are light and the way

1408
01:01:47,910 --> 01:01:45,969
electromagnetic waves work is as follows

1409
01:01:50,640 --> 01:01:47,920
so think about a radio transmitter and a

1410
01:01:52,170 --> 01:01:50,650
radio receiver there is an antenna at

1411
01:01:54,269 --> 01:01:52,180
the Trant for the transmitter you can

1412
01:01:57,359 --> 01:01:54,279
see those antenna towers on antenna Hill

1413
01:02:01,140 --> 01:01:57,369

across the highway so those antennas

1414
01:02:03,359 --> 01:02:01,150
have metal and what happens is they set

1415
01:02:05,940 --> 01:02:03,369
up electronics so that the electrons in

1416
01:02:08,249 --> 01:02:05,950
that metal shake up and down those

1417
01:02:09,959 --> 01:02:08,259
electrons have an electric field and

1418
01:02:13,019 --> 01:02:09,969
when those electrons wiggle up and down

1419
01:02:14,849 --> 01:02:13,029
they send out a propagating disturbance

1420
01:02:17,549 --> 01:02:14,859
in the electromagnetic fields and that

1421
01:02:19,440 --> 01:02:17,559
wave travels to the antenna in your car

1422
01:02:21,749 --> 01:02:19,450
and the antenna of your car has a bunch

1423
01:02:23,519 --> 01:02:21,759
of free electrons and what happens is

1424
01:02:25,589 --> 01:02:23,529
this wave comes along it hits these

1425
01:02:27,630 --> 01:02:25,599
electrons and it sets those electrons in

1426
01:02:29,190 --> 01:02:27,640
motion and then your radio processes

1427
01:02:34,140 --> 01:02:29,200
that signal and play

1428
01:02:37,589 --> 01:02:34,150
top 40 hits or whatever else so that's

1429
01:02:40,410 --> 01:02:37,599
how electromagnetic waves work if I set

1430
01:02:42,510 --> 01:02:40,420
electric charges in motion it sends out

1431
01:02:44,250 --> 01:02:42,520
waves and then those waves set other

1432
01:02:47,310 --> 01:02:44,260
electric charges in motion and that's

1433
01:02:50,910 --> 01:02:47,320
how we use these for communication it

1434
01:02:53,400 --> 01:02:50,920
turns out that in gravity there is

1435
01:02:55,079 --> 01:02:53,410
something similar if I take a massive

1436
01:02:57,030 --> 01:02:55,089
object that has a gravitational field

1437
01:03:00,089 --> 01:02:57,040
like the Sun has a gravitational field

1438
01:03:01,920 --> 01:03:00,099

if I were to say shake the Sun up and

1439
01:03:03,329 --> 01:03:01,930
down that would give rise to a

1440
01:03:05,520 --> 01:03:03,339
propagating disturbance in the

1441
01:03:07,680 --> 01:03:05,530
gravitational field and then if there

1442
01:03:10,200 --> 01:03:07,690
was some other test mass like a planet

1443
01:03:14,849 --> 01:03:10,210
far away that planet would get set in

1444
01:03:16,970 --> 01:03:14,859
motion so this is a picture of what

1445
01:03:20,370 --> 01:03:16,980
would happen if a gravitational wave

1446
01:03:22,230 --> 01:03:20,380
hits a spherical object what a

1447
01:03:24,750 --> 01:03:22,240
gravitational wave actually does is not

1448
01:03:26,430 --> 01:03:24,760
shake the object up and down as it does

1449
01:03:29,370 --> 01:03:26,440
with an electron but it actually gives

1450
01:03:31,859 --> 01:03:29,380
rise to distortions in the shape of this

1451
01:03:33,870 --> 01:03:31,869
spherical object that elongates it in

1452
01:03:35,220 --> 01:03:33,880
this direction and then elongates in

1453
01:03:37,530 --> 01:03:35,230
this direction in this direction this

1454
01:03:40,020 --> 01:03:37,540
direction etc so it would take an object

1455
01:03:42,839 --> 01:03:40,030
and sort of make it wobble around that

1456
01:03:44,190 --> 01:03:42,849
shape wobble around so inflation

1457
01:03:45,930 --> 01:03:44,200
predicts that the universe would be

1458
01:03:48,180 --> 01:03:45,940
filled with these gravitational waves

1459
01:03:53,490 --> 01:03:48,190
and in particular those gravitational

1460
01:03:57,420 --> 01:03:53,500
waves would hits the Cosmic Microwave

1461
01:03:58,890 --> 01:03:57,430
Background surface of last scattering at

1462
01:04:00,540 --> 01:03:58,900
the Cosmic Microwave Background we're

1463
01:04:02,160 --> 01:04:00,550

looking at a spherical surface at the

1464
01:04:05,430 --> 01:04:02,170
edge of the universe at the edge of the

1465
01:04:06,930 --> 01:04:05,440
observable universe in the absence of a

1466
01:04:08,640 --> 01:04:06,940
gravitational wave that surface is

1467
01:04:10,950 --> 01:04:08,650
perfectly spherical but if these

1468
01:04:13,500 --> 01:04:10,960
inflationary gravitational waves exist

1469
01:04:15,630 --> 01:04:13,510
they would distort the shape of that

1470
01:04:20,220 --> 01:04:15,640
surface of last scattering some

1471
01:04:26,370 --> 01:04:20,230
particular way so what my colleagues and

1472
01:04:29,910 --> 01:04:26,380
I and another group realized in 1996 is

1473
01:04:32,609 --> 01:04:29,920
that the gravitational waves produced by

1474
01:04:34,559 --> 01:04:32,619
inflation give rise to a signature in

1475
01:04:38,160 --> 01:04:34,569
the polarization of the Cosmic Microwave

1476
01:04:40,050 --> 01:04:38,170
Background so it turns out that light

1477
01:04:43,340 --> 01:04:40,060
has properties that are apparent to all

1478
01:04:45,599 --> 01:04:43,350
of us light can be brighter or faint

1479
01:04:47,640 --> 01:04:45,609
some things are very bright and some

1480
01:04:51,870 --> 01:04:47,650
things are very faint light also has

1481
01:04:53,430 --> 01:04:51,880
color it can be red green blue etc it

1482
01:04:55,260 --> 01:04:53,440
turns out that there's another property

1483
01:04:58,500 --> 01:04:55,270
the light has that we generally that our

1484
01:05:01,590 --> 01:04:58,510
eyes are not really tuned to detect and

1485
01:05:04,140 --> 01:05:01,600
that is polarization so remember an

1486
01:05:05,940 --> 01:05:04,150
electromagnetic wave is a wave so if I

1487
01:05:07,530 --> 01:05:05,950
shake an electron up and down the

1488
01:05:10,260 --> 01:05:07,540

electromagnetic wave is gonna go like

1489
01:05:11,460 --> 01:05:10,270
this run into you and if you have an

1490
01:05:13,200 --> 01:05:11,470
antenna that's pointed in this direction

1491
01:05:15,420 --> 01:05:13,210
then the electrons will shake up and

1492
01:05:17,310 --> 01:05:15,430
down but if I have an intent of its

1493
01:05:18,750 --> 01:05:17,320
point in this direction the electrons

1494
01:05:21,840 --> 01:05:18,760
can't shake up and down there's nowhere

1495
01:05:24,120 --> 01:05:21,850
for them to go so if I have an antenna

1496
01:05:25,410 --> 01:05:24,130
that's oriented this way I can tell

1497
01:05:27,540 --> 01:05:25,420
whether the doctor magnetic wave is

1498
01:05:29,220 --> 01:05:27,550
coming this way and if I have an antenna

1499
01:05:30,690 --> 01:05:29,230
oriented this way I can detect

1500
01:05:33,000 --> 01:05:30,700
electromagnetic waves where they are

1501
01:05:35,849 --> 01:05:33,010
shaking is in the horizontal direction

1502
01:05:38,010 --> 01:05:35,859
and you can actually detect this if you

1503
01:05:40,710 --> 01:05:38,020
have polarized sunglasses next time you

1504
01:05:43,349 --> 01:05:40,720
go to the ATM machine most ATM machines

1505
01:05:45,300 --> 01:05:43,359
are LCD screens most out most LCD

1506
01:05:47,490 --> 01:05:45,310
screens are polarized if you take your

1507
01:05:51,090 --> 01:05:47,500
polarized sunglasses and rotate them by

1508
01:05:53,430 --> 01:05:51,100
45 degrees the screen will disappear so

1509
01:05:56,310 --> 01:05:53,440
light is polarized and you can measure

1510
01:05:57,510 --> 01:05:56,320
it it's easy to detect polarization so

1511
01:06:00,620 --> 01:05:57,520
here's actually a picture of what I told

1512
01:06:05,220 --> 01:06:00,630
you before electromagnetic waves are

1513
01:06:07,380 --> 01:06:05,230

oops electromagnetic waves are what we

1514
01:06:10,320 --> 01:06:07,390
call transverse waves they shake up and

1515
01:06:12,750 --> 01:06:10,330
down or side to side and this isn't

1516
01:06:15,720 --> 01:06:12,760
distinction two longitudinal waves like

1517
01:06:17,790 --> 01:06:15,730
sound waves so when I talk there's a

1518
01:06:20,990 --> 01:06:17,800
sound wave that propagates it actually

1519
01:06:22,980 --> 01:06:21,000
has a wave that profited compresses

1520
01:06:26,430 --> 01:06:22,990
along the direction of which it's

1521
01:06:28,140 --> 01:06:26,440
propagating anyway electromagnetic waves

1522
01:06:30,030 --> 01:06:28,150
are transverse waves and so they can

1523
01:06:33,960 --> 01:06:30,040
have this linear polarization that's

1524
01:06:35,790 --> 01:06:33,970
either up and down or side to side so

1525
01:06:37,290 --> 01:06:35,800
now suppose I look at an image there's a

1526
01:06:39,120 --> 01:06:37,300
polarization over here there's a

1527
01:06:40,500 --> 01:06:39,130
polarization over here polarization over

1528
01:06:45,170 --> 01:06:40,510
here there could be a polarization and

1529
01:06:48,090 --> 01:06:45,180
every point so here is an image a

1530
01:06:50,160 --> 01:06:48,100
polarized pattern that I can draw on the

1531
01:06:51,840 --> 01:06:50,170
surface of the board and here's another

1532
01:06:53,940 --> 01:06:51,850
polarization pattern in the neck and

1533
01:06:55,440 --> 01:06:53,950
draw and here's another polarization

1534
01:06:56,069 --> 01:06:55,450
pattern here's another polarization

1535
01:06:58,169 --> 01:06:56,079
pattern

1536
01:06:59,819 --> 01:06:58,179
the difference between the ones on the

1537
01:07:01,859 --> 01:06:59,829
left and the ones on the right is that

1538
01:07:04,169 --> 01:07:01,869

the ones on the right have a handedness

1539
01:07:06,269 --> 01:07:04,179
this one swirls around in a

1540
01:07:08,429 --> 01:07:06,279
counterclockwise direction and this

1541
01:07:10,140 --> 01:07:08,439
rolls around in a clockwise direction if

1542
01:07:12,929 --> 01:07:10,150
I look at this in a mirror it would look

1543
01:07:15,120 --> 01:07:12,939
like this and vice versa if I were to

1544
01:07:16,709 --> 01:07:15,130
look at this in a mirror would look the

1545
01:07:19,229 --> 01:07:16,719
same if I look at this in the mirror it

1546
01:07:22,079 --> 01:07:19,239
would look the same so these we call in

1547
01:07:24,660 --> 01:07:22,089
technical jargon emotes in these we call

1548
01:07:27,150 --> 01:07:24,670
in technical jargon be modes so the B

1549
01:07:29,969 --> 01:07:27,160
modes have the swirling pattern and what

1550
01:07:32,609 --> 01:07:29,979
we realized back in 1996 is that

1551
01:07:35,059 --> 01:07:32,619
gravitational waves give rise to the

1552
01:07:38,239 --> 01:07:35,069
swirling pattern in the CMB polarization

1553
01:07:42,959 --> 01:07:38,249
so this is something that we pointed out

1554
01:07:44,759 --> 01:07:42,969
in 1996 and various other theoretical

1555
01:07:47,729 --> 01:07:44,769
physicists studied it and found it

1556
01:07:48,809 --> 01:07:47,739
interesting and experimental physicists

1557
01:07:50,969 --> 01:07:48,819
also thought that it might be

1558
01:07:53,339 --> 01:07:50,979
interesting to try to measure look for a

1559
01:07:55,979 --> 01:07:53,349
swirling pattern in the polarization of

1560
01:07:58,160 --> 01:07:55,989
the Cosmic Microwave Background so since

1561
01:08:00,299 --> 01:07:58,170
then there have been a huge number of

1562
01:08:03,449 --> 01:08:00,309
independent experimental groups that

1563
01:08:05,219 --> 01:08:03,459

have been looking for this so this ABS

1564
01:08:07,049 --> 01:08:05,229
stands for a B mode search this is a

1565
01:08:08,849 --> 01:08:07,059
Princeton led collaboration light bird

1566
01:08:09,689 --> 01:08:08,859
is a Japanese project that's on the

1567
01:08:11,880 --> 01:08:09,699
drawing board

1568
01:08:13,799 --> 01:08:11,890
he Beck's was a University of Minnesota

1569
01:08:17,189 --> 01:08:13,809
LEDs balloon experiment that flew

1570
01:08:21,030 --> 01:08:17,199
recently the atacama cosmology telescope

1571
01:08:24,269 --> 01:08:21,040
is a Princeton led collaboration at in

1572
01:08:26,549 --> 01:08:24,279
Chile the Polar Bear Simon's array is I

1573
01:08:27,839 --> 01:08:26,559
believe also in actually I don't know

1574
01:08:33,569 --> 01:08:27,849
where it is I forget I think it's also

1575
01:08:36,089 --> 01:08:33,579
in Chile this is a UCSD UC Berkeley LED

1576
01:08:37,319 --> 01:08:36,099
collaboration the Planck satellite was

1577
01:08:40,379 --> 01:08:37,329
not designed to make these measurements

1578
01:08:43,140 --> 01:08:40,389
but they did a last-minute change to the

1579
01:08:45,289 --> 01:08:43,150
design to measure polarization Pipers in

1580
01:08:48,599 --> 01:08:45,299
NASA Goddard Space Flight Center effort

1581
01:08:51,260 --> 01:08:48,609
LSP is a Rome a project of an Italian

1582
01:08:53,939 --> 01:08:51,270
project spider is a project led by

1583
01:08:56,459 --> 01:08:53,949
Princeton University SP T poses huge

1584
01:08:58,229 --> 01:08:56,469
collaboration led by University of

1585
01:08:59,849 --> 01:08:58,239
Chicago and then there's also a project

1586
01:09:01,649 --> 01:08:59,859
right across the street called the class

1587
01:09:02,220 --> 01:09:01,659
telescope led by Chuck Bennett so V

1588
01:09:05,189 --> 01:09:02,230

marriage

1589
01:09:07,319 --> 01:09:05,199
um that's also looking for the signal so

1590
01:09:09,329 --> 01:09:07,329
this is a big deal and a lot of

1591
01:09:09,870 --> 01:09:09,339
experimental groups have been racing to

1592
01:09:11,610 --> 01:09:09,880
detect

1593
01:09:14,790 --> 01:09:11,620
the swirling pattern and the CMB

1594
01:09:17,160 --> 01:09:14,800
polarization so that's why there was a

1595
01:09:19,880 --> 01:09:17,170
lot of attention given to this

1596
01:09:24,330 --> 01:09:19,890
announcement on the 17th of March 2014

1597
01:09:26,160 --> 01:09:24,340
of detection of the swirling pattern so

1598
01:09:27,690 --> 01:09:26,170
this is actually the map of the Cosmic

1599
01:09:29,340 --> 01:09:27,700
Microwave Background polarization that

1600
01:09:31,560 --> 01:09:29,350
this collaboration made that the sky

1601
01:09:33,360 --> 01:09:31,570
telescope made and you can see the

1602
01:09:35,550 --> 01:09:33,370
swirling pattern so around this red spot

1603
01:09:38,130 --> 01:09:35,560
the polarization swirling in this

1604
01:09:40,170 --> 01:09:38,140
direction and around this blue spot over

1605
01:09:44,970 --> 01:09:40,180
here it's sort of swirling in the other

1606
01:09:47,070 --> 01:09:44,980
direction so this if it is what they

1607
01:09:50,540 --> 01:09:47,080
believe it they if it's what they claim

1608
01:09:54,660 --> 01:09:50,550
it is what they think it is is amazing

1609
01:09:57,930 --> 01:09:54,670
so the question now is whether they are

1610
01:10:00,420 --> 01:09:57,940
really seeing a V mode signal from

1611
01:10:02,970 --> 01:10:00,430
gravitational waves from inflation or

1612
01:10:06,240 --> 01:10:02,980
possibly just some contamination from

1613
01:10:07,980 --> 01:10:06,250

dust in the Milky Way so when we look at

1614
01:10:10,710 --> 01:10:07,990
this Cosmic Microwave Background we have

1615
01:10:13,050 --> 01:10:10,720
to look through our own galaxy and it

1616
01:10:15,510 --> 01:10:13,060
turns out that our own galaxy has a lot

1617
01:10:18,600 --> 01:10:15,520
of interstellar dust and this

1618
01:10:21,630 --> 01:10:18,610
interstellar dust can emit light that

1619
01:10:24,330 --> 01:10:21,640
can be polarized and so we're not really

1620
01:10:27,270 --> 01:10:24,340
sure whether what they're seeing is

1621
01:10:29,820 --> 01:10:27,280
gravitational waves or dust so back in

1622
01:10:32,610 --> 01:10:29,830
march bicep2 actually provided several

1623
01:10:34,110 --> 01:10:32,620
fairly persuasive arguments that their

1624
01:10:37,470 --> 01:10:34,120
data does not look like what we would

1625
01:10:38,970 --> 01:10:37,480
expect dust to look like but other

1626
01:10:40,320 --> 01:10:38,980
people since then have said well we

1627
01:10:41,970 --> 01:10:40,330
don't really know what the slips like

1628
01:10:43,910 --> 01:10:41,980
interstellar dust is very complicated

1629
01:10:46,830 --> 01:10:43,920
anybody's trying to sweep up a floor

1630
01:10:50,880 --> 01:10:46,840
knows that dust can be very very

1631
01:10:52,920 --> 01:10:50,890
complicated and more recently back in

1632
01:10:57,840 --> 01:10:52,930
September the Planck satellite released

1633
01:10:59,850 --> 01:10:57,850
new data on dust that actually seems to

1634
01:11:02,010 --> 01:10:59,860
indicate the dust does not look like

1635
01:11:05,640 --> 01:11:02,020
what bicep2 thought it should look like

1636
01:11:08,400 --> 01:11:05,650
back in March so we don't really know

1637
01:11:09,780 --> 01:11:08,410
now whether that signal that b-mode

1638
01:11:12,810 --> 01:11:09,790

signals that they detected is

1639
01:11:14,820 --> 01:11:12,820
gravitational waves or dust so what

1640
01:11:16,410 --> 01:11:14,830
we're trying to do now is figure it out

1641
01:11:18,030 --> 01:11:16,420
and one way that we're hoping to figure

1642
01:11:21,210 --> 01:11:18,040
it out is through this frequency

1643
01:11:23,040 --> 01:11:21,220
dependence so I told you that light has

1644
01:11:23,630 --> 01:11:23,050
a electromagnetic frequency less

1645
01:11:25,790 --> 01:11:23,640
terminated

1646
01:11:28,760 --> 01:11:25,800
sequence II and there are broad range of

1647
01:11:30,680 --> 01:11:28,770
electromagnetic frequencies it turns out

1648
01:11:33,470 --> 01:11:30,690
that the B mode signal that they are

1649
01:11:36,530 --> 01:11:33,480
looking for would be very large at

1650
01:11:38,090 --> 01:11:36,540
roughly 150 gigahertz the

1651
01:11:40,280 --> 01:11:38,100
electromagnetic frequency at which the

1652
01:11:41,960 --> 01:11:40,290
bicep2 measurements are made but smaller

1653
01:11:44,930 --> 01:11:41,970
at higher frequencies and smaller at

1654
01:11:47,900 --> 01:11:44,940
lower frequencies dust on the other hand

1655
01:11:50,870 --> 01:11:47,910
would be much larger at higher

1656
01:11:53,510 --> 01:11:50,880
frequencies than at lower frequencies so

1657
01:11:55,310 --> 01:11:53,520
what bicep did in order to try to

1658
01:11:57,740 --> 01:11:55,320
distinguish whether they were looking at

1659
01:12:00,890 --> 01:11:57,750
the Cosmic Microwave Background or dust

1660
01:12:03,800 --> 01:12:00,900
was used data from 150 gigahertz and

1661
01:12:07,240 --> 01:12:03,810
weaker data less lower signal-to-noise

1662
01:12:10,520 --> 01:12:07,250
data from 100 gigahertz complemented by

1663
01:12:12,380 --> 01:12:10,530

not very precise information from W map

1664
01:12:14,210 --> 01:12:12,390
at low frequencies and not very precise

1665
01:12:20,180 --> 01:12:14,220
information from Planck at higher

1666
01:12:21,920 --> 01:12:20,190
frequencies so the idea that they the

1667
01:12:24,140 --> 01:12:21,930
algorithms they used were good

1668
01:12:28,220 --> 01:12:24,150
algorithms but the data available were

1669
01:12:29,900 --> 01:12:28,230
not very very good so what my colleagues

1670
01:12:31,430 --> 01:12:29,910
across the street Chuck Bennett and Toby

1671
01:12:33,800 --> 01:12:31,440
marrieds are trying to do with this some

1672
01:12:36,320 --> 01:12:33,810
class telescope cosmology large angular

1673
01:12:37,880 --> 01:12:36,330
scale surveyor is to try to do this

1674
01:12:40,370 --> 01:12:37,890
multi frequency measurement more

1675
01:12:43,100 --> 01:12:40,380
precisely so here's another picture of

1676
01:12:45,830 --> 01:12:43,110
this that I along lines I showed you so

1677
01:12:47,930 --> 01:12:45,840
the signal strength for the for a

1678
01:12:49,430 --> 01:12:47,940
gravitational waves from the Cosman the

1679
01:12:51,950 --> 01:12:49,440
Cosmic Microwave Background looks like

1680
01:12:55,340 --> 01:12:51,960
this whereas the signal from the galaxy

1681
01:12:58,130 --> 01:12:55,350
goes down and then back up and they

1682
01:13:00,950 --> 01:12:58,140
actually have hope to image the sky in

1683
01:13:02,900 --> 01:13:00,960
four frequencies 40 90 150 and 200 20

1684
01:13:05,330 --> 01:13:02,910
gigahertz and if they can measure the

1685
01:13:07,250 --> 01:13:05,340
relative strength of the signals in

1686
01:13:09,050 --> 01:13:07,260
these four different frequencies they

1687
01:13:11,360 --> 01:13:09,060
can distinguish the contribution from

1688
01:13:13,940 --> 01:13:11,370

the Milky Way from the cosmic signal

1689
01:13:16,730 --> 01:13:13,950
that we're really interested in the

1690
01:13:20,150 --> 01:13:16,740
other thing that we hope to do is try to

1691
01:13:21,730 --> 01:13:20,160
use a spatial the spatial dependence of

1692
01:13:25,400 --> 01:13:21,740
the signal roughly a cross correlation

1693
01:13:28,100 --> 01:13:25,410
so Planck provides a map of the dust it

1694
01:13:29,840 --> 01:13:28,110
tells us where the dust is and then we

1695
01:13:31,340 --> 01:13:29,850
can look at the bicep2 signal and see

1696
01:13:31,730 --> 01:13:31,350
whether there be mode amplitude is

1697
01:13:34,580 --> 01:13:31,740
bigger

1698
01:13:36,569 --> 01:13:34,590
we're playing causes of dust is and it

1699
01:13:39,479 --> 01:13:36,579
is very very literally like trying to

1700
01:13:42,540 --> 01:13:39,489
fingerprints so we have a fingerprint of

1701
01:13:44,040 --> 01:13:42,550
dust from Planck and this is what bicep2

1702
01:13:45,959 --> 01:13:44,050
might look like and they want to know

1703
01:13:49,919 --> 01:13:45,969
whether this fingerprint looks the same

1704
01:13:52,770 --> 01:13:49,929
as this fingerprint so the question is

1705
01:13:54,209 --> 01:13:52,780
when we actually image the dust map

1706
01:13:58,260 --> 01:13:54,219
which is being provided by the Planck

1707
01:14:01,950 --> 01:13:58,270
satellite will it look more like this or

1708
01:14:04,379 --> 01:14:01,960
like this and the answer is we don't

1709
01:14:07,589 --> 01:14:04,389
know the measurements have not been made

1710
01:14:09,720 --> 01:14:07,599
yet with a sufficient precision but we

1711
01:14:12,750 --> 01:14:09,730
hope that they will in the next few

1712
01:14:14,640 --> 01:14:12,760
years so the next steps are to overlay

1713
01:14:16,470 --> 01:14:14,650

the Planck and the bicep2 maps to see

1714
01:14:17,939 --> 01:14:16,480
whether they look the same or not if

1715
01:14:19,740 --> 01:14:17,949
they look completely different that

1716
01:14:22,350 --> 01:14:19,750
provides some reasonable evidence that

1717
01:14:23,910 --> 01:14:22,360
bicep2 is seen gravitational waves if

1718
01:14:27,600 --> 01:14:23,920
they look the same then Planck the

1719
01:14:29,459 --> 01:14:27,610
bicep2 is probably just seeing dust in

1720
01:14:31,620 --> 01:14:29,469
science things are not true because

1721
01:14:33,240 --> 01:14:31,630
somebody or some collaboration says

1722
01:14:35,689 --> 01:14:33,250
they're true they're true because many

1723
01:14:37,799 --> 01:14:35,699
different scientists make independent

1724
01:14:39,629 --> 01:14:37,809
observations and come to the same

1725
01:14:43,080 --> 01:14:39,639
conclusions and so there are all these

1726
01:14:45,209 --> 01:14:43,090
other competing telescopes which are you

1727
01:14:47,280 --> 01:14:45,219
know catching up to bicep2 in terms of

1728
01:14:48,870 --> 01:14:47,290
sensitivity and if bicep2 is seen

1729
01:14:50,669 --> 01:14:48,880
gravitational waves these other guys

1730
01:14:52,229 --> 01:14:50,679
should be seeing them too there's the

1731
01:14:54,660 --> 01:14:52,239
frequency dependence that I talked

1732
01:14:56,729 --> 01:14:54,670
talked about and then if there is a

1733
01:14:58,260 --> 01:14:56,739
gravitational wave signal it should be

1734
01:15:00,359 --> 01:14:58,270
the same all over the sky

1735
01:15:02,339 --> 01:15:00,369
whereas the dust signal is brighter in

1736
01:15:05,520 --> 01:15:02,349
certain region of the sky than in other

1737
01:15:07,859 --> 01:15:05,530
regions of the sky so I am a theoretical

1738
01:15:10,430 --> 01:15:07,869

physicist my job is to make predictions

1739
01:15:14,160 --> 01:15:10,440
and so I am going to make a prediction

1740
01:15:18,879 --> 01:15:14,170
my prediction is that we will figure it

1741
01:15:24,680 --> 01:15:21,950
but this is a very exciting so you know

1742
01:15:26,030 --> 01:15:24,690
back in early summer when I agreed to

1743
01:15:27,890 --> 01:15:26,040
give this talk I thought you know this

1744
01:15:29,590 --> 01:15:27,900
is gonna be the victory tour talk you

1745
01:15:31,910 --> 01:15:29,600
know we discover gravitational waves

1746
01:15:32,689 --> 01:15:31,920
someone's gonna get a Nobel Prize and

1747
01:15:34,370 --> 01:15:32,699
this is great

1748
01:15:37,370 --> 01:15:34,380
and we've you know talking about this

1749
01:15:39,350 --> 01:15:37,380
decades from now but I don't know so I

1750
01:15:41,270 --> 01:15:39,360
have to say that the arguments the

1751
01:15:43,520 --> 01:15:41,280
bicep2 gave that it's not dust we're

1752
01:15:45,649 --> 01:15:43,530
very very convincing at the time and

1753
01:15:47,510 --> 01:15:45,659
there's still many intriguing things

1754
01:15:50,689 --> 01:15:47,520
about the data that suggests that it's

1755
01:15:53,270 --> 01:15:50,699
not obviously dust but it is true that

1756
01:15:54,919 --> 01:15:53,280
since then we've realized that dust is

1757
01:15:57,890 --> 01:15:54,929
more complicated than we thought back in

1758
01:15:59,780 --> 01:15:57,900
March so we really don't know I do think

1759
01:16:02,419 --> 01:15:59,790
there's some good reason to believe that

1760
01:16:04,640 --> 01:16:02,429
we may at the end of the day be seeing

1761
01:16:06,950 --> 01:16:04,650
gravitational waves but I don't know yet

1762
01:16:08,600 --> 01:16:06,960
if these are indeed gravitational waves

1763
01:16:11,479 --> 01:16:08,610

it's as exciting as it gets

1764
01:16:13,280 --> 01:16:11,489
we're seeing some possible consequences

1765
01:16:15,890 --> 01:16:13,290
of the unification of the fundamental

1766
01:16:17,660 --> 01:16:15,900
forces at energy scales much greater

1767
01:16:19,910 --> 01:16:17,670
than those accessible with laboratory

1768
01:16:22,040 --> 01:16:19,920
experiments this would constitute the

1769
01:16:23,959 --> 01:16:22,050
first detection of gravitational waves I

1770
01:16:25,760 --> 01:16:23,969
did not mention this but these

1771
01:16:28,879 --> 01:16:25,770
gravitational waves are produced by a

1772
01:16:30,350 --> 01:16:28,889
Hawking like process in the early

1773
01:16:34,939 --> 01:16:30,360
universe so it would actually be

1774
01:16:37,280 --> 01:16:34,949
discovery of Hawking radiation the

1775
01:16:39,830 --> 01:16:37,290
physics that produces this in some sense

1776
01:16:41,419 --> 01:16:39,840
merges gravity and quantum mechanics or

1777
01:16:43,040 --> 01:16:41,429
at least scratches the surface of a

1778
01:16:45,080 --> 01:16:43,050
merger of gravity and quantum mechanics

1779
01:16:46,610 --> 01:16:45,090
and the biggest thing that theoretical

1780
01:16:49,189 --> 01:16:46,620
physicists have been trying to do in

1781
01:16:51,260 --> 01:16:49,199
20th century in 21st century science is

1782
01:16:53,209 --> 01:16:51,270
merged general relativity Einstein's

1783
01:16:56,149 --> 01:16:53,219
general relativity with the laws of

1784
01:16:58,669 --> 01:16:56,159
quantum mechanics and if this is what we

1785
01:17:01,010 --> 01:16:58,679
think it is this is actually scratching

1786
01:17:02,510 --> 01:17:01,020
the surface of what may ultimately prove

1787
01:17:04,430 --> 01:17:02,520
to be a merger between gravity and

1788
01:17:06,140 --> 01:17:04,440

quantum mechanics and perhaps most

1789
01:17:07,879 --> 01:17:06,150
exciting is that if this is what we

1790
01:17:10,220 --> 01:17:07,889
think it is if it turns out to really be

1791
01:17:12,439 --> 01:17:10,230
inflationary gravitational waves and we

1792
01:17:14,149 --> 01:17:12,449
are actually seeing a brand-new signal

1793
01:17:15,320 --> 01:17:14,159
from a trillionth of a trillionth of a

1794
01:17:18,140 --> 01:17:15,330
trillionth of a second after the Big

1795
01:17:20,600 --> 01:17:18,150
Bang and if they've detected are these B

1796
01:17:22,490 --> 01:17:20,610
modes from inflate from inflation then

1797
01:17:24,979 --> 01:17:22,500
what we've only discovered so far is a

1798
01:17:26,540 --> 01:17:24,989
rosetta stone and you know it took many

1799
01:17:28,860 --> 01:17:26,550
years after the discovery of the Rosetta

1800
01:17:31,350 --> 01:17:28,870
Stone to actually craft the code

1801
01:17:33,240 --> 01:17:31,360
figure out what's written there and over

1802
01:17:35,130 --> 01:17:33,250
the next few decades if these measures

1803
01:17:36,840 --> 01:17:35,140
if this is these are be modes we can

1804
01:17:39,120 --> 01:17:36,850
measure these be modes more precisely

1805
01:17:39,990 --> 01:17:39,130
through the same types of analyses that

1806
01:17:42,390 --> 01:17:40,000
we've done in the Cosmic Microwave

1807
01:17:44,280 --> 01:17:42,400
Background maps we have so far and we

1808
01:17:47,640 --> 01:17:44,290
have an entirely new avenue to study

1809
01:17:51,000 --> 01:17:47,650
what happened very first microsecond

1810
01:18:05,460 --> 01:17:51,010
after the Big Bang so I will close by

1811
01:18:14,800 --> 01:18:12,250
okay so y'all get all that complex feel

1812
01:18:28,660 --> 01:18:14,810
lots of cool things I'm sure there are a

1813
01:18:30,400 --> 01:18:28,670

few questions how about you should you

1814
01:18:33,520 --> 01:18:30,410
repeat the question for the webcasting

1815
01:18:35,590 --> 01:18:33,530
audience so the question is whether the

1816
01:18:36,940 --> 01:18:35,600
Cosmic Microwave Background is affected

1817
01:18:38,170 --> 01:18:36,950
by gravitational lensing

1818
01:18:40,900 --> 01:18:38,180
so this Cosmic Microwave Background

1819
01:18:42,790 --> 01:18:40,910
comes from a very large distance so this

1820
01:18:44,140 --> 01:18:42,800
light you know it's emitted from the

1821
01:18:46,510 --> 01:18:44,150
cosmic microwave background surface of

1822
01:18:48,190 --> 01:18:46,520
mascara it goes a very very long way

1823
01:18:50,710 --> 01:18:48,200
before you know we see it in our

1824
01:18:52,210 --> 01:18:50,720
telescope and it passes by a lot of

1825
01:18:54,100 --> 01:18:52,220
things a lot of galaxies and clusters of

1826
01:18:55,750 --> 01:18:54,110
galaxies and we know that general

1827
01:18:58,150 --> 01:18:55,760
relativity bends the trajectories of

1828
01:18:59,890 --> 01:18:58,160
light rays so you might ask whether that

1829
01:19:01,750 --> 01:18:59,900
Cosmic Microwave Background image is

1830
01:19:06,340 --> 01:19:01,760
distorted by this gravitational lensing

1831
01:19:08,020 --> 01:19:06,350
and it turns out that it is and this was

1832
01:19:12,010 --> 01:19:08,030
one of the big results of the Planck

1833
01:19:13,450 --> 01:19:12,020
satellite last March March of 2013 now I

1834
01:19:16,000 --> 01:19:13,460
don't have the image with me they

1835
01:19:18,850 --> 01:19:16,010
actually have measured the distribution

1836
01:19:20,050 --> 01:19:18,860
of mass in the universe by the effects

1837
01:19:22,060 --> 01:19:20,060
of gravitational and by the

1838
01:19:24,070 --> 01:19:22,070

gravitational lensing distortions of the

1839
01:19:26,680 --> 01:19:24,080
Cosmic Microwave Background so the

1840
01:19:29,340 --> 01:19:26,690
answer is yes and it's one of the the

1841
01:19:42,040 --> 01:19:29,350
major triumphs of the Planck satellite

1842
01:19:44,860 --> 01:19:42,050
okay other questions so there are

1843
01:19:47,080 --> 01:19:44,870
different ideas about what it is and

1844
01:19:50,020 --> 01:19:47,090
most of it is probably silicates and

1845
01:19:54,790 --> 01:19:50,030
these dust particles have a wide variety

1846
01:19:57,310 --> 01:19:54,800
of sizes but a micron is a typical size

1847
01:20:01,090 --> 01:19:57,320
so like they're they're much smaller

1848
01:20:03,310 --> 01:20:01,100
than sand particles I think you know if

1849
01:20:05,530 --> 01:20:03,320
you take a to talk to erasers filled

1850
01:20:06,970 --> 01:20:05,540
with talk and bang them I think that

1851
01:20:12,669 --> 01:20:06,980
those chalk dust particles are

1852
01:20:19,419 --> 01:20:14,890
it's you know tens of grams per

1853
01:20:22,600 --> 01:20:19,429
centimeter cubed it's like sand so very

1854
01:20:24,850 --> 01:20:22,610
small we don't know what it is in detail

1855
01:20:28,629 --> 01:20:24,860
there are various ideas and then it also

1856
01:20:31,629 --> 01:20:28,639
merges into things called PAH molecules

1857
01:20:34,930 --> 01:20:31,639
so a very small dust particle finds up

1858
01:20:37,000 --> 01:20:34,940
looking like a very big molecule but

1859
01:20:44,260 --> 01:20:37,010
basically it's you know dust like you

1860
01:20:47,350 --> 01:20:44,270
know a chalkboard dust gravitational

1861
01:20:58,270 --> 01:20:47,360
waves turn out to be some source of

1862
01:21:00,339 --> 01:20:58,280
humongous amounts of energy is whether

1863
01:21:02,260 --> 01:21:00,349

the gravitational waves might turn out

1864
01:21:05,169 --> 01:21:02,270
to be a huge source of energy that we

1865
01:21:07,209 --> 01:21:05,179
could tap into so the answer is no so

1866
01:21:08,830 --> 01:21:07,219
the there are upper limits to the energy

1867
01:21:11,169 --> 01:21:08,840
density of these gravitational waves and

1868
01:21:12,760 --> 01:21:11,179
the the best upper limit is that it's

1869
01:21:14,260 --> 01:21:12,770
one tenth of the energy density in the

1870
01:21:17,310 --> 01:21:14,270
Cosmic Microwave Background

1871
01:21:22,750 --> 01:21:17,320
and that's a very small energy density

1872
01:21:25,930 --> 01:21:22,760
so the roughly 400 sir roughly 400

1873
01:21:28,870 --> 01:21:25,940
photons per cubic centimeter and there

1874
01:21:31,629 --> 01:21:28,880
are very long wavelengths are very low

1875
01:21:34,419 --> 01:21:31,639
energy photons more difficult part is

1876
01:21:36,490 --> 01:21:34,429
the tap into question detecting the

1877
01:21:38,560 --> 01:21:36,500
gravitational wave is extremely

1878
01:21:40,149 --> 01:21:38,570
difficult the motions that these

1879
01:21:45,549 --> 01:21:40,159
gravitational waves would induce and

1880
01:21:48,220 --> 01:21:45,559
test masses is extremely feeble and just

1881
01:21:51,970 --> 01:21:48,230
the idea of getting energy from waves is

1882
01:21:54,370 --> 01:21:51,980
tricky so Tesla had this idea so Tesla

1883
01:21:55,930 --> 01:21:54,380
was a genius but he's also a semi not he

1884
01:21:58,330 --> 01:21:55,940
had this idea that we could do energy

1885
01:22:01,600 --> 01:21:58,340
transmission not by laying cables but by

1886
01:22:03,609 --> 01:22:01,610
a propagating radio waves and it didn't

1887
01:22:06,919 --> 01:22:03,619
work and he blew up several things

1888
01:22:12,779 --> 01:22:10,319

forty orders of magnitude longer than

1889
01:22:15,180 --> 01:22:12,789
gravitational waves so if we can't do

1890
01:22:21,720 --> 01:22:15,190
with electromagnetic waves it's not hey

1891
01:22:24,629 --> 01:22:21,730
40 orders just a bit over here this sort

1892
01:22:27,350 --> 01:22:24,639
of follow-up to the first question how

1893
01:22:31,379 --> 01:22:27,360
do we know that sort of the image of the

1894
01:22:33,510 --> 01:22:31,389
microwave pattern mentioned by Coby and

1895
01:22:36,000 --> 01:22:33,520
the subsequent satellites has not been

1896
01:22:40,970 --> 01:22:36,010
distorted by other intervening sources

1897
01:22:43,649 --> 01:22:40,980
of microwave or so it turns out that the

1898
01:22:46,109 --> 01:22:43,659
predictions of inflation for the Cosmic

1899
01:22:51,529 --> 01:22:46,119
Microwave Background pattern are very

1900
01:22:54,779 --> 01:22:51,539
very precise and the prediction is that

1901
01:22:57,930 --> 01:22:54,789
the image should be a what we call the

1902
01:23:00,180 --> 01:22:57,940
Gaussian random map so it's a very very

1903
01:23:03,089 --> 01:23:00,190
specific prediction so you know what a

1904
01:23:04,620 --> 01:23:03,099
bell curve is right bell curve goes up

1905
01:23:07,850 --> 01:23:04,630
and it goes down has a very precise

1906
01:23:11,430 --> 01:23:07,860
mathematical description anything else

1907
01:23:12,990 --> 01:23:11,440
is not a bell curve so if I draw a curve

1908
01:23:14,310 --> 01:23:13,000
that goes like that that's not a bell

1909
01:23:16,080 --> 01:23:14,320
curve if I draw a triangle it's not a

1910
01:23:18,359 --> 01:23:16,090
bell curve a square is not a bell curve

1911
01:23:20,549 --> 01:23:18,369
anything that's not a bell curve is not

1912
01:23:23,010 --> 01:23:20,559
a bell curve and anything that's not a

1913
01:23:26,000 --> 01:23:23,020

Gaussian random map is not a Gaussian

1914
01:23:30,000 --> 01:23:26,010
random map and it turns out that the the

1915
01:23:33,660 --> 01:23:30,010
images are Gaussian to one part in

1916
01:23:36,029 --> 01:23:33,670
10,000 so we know that the distortions

1917
01:23:38,040 --> 01:23:36,039
are extremely small but we now can't

1918
01:23:41,520 --> 01:23:38,050
detect these very tiniest or seems very

1919
01:23:43,560 --> 01:23:41,530
tiny distortions we can attribute very

1920
01:23:47,569 --> 01:23:43,570
precisely to the effects of

1921
01:23:50,850 --> 01:23:47,579
gravitational lensing in the back there

1922
01:23:53,220 --> 01:23:50,860
just a simple question but the on the B

1923
01:23:54,629 --> 01:23:53,230
modes but that create bumps on the

1924
01:23:56,700 --> 01:23:54,639
outside edges

1925
01:24:00,779 --> 01:23:56,710
maybe I'm saying it simply but the

1926
01:24:03,240 --> 01:24:00,789
outside edges of where you have

1927
01:24:05,010 --> 01:24:03,250
inflation if you had one picture where

1928
01:24:07,859 --> 01:24:05,020
there was like kind of a a ball with

1929
01:24:11,069 --> 01:24:07,869
spirals well those B modes actually

1930
01:24:13,379 --> 01:24:11,079
rotate and create like dimples on the

1931
01:24:15,060 --> 01:24:13,389
outside edge or how does that work it's

1932
01:24:17,720 --> 01:24:15,070
the other way around so what happens is

1933
01:24:20,640 --> 01:24:17,730
that there's surface of last scattering

1934
01:24:23,069 --> 01:24:20,650
the light that we see from in the Cosmic

1935
01:24:26,609 --> 01:24:23,079
Microwave Background is actually emitted

1936
01:24:28,799 --> 01:24:26,619
from the surface of last scattering it

1937
01:24:31,439 --> 01:24:28,809
comes in it starts jiggling starts

1938
01:24:33,060 --> 01:24:31,449

moving it around and those motions are

1939
01:24:37,140 --> 01:24:33,070
what gives rise to the polarization

1940
01:24:38,370 --> 01:24:37,150
pattern so it's those motions induced by

1941
01:24:41,520 --> 01:24:38,380
the gravitational waves give rise to

1942
01:24:47,339 --> 01:24:41,530
that polarization pattern not vice versa

1943
01:24:48,930 --> 01:24:47,349
I was just asking well that is their

1944
01:24:51,660 --> 01:24:48,940
varying density or something that's

1945
01:24:53,129 --> 01:24:51,670
creating that and and is it a flat wall

1946
01:24:55,049 --> 01:24:53,139
on the outside edge of that or is it

1947
01:24:56,790 --> 01:24:55,059
something that that that energy goes

1948
01:25:01,049 --> 01:24:56,800
both directions or is it only coming one

1949
01:25:02,640 --> 01:25:01,059
way oh it's going in all directions but

1950
01:25:10,259 --> 01:25:02,650
we only the see the stuff that's coming

1951
01:25:14,069 --> 01:25:10,269
towards us okay yeah question here Hey

1952
01:25:16,470 --> 01:25:14,079
in this the COBE and w map actin and

1953
01:25:20,279 --> 01:25:16,480
puck background radiation

1954
01:25:22,979 --> 01:25:20,289
you mentioned hotter and colder

1955
01:25:27,240 --> 01:25:22,989
is that a spectral or an intensity or is

1956
01:25:29,009 --> 01:25:27,250
it the same difference so hotter and

1957
01:25:33,029 --> 01:25:29,019
colder means brighter what I should have

1958
01:25:34,410 --> 01:25:33,039
said is brighter and fainter that's an

1959
01:25:35,990 --> 01:25:34,420
intensity measurement or is it a

1960
01:25:37,259 --> 01:25:36,000
specular the difference in frequency

1961
01:25:42,270 --> 01:25:37,269
wavelength

1962
01:25:43,560 --> 01:25:42,280
it's an intensity measurement and I can

1963
01:25:45,870 --> 01:25:43,570

tell you more if you want more detailed

1964
01:25:47,370 --> 01:25:45,880
information about how what precise

1965
01:25:55,109 --> 01:25:47,380
they're measuring but it's an intensity

1966
01:25:57,359 --> 01:25:55,119
measurement okay lights because the

1967
01:25:59,850 --> 01:25:57,369
speed of light is what is faster than

1968
01:26:01,709 --> 01:25:59,860
the rate of that car and you just said

1969
01:26:03,120 --> 01:26:01,719
we can't see things going away from us

1970
01:26:05,279 --> 01:26:03,130
so you've said all the galaxies are

1971
01:26:07,109 --> 01:26:05,289
moving faster than the speed of light so

1972
01:26:13,080 --> 01:26:07,119
we can't see things moving away from us

1973
01:26:14,910 --> 01:26:13,090
oh we're moving in this direction and

1974
01:26:16,919 --> 01:26:14,920
everything's expanding we should be

1975
01:26:19,470 --> 01:26:16,929
looking this way and not see anything

1976
01:26:21,779 --> 01:26:19,480
but if we look back the other way we

1977
01:26:24,689 --> 01:26:21,789
should see you know things coming

1978
01:26:25,830 --> 01:26:24,699
towards us unless they should be a

1979
01:26:28,410 --> 01:26:25,840
little bit more dense

1980
01:26:30,870 --> 01:26:28,420
so now that you've told me about the Big

1981
01:26:33,300 --> 01:26:30,880
Bang it makes me think that whatever

1982
01:26:35,100 --> 01:26:33,310
that source is over here there's not one

1983
01:26:37,310 --> 01:26:35,110
Big Bang it makes it seem like this a

1984
01:26:39,480 --> 01:26:37,320
series of things so that additional

1985
01:26:42,240 --> 01:26:39,490
matter would be released from that

1986
01:26:44,100 --> 01:26:42,250
source like you know peeling an onion

1987
01:26:47,160 --> 01:26:44,110
and now you've has layers of one layer

1988
01:26:49,080 --> 01:26:47,170

bangs the next layer bangs the next

1989
01:26:51,030 --> 01:26:49,090
layer so that when we look that way

1990
01:26:53,880 --> 01:26:51,040
we don't see anything but when we look

1991
01:26:58,430 --> 01:26:53,890
back we can still see matters upcoming

1992
01:27:02,300 --> 01:26:58,440
tours okay so this is so the

1993
01:27:05,100 --> 01:27:02,310
understanding the Big Bang

1994
01:27:08,580 --> 01:27:05,110
it's probably the it's the hardest thing

1995
01:27:11,040 --> 01:27:08,590
to explain and to understand and I had

1996
01:27:19,370 --> 01:27:11,050
to take general relativity and cosmology

1997
01:27:24,450 --> 01:27:22,110
explosions so the Big Bang is all often

1998
01:27:25,920 --> 01:27:24,460
described as an explosion but it's kind

1999
01:27:27,960 --> 01:27:25,930
of a misnomer because when we think of

2000
01:27:30,510 --> 01:27:27,970
explosions you know we think of

2001
01:27:34,580 --> 01:27:30,520
something over there blowing up and then

2002
01:27:36,960 --> 01:27:34,590
we see it but that's not the big bang

2003
01:27:40,650 --> 01:27:36,970
what we observe is that the entire

2004
01:27:45,060 --> 01:27:40,660
universe is expanding imagine that I had

2005
01:27:48,030 --> 01:27:45,070
a balloon that was very small and I were

2006
01:27:49,950 --> 01:27:48,040
to I blew it up slowly and think about

2007
01:27:55,890 --> 01:27:49,960
the surface which is a two-dimensional

2008
01:27:57,960 --> 01:27:55,900
universe every point on that universe is

2009
01:27:59,520 --> 01:27:57,970
moving away from every other point every

2010
01:28:01,590 --> 01:27:59,530
point on the surface the balloon is

2011
01:28:05,490 --> 01:28:01,600
moving away from every other points as I

2012
01:28:06,840 --> 01:28:05,500
blow it up but there is no place on the

2013
01:28:11,250 --> 01:28:06,850

balloon that's different than any other

2014
01:28:13,770 --> 01:28:11,260
place and the expanding universe is a

2015
01:28:31,190 --> 01:28:13,780
three dimensional analog of the surface

2016
01:28:34,550 --> 01:28:33,020
the circuits have another bubble and

2017
01:28:37,100 --> 01:28:34,560
they started a balloon and they're all

2018
01:28:38,600 --> 01:28:37,110
expanding yeah we can't do that so so so

2019
01:28:41,720 --> 01:28:38,610
the problem with this analogy is that

2020
01:28:44,360 --> 01:28:41,730
when we look at the the balloon it's a

2021
01:28:46,220 --> 01:28:44,370
two-dimensional surface that we can see

2022
01:28:49,040 --> 01:28:46,230
because we're in three dimensions and

2023
01:28:50,600 --> 01:28:49,050
for this analogy to work really well we

2024
01:28:51,410 --> 01:28:50,610
would have to live in four dimensions

2025
01:28:53,780 --> 01:28:51,420
and be able to look at our

2026
01:28:56,210 --> 01:28:53,790
three-dimensional universe from outside

2027
01:28:59,240 --> 01:28:56,220
it we can talk afterwards I can try to

2028
01:29:02,780 --> 01:28:59,250
explain the expansion of expansion

2029
01:29:05,510 --> 01:29:02,790
spaces be the stretching of space and

2030
01:29:08,420 --> 01:29:05,520
not really moving through space is one

2031
01:29:10,250 --> 01:29:08,430
of the fundamental pieces that you have

2032
01:29:11,870 --> 01:29:10,260
to grasp in order for a lot of this to

2033
01:29:20,270 --> 01:29:11,880
some of this to make sense all right

2034
01:29:23,510 --> 01:29:20,280
we've hit at a good amount of time next

2035
01:29:28,760 --> 01:29:23,520
month December we will have Joshua peak

2036
01:29:31,760 --> 01:29:28,770
on outer space the landing on the

2037
01:29:35,270 --> 01:29:31,770
Rosetta on comet rubber ducky cheerio

2038
01:29:36,770 --> 01:29:35,280

mom Gerasimenko is like what did we

2039
01:29:37,460 --> 01:29:36,780
figure out was 11 a.m. tomorrow or

2040
01:29:41,780 --> 01:29:37,470
something like that

2041
01:29:43,700 --> 01:29:41,790
Eastern Time and somebody put up here

2042
01:29:48,170 --> 01:29:43,710
that Adam riess is getting yet another

2043
01:29:50,030 --> 01:29:48,180
prize and it's going to be simulcast on

2044
01:29:52,820 --> 01:29:50,040
the Discovery Channel and Science

2045
01:29:54,530 --> 01:29:52,830
Channel 6 p.m. Saturday with hosted by

2046
01:29:57,440 --> 01:29:54,540
Seth MacFarlane and other things like

2047
01:29:58,970 --> 01:29:57,450
that so you want to see yet another

2048
01:30:00,530 --> 01:29:58,980
thing for Adam riess go ahead alright