1
00:01:12,610 --> 00:00:29,540
[Music]

2
00:01:30,750 --> 00:01:12,860
[Applause]

3
00:02:34,420 --> 00:01:48,200
[Music]

4
00:02:40,610 --> 00:02:36,410
NASA's Jet Propulsion Laboratory

5
00:02:43,040 --> 00:02:40,620
presents the von Karman lecture a series

6
00:02:45,650 --> 00:02:43,050
of talks by scientists and engineers who

7
00:02:48,150 --> 00:02:45,660
are exploring our planet our solar

8
00:03:04,300 --> 00:02:48,160
system and all that lies beyond

9
00:03:09,920 --> 00:03:07,940
hey everybody well welcome to our

10
00:03:11,540 --> 00:03:09,930
monthly public talk here at NASA's Jet

11
00:03:12,190 --> 00:03:11,550
Propulsion Laboratory my name is Preston

12
00:03:16,580 --> 00:03:12,200
dykes

13
00:03:20,420 --> 00:03:16,590

well it's October and Halloween is just

14
00:03:22,850 --> 00:03:20,430
a couple of weeks away this is a time of

15
00:03:25,930 --> 00:03:22,860
year when we become acutely aware that

16
00:03:29,390 --> 00:03:25,940
there are things out there in the dark

17
00:03:30,530 --> 00:03:29,400
things beyond our understanding so in

18
00:03:32,750 --> 00:03:30,540
the spirit of the season

19
00:03:34,250 --> 00:03:32,760
we've prepared a talk for you about two

20
00:03:37,580 --> 00:03:34,260
of the most terrifying

21
00:03:40,790 --> 00:03:37,590
I mean fascinating mysteries of the

22
00:03:43,610 --> 00:03:40,800
cosmos these are the enigmatic dark

23
00:03:45,110 --> 00:03:43,620
matter and dark energy will have a

24
00:03:47,090 --> 00:03:45,120
single talk tonight in which our two

25
00:03:48,350 --> 00:03:47,100
speakers will share the stage and then

26
00:03:50,240 --> 00:03:48,360
we'll take your questions and if you're

27
00:03:51,140 --> 00:03:50,250
watching the live webcast on youtube

28
00:03:53,120 --> 00:03:51,150
we'll work in a few of your questions

29
00:03:56,540 --> 00:03:53,130
from the chat as well so now to

30
00:03:59,510 --> 00:03:56,550
introduce our speakers our speakers this

31
00:04:01,430 --> 00:03:59,520
month are a unique pairing Alena

32
00:04:03,590 --> 00:04:01,440
Kiessling and Jason Rhodes are both

33
00:04:05,150 --> 00:04:03,600
astrophysicists at JPL where they are

34
00:04:07,970 --> 00:04:05,160
involved in a variety of exciting

35
00:04:09,430 --> 00:04:07,980
astronomy projects both have a history

36
00:04:12,200 --> 00:04:09,440
of using a technique called

37
00:04:14,630 --> 00:04:12,210
gravitational lensing to study dark

38
00:04:16,340 --> 00:04:14,640

matter and dark energy she's worked on

39
00:04:18,830 --> 00:04:16,350
simulating it while he's worked on

40
00:04:20,840 --> 00:04:18,840
measuring it but what's really special

41
00:04:23,570 --> 00:04:20,850
is that these two gifted researchers

42
00:04:26,960 --> 00:04:23,580
were pulled together by let's call it a

43
00:04:29,619 --> 00:04:26,970
mutual force of attraction you see they

44
00:04:32,510 --> 00:04:29,629
just happen to be married to each other

45
00:04:34,640 --> 00:04:32,520
so we think you'll enjoy their take on

46
00:04:36,980 --> 00:04:34,650
the dark and mysterious forces at work

47
00:04:48,060 --> 00:04:36,990
in the universe around us so please

48
00:04:53,790 --> 00:04:51,390
thank you so much Preston Jason and I

49
00:04:59,250 --> 00:04:53,800
are so excited to be here tonight and

50
00:05:02,880 --> 00:04:59,260
Wow look at this crowd it is so big very

51
00:05:05,280 --> 00:05:02,890
exciting and as science interested

52
00:05:10,070 --> 00:05:05,290
people I'm sure that you can all also

53
00:05:13,620 --> 00:05:10,080
agree that the universe is really big

54
00:05:15,990 --> 00:05:13,630
but sometimes it's hard to think about

55
00:05:19,100 --> 00:05:16,000
really really big things so let's try to

56
00:05:22,170 --> 00:05:19,110
put it into context a little bit for you

57
00:05:24,810 --> 00:05:22,180
let's talk about some big numbers to

58
00:05:27,870 --> 00:05:24,820
start with numbers like a million a

59
00:05:31,140 --> 00:05:27,880
billion and a trillion there was a study

60
00:05:33,060 --> 00:05:31,150
done that found that 35% of people

61
00:05:36,090 --> 00:05:33,070
thought that these numbers were equally

62
00:05:37,890 --> 00:05:36,100
spaced on a number line I can tell you

63
00:05:41,280 --> 00:05:37,900

that this is not correct

64
00:05:43,890 --> 00:05:41,290
so if you had zero at one end of a

65
00:05:46,830 --> 00:05:43,900
number line that's 10 centimeters long

66
00:05:49,560 --> 00:05:46,840
and you had 1 billion at the other end

67
00:05:53,070 --> 00:05:49,570
of that same number line 1 million would

68
00:05:57,030 --> 00:05:53,080
be just one human hair width away from 0

69
00:06:00,480 --> 00:05:57,040
so 1 million is almost nothing compared

70
00:06:02,490 --> 00:06:00,490
to 1 billion we can put this a little

71
00:06:05,400 --> 00:06:02,500
bit more into context with some things

72
00:06:08,550 --> 00:06:05,410
that we're all familiar with so let's

73
00:06:10,320 --> 00:06:08,560
take a dime 10 cents I'm walking along

74
00:06:12,180 --> 00:06:10,330
this street I see a dime on the ground

75
00:06:16,380 --> 00:06:12,190
but I've got a bit of a sore back and

76
00:06:19,950 --> 00:06:16,390
I'm just I'm not gonna pick it up a dime

77
00:06:23,310 --> 00:06:19,960
compared to $100 which is a nice dinner

78
00:06:25,520 --> 00:06:23,320
out in Los Angeles for Jason and I so 10

79
00:06:27,990 --> 00:06:25,530
cents is almost nothing compared to that

80
00:06:30,570 --> 00:06:28,000
$100 and that's the same as the

81
00:06:34,050 --> 00:06:30,580
difference between 1 million and 1

82
00:06:38,360 --> 00:06:34,060
billion now let's look at a larger

83
00:06:41,040 --> 00:06:38,370
number so we've got $100 compared to

84
00:06:42,780 --> 00:06:41,050
$100,000 which is the equivalent of a

85
00:06:43,290 --> 00:06:42,790
down payment on a house here in Los

86
00:06:47,610 --> 00:06:43,300
Angeles

87
00:06:50,520 --> 00:06:47,620
so the $100 is almost nothing compared

88
00:06:54,210 --> 00:06:50,530

to the $100,000 and this is the

89
00:06:56,550 --> 00:06:54,220
equivalent of 1 billion to 1 trillion so

90
00:06:59,640 --> 00:06:56,560
these numbers really are very very

91
00:07:02,879 --> 00:06:59,650
different to each other the 10 cents

92
00:07:06,189 --> 00:07:02,889
really insignificant compared to the

93
00:07:10,270 --> 00:07:06,199
$100,000 just like 1 million is very

94
00:07:12,700 --> 00:07:10,280
insignificant compared to 1 trillion so

95
00:07:15,040 --> 00:07:12,710
now that we've got some context on the

96
00:07:17,950 --> 00:07:15,050
relative sizes of the numbers we can put

97
00:07:19,420 --> 00:07:17,960
it into context with the universe so

98
00:07:22,689 --> 00:07:19,430
when I was a kid I thought the earth was

99
00:07:25,360 --> 00:07:22,699
really big and my parents used to take

100
00:07:27,670 --> 00:07:25,370
me out into the desert of Australia and

101
00:07:30,129 --> 00:07:27,680
we were looking for opals and one day I

102
00:07:32,409 --> 00:07:30,139
found an opal eyes dinosaur bone this

103
00:07:34,809 --> 00:07:32,419
was really exciting for me and it

104
00:07:37,269 --> 00:07:34,819
started me on my career in astrophysics

105
00:07:40,629 --> 00:07:37,279
and I wanted to learn how the earth

106
00:07:43,179 --> 00:07:40,639
began and evolved over time but then I

107
00:07:45,990 --> 00:07:43,189
realized that I wasn't really thinking

108
00:07:50,769 --> 00:07:46,000
big enough

109
00:07:55,149 --> 00:07:50,779
did you know that about 1 million earths

110
00:07:59,559 --> 00:07:55,159
would fit inside the Sun our Sun and our

111
00:08:03,219 --> 00:07:59,569
Sun is a star and there are around 100

112
00:08:06,879 --> 00:08:03,229
billion stars in a galaxy and there's

113
00:08:10,719 --> 00:08:06,889

around 100 billion galaxies in the

114
00:08:15,879 --> 00:08:10,729
universe so that's 100 billion galaxies

115
00:08:19,480 --> 00:08:15,889
times 100 billion stars or 10 billion

116
00:08:22,959 --> 00:08:19,490
trillion stars in the universe now that

117
00:08:25,540 --> 00:08:22,969
is an enormous number I started to get

118
00:08:27,670 --> 00:08:25,550
an idea of just how big the universe was

119
00:08:30,399 --> 00:08:27,680
and I knew that I needed to understand

120
00:08:32,860 --> 00:08:30,409
how the universe began and evolved over

121
00:08:35,850 --> 00:08:32,870
time that's how I got into astrophysics

122
00:08:39,370 --> 00:08:35,860
but as Jason's going to tell you next

123
00:08:42,339 --> 00:08:39,380
this 10 billion trillion stars in the

124
00:08:46,769 --> 00:08:42,349
universe is really just a tiny fraction

125
00:08:49,180 --> 00:08:46,779
of everything there is so Lena and I are

126
00:08:51,340 --> 00:08:49,190
cosmologists those are scientists that

127
00:08:54,130 --> 00:08:51,350
study the contents of the universe and

128
00:08:57,040 --> 00:08:54,140
when a cosmologists starts to talk he or

129
00:08:58,810 --> 00:08:57,050
she usually starts with this chart the

130
00:09:01,630 --> 00:08:58,820
universe as a pie chart and it's a pie

131
00:09:03,699 --> 00:09:01,640
because it's round and this is the

132
00:09:05,230 --> 00:09:03,709
contents of the universe and you can see

133
00:09:07,060 --> 00:09:05,240
that the contents of the universe are

134
00:09:09,400 --> 00:09:07,070
divided up into very uneven pieces

135
00:09:10,950 --> 00:09:09,410
probably very unfair pieces for those

136
00:09:12,510 --> 00:09:10,960
kids that want the big

137
00:09:15,090 --> 00:09:12,520
piece of the pie but maybe their brother

138
00:09:19,410 --> 00:09:15,100

or sister gets the bigger piece but the

139
00:09:22,200 --> 00:09:19,420
universe is not given to very even

140
00:09:25,580 --> 00:09:22,210
pieces the pieces that Alena was talking

141
00:09:29,340 --> 00:09:25,590
about the stars here only make up about

142
00:09:31,830 --> 00:09:29,350
1% of the universe there's a lot more

143
00:09:34,080 --> 00:09:31,840
gas in the universe than that that's a

144
00:09:37,170 --> 00:09:34,090
few percent and one of the things that

145
00:09:40,470 --> 00:09:37,180
we found in the past few years is that

146
00:09:42,480 --> 00:09:40,480
almost every star we think has a planet

147
00:09:44,640 --> 00:09:42,490
so we think that those 10 billion

148
00:09:46,860 --> 00:09:44,650
trillion stars that Alena was talking

149
00:09:49,110 --> 00:09:46,870
about in the universe probably each have

150
00:09:51,660 --> 00:09:49,120
at least one planet but those planets

151
00:09:54,300 --> 00:09:51,670
are such a small part of the universe

152
00:09:56,940 --> 00:09:54,310
they don't even show up on this pie

153
00:10:00,180 --> 00:09:56,950
chart the other piece of what we call

154
00:10:02,910 --> 00:10:00,190
normal matter is neutrinos neutrinos are

155
00:10:05,520 --> 00:10:02,920
small ghostly particles billions of

156
00:10:07,470 --> 00:10:05,530
which pass through you every second but

157
00:10:09,600 --> 00:10:07,480
you can't feel them but we know they're

158
00:10:11,970 --> 00:10:09,610
there but all the stuff I've talked

159
00:10:14,070 --> 00:10:11,980
about is what we call normal matter it's

160
00:10:16,320 --> 00:10:14,080
the stuff we can see in the universe is

161
00:10:18,120 --> 00:10:16,330
the stuff we can detect it's the stuff

162
00:10:20,640 --> 00:10:18,130
that we see with telescopes in our eyes

163
00:10:24,000 --> 00:10:20,650

it's you and me that only makes up about

164
00:10:25,710 --> 00:10:24,010
five percent of the universe and we've

165
00:10:28,770 --> 00:10:25,720
known for the better part of a century

166
00:10:30,990 --> 00:10:28,780
now that most of the matter in the

167
00:10:34,440 --> 00:10:31,000
universe is dark matter

168
00:10:36,990 --> 00:10:34,450
it's a ghostly form of matter that's not

169
00:10:38,460 --> 00:10:37,000
giving off light it's not absorbing

170
00:10:40,380 --> 00:10:38,470
light and that's why we call it dark

171
00:10:43,530 --> 00:10:40,390
matter and when I went into graduate

172
00:10:45,990 --> 00:10:43,540
school in the 1990s after college I

173
00:10:48,120 --> 00:10:46,000
wanted like Alena to understand the

174
00:10:49,770 --> 00:10:48,130
concepts of the universe so I went to

175
00:10:52,740 --> 00:10:49,780
graduate school thinking I'm gonna

176
00:10:54,210 --> 00:10:52,750
figure out what this dark matter is but

177
00:10:56,160 --> 00:10:54,220
a funny thing happened while I was in

178
00:10:58,500 --> 00:10:56,170
graduate school some of my colleagues

179
00:11:00,930 --> 00:10:58,510
doing some work that will tell you about

180
00:11:02,610 --> 00:11:00,940
later in this talk realized that the

181
00:11:04,350 --> 00:11:02,620
dark matter is it even the biggest

182
00:11:06,780 --> 00:11:04,360
component of the universe there's a

183
00:11:09,720 --> 00:11:06,790
bigger component of the universe that we

184
00:11:12,840 --> 00:11:09,730
call dark energy so when I finished

185
00:11:15,390 --> 00:11:12,850
graduate school in 1999 like Alena I

186
00:11:17,400 --> 00:11:15,400
realized the universe was much bigger

187
00:11:19,650 --> 00:11:17,410
than I thought and I needed to think

188
00:11:22,560 --> 00:11:19,660

bigger and so now I'm trying to figure

189
00:11:24,300 --> 00:11:22,570
out what the dark matter and the dark

190
00:11:26,670 --> 00:11:24,310
energy are so we

191
00:11:30,240 --> 00:11:26,680
know what these things are let's talk

192
00:11:32,160 --> 00:11:30,250
about what we do know about them tonight

193
00:11:37,380 --> 00:11:32,170
and we're gonna start by talking a

194
00:11:40,410 --> 00:11:37,390
little bit about dark matter before we

195
00:11:43,350 --> 00:11:40,420
move on I want to share a little story

196
00:11:47,250 --> 00:11:43,360
with you so let's let's take a look at

197
00:11:51,650 --> 00:11:47,260
what Jason's wearing here tonight I I

198
00:11:54,620 --> 00:11:51,660
came across Jason earlier with his tie

199
00:11:58,350 --> 00:11:54,630
measuring there with a ruler

200
00:12:02,519 --> 00:11:58,360
Jason what is she doing seriously

201
00:12:04,700 --> 00:12:02,529
and he said well Halloween themed so I'm

202
00:12:09,480 --> 00:12:04,710
gonna dress up as the universe

203
00:12:18,710 --> 00:12:09,490
anam I'm just making sure that my tie is

204
00:12:26,850 --> 00:12:21,269
that's what it's like being married to a

205
00:12:31,410 --> 00:12:26,860
cosmologists so let's talk about Dark

206
00:12:34,680 --> 00:12:31,420
Matter back in the 1930s here in

207
00:12:36,900 --> 00:12:34,690
Pasadena California at Caltech a

208
00:12:39,000 --> 00:12:36,910
scientist named Fritz Zwicky was looking

209
00:12:41,400 --> 00:12:39,010
at galaxies in the sky and he was trying

210
00:12:42,590 --> 00:12:41,410
to understand how they move relative to

211
00:12:45,540 --> 00:12:42,600
each other

212
00:12:47,160 --> 00:12:45,550
and while he was observing their

213
00:12:49,860 --> 00:12:47,170

movements he realized that there had to

214
00:12:52,290 --> 00:12:49,870
be something unseen in the universe to

215
00:12:54,780 --> 00:12:52,300
be causing those galaxies to be moving

216
00:12:57,660 --> 00:12:54,790
the way that they were and he called

217
00:13:02,180 --> 00:12:57,670
this unseen unknown component of the

218
00:13:05,940 --> 00:13:02,190
universe dark matter fast forward to the

219
00:13:08,190 --> 00:13:05,950
1960s and the scientist Vera Rubin she

220
00:13:10,470 --> 00:13:08,200
was looking at individual galaxies and

221
00:13:13,560 --> 00:13:10,480
trying to understand how their stars

222
00:13:16,650 --> 00:13:13,570
rotate so if we look at our galaxy up

223
00:13:19,290 --> 00:13:16,660
here we've got lots more stars in the

224
00:13:22,050 --> 00:13:19,300
center than we do at the outskirts and

225
00:13:25,680 --> 00:13:22,060
Vera Rubin was looking at how fast those

226
00:13:29,400 --> 00:13:25,690
stars were rotating around in my figure

227
00:13:32,880 --> 00:13:29,410
here we're showing increasing velocity

228
00:13:33,960 --> 00:13:32,890
as we go up for the stars and as we go

229
00:13:36,540 --> 00:13:33,970
to the right

230
00:13:39,890 --> 00:13:36,550
we've got increasing distance from the

231
00:13:42,720 --> 00:13:39,900
center of the galaxy what scientists

232
00:13:45,090 --> 00:13:42,730
expected to see at that when they first

233
00:13:47,040 --> 00:13:45,100
started looking at these stars was that

234
00:13:49,170 --> 00:13:47,050
the stars at the outskirts would be

235
00:13:51,660 --> 00:13:49,180
moving slower than the stars at the

236
00:13:56,430 --> 00:13:51,670
interior and that's shown with this blue

237
00:13:59,340 --> 00:13:56,440
curve but when Vera Rubin measured the

238
00:14:01,829 --> 00:13:59,350

velocities of the star she found that

239
00:14:04,410 --> 00:14:01,839
they were actually moving at the same

240
00:14:09,060 --> 00:14:04,420
velocity no matter how far out she

241
00:14:12,569 --> 00:14:09,070
looked and the only explanation for this

242
00:14:15,090 --> 00:14:12,579
is that there's some form of unseen dark

243
00:14:18,150 --> 00:14:15,100
matter holding that galaxy together

244
00:14:20,880 --> 00:14:18,160
because without that matter to hold the

245
00:14:23,069 --> 00:14:20,890
galaxies together those stars rotating

246
00:14:25,470 --> 00:14:23,079
that quickly would be flung out away

247
00:14:27,350 --> 00:14:25,480
from the galaxies and this is considered

248
00:14:32,530 --> 00:14:27,360
the first real

249
00:14:38,120 --> 00:14:35,630
so fast-forward a few more decades after

250
00:14:41,000 --> 00:14:38,130
Veera Reubens incredibly important work

251
00:14:44,180 --> 00:14:41,010
and we have a lot more evidence for dark

252
00:14:46,400 --> 00:14:44,190
matter I'm showing here a baby picture

253
00:14:48,380 --> 00:14:46,410
of the universe this is the universe

254
00:14:50,660 --> 00:14:48,390
wouldn't was only three hundred thousand

255
00:14:53,480 --> 00:14:50,670
years old after the Big Bang which

256
00:14:55,759 --> 00:14:53,490
happened thirteen billion years ago this

257
00:14:58,460 --> 00:14:55,769
is a map of the temperature of the

258
00:15:01,639 --> 00:14:58,470
universe and in this map you see hot and

259
00:15:04,310 --> 00:15:01,649
cold spots red and blue spots and in

260
00:15:06,740 --> 00:15:04,320
fact those hot and cold spots are almost

261
00:15:08,660 --> 00:15:06,750
the same temperature the difference

262
00:15:11,840 --> 00:15:08,670
between the hot and cold spots is only

263
00:15:15,380 --> 00:15:11,850

about one part in 10,000 so we had an

264
00:15:18,190 --> 00:15:15,390
almost uniform early universe with tiny

265
00:15:21,560 --> 00:15:18,200
fluctuations and those fluctuations

266
00:15:23,360 --> 00:15:21,570
correspond to over dense and under dense

267
00:15:25,160 --> 00:15:23,370
parts of the universe that is parts of

268
00:15:27,259 --> 00:15:25,170
the universe where there was more stuff

269
00:15:29,600 --> 00:15:27,269
and parts of the universe where there

270
00:15:32,090 --> 00:15:29,610
was less stuff and a part where there's

271
00:15:34,519 --> 00:15:32,100
more stuff there's more gravity there's

272
00:15:35,960 --> 00:15:34,529
more mass there's more gravity and those

273
00:15:38,990 --> 00:15:35,970
parts grew through what we call

274
00:15:41,180 --> 00:15:39,000
gravitational instability they accreted

275
00:15:43,730 --> 00:15:41,190
stuff from around them and they

276
00:15:45,860 --> 00:15:43,740
eventually became the galaxies and

277
00:15:49,009 --> 00:15:45,870
clusters of galaxies that we see today

278
00:15:51,800 --> 00:15:49,019
so from a very early universe that was

279
00:15:54,740 --> 00:15:51,810
extremely uniform we have a very

280
00:15:57,110 --> 00:15:54,750
clustered universe today with galaxies

281
00:15:59,509 --> 00:15:57,120
and clusters of galaxies like the ones

282
00:16:01,340 --> 00:15:59,519
I'm showing in this picture here this

283
00:16:04,759 --> 00:16:01,350
picture is one of the deepest images

284
00:16:06,740 --> 00:16:04,769
we've ever taken of the cosmos and this

285
00:16:09,130 --> 00:16:06,750
is a picture taken with the Hubble Space

286
00:16:12,410 --> 00:16:09,140
Telescope called the Ultra Deep Field

287
00:16:15,050 --> 00:16:12,420
this picture is a very very small piece

288
00:16:16,550 --> 00:16:15,060

of the sky if I managed to pick up that

289
00:16:19,069 --> 00:16:16,560
dime that Alina was talking about

290
00:16:21,710 --> 00:16:19,079
earlier and I held that dime at arm's

291
00:16:24,319 --> 00:16:21,720
length Roosevelts I would cover about

292
00:16:26,860 --> 00:16:24,329
the same area of the sky as this picture

293
00:16:30,259 --> 00:16:26,870
here but in this picture we're seeing

294
00:16:33,769 --> 00:16:30,269
5,000 galaxies each of those small

295
00:16:36,230 --> 00:16:33,779
smudges of light there is a galaxy much

296
00:16:38,240 --> 00:16:36,240
like our own Milky Way galaxy which as

297
00:16:40,720 --> 00:16:38,250
Alina told you has a hundred billion

298
00:16:42,759 --> 00:16:40,730
stars so there's many many

299
00:16:45,310 --> 00:16:42,769
galaxies in the sky and what we now

300
00:16:46,870 --> 00:16:45,320
realize is without the dark matter

301
00:16:49,780 --> 00:16:46,880
well you never would have had enough

302
00:16:52,180 --> 00:16:49,790
stuff for this very early uniform

303
00:16:55,480 --> 00:16:52,190
universe to become the very clumpy

304
00:16:57,939 --> 00:16:55,490
universe we see today but keep in mind

305
00:17:00,850 --> 00:16:57,949
with this picture we're seeing here

306
00:17:03,730 --> 00:17:00,860
we're only seeing the tip of the iceberg

307
00:17:05,679 --> 00:17:03,740
we're seeing the visible matter we're

308
00:17:08,020 --> 00:17:05,689
not seeing the invisible underpart

309
00:17:12,819 --> 00:17:08,030
they're of the iceberg that's the dark

310
00:17:14,199 --> 00:17:12,829
matter holding everything together so

311
00:17:16,030 --> 00:17:14,209
now I'm going to digress a little bit

312
00:17:18,730 --> 00:17:16,040
and I'm gonna talk about the growth of a

313
00:17:24,610 --> 00:17:18,740

different structure this is the earliest

314
00:17:26,590 --> 00:17:24,620
known picture of Jason and Alina it was

315
00:17:29,409 --> 00:17:26,600
taken about ten years ago at a

316
00:17:31,720 --> 00:17:29,419
conference in Scotland where Alina was

317
00:17:34,419 --> 00:17:31,730
living at the time and at this

318
00:17:38,049 --> 00:17:34,429
conference we were studying dark matter

319
00:17:39,730 --> 00:17:38,059
and how to measure it and I don't know

320
00:17:43,169 --> 00:17:39,740
but it looks to me a little bit like

321
00:17:46,690 --> 00:17:43,179
Elena's even ignoring me in this picture

322
00:17:51,700 --> 00:17:46,700
but like in the early universe there was

323
00:17:54,850 --> 00:17:51,710
a small attraction I'm sure an an

324
00:17:57,760 --> 00:17:54,860
attraction grew over time and eventually

325
00:18:03,880 --> 00:17:57,770
Alena moved here to JPL and we ended up

326
00:18:06,430 --> 00:18:03,890
with the structure we see today so I'm

327
00:18:08,289 --> 00:18:06,440
gonna now switch you here to hear about

328
00:18:11,080 --> 00:18:08,299
science so I'm gonna switch back and

329
00:18:13,900 --> 00:18:11,090
talk about science again so I'm going to

330
00:18:17,409 --> 00:18:13,910
tell you about how we measure dark

331
00:18:19,419 --> 00:18:17,419
matter since it's invisible what I have

332
00:18:23,740 --> 00:18:19,429
here is a cartoon of how we measure dark

333
00:18:27,340 --> 00:18:23,750
matter in cosmology we measure distances

334
00:18:29,590 --> 00:18:27,350
with a unit called Z so we're here at Z

335
00:18:31,480 --> 00:18:29,600
of 0 we're the observer where zero

336
00:18:33,909 --> 00:18:31,490
distance from ourselves and here's our

337
00:18:35,980 --> 00:18:33,919
telescope and we look at distant

338
00:18:38,350 --> 00:18:35,990

galaxies out in the universe these

339
00:18:40,030 --> 00:18:38,360
distant galaxies that are of Z about 1

340
00:18:42,520 --> 00:18:40,040
and that might sound like a small

341
00:18:44,799 --> 00:18:42,530
distance but how we do it in cosmology

342
00:18:46,870 --> 00:18:44,809
is a distance of one is actually about

343
00:18:49,090 --> 00:18:46,880
halfway to the edge of the visible

344
00:18:52,620 --> 00:18:49,100
universe so this is a very distant

345
00:18:55,650 --> 00:18:52,630
galaxy in the absence of

346
00:18:57,390 --> 00:18:55,660
anything between us and that galaxy the

347
00:19:01,020 --> 00:18:57,400
light from this galaxy would take a

348
00:19:02,880 --> 00:19:01,030
straight path to us but we know from the

349
00:19:05,550 --> 00:19:02,890
work that Veera Reuben and others did

350
00:19:07,980 --> 00:19:05,560
that there's all this dark matter out

351
00:19:09,450 --> 00:19:07,990
there in the universe and we're

352
00:19:11,490 --> 00:19:09,460
particularly sensitive with this

353
00:19:13,500 --> 00:19:11,500
technique to dark matter that's about

354
00:19:16,260 --> 00:19:13,510
halfway between us and the distant

355
00:19:18,630 --> 00:19:16,270
galaxy excuse me

356
00:19:20,730 --> 00:19:18,640
one of the consequences of Einstein's

357
00:19:24,600 --> 00:19:20,740
theory of relativity our theory of

358
00:19:26,760 --> 00:19:24,610
gravity is that mass bends space so what

359
00:19:29,040 --> 00:19:26,770
this means is the light when it gets

360
00:19:31,500 --> 00:19:29,050
near this dark matter won't take a

361
00:19:33,630 --> 00:19:31,510
straight path to us that light is going

362
00:19:37,140 --> 00:19:33,640
to take a distorted and curved path and

363
00:19:38,820 --> 00:19:37,150

I'm showing a very very exaggerated

364
00:19:42,360 --> 00:19:38,830
version of that here so it's easier to

365
00:19:45,030 --> 00:19:42,370
see the consequence of this is that we

366
00:19:48,600 --> 00:19:45,040
will not see the galaxy as it actually

367
00:19:51,000 --> 00:19:48,610
is we'll see a distorted version of the

368
00:19:54,480 --> 00:19:51,010
galaxy so the dark matter between us

369
00:19:57,300 --> 00:19:54,490
which we can't see has distorted our

370
00:19:59,340 --> 00:19:57,310
image of this distant galaxy and in

371
00:20:02,700 --> 00:19:59,350
doing so it's telling us something about

372
00:20:05,400 --> 00:20:02,710
the dark matter now these distortions

373
00:20:08,220 --> 00:20:05,410
are usually quite small but sometimes

374
00:20:10,950 --> 00:20:08,230
they can be quite large and we call this

375
00:20:13,530 --> 00:20:10,960
strong gravitational lensing what I'm

376
00:20:15,870 --> 00:20:13,540
showing here is a picture of a galaxy

377
00:20:18,960 --> 00:20:15,880
cluster all the bright spots here are

378
00:20:21,540 --> 00:20:18,970
nearby galaxies and they're part of a

379
00:20:24,330 --> 00:20:21,550
cluster of galaxies and that cluster has

380
00:20:26,700 --> 00:20:24,340
a lot of dark matter in it it's very

381
00:20:30,150 --> 00:20:26,710
massive and the consequence is that

382
00:20:33,330 --> 00:20:30,160
galaxies behind that cluster have their

383
00:20:36,480 --> 00:20:33,340
images magnified and changed by this

384
00:20:40,860 --> 00:20:36,490
gravitational lensing technique so these

385
00:20:42,900 --> 00:20:40,870
giant arcs you see like that this point

386
00:20:45,570 --> 00:20:42,910
is a little tricky like that and all

387
00:20:48,450 --> 00:20:45,580
around these giant arcs are actually

388
00:20:51,180 --> 00:20:48,460

very distant galaxies that would be only

389
00:20:53,700 --> 00:20:51,190
tiny smudges on here if it wasn't for

390
00:20:56,610 --> 00:20:53,710
the gravitational lensing caused by the

391
00:20:59,180 --> 00:20:56,620
dark matter in these galaxy clusters so

392
00:21:02,430 --> 00:20:59,190
this is great evidence for dark matter

393
00:21:04,470 --> 00:21:02,440
again we can't see it but we can see its

394
00:21:05,580 --> 00:21:04,480
effect on these distant galaxies and

395
00:21:07,620 --> 00:21:05,590
seeing the

396
00:21:12,120 --> 00:21:07,630
fact of dark-matter on distant galaxies

397
00:21:15,090 --> 00:21:12,130
makes us a scientist really happy and I

398
00:21:17,399 --> 00:21:15,100
have to I have to clarify here this is

399
00:21:20,070 --> 00:21:17,409
not an image that we created on our

400
00:21:21,840 --> 00:21:20,080
computer for this talk this is an actual

401
00:21:24,899 --> 00:21:21,850
image taken with the Hubble Space

402
00:21:27,299 --> 00:21:24,909
Telescope strong gravitational lensing

403
00:21:29,640 --> 00:21:27,309
and I think it's the universe telling us

404
00:21:34,230 --> 00:21:29,650
we should be happy about the clues it's

405
00:21:37,950 --> 00:21:34,240
giving us about dark matter so I'm going

406
00:21:39,960 --> 00:21:37,960
to tell you with one more analogy I'm

407
00:21:43,350 --> 00:21:39,970
gonna use another analogy for how we

408
00:21:45,799 --> 00:21:43,360
measure dark matter this is a penny in

409
00:21:48,539 --> 00:21:45,809
the pool that's the analogy here and

410
00:21:50,490 --> 00:21:48,549
full disclosure Alena and I don't

411
00:21:52,110 --> 00:21:50,500
actually have a pool so you're looking

412
00:21:56,220 --> 00:21:52,120
at a penny in our bathtub

413
00:21:58,950 --> 00:21:56,230

but penny in the pool sounds better so

414
00:22:02,370 --> 00:21:58,960
in this analogy the penny is like the

415
00:22:04,649 --> 00:22:02,380
distant galaxy and the water in our

416
00:22:07,049 --> 00:22:04,659
bathtub or the water in a pool is like

417
00:22:09,240 --> 00:22:07,059
the dark matter you don't see the water

418
00:22:11,700 --> 00:22:09,250
here but you know it's there because you

419
00:22:13,860 --> 00:22:11,710
see the effect on the image of the penny

420
00:22:16,139 --> 00:22:13,870
so what's happening is the light is

421
00:22:18,630 --> 00:22:16,149
coming to us from the penny and it's

422
00:22:20,700 --> 00:22:18,640
taking some distorted path that changes

423
00:22:23,880 --> 00:22:20,710
our perceived shape of the penny so that

424
00:22:26,010 --> 00:22:23,890
we know the water is there in much the

425
00:22:28,560 --> 00:22:26,020
same way as the light from a distant

426
00:22:30,750 --> 00:22:28,570
galaxy comes to us takes a distorted

427
00:22:34,560 --> 00:22:30,760
path through the dark matter and we see

428
00:22:36,299 --> 00:22:34,570
a distorted image of that galaxy but we

429
00:22:38,789 --> 00:22:36,309
don't see the dark matter we don't see

430
00:22:41,399 --> 00:22:38,799
the water now you can imagine that I

431
00:22:43,529 --> 00:22:41,409
can't tell very much about the water in

432
00:22:46,529 --> 00:22:43,539
my tub from just looking at this one

433
00:22:50,130 --> 00:22:46,539
penny but if I had a big pool and I

434
00:22:52,519 --> 00:22:50,140
threw thousands or perhaps billions of

435
00:22:55,230 --> 00:22:52,529
pennies at the bottom of the pool I

436
00:22:57,570 --> 00:22:55,240
could tell a lot about the water in that

437
00:22:59,789 --> 00:22:57,580
pool by looking at how the shapes of

438
00:23:01,740 --> 00:22:59,799

those pennies appeared to me I could

439
00:23:04,320 --> 00:23:01,750
tell the density of the water and how

440
00:23:08,010 --> 00:23:04,330
much water there was and in the same way

441
00:23:09,480 --> 00:23:08,020
in the 2020s we're going to launch some

442
00:23:11,399 --> 00:23:09,490
telescopes into space and we're going to

443
00:23:13,230 --> 00:23:11,409
use some telescopes on the ground that

444
00:23:16,139 --> 00:23:13,240
are going to measure billions of

445
00:23:18,410 --> 00:23:16,149
galaxies shapes across the universe and

446
00:23:21,210 --> 00:23:18,420
that's going to tell us a lot

447
00:23:23,010 --> 00:23:21,220
about the properties of dark matter

448
00:23:24,270 --> 00:23:23,020
that's how we're learning about dark

449
00:23:27,600 --> 00:23:24,280
matter now and that's how we're gonna

450
00:23:29,670 --> 00:23:27,610
learn about dark matter in the future so

451
00:23:31,800 --> 00:23:29,680
we've talked a little bit about dark

452
00:23:33,840 --> 00:23:31,810
matter but that's not the biggest

453
00:23:35,850 --> 00:23:33,850
component of the universe as I found out

454
00:23:36,960 --> 00:23:35,860
when I was in graduate school and as my

455
00:23:38,880 --> 00:23:36,970
colleagues found out when I was in

456
00:23:43,340 --> 00:23:38,890
graduate school so we have to think

457
00:23:52,740 --> 00:23:50,310
all right so what dark energy it's

458
00:23:55,770 --> 00:23:52,750
Halloween so I have to scare you all a

459
00:23:58,490 --> 00:23:55,780
little bit with the equation but I don't

460
00:24:01,020 --> 00:23:58,500
want to squeeze scare you too much so

461
00:24:03,270 --> 00:24:01,030
this is the only equation in our talk

462
00:24:05,370 --> 00:24:03,280
today and I can reassure you it isn't

463
00:24:08,580 --> 00:24:05,380

actually all that difficult this is

464
00:24:10,410 --> 00:24:08,590
Einsteins field equation and it explains

465
00:24:12,210 --> 00:24:10,420
everything that's going on in the

466
00:24:17,070 --> 00:24:12,220
universe just in this one simple

467
00:24:21,240 --> 00:24:17,080
equation on the left here this term

468
00:24:25,230 --> 00:24:21,250
we've got gravity which curves space on

469
00:24:28,830 --> 00:24:25,240
the right we have all the stuff in the

470
00:24:30,870 --> 00:24:28,840
universe the matter and the energy now

471
00:24:33,300 --> 00:24:30,880
keep in mind this is at a time when

472
00:24:35,880 --> 00:24:33,310
Einstein was coming up with this that

473
00:24:38,580 --> 00:24:35,890
they knew about normal matter and they

474
00:24:40,740 --> 00:24:38,590
knew about dark matter so that's the

475
00:24:44,310 --> 00:24:40,750
kind of stuff that Einstein was thinking

476
00:24:45,900 --> 00:24:44,320
about and around that time his Einstein

477
00:24:48,860 --> 00:24:45,910
and his colleagues thought that the

478
00:24:52,040 --> 00:24:48,870
universe was static that is it wasn't

479
00:24:55,830 --> 00:24:52,050
collapsing and it wasn't expanding and

480
00:24:58,290 --> 00:24:55,840
so in order to keep the universe from

481
00:25:01,190 --> 00:24:58,300
collapsing in on itself under gravity

482
00:25:03,750 --> 00:25:01,200
because of all of this stuff in it

483
00:25:06,090 --> 00:25:03,760
Einstein introduced what he called the

484
00:25:08,820 --> 00:25:06,100
cosmological constant and this was

485
00:25:15,660 --> 00:25:08,830
supposed to hold the universe up against

486
00:25:19,800 --> 00:25:15,670
collapsing in on itself fast forward a

487
00:25:22,290 --> 00:25:19,810
few years and we've got Hubble Edwin

488
00:25:25,050 --> 00:25:22,300

Hubble he's here in Los Angeles and he's

489
00:25:28,050 --> 00:25:25,060
working at the Mount Wilson telescope

490
00:25:31,130 --> 00:25:28,060
which is in Los Angeles Hubble was

491
00:25:33,230 --> 00:25:31,140
interested at looking at galaxies in

492
00:25:37,100 --> 00:25:33,240
universe and determining what velocity

493
00:25:41,570 --> 00:25:37,110
that they were moving so on this figure

494
00:25:44,260 --> 00:25:41,580
here we have distance increasing away

495
00:25:48,110 --> 00:25:44,270
from us as we go right and velocity

496
00:25:51,169 --> 00:25:48,120
increasing as we go up and what Hubble

497
00:25:53,299 --> 00:25:51,179
was able to see when he was looking at

498
00:25:56,240 --> 00:25:53,309
these galaxies is that no matter what

499
00:26:00,049 --> 00:25:56,250
direction he looked the further away a

500
00:26:03,650 --> 00:26:00,059
galaxy was the faster it was moving away

501
00:26:08,530 --> 00:26:03,660
from us and the only explanation for

502
00:26:13,360 --> 00:26:08,540
this is if the universe is expanding

503
00:26:19,220 --> 00:26:16,549
so after this amazing work that Edwin

504
00:26:22,100 --> 00:26:19,230
Hubble did scientists launched a

505
00:26:23,900 --> 00:26:22,110
telescope and named it in honor of him

506
00:26:25,880 --> 00:26:23,910
the Hubble Space Telescope and I'm

507
00:26:29,060 --> 00:26:25,890
absolutely certain that everybody here

508
00:26:30,409 --> 00:26:29,070
has heard of this amazing telescope one

509
00:26:33,770 --> 00:26:30,419
of the projects that the Hubble Space

510
00:26:37,580 --> 00:26:33,780
Telescope continued was exactly what

511
00:26:40,430 --> 00:26:37,590
Hubble started it looked at distant

512
00:26:45,080 --> 00:26:40,440
galaxies and it determined how fast they

513
00:26:49,460 --> 00:26:45,090

were moving and the data in this figure

514
00:26:52,039 --> 00:26:49,470
that I'm showing here is encompassed

515
00:26:54,740 --> 00:26:52,049
Hubble's data is just that first tiny

516
00:26:57,770 --> 00:26:54,750
little bit of this figure so the Hubble

517
00:27:00,260 --> 00:26:57,780
Space Telescope has shown that further

518
00:27:03,169 --> 00:27:00,270
and further away it is still true that

519
00:27:06,260 --> 00:27:03,179
the galaxies are moving further faster

520
00:27:12,010 --> 00:27:06,270
away from us so the only explanation for

521
00:27:20,960 --> 00:27:17,870
and so in an expanding universe you no

522
00:27:24,080 --> 00:27:20,970
longer have to hold the universe up from

523
00:27:27,110 --> 00:27:24,090
collapsing under gravity and we don't

524
00:27:30,380 --> 00:27:27,120
need a cosmological constant Einstein

525
00:27:34,610 --> 00:27:30,390
called this the biggest blunder of his

526
00:27:39,460 --> 00:27:34,620
career he struck it from the record he's

527
00:27:45,890 --> 00:27:42,950
well there's two ways that an expanding

528
00:27:49,180 --> 00:27:45,900
universe could behave over time on the

529
00:27:53,090 --> 00:27:49,190
left I'm showing an expanding universe

530
00:27:55,760 --> 00:27:53,100
that expands for some time after the Big

531
00:27:58,520 --> 00:27:55,770
Bang here in the past and eventually

532
00:28:01,670 --> 00:27:58,530
collapses in on itself under its own

533
00:28:04,220 --> 00:28:01,680
gravity at some time in the future and

534
00:28:06,710 --> 00:28:04,230
we call that the Big Crunch so that's

535
00:28:09,230 --> 00:28:06,720
one possibility if there's enough stuff

536
00:28:12,110 --> 00:28:09,240
in the universe that the universe would

537
00:28:16,550 --> 00:28:12,120
eventually collapse in on itself because

538
00:28:18,560 --> 00:28:16,560

of gravity another possibility is an

539
00:28:21,170 --> 00:28:18,570
expanding universe that keeps expanding

540
00:28:23,270 --> 00:28:21,180
forever but expands slower and slower

541
00:28:25,100 --> 00:28:23,280
that is the universe that starts out

542
00:28:25,400 --> 00:28:25,110
expanding quite quickly after the Big

543
00:28:28,460 --> 00:28:25,410
Bang

544
00:28:31,490 --> 00:28:28,470
but gravity tends to slow the universe's

545
00:28:34,370 --> 00:28:31,500
expansion down an analogy I want to use

546
00:28:37,340 --> 00:28:34,380
for that is our very own voyager over

547
00:28:40,270 --> 00:28:37,350
here this was launched some 40 years ago

548
00:28:45,140 --> 00:28:40,280
not this one this is a model of course

549
00:28:47,630 --> 00:28:45,150
by JPL and it left the Earth's gravity

550
00:28:50,480 --> 00:28:47,640
and it eventually left the solar system

551
00:28:51,920 --> 00:28:50,490
a few years ago so the voyager like this

552
00:28:54,830 --> 00:28:51,930
expanding universe is going to keep

553
00:28:57,200 --> 00:28:54,840
moving away from us forever but it's

554
00:28:59,030 --> 00:28:57,210
always slowing down and it's always

555
00:29:01,190 --> 00:28:59,040
slowing down because the Sun is always

556
00:29:05,030 --> 00:29:01,200
tugging on it a little bit

557
00:29:07,670 --> 00:29:05,040
so in this expanding universe here we

558
00:29:11,150 --> 00:29:07,680
have an expansion that's slowing down

559
00:29:15,770 --> 00:29:11,160
under the force of gravity so I'm going

560
00:29:18,670 --> 00:29:15,780
to use another analogy here and I swear

561
00:29:21,200 --> 00:29:18,680
this was full before the before the show

562
00:29:23,660 --> 00:29:21,210
but the expanding universe that

563
00:29:26,240 --> 00:29:23,670

eventually collapses in on itself is

564
00:29:28,670 --> 00:29:26,250
like this you throw it up and it comes

565
00:29:34,160 --> 00:29:28,680
down that's how we know gravity works in

566
00:29:37,040 --> 00:29:34,170
our daily lives so that's this character

567
00:29:41,360 --> 00:29:37,050
here this is the expanding universe that

568
00:29:43,970 --> 00:29:41,370
collapses in on itself under gravity the

569
00:29:45,860 --> 00:29:43,980
second fella or woman here that's

570
00:29:47,600 --> 00:29:45,870
throwing the ball is throwing the ball

571
00:29:48,500 --> 00:29:47,610
that's going to keep going away but

572
00:29:50,160 --> 00:29:48,510
slower and slower

573
00:29:52,830 --> 00:29:50,170
that's the other

574
00:29:55,799 --> 00:29:52,840
expanding universe an expanding universe

575
00:29:58,650 --> 00:29:55,809
the expanse forever but it's slowing

576
00:30:01,230 --> 00:29:58,660
down the whole time so in the 1990s

577
00:30:03,270 --> 00:30:01,240
there were two groups at the same time

578
00:30:05,490 --> 00:30:03,280
in the world trying to understand which

579
00:30:07,680 --> 00:30:05,500
of these scenarios was correct and how

580
00:30:10,530 --> 00:30:07,690
fast the universe was expanding and how

581
00:30:14,070 --> 00:30:10,540
fast and it expanded in the past and

582
00:30:16,169 --> 00:30:14,080
both of those groups found an answer and

583
00:30:18,990 --> 00:30:16,179
that answer was a universe that looked

584
00:30:20,970 --> 00:30:19,000
like this universe that was expanding

585
00:30:24,110 --> 00:30:20,980
but faster and faster

586
00:30:27,200 --> 00:30:24,120
much like Hubble's mind was blown

587
00:30:29,700 --> 00:30:27,210
cosmologists minds were blown in the

588
00:30:32,039 --> 00:30:29,710

1990s when they realized that the

589
00:30:35,039 --> 00:30:32,049
universe did not have an expansion that

590
00:30:38,340 --> 00:30:35,049
was slowing down due to gravity it had

591
00:30:40,770 --> 00:30:38,350
an expansion that was speeding up due to

592
00:30:43,110 --> 00:30:40,780
something else and so we have to have a

593
00:30:45,810 --> 00:30:43,120
third diagram and this is the diagram

594
00:30:48,270 --> 00:30:45,820
that we think represents what's really

595
00:30:50,100 --> 00:30:48,280
happening in our universe that's a

596
00:30:52,590 --> 00:30:50,110
universe that started out at a big bang

597
00:30:56,010 --> 00:30:52,600
it started out expanding somewhat slowly

598
00:30:58,590 --> 00:30:56,020
and as time has gone on it's expanded

599
00:31:00,000 --> 00:30:58,600
faster and faster and faster and it

600
00:31:03,299 --> 00:31:00,010
looks like it's going to keep expanding

601
00:31:05,460 --> 00:31:03,309
faster and faster in the future so we

602
00:31:08,159 --> 00:31:05,470
don't know why that is and we gave the

603
00:31:10,830 --> 00:31:08,169
name of whatever is causing that dark

604
00:31:12,419 --> 00:31:10,840
energy so another way to put it is dark

605
00:31:15,500 --> 00:31:12,429
energy is the name we gave to our

606
00:31:18,870 --> 00:31:15,510
ignorance of whatever is causing this

607
00:31:25,980 --> 00:31:18,880
ever-increasing rate of expansion of the

608
00:31:28,850 --> 00:31:25,990
universe so now we have a universe that

609
00:31:31,440 --> 00:31:28,860
is not only expanding but it's

610
00:31:34,320 --> 00:31:31,450
accelerating in its expansion so

611
00:31:36,120 --> 00:31:34,330
something needs to happen to Einstein's

612
00:31:39,990 --> 00:31:36,130
field equations in order to accommodate

613
00:31:43,230 --> 00:31:40,000

this accelerating expansion and it turns

614
00:31:45,830 --> 00:31:43,240
out that this can be accounted for in

615
00:31:49,380 --> 00:31:45,840
the form of Einstein's original

616
00:31:51,900 --> 00:31:49,390
cosmological constant and scientists

617
00:31:54,150 --> 00:31:51,910
were able to add this back into

618
00:31:56,610 --> 00:31:54,160
Einsteins field equations in the form of

619
00:32:00,100 --> 00:31:56,620
dark energy

620
00:32:03,820 --> 00:32:00,110
Einstein's biggest blunder went on to

621
00:32:07,840 --> 00:32:03,830
win Nobel Prize in Physics in 2011 for

622
00:32:10,210 --> 00:32:07,850
dark energy so what a triumph and as

623
00:32:13,450 --> 00:32:10,220
you'll notice up here I've said that the

624
00:32:16,990 --> 00:32:13,460
cosmological constant may not be a

625
00:32:19,420 --> 00:32:17,000
constant so scientists still don't

626
00:32:22,930 --> 00:32:19,430
really know very much about dark energy

627
00:32:26,020 --> 00:32:22,940
at all and theorists are coming up with

628
00:32:29,200 --> 00:32:26,030
different ideas all the time about what

629
00:32:32,020 --> 00:32:29,210
dark energy might be and there's no

630
00:32:34,660 --> 00:32:32,030
evidence that says that it does or does

631
00:32:36,760 --> 00:32:34,670
not have to be a constant it could

632
00:32:39,750 --> 00:32:36,770
change over time and so it's really

633
00:32:42,400 --> 00:32:39,760
important for scientists to investigate

634
00:32:47,370 --> 00:32:42,410
dark energy in the future to try and

635
00:32:52,480 --> 00:32:49,960
we've talked a little bit about dark

636
00:32:57,790 --> 00:32:52,490
energy and dark matter but how do they

637
00:33:00,460 --> 00:32:57,800
work together in the universe on the one

638
00:33:02,200 --> 00:33:00,470

hand we've got dark energy and it's this

639
00:33:06,160 --> 00:33:02,210
kind of repulsive force that's pushing

640
00:33:08,170 --> 00:33:06,170
things apart while dark matter is an

641
00:33:10,950 --> 00:33:08,180
attractive force it's bringing things

642
00:33:16,420 --> 00:33:14,200
dark energy affects the speed at which

643
00:33:19,390 --> 00:33:16,430
the universe expands and we now know

644
00:33:22,540 --> 00:33:19,400
that the universe is accelerating in its

645
00:33:27,850 --> 00:33:22,550
expansion while dark matter affects how

646
00:33:30,610 --> 00:33:27,860
clustered objects like galaxies are dark

647
00:33:34,420 --> 00:33:30,620
energy causes everything to move away

648
00:33:37,180 --> 00:33:34,430
from everything else while dark matter

649
00:33:39,670 --> 00:33:37,190
causes objects like galaxies to want to

650
00:33:42,580 --> 00:33:39,680
move toward one another so there's this

651
00:33:44,380 --> 00:33:42,590
real push and pull going on between dark

652
00:33:47,920 --> 00:33:44,390
matter and dark energy in the universe

653
00:33:51,790 --> 00:33:47,930
and so scientists need to investigate

654
00:33:54,220 --> 00:33:51,800
the universe over time in order to see

655
00:33:56,380 --> 00:33:54,230
what's going on with the clustering and

656
00:33:59,440 --> 00:33:56,390
the expansion of the universe over time

657
00:34:04,609 --> 00:33:59,450
to try and understand more about both

658
00:34:09,389 --> 00:34:06,840
so how are we going to measure dark

659
00:34:12,210 --> 00:34:09,399
energy in the future well it turns out

660
00:34:14,490 --> 00:34:12,220
that gravitational lensing technique

661
00:34:16,139 --> 00:34:14,500
that we talked about earlier is one of

662
00:34:19,530 --> 00:34:16,149
the primary ways we're gonna measure

663
00:34:22,440 --> 00:34:19,540

dark energy in the future and so on the

664
00:34:25,109 --> 00:34:22,450
left here I'm showing a very stylized

665
00:34:27,240 --> 00:34:25,119
view of how this gravitational lensing

666
00:34:29,369 --> 00:34:27,250
works we've got these distant galaxies

667
00:34:31,049 --> 00:34:29,379
and you can sort of see the ghostly dark

668
00:34:33,059 --> 00:34:31,059
matter and as the light from those

669
00:34:35,879 --> 00:34:33,069
distant galaxies comes to us through

670
00:34:38,250 --> 00:34:35,889
that dark matter the shapes of those

671
00:34:40,349 --> 00:34:38,260
galaxies are changed and again this is

672
00:34:42,389 --> 00:34:40,359
an exaggeration we don't usually see

673
00:34:45,149 --> 00:34:42,399
shape changes this strong and the shape

674
00:34:46,710 --> 00:34:45,159
changes occur over very very long time

675
00:34:48,359 --> 00:34:46,720
periods so we wouldn't see it changing

676
00:34:51,270 --> 00:34:48,369
like this this is just to give you an

677
00:34:55,470 --> 00:34:51,280
idea of how we're measuring that dark

678
00:34:57,960 --> 00:34:55,480
matter and what we do is we look at the

679
00:34:59,970 --> 00:34:57,970
dark matter at different times in the

680
00:35:02,880 --> 00:34:59,980
history of the universe and this tells

681
00:35:04,680 --> 00:35:02,890
us how the dark matter is evolving so

682
00:35:06,420 --> 00:35:04,690
one of the things that we did about ten

683
00:35:08,760 --> 00:35:06,430
years ago some of my colleagues and I is

684
00:35:11,099 --> 00:35:08,770
we used the Hubble Space Telescope to

685
00:35:14,609 --> 00:35:11,109
make the map of the dark matter in a

686
00:35:16,589 --> 00:35:14,619
very tiny area of the sky and we looked

687
00:35:18,839 --> 00:35:16,599
very far away and we were able to make a

688
00:35:20,400 --> 00:35:18,849

dark matter map of the dark matter in

689
00:35:22,559 --> 00:35:20,410
that area of the sky as it appeared

690
00:35:24,870 --> 00:35:22,569
about six and a half billion years ago

691
00:35:27,690 --> 00:35:24,880
and then we looked a little bit closer

692
00:35:29,789 --> 00:35:27,700
and the way we do that is distant

693
00:35:32,220 --> 00:35:29,799
galaxies the light takes some time to

694
00:35:34,440 --> 00:35:32,230
reach us and so the further out we look

695
00:35:37,079 --> 00:35:34,450
the further back in the universe we're

696
00:35:39,420 --> 00:35:37,089
looking so we looked at the dark matter

697
00:35:41,160 --> 00:35:39,430
map about five billion years ago and

698
00:35:42,809 --> 00:35:41,170
then we looked at the dark matter map

699
00:35:45,750 --> 00:35:42,819
about three and a half billion years ago

700
00:35:48,480 --> 00:35:45,760
and in doing so we created a

701
00:35:51,120 --> 00:35:48,490
three-dimensional map of the dark matter

702
00:35:52,740 --> 00:35:51,130
in this tiny area of the sky and when I

703
00:35:54,839 --> 00:35:52,750
say a tiny area of the sky it was about

704
00:35:55,410 --> 00:35:54,849
two square degrees on the sky well what

705
00:35:58,380 --> 00:35:55,420
does that mean

706
00:36:00,349 --> 00:35:58,390
the Tolle sky is about forty thousand

707
00:36:04,319 --> 00:36:00,359
square degrees so we looked at about 1

708
00:36:07,380 --> 00:36:04,329
mm or less than about less than one

709
00:36:09,630 --> 00:36:07,390
twentieth of a percent of the sky a very

710
00:36:11,400 --> 00:36:09,640
small amount of the sky and with the

711
00:36:13,920 --> 00:36:11,410
Hubble Space Telescope and what we were

712
00:36:16,200 --> 00:36:13,930
able to show is that the clustering of

713
00:36:17,070 --> 00:36:16,210

this dark matter changed over time and

714
00:36:19,710 --> 00:36:17,080
it changed

715
00:36:21,870 --> 00:36:19,720
over a time in a way that's given by the

716
00:36:23,970 --> 00:36:21,880
attractive force of gravity wanting to

717
00:36:26,310 --> 00:36:23,980
pull the dark matter together and the

718
00:36:29,370 --> 00:36:26,320
repulsive nature of the dark energy

719
00:36:31,950 --> 00:36:29,380
wanting to push things apart so by using

720
00:36:33,870 --> 00:36:31,960
this gravitational lensing technique we

721
00:36:36,600 --> 00:36:33,880
can study both the dark matter and the

722
00:36:40,430 --> 00:36:36,610
dark energy and that's what we're going

723
00:36:42,840 --> 00:36:40,440
to do in the 2020s there's three primary

724
00:36:45,120 --> 00:36:42,850
telescopes that we're going to use in

725
00:36:46,050 --> 00:36:45,130
the 2020s to do this gravitational

726
00:36:48,540 --> 00:36:46,060
lensing

727
00:36:51,750 --> 00:36:48,550
technique to study dark matter and dark

728
00:36:54,780 --> 00:36:51,760
energy the first is the large synoptic

729
00:36:57,240 --> 00:36:54,790
survey telescope this is a 8 meter

730
00:36:59,370 --> 00:36:57,250
ground-based telescope 8 meters is the

731
00:37:01,650 --> 00:36:59,380
length or the the diameter of the mirror

732
00:37:03,960 --> 00:37:01,660
and keep in mind that for a telescope

733
00:37:05,730 --> 00:37:03,970
the diameter of the mirror is what is

734
00:37:07,830 --> 00:37:05,740
driving the power of the telescope

735
00:37:09,840 --> 00:37:07,840
because it determines how many photons

736
00:37:13,010 --> 00:37:09,850
how much light that telescope can

737
00:37:15,510 --> 00:37:13,020
collect and there's about 24

738
00:37:18,150 --> 00:37:15,520

international contributors 24 countries

739
00:37:19,770 --> 00:37:18,160
helping the u.s. build and eventually

740
00:37:22,320 --> 00:37:19,780
operate this large synoptic survey

741
00:37:24,720 --> 00:37:22,330
telescope there's about 900 people

742
00:37:26,700 --> 00:37:24,730
worldwide working on the dark energy

743
00:37:30,240 --> 00:37:26,710
planning planning for the dark energy

744
00:37:33,030 --> 00:37:30,250
survey with this LSST a second mission

745
00:37:35,880 --> 00:37:33,040
is a space mission from the European

746
00:37:37,730 --> 00:37:35,890
Space Agency called Euclid now when we

747
00:37:39,690 --> 00:37:37,740
measure the expansion of the universe

748
00:37:41,970 --> 00:37:39,700
scientists say we're measuring the

749
00:37:45,060 --> 00:37:41,980
geometry or shape of the universe and

750
00:37:47,220 --> 00:37:45,070
you might remember Euclid is the father

751
00:37:49,920 --> 00:37:47,230
of geometry so that's how this Euclid

752
00:37:52,320 --> 00:37:49,930
mission got its name we plan to launch

753
00:37:55,410 --> 00:37:52,330
this Euclid mission into space in 2022

754
00:37:59,100 --> 00:37:55,420
and there's about 1,500 people working

755
00:38:01,460 --> 00:37:59,110
on Euclid around the world to do a dark

756
00:38:05,310 --> 00:38:01,470
matter and dark energy experiment and

757
00:38:07,770 --> 00:38:05,320
the final experiment we're going to talk

758
00:38:11,100 --> 00:38:07,780
about tonight is w first the wide field

759
00:38:13,110 --> 00:38:11,110
Infrared Survey telescope this is a NASA

760
00:38:16,110 --> 00:38:13,120
telescope that's going to be launched in

761
00:38:18,390 --> 00:38:16,120
2025 and it's going to do investigations

762
00:38:20,730 --> 00:38:18,400
into dark energy and dark matter and

763
00:38:22,710 --> 00:38:20,740

it's also going to look for exoplanets

764
00:38:23,610 --> 00:38:22,720
these are planets outside of our solar

765
00:38:26,040 --> 00:38:23,620
system

766
00:38:28,740 --> 00:38:26,050
and I mentioned those earlier that there

767
00:38:30,600 --> 00:38:28,750
might be more than 10 billion trillion

768
00:38:33,420 --> 00:38:30,610
planets in the universe

769
00:38:39,950 --> 00:38:33,430
and we want to find some of those with W

770
00:38:43,200 --> 00:38:39,960
first okay still me

771
00:38:45,210 --> 00:38:43,210
so I'm gonna talk a bit more about W

772
00:38:47,700 --> 00:38:45,220
first so W first is a telescope that's

773
00:38:50,100 --> 00:38:47,710
gonna be launched into space it's got a

774
00:38:52,470 --> 00:38:50,110
metre mirror that's two point four

775
00:38:54,840 --> 00:38:52,480
meters across so for those of you that

776
00:38:56,970 --> 00:38:54,850
know your space telescopes that's the

777
00:38:59,610 --> 00:38:56,980
same size as the mirror on the Hubble

778
00:39:01,620 --> 00:38:59,620
Space Telescope which is the one that we

779
00:39:04,890 --> 00:39:01,630
use to do this dark matter study on a

780
00:39:06,780 --> 00:39:04,900
very tiny area of the sky about ten

781
00:39:08,340 --> 00:39:06,790
years ago so you might ask why didn't we

782
00:39:11,100 --> 00:39:08,350
just use the Hubble Space Telescope to

783
00:39:13,740 --> 00:39:11,110
look at more of the sky and the reason

784
00:39:15,960 --> 00:39:13,750
is it takes too long to do this with the

785
00:39:19,350 --> 00:39:15,970
hubble space telescope and the reason we

786
00:39:21,750 --> 00:39:19,360
can do it with w first in the future is

787
00:39:24,450 --> 00:39:21,760
because of w first really powerful

788
00:39:26,460 --> 00:39:24,460

camera I'm showing here the Andromeda

789
00:39:28,290 --> 00:39:26,470
galaxy that's the galaxy nearest our own

790
00:39:31,260 --> 00:39:28,300
Milky Way it's about two-and-a-half

791
00:39:33,480 --> 00:39:31,270
million light years away and this is a

792
00:39:35,280 --> 00:39:33,490
picture taken from the ground and a few

793
00:39:37,350 --> 00:39:35,290
years ago one of our colleagues decided

794
00:39:40,320 --> 00:39:37,360
she wanted to study the individual stars

795
00:39:42,600 --> 00:39:40,330
in the Andromeda galaxy and to do that

796
00:39:44,100 --> 00:39:42,610
she used the Hubble Space Telescope and

797
00:39:48,750 --> 00:39:44,110
she pointed the Hubble Space Telescope

798
00:39:51,060 --> 00:39:48,760
at this galaxy about 400 times to cover

799
00:39:52,740 --> 00:39:51,070
about half the galaxy because the Hubble

800
00:39:55,620 --> 00:39:52,750
Space Telescope has a pretty small

801
00:39:56,910 --> 00:39:55,630
camera so it took 400 pointings of the

802
00:40:01,080 --> 00:39:56,920
hubble space telescope

803
00:40:03,450 --> 00:40:01,090
to look at this galaxy takes two with w

804
00:40:05,910 --> 00:40:03,460
first so we're gonna do the same types

805
00:40:07,260 --> 00:40:05,920
of studies of dark matter that were

806
00:40:10,530 --> 00:40:07,270
possible with the Hubble Space Telescope

807
00:40:14,130 --> 00:40:10,540
but hundreds or even thousands of times

808
00:40:16,920 --> 00:40:14,140
faster with W first and that's the power

809
00:40:19,380 --> 00:40:16,930
that W first is going to unleash it's a

810
00:40:22,080 --> 00:40:19,390
Hubble Space Telescope quality

811
00:40:25,680 --> 00:40:22,090
instrument but with a much bigger camera

812
00:40:32,130 --> 00:40:25,690
due to advances in creating detectors

813
00:40:34,950 --> 00:40:32,140

and pixels so Jason's talked about the W

814
00:40:37,800 --> 00:40:34,960
first camera and let's compare the W

815
00:40:40,560 --> 00:40:37,810
first camera to the camera on the large

816
00:40:41,640 --> 00:40:40,570
synoptic survey telescope but first to

817
00:40:45,180 --> 00:40:41,650
give you some

818
00:40:50,069 --> 00:40:45,190
context again the camera on your cell

819
00:40:54,870 --> 00:40:50,079
phone is maybe about 8 million pixels or

820
00:41:00,210 --> 00:40:54,880
8 megapixels the camera on W fest is

821
00:41:03,000 --> 00:41:00,220
around 300 megapixels and the camera on

822
00:41:07,799 --> 00:41:03,010
the large synoptic survey telescope is

823
00:41:10,799 --> 00:41:07,809
around 3,000 megapixels or 3 Giga pixels

824
00:41:13,079 --> 00:41:10,809
so this is just enormous and what

825
00:41:16,950 --> 00:41:13,089
scientists are going to use this camera

826
00:41:20,279 --> 00:41:16,960
for is every 5 nights they will take a

827
00:41:24,930 --> 00:41:20,289
picture of the entire southern sky and

828
00:41:27,089 --> 00:41:24,940
they will do this for 10 years so this

829
00:41:30,359 --> 00:41:27,099
is going to give scientists an

830
00:41:32,789 --> 00:41:30,369
incredibly deep image of the universe

831
00:41:36,630 --> 00:41:32,799
but it's also going to be like taking a

832
00:41:40,230 --> 00:41:36,640
movie of how the sky is changing over

833
00:41:43,200 --> 00:41:40,240
time this is going to be incredible data

834
00:41:46,559 --> 00:41:43,210
for the scientists to investigate dark

835
00:41:49,680 --> 00:41:46,569
matter and dark energy and Jason

836
00:41:52,529 --> 00:41:49,690
mentioned earlier that it takes a lot of

837
00:41:57,450 --> 00:41:52,539
scientists to try to understand this

838
00:42:00,779 --> 00:41:57,460

unknown 95% of the universe and the

839
00:42:02,670 --> 00:42:00,789
Euclid Space Telescope some of the

840
00:42:06,240 --> 00:42:02,680
scientists got together earlier this

841
00:42:08,640 --> 00:42:06,250
year in summer in Helsinki in Finland

842
00:42:11,039 --> 00:42:08,650
and we were working together getting

843
00:42:13,440 --> 00:42:11,049
ready for the Euclid Space Telescope

844
00:42:16,799 --> 00:42:13,450
which will be the first telescope

845
00:42:19,859 --> 00:42:16,809
entirely dedicated to investigating dark

846
00:42:22,319 --> 00:42:19,869
matter and dark energy and we took a

847
00:42:26,480 --> 00:42:22,329
photo of ourselves to commemorate the

848
00:42:30,170 --> 00:42:26,490
moment and here is Jason and I

849
00:42:33,430 --> 00:42:30,180
and notice Jason is not looking at the

850
00:42:38,120 --> 00:42:33,440
camera because he's looking at his phone

851
00:42:41,839 --> 00:42:38,130
doing emails this is also what it's like

852
00:42:44,060 --> 00:42:41,849
being married to a cosmologists so I

853
00:42:47,089 --> 00:42:44,070
looked at this photo and I realized

854
00:42:50,450 --> 00:42:47,099
something interesting these are the

855
00:42:54,650 --> 00:42:50,460
scientists from Pasadena who attended

856
00:42:57,290 --> 00:42:54,660
this meeting and I worked out that the

857
00:43:01,760 --> 00:42:57,300
scientists from Pasadena make up the 5%

858
00:43:07,460 --> 00:43:01,770
normal portion of this scientist in you

859
00:43:10,550 --> 00:43:07,470
clip so maybe you're asking why are we

860
00:43:13,700 --> 00:43:10,560
doing 3 different experiments to

861
00:43:17,150 --> 00:43:13,710
investigate the same thing in the 2020s

862
00:43:22,430 --> 00:43:17,160
and it's a good question and we get

863
00:43:24,260 --> 00:43:22,440

asked it a lot so dark energy I think

864
00:43:26,120 --> 00:43:24,270
I've told you we we really don't know

865
00:43:28,880 --> 00:43:26,130
what it is scientists have no idea I

866
00:43:30,829 --> 00:43:28,890
think you now know as much as I do

867
00:43:37,010 --> 00:43:30,839
about dark energy you can pick up your

868
00:43:39,320 --> 00:43:37,020
PhD at the door and so in order to try

869
00:43:46,160 --> 00:43:39,330
to understand what's going on with this

870
00:43:49,430 --> 00:43:46,170
this really on difficult concept it

871
00:43:53,180 --> 00:43:49,440
takes a lot of different investigations

872
00:43:55,700 --> 00:43:53,190
and so it's really useful to be able to

873
00:43:57,200 --> 00:43:55,710
cross-check between the different

874
00:43:59,780 --> 00:43:57,210
experiments to understand what's going

875
00:44:01,220 --> 00:43:59,790
on and each of the experiments that

876
00:44:05,630 --> 00:44:01,230
Jason and I have talked about this

877
00:44:07,579 --> 00:44:05,640
evening have their own special skills

878
00:44:11,210 --> 00:44:07,589
and they're highly complementary with

879
00:44:14,960 --> 00:44:11,220
each other so the Euclid Space Telescope

880
00:44:17,570 --> 00:44:14,970
is going to be in space which means it's

881
00:44:19,070 --> 00:44:17,580
above the Earth's atmosphere and Jason

882
00:44:22,760 --> 00:44:19,080
told you that we want to measure the

883
00:44:24,200 --> 00:44:22,770
shapes of the distant galaxies I'm sure

884
00:44:27,280 --> 00:44:24,210
you've all heard about the song twinkle

885
00:44:30,140 --> 00:44:27,290
twinkle little star on earth

886
00:44:32,030 --> 00:44:30,150
stars twinkle because the light from

887
00:44:34,550 --> 00:44:32,040
those stars is traveling through the

888
00:44:38,030 --> 00:44:34,560

atmosphere of the earth and that's

889
00:44:39,790 --> 00:44:38,040
causing them to twinkle but if you get

890
00:44:43,810 --> 00:44:39,800
outside of the atmosphere

891
00:44:45,070 --> 00:44:43,820
then those stars are very precise and so

892
00:44:47,740 --> 00:44:45,080
getting outside of the atmosphere

893
00:44:50,440 --> 00:44:47,750
enables scientists to measure the shapes

894
00:44:52,840 --> 00:44:50,450
of these galaxies very precisely and

895
00:44:58,390 --> 00:44:52,850
Euclid is going to do this over a very

896
00:45:00,370 --> 00:44:58,400
wide area 20,000 square degrees the

897
00:45:02,500 --> 00:45:00,380
large synoptic survey telescope however

898
00:45:04,630 --> 00:45:02,510
is on the ground so they have to deal

899
00:45:06,660 --> 00:45:04,640
with the atmosphere when they're trying

900
00:45:10,720 --> 00:45:06,670
to measure these shapes

901
00:45:14,080 --> 00:45:10,730
however LSST is going to measure the

902
00:45:17,100 --> 00:45:14,090
entire southern sky every night every 5

903
00:45:20,170 --> 00:45:17,110
nights for 10 years which will enable

904
00:45:22,450 --> 00:45:20,180
incredibly deep images of the universe

905
00:45:25,750 --> 00:45:22,460
will be looking much much further back

906
00:45:28,060 --> 00:45:25,760
in time and so we're getting the

907
00:45:29,980 --> 00:45:28,070
evolution of what's going on with the

908
00:45:34,050 --> 00:45:29,990
dark matter and dark energy over time

909
00:45:37,810 --> 00:45:34,060
and finally w first which will launch in

910
00:45:40,870 --> 00:45:37,820
2025 has been designed to be the most

911
00:45:43,840 --> 00:45:40,880
precise camera it's going to take these

912
00:45:47,020 --> 00:45:43,850
sharpest images and it will take the

913
00:45:49,750 --> 00:45:47,030

deepest images as well so by combining

914
00:45:52,510 --> 00:45:49,760
and comparing these three experiments

915
00:45:54,400 --> 00:45:52,520
scientists are going to be able to make

916
00:45:57,220 --> 00:45:54,410
sure that we really understand what's

917
00:46:02,050 --> 00:45:57,230
going on and confirm any new exciting

918
00:46:03,910 --> 00:46:02,060
discoveries so we've told you a bit

919
00:46:07,570 --> 00:46:03,920
about how we're going to measure dark

920
00:46:09,010 --> 00:46:07,580
energy and dark matter in the 2020s and

921
00:46:10,950 --> 00:46:09,020
you still might wonder what why do we

922
00:46:13,300 --> 00:46:10,960
want to measure that well I think

923
00:46:15,070 --> 00:46:13,310
honestly for Alena and I and a lot of

924
00:46:17,350 --> 00:46:15,080
our colleagues is we're curious we want

925
00:46:19,390 --> 00:46:17,360
to understand how the universe works but

926
00:46:20,890 --> 00:46:19,400
for everybody I think you probably want

927
00:46:23,200 --> 00:46:20,900
to know what's going to happen in the

928
00:46:25,330 --> 00:46:23,210
universe in the future and really the

929
00:46:28,540 --> 00:46:25,340
future of the universe how the universe

930
00:46:30,820 --> 00:46:28,550
evolves over time in the coming tens of

931
00:46:33,250 --> 00:46:30,830
billions of years is going to be

932
00:46:34,960 --> 00:46:33,260
determined by the properties of dark

933
00:46:37,420 --> 00:46:34,970
energy and we just don't know those

934
00:46:40,030 --> 00:46:37,430
properties very well we think that

935
00:46:41,830 --> 00:46:40,040
there's probably two scenarios that

936
00:46:44,680 --> 00:46:41,840
might play out and that's what we think

937
00:46:46,840 --> 00:46:44,690
now and we're not sure which one of

938
00:46:49,430 --> 00:46:46,850

those two scenarios will play out and we

939
00:46:50,839 --> 00:46:49,440
want to study the dark matter and the

940
00:46:52,640 --> 00:46:50,849
dark energy to find out which one of

941
00:46:53,930 --> 00:46:52,650
those scenarios will play out we're

942
00:46:58,609 --> 00:46:53,940
gonna tell you a little bit about those

943
00:47:04,359 --> 00:46:58,619
two possible scenarios now so if dark

944
00:47:07,040 --> 00:47:04,369
energy isn't too strong galaxies will

945
00:47:10,490 --> 00:47:07,050
continue moving away from each other

946
00:47:12,349 --> 00:47:10,500
like Edwin Hubble discovered and they're

947
00:47:16,839 --> 00:47:12,359
going to continue moving away from each

948
00:47:20,599 --> 00:47:16,849
other faster and faster until eventually

949
00:47:23,000 --> 00:47:20,609
they'll be so far apart that they won't

950
00:47:24,829 --> 00:47:23,010
be able to see each other and the

951
00:47:28,460 --> 00:47:24,839
universe will become an incredibly

952
00:47:34,460 --> 00:47:28,470
lonely place and our galaxy will be

953
00:47:41,569 --> 00:47:34,470
alone Jason where did you go I can't see

954
00:47:43,220 --> 00:47:41,579
you don't worry I'm here so that's what

955
00:47:45,559 --> 00:47:43,230
the universe is gonna end up looking

956
00:47:48,470 --> 00:47:45,569
like we'll have a universe where we're

957
00:47:50,750 --> 00:47:48,480
in our galaxy and we can't see those

958
00:47:54,890 --> 00:47:50,760
distant galaxies anymore they've moved

959
00:47:57,650 --> 00:47:54,900
too far away and so sometimes I've tried

960
00:47:59,329 --> 00:47:57,660
in the past to use this in my funding

961
00:48:02,120 --> 00:47:59,339
proposals to NASA I say you've really

962
00:48:04,280 --> 00:48:02,130
got a fund this dark energy study right

963
00:48:06,050 --> 00:48:04,290

now because eventually I'm not gonna be

964
00:48:08,150 --> 00:48:06,060
able to see these distant galaxies if

965
00:48:10,550 --> 00:48:08,160
you don't send me the money and it

966
00:48:12,620 --> 00:48:10,560
doesn't work anymore because I think my

967
00:48:15,260 --> 00:48:12,630
colleagues at NASA headquarters have

968
00:48:17,390 --> 00:48:15,270
realized that this happens many many

969
00:48:18,710 --> 00:48:17,400
tens of billions of years for now so

970
00:48:23,359 --> 00:48:18,720
they think I have plenty of time to

971
00:48:26,420 --> 00:48:23,369
measure before this happens and so we've

972
00:48:29,960 --> 00:48:26,430
told you about a lonely end a possible

973
00:48:32,210 --> 00:48:29,970
lonely end kind of a sad in maybe to the

974
00:48:36,410 --> 00:48:32,220
universe but it's not the scariest

975
00:48:39,230 --> 00:48:36,420
possible end to the universe so Alena

976
00:48:41,030 --> 00:48:39,240
and I hold this closure we do not have a

977
00:48:44,359 --> 00:48:41,040
pool we told you that earlier but we do

978
00:48:47,480 --> 00:48:44,369
have a fire pit so in honor of Halloween

979
00:48:49,550 --> 00:48:47,490
we want you to all come sit with us

980
00:48:53,720 --> 00:48:49,560
around the campfire and we're gonna tell

981
00:48:58,849 --> 00:48:53,730
you a scary story about another possible

982
00:49:00,020 --> 00:48:58,859
future of the universe so if dark energy

983
00:49:05,540 --> 00:49:00,030
is

984
00:49:09,560 --> 00:49:05,550
believe then the universe will

985
00:49:12,430 --> 00:49:09,570
eventually end at around 60 million

986
00:49:15,590 --> 00:49:12,440
years before the end of the universe

987
00:49:18,230 --> 00:49:15,600
galaxies will begin to rip apart

988
00:49:20,270 --> 00:49:18,240

so unlike the scenario we talked about

989
00:49:23,360 --> 00:49:20,280
earlier where the galaxy remained

990
00:49:25,430 --> 00:49:23,370
together in this scenario dark energy

991
00:49:30,260 --> 00:49:25,440
becomes so strong that it starts to

992
00:49:32,930 --> 00:49:30,270
fling the Stars away inside galaxies at

993
00:49:33,680 --> 00:49:32,940
about three months before the end of the

994
00:49:37,850 --> 00:49:33,690
universe

995
00:49:39,980 --> 00:49:37,860
in this scenario even solar systems are

996
00:49:42,680 --> 00:49:39,990
going to get ripped apart that is

997
00:49:44,690 --> 00:49:42,690
planets are going to be shot away from

998
00:49:48,830 --> 00:49:44,700
their stars because of the ever

999
00:49:51,980 --> 00:49:48,840
increasing expansion of the universe now

1000
00:49:54,890 --> 00:49:51,990
it's not quite as scary as you might

1001
00:49:55,670 --> 00:49:54,900
think for us because long before that

1002
00:49:57,920 --> 00:49:55,680
happens

1003
00:50:00,080 --> 00:49:57,930
our Sun will turn into a red giant star

1004
00:50:02,240 --> 00:50:00,090
and gobble up the earth so I hope I made

1005
00:50:07,610 --> 00:50:02,250
you feel a lot better about this end of

1006
00:50:10,940 --> 00:50:07,620
the universe scenario at a few minutes

1007
00:50:13,790 --> 00:50:10,950
before the end of the universe even

1008
00:50:16,760 --> 00:50:13,800
stars and planets will begin to get

1009
00:50:19,400 --> 00:50:16,770
ripped apart by how strong the dark

1010
00:50:23,030 --> 00:50:19,410
energy has become and stretching out the

1011
00:50:26,330 --> 00:50:23,040
universe in the final moments of the

1012
00:50:28,610 --> 00:50:26,340
universe even atoms are gonna be ripped

1013
00:50:31,640 --> 00:50:28,620

apart that is electrons are going to be

1014
00:50:33,290 --> 00:50:31,650
ripped from the nucleus and protons and

1015
00:50:36,770 --> 00:50:33,300
neutrons are going to be ripped apart

1016
00:50:39,890 --> 00:50:36,780
and in fact we think the very fabric of

1017
00:50:44,600 --> 00:50:39,900
space will start to rip apart in what we

1018
00:50:46,910 --> 00:50:44,610
call a big rip so these are that

1019
00:50:51,130 --> 00:50:46,920
scientists are very very clever with our

1020
00:50:53,839 --> 00:50:51,140
naming everything's big or dark

1021
00:50:56,660 --> 00:50:53,849
these are the two possible scenarios

1022
00:50:59,269 --> 00:50:56,670
that scientists think might happen with

1023
00:51:01,549 --> 00:50:59,279
dark energy and I don't find either of

1024
00:51:04,870 --> 00:51:01,559
them particularly happy a very lonely

1025
00:51:07,089 --> 00:51:04,880
end or the universe being ripped apart

1026
00:51:11,029 --> 00:51:07,099
fortunately this is not gonna happen for

1027
00:51:13,729 --> 00:51:11,039
many many billions of years and we've

1028
00:51:15,709 --> 00:51:13,739
got a lot of time to study the dark

1029
00:51:18,620 --> 00:51:15,719
matter and study the dark energy and

1030
00:51:20,509 --> 00:51:18,630
find out which scenario might happen and

1031
00:51:23,900 --> 00:51:20,519
of course humans are pretty ingenious

1032
00:51:26,029 --> 00:51:23,910
and maybe in the coming billions of

1033
00:51:27,620 --> 00:51:26,039
years we can use that ingenuity to

1034
00:51:30,380 --> 00:51:27,630
figure out how to harness the dark

1035
00:51:35,449 --> 00:51:30,390
matter and dark energy and control the

1036
00:51:37,309 --> 00:51:35,459
universe maybe for a happier fate so

1037
00:51:39,410 --> 00:51:37,319
Jason and I really want to thank you all

1038
00:51:41,630 --> 00:51:39,420

so much for being here with us tonight

1039
00:51:43,069 --> 00:51:41,640
it has been an incredible privilege for

1040
00:51:45,349 --> 00:51:43,079
us to talk to you about the dark

1041
00:51:47,660 --> 00:51:45,359
universe and we would be delighted to

1042
00:51:58,470 --> 00:51:47,670
take some of your questions thank you

1043
00:52:04,079 --> 00:52:01,770
I want to thank Preston know with this

1044
00:52:05,700 --> 00:52:04,089
altogether I don't know if you think so

1045
00:52:07,680 --> 00:52:05,710
you guys can go ahead and head towards

1046
00:52:11,970 --> 00:52:07,690
center stage here and we'll get set up

1047
00:52:13,740 --> 00:52:11,980
for our Q&A so yeah you guys can wander

1048
00:52:16,560 --> 00:52:13,750
on over there that was a really great

1049
00:52:18,420 --> 00:52:16,570
talk because I think a lot of us find

1050
00:52:20,670 --> 00:52:18,430
these topics really mysterious and we

1051
00:52:23,460 --> 00:52:20,680
don't even we need that kind of primer

1052
00:52:26,329 --> 00:52:23,470
to help us get just basic bearings on

1053
00:52:29,640 --> 00:52:26,339
something so mysterious

1054
00:52:30,660 --> 00:52:29,650
well now it's time for your questions if

1055
00:52:32,460 --> 00:52:30,670
you have one please come to the

1056
00:52:34,740 --> 00:52:32,470
microphone I see some folks lining up

1057
00:52:36,630 --> 00:52:34,750
and in the center there so if you

1058
00:52:38,280 --> 00:52:36,640
submitted one on the YouTube chat we'll

1059
00:52:40,470 --> 00:52:38,290
get to a couple of those as well so

1060
00:52:45,359 --> 00:52:40,480
we're all set now go ahead with your

1061
00:52:48,089 --> 00:52:45,369
question Thanks all mass has gravity and

1062
00:52:51,390 --> 00:52:48,099
all matter has mass do you know any way

1063
00:52:57,720 --> 00:52:51,400

to figure out how much mass and gravity

1064
00:53:00,120 --> 00:52:57,730
duct matter has so we were asked do we

1065
00:53:02,849 --> 00:53:00,130
know any way to figure out how much mass

1066
00:53:05,130 --> 00:53:02,859
and gravity dark matter has and the

1067
00:53:07,770 --> 00:53:05,140
answer is yes we know only one way to

1068
00:53:09,420 --> 00:53:07,780
figure out how much mass dark matter has

1069
00:53:11,640 --> 00:53:09,430
and that's through this gravitational

1070
00:53:14,460 --> 00:53:11,650
lensing technique that I talked about

1071
00:53:16,650 --> 00:53:14,470
tonight that's our only way of measuring

1072
00:53:19,410 --> 00:53:16,660
the dark matter because it doesn't give

1073
00:53:21,240 --> 00:53:19,420
off light and it doesn't absorb light so

1074
00:53:23,790 --> 00:53:21,250
we have to look at it indirectly through

1075
00:53:25,319 --> 00:53:23,800
its effect on these distant galaxies so

1076
00:53:31,620 --> 00:53:25,329
that's the technique we use to figure

1077
00:53:32,700 --> 00:53:31,630
out how much mass dark matter has all

1078
00:53:38,579 --> 00:53:32,710
right so I actually have two questions

1079
00:53:41,970 --> 00:53:38,589
one do you take interns yes we do okay

1080
00:53:43,290 --> 00:53:41,980
starting in December contact one of us

1081
00:53:45,089 --> 00:53:43,300
all right

1082
00:53:48,720 --> 00:53:45,099
and number two how does the heat death

1083
00:53:50,069 --> 00:53:48,730
Theory factor into all of this I I don't

1084
00:53:50,970 --> 00:53:50,079
know the answer to that so I'm gonna

1085
00:53:54,750 --> 00:53:50,980
give it to Jason

1086
00:53:57,230 --> 00:53:54,760
so heat theory says that stars will

1087
00:54:02,160 --> 00:53:57,240
eventually burn out they'll burn their

1088
00:54:04,319 --> 00:54:02,170

burn their fuel up and the eventually

1089
00:54:07,290 --> 00:54:04,329
will become universal become colder and

1090
00:54:09,569 --> 00:54:07,300
colder and colder and and and more

1091
00:54:11,520 --> 00:54:09,579
diffuse and more diffuse and that's the

1092
00:54:13,710 --> 00:54:11,530
future of the universe

1093
00:54:17,430 --> 00:54:13,720
that we thought might happen before we

1094
00:54:19,080 --> 00:54:17,440
discovered the dark energy so that's a

1095
00:54:21,000 --> 00:54:19,090
future of the universe that this

1096
00:54:22,650 --> 00:54:21,010
ever-expanding universe that was

1097
00:54:25,860 --> 00:54:22,660
expanding slower and slower and slower

1098
00:54:27,630 --> 00:54:25,870
just kind of peter out but with the dark

1099
00:54:31,430 --> 00:54:27,640
energy we think there's likely different

1100
00:54:34,320 --> 00:54:31,440
scenarios for the future of the universe

1101
00:54:35,430 --> 00:54:34,330
all right thank you and yeah if you want

1102
00:54:37,380 --> 00:54:35,440
to if you want to look into internships

1103
00:54:41,730 --> 00:54:37,390
go to the JPL website you can find

1104
00:54:43,140 --> 00:54:41,740
information there we do take interns so

1105
00:54:44,610 --> 00:54:43,150
if we're looking at the universe and the

1106
00:54:46,440 --> 00:54:44,620
universe is looking at us what's the

1107
00:54:51,450 --> 00:54:46,450
probability of the universe's staying

1108
00:54:53,400 --> 00:54:51,460
the same so the question is we're

1109
00:54:54,690 --> 00:54:53,410
looking at the universe and the universe

1110
00:54:57,530 --> 00:54:54,700
is looking at us and what is the

1111
00:54:59,370 --> 00:54:57,540
probability of it staying the same so

1112
00:55:01,470 --> 00:54:59,380
scientists as they're looking at the

1113
00:55:04,020 --> 00:55:01,480

universe right now we're watching it

1114
00:55:07,050 --> 00:55:04,030
change all the time because light has a

1115
00:55:10,140 --> 00:55:07,060
finite velocity so we are looking

1116
00:55:12,660 --> 00:55:10,150
further back in time as we look out into

1117
00:55:15,050 --> 00:55:12,670
the distant universe and so the

1118
00:55:17,610 --> 00:55:15,060
probability of it staying the same is

1119
00:55:23,550 --> 00:55:17,620
zero we're watching it change all the

1120
00:55:25,170 --> 00:55:23,560
time okay thank you thank you as I was

1121
00:55:27,690 --> 00:55:25,180
wondering if you could clarify the

1122
00:55:30,120 --> 00:55:27,700
effects of gravitational lensing I've

1123
00:55:33,810 --> 00:55:30,130
heard it the different effects

1124
00:55:37,590 --> 00:55:33,820
attributed to it such as magnifying the

1125
00:55:39,210 --> 00:55:37,600
stars or galaxies far beyond the amount

1126
00:55:41,310 --> 00:55:39,220
that we could get through our telescopes

1127
00:55:43,890 --> 00:55:41,320
if it wasn't aided by gravitational

1128
00:55:45,510 --> 00:55:43,900
Lindsey I've also seen in the slides you

1129
00:55:47,910 --> 00:55:45,520
showed here are some subtypes of

1130
00:55:50,970 --> 00:55:47,920
spherical aberration which highly

1131
00:55:55,020 --> 00:55:50,980
distorts the image and then I've even

1132
00:55:59,280 --> 00:55:55,030
seen decades ago examples where there

1133
00:56:02,370 --> 00:55:59,290
were literally newer images of galaxies

1134
00:56:04,680 --> 00:56:02,380
in formations like reflected upon each

1135
00:56:06,600 --> 00:56:04,690
other I don't really understand how all

1136
00:56:09,810 --> 00:56:06,610
those things happen perhaps you could

1137
00:56:13,650 --> 00:56:09,820
tie it together for us sure so the

1138
00:56:16,350 --> 00:56:13,660

question is about what we scientists

1139
00:56:19,440 --> 00:56:16,360
call strong gravitational lensing where

1140
00:56:21,720 --> 00:56:19,450
light from a distant galaxy is traveling

1141
00:56:22,450 --> 00:56:21,730
towards us and it is being distorted by

1142
00:56:24,670 --> 00:56:22,460
a hue

1143
00:56:27,940 --> 00:56:24,680
of dark matter and that light is

1144
00:56:30,070 --> 00:56:27,950
traveling quite close to the large

1145
00:56:34,150 --> 00:56:30,080
amount of dark matter which is causing a

1146
00:56:37,300 --> 00:56:34,160
large lensing effect and one in in

1147
00:56:39,970 --> 00:56:37,310
physics we can look at how light

1148
00:56:41,349 --> 00:56:39,980
deflects as it goes through this dark

1149
00:56:47,230 --> 00:56:41,359
matter and these are quite simple

1150
00:56:50,500 --> 00:56:47,240
equations to to understand but we expect

1151
00:56:53,560 --> 00:56:50,510
to see a number of different galaxies in

1152
00:56:56,079 --> 00:56:53,570
this strong gravitational lensing so

1153
00:56:57,910 --> 00:56:56,089
multiple images is one of the

1154
00:57:00,070 --> 00:56:57,920
consequences of this strong

1155
00:57:01,930 --> 00:57:00,080
gravitational lensing and you can

1156
00:57:04,390 --> 00:57:01,940
sometimes even do this with a wine glass

1157
00:57:05,920 --> 00:57:04,400
and some water it's the same kind of

1158
00:57:07,870 --> 00:57:05,930
effect of the light traveling through

1159
00:57:11,260 --> 00:57:07,880
when you're looking at the reflections

1160
00:57:14,200 --> 00:57:11,270
of the light going through the glass and

1161
00:57:16,900 --> 00:57:14,210
so all of the things that you mentioned

1162
00:57:20,430 --> 00:57:16,910
the giant arcs the multiple images the

1163
00:57:24,700 --> 00:57:20,440

magnification there are consequences of

1164
00:57:28,150 --> 00:57:24,710
strong gravitational lensing do you want

1165
00:57:31,630 --> 00:57:28,160
to yeah you had mentioned multiple

1166
00:57:33,940 --> 00:57:31,640
images of the same galaxy and a way to

1167
00:57:36,730 --> 00:57:33,950
think of that is if if you have a very

1168
00:57:38,770 --> 00:57:36,740
strong lens here a lot of dark matter

1169
00:57:40,630 --> 00:57:38,780
and the galaxies back here some of the

1170
00:57:41,770 --> 00:57:40,640
light is going to come this way it's

1171
00:57:43,570 --> 00:57:41,780
going to come to your eyes some of the

1172
00:57:45,430 --> 00:57:43,580
light is going to come that way to your

1173
00:57:47,320 --> 00:57:45,440
eye and what your eye is gonna see is an

1174
00:57:50,260 --> 00:57:47,330
image of that distant galaxy here and

1175
00:57:52,060 --> 00:57:50,270
here so we can get multiple images of

1176
00:57:53,829 --> 00:57:52,070
the distant galaxy from this

1177
00:57:55,570 --> 00:57:53,839
gravitational lensing effect and that

1178
00:57:58,000 --> 00:57:55,580
was one of the surprising things that

1179
00:58:00,099 --> 00:57:58,010
people started to discover when we

1180
00:58:01,390 --> 00:58:00,109
started to have the quality of images

1181
00:58:04,720 --> 00:58:01,400
that we get from the Hubble Space

1182
00:58:07,089 --> 00:58:04,730
Telescope so then the effect depends on

1183
00:58:10,210 --> 00:58:07,099
the line of sight and the relative

1184
00:58:11,980 --> 00:58:10,220
position of the dark energy or that

1185
00:58:14,470 --> 00:58:11,990
that's exactly right it depends on the

1186
00:58:16,630 --> 00:58:14,480
line of sight and the relative positions

1187
00:58:19,390 --> 00:58:16,640
of the dark matter and the distant

1188
00:58:22,180 --> 00:58:19,400

galaxies so we know something about

1189
00:58:28,060 --> 00:58:22,190
where the the dark matter is in cloaks

1190
00:58:30,190 --> 00:58:28,070
relative to the totality of space we do

1191
00:58:31,900 --> 00:58:30,200
know where the dark matter is because we

1192
00:58:34,950 --> 00:58:31,910
can back that out using these equations

1193
00:58:37,410 --> 00:58:34,960
when we see these gravitational lenses

1194
00:58:39,450 --> 00:58:37,420
so it's using these gravitational lenses

1195
00:58:41,849 --> 00:58:39,460
that's how we measure where the dark

1196
00:58:44,099 --> 00:58:41,859
matter is and how much there is does it

1197
00:58:48,120 --> 00:58:44,109
correlate with any other visible objects

1198
00:58:50,609 --> 00:58:48,130
in the known universe the position of

1199
00:58:52,950 --> 00:58:50,619
the dark matter it turns out it

1200
00:58:55,230 --> 00:58:52,960
correlates quite well usually with the

1201
00:58:57,120 --> 00:58:55,240
position of the luminous matter the

1202
00:58:59,970 --> 00:58:57,130
normal matter the stuff we see and

1203
00:59:01,890 --> 00:58:59,980
that's because the dark matter forms

1204
00:59:04,620 --> 00:59:01,900
sort of a well where the normal matter

1205
00:59:06,150 --> 00:59:04,630
collects it's like a gravitational well

1206
00:59:07,799 --> 00:59:06,160
the normal matter collects where there's

1207
00:59:09,450 --> 00:59:07,809
a lot of dark matter okay we're gonna

1208
00:59:11,490 --> 00:59:09,460
move on to one of our questions from

1209
00:59:15,240 --> 00:59:11,500
YouTube thanks very much

1210
00:59:18,299 --> 00:59:15,250
SSR 98 has a good one for cosmologists

1211
00:59:21,900 --> 00:59:18,309
if the universe is expanding what is it

1212
00:59:26,520 --> 00:59:21,910
expanding into how's it classic it's a

1213
00:59:28,290 --> 00:59:26,530

real classic question sorry if the

1214
00:59:31,470 --> 00:59:28,300
universe is expanding what is it

1215
00:59:34,140 --> 00:59:31,480
expanding into and the very unsatisfying

1216
00:59:37,440 --> 00:59:34,150
answer is that the universe is really

1217
00:59:42,440 --> 00:59:37,450
everything so it is there's nothing

1218
00:59:50,329 --> 00:59:45,420
sorry do you have a better way of saying

1219
00:59:55,009 --> 00:59:52,579
it's a it's something that's very

1220
00:59:57,679 --> 00:59:55,019
difficult for our minds to get around

1221
01:00:01,219 --> 00:59:57,689
because we can only think in the the

1222
01:00:04,160 --> 01:00:01,229
three dimensions we see but the universe

1223
01:00:07,009 --> 01:00:04,170
is expanding its getting bigger and

1224
01:00:09,439 --> 01:00:07,019
there's more universe today than there

1225
01:00:11,630 --> 01:00:09,449
was yesterday and tomorrow it's gonna be

1226
01:00:14,209 --> 01:00:11,640
even bigger so you heard it here you're

1227
01:00:16,429 --> 01:00:14,219
getting more big bang for your buck next

1228
01:00:19,339 --> 01:00:16,439
question it's actually what my question

1229
01:00:23,959 --> 01:00:19,349
was gonna be okay but you don't consider

1230
01:00:26,059 --> 01:00:23,969
it the big void or some infinite haze

1231
01:00:28,849 --> 01:00:26,069
that this is all expanding into youth

1232
01:00:31,609 --> 01:00:28,859
that's not part of your study not part

1233
01:00:34,699 --> 01:00:31,619
of your consideration so it's not in the

1234
01:00:36,739 --> 01:00:34,709
in the following sense is that we think

1235
01:00:39,109 --> 01:00:36,749
if we look at how the universe has

1236
01:00:41,509 --> 01:00:39,119
evolved we can watch that sort of

1237
01:00:44,420 --> 01:00:41,519
backwards as a movie in Reverse and

1238
01:00:46,370 --> 01:00:44,430

eventually we get back to an infinitely

1239
01:00:49,189 --> 01:00:46,380
dense and infinitely small point in the

1240
01:00:52,039 --> 01:00:49,199
past about 13 some billion years ago and

1241
01:00:54,229 --> 01:00:52,049
after that it that there was a big bang

1242
01:00:55,849 --> 01:00:54,239
and it started to expand and so it

1243
01:00:58,640 --> 01:00:55,859
doesn't mean at that point was sitting

1244
01:01:01,039 --> 01:00:58,650
in space all of space was at an

1245
01:01:03,469 --> 01:01:01,049
infinitesimally small point and we're

1246
01:01:06,529 --> 01:01:03,479
just getting more space it's something

1247
01:01:08,749 --> 01:01:06,539
that as cosmologists we learn to

1248
01:01:11,239 --> 01:01:08,759
understand the equations and the

1249
01:01:13,429 --> 01:01:11,249
equations fit our observations but as

1250
01:01:15,380 --> 01:01:13,439
humans it's pretty hard to get our mind

1251
01:01:17,929 --> 01:01:15,390
around that because it's not something

1252
01:01:20,539 --> 01:01:17,939
we can visualize very easily or multiple

1253
01:01:23,269 --> 01:01:20,549
dimensions I suppose that's another

1254
01:01:25,519 --> 01:01:23,279
possible explanation but for me I can't

1255
01:01:34,039 --> 01:01:25,529
think in multiple dimensions either just

1256
01:01:36,559 --> 01:01:34,049
the math I can only see the map so by

1257
01:01:39,380 --> 01:01:36,569
the way what happened if the universe

1258
01:01:42,079 --> 01:01:39,390
Kiton with this accelerating expansion

1259
01:01:46,329 --> 01:01:42,089
would one day expand faster than light

1260
01:01:51,549 --> 01:01:49,089
so yes the universe will eventually be

1261
01:01:55,509 --> 01:01:51,559
expanding faster than light speed so

1262
01:01:57,130 --> 01:01:55,519
nothing in the universe can itself no

1263
01:01:59,529 --> 01:01:57,140

piece of matter no piece of light can

1264
01:02:01,239 --> 01:01:59,539
move faster than light but space can

1265
01:02:04,150 --> 01:02:01,249
expand faster than the speed of light

1266
01:02:06,880 --> 01:02:04,160
right so what if the space between each

1267
01:02:09,459 --> 01:02:06,890
of the individual matter molecules and

1268
01:02:10,779 --> 01:02:09,469
stuff all that starts expanding faster

1269
01:02:12,219 --> 01:02:10,789
than light does that means that no

1270
01:02:13,929 --> 01:02:12,229
molecule will be able to touch each

1271
01:02:16,449 --> 01:02:13,939
other like no particle would be able to

1272
01:02:17,769 --> 01:02:16,459
touch each other because no nothing

1273
01:02:20,199 --> 01:02:17,779
could really move faster than light

1274
01:02:23,380 --> 01:02:20,209
that's one of the possible scenarios

1275
01:02:25,120 --> 01:02:23,390
that we talked about at the end that we

1276
01:02:27,849 --> 01:02:25,130
can't see anything else because it's all

1277
01:02:31,539 --> 01:02:27,859
moved faster than light away from us and

1278
01:02:33,549 --> 01:02:31,549
it's your chance that dark matter dark

1279
01:02:36,249 --> 01:02:33,559
energy phenomenons that were observing

1280
01:02:39,459 --> 01:02:36,259
is possibly just the curvature of

1281
01:02:41,469 --> 01:02:39,469
space-time itself but instead of being

1282
01:02:43,569 --> 01:02:41,479
curved by the stuff that we can't see

1283
01:02:46,410 --> 01:02:43,579
it's curved by something that we don't

1284
01:02:49,569 --> 01:02:46,420
know or it's just curves to begin with

1285
01:02:51,219 --> 01:02:49,579
so the question was this the dark matter

1286
01:02:51,939 --> 01:02:51,229
and dark energy just a curvature of

1287
01:02:54,910 --> 01:02:51,949
space-time

1288
01:02:57,759 --> 01:02:54,920

well we described gravity as the

1289
01:02:59,439 --> 01:02:57,769
curvature of space-time that's how we

1290
01:03:01,239 --> 01:02:59,449
describe gravity with our gravity

1291
01:03:06,849 --> 01:03:01,249
equations that Elina was talking about

1292
01:03:09,669 --> 01:03:06,859
in the talk and in fact that it's it's

1293
01:03:11,109 --> 01:03:09,679
equivalent to what you described so it

1294
01:03:13,689 --> 01:03:11,119
might be that we don't understand

1295
01:03:15,669 --> 01:03:13,699
gravity very well we think we do but if

1296
01:03:18,039 --> 01:03:15,679
we don't that could explain something a

1297
01:03:21,130 --> 01:03:18,049
big housing bubble even putting gravity

1298
01:03:24,130 --> 01:03:21,140
into particle physics that's true we

1299
01:03:26,380 --> 01:03:24,140
don't have a complete model of particle

1300
01:03:28,269 --> 01:03:26,390
physics that includes gravity all right

1301
01:03:30,370 --> 01:03:28,279
onto another question from YouTube Jane

1302
01:03:35,620 --> 01:03:30,380
wants to know if ordinary particles can

1303
01:03:38,140 --> 01:03:35,630
become dark matter so ten ordinary

1304
01:03:40,569 --> 01:03:38,150
particles become dark matter and I would

1305
01:03:42,609 --> 01:03:40,579
say that the answer to that that

1306
01:03:45,459 --> 01:03:42,619
scientists currently believe is no we

1307
01:03:49,870 --> 01:03:45,469
have normal matter that we understand

1308
01:03:54,009 --> 01:03:49,880
and and it reflects electromagnetic

1309
01:03:55,509 --> 01:03:54,019
light and it emits radiation but I don't

1310
01:03:58,000 --> 01:03:55,519
think that we think it can turn into

1311
01:03:59,500 --> 01:03:58,010
dark matter but that doesn't mean that

1312
01:04:01,780 --> 01:03:59,510
something couldn't be discovered in the

1313
01:04:06,940 --> 01:04:01,790

future because we don't know all that

1314
01:04:09,550 --> 01:04:06,950
much about it I am clearly the dumbest

1315
01:04:12,160 --> 01:04:09,560
person in this room as this question

1316
01:04:14,290 --> 01:04:12,170
will prove I want to follow you and I'm

1317
01:04:16,300 --> 01:04:14,300
mostly there but if I understand what

1318
01:04:19,930 --> 01:04:16,310
you're saying there's a distortion that

1319
01:04:22,090 --> 01:04:19,940
we are seeing and so we're assuming it's

1320
01:04:25,980 --> 01:04:22,100
dark matter is there any other theories

1321
01:04:28,450 --> 01:04:25,990
or does the math just say nope that's it

1322
01:04:31,240 --> 01:04:28,460
so we're seeing these gravitational

1323
01:04:33,250 --> 01:04:31,250
lensing distortions and the question is

1324
01:04:35,590 --> 01:04:33,260
are we assuming that this is dark matter

1325
01:04:37,930 --> 01:04:35,600
or are there other theories that could

1326
01:04:41,320 --> 01:04:37,940
explain it and for a long time there

1327
01:04:44,050 --> 01:04:41,330
were lots of scientists that wanted to

1328
01:04:47,140 --> 01:04:44,060
come up with a modified theory of

1329
01:04:51,130 --> 01:04:47,150
gravity that didn't need an unseen form

1330
01:04:52,660 --> 01:04:51,140
of matter and over time there were lots

1331
01:04:54,610 --> 01:04:52,670
of experiments that scientists were

1332
01:04:57,760 --> 01:04:54,620
undertaking and they were able to rule

1333
01:05:00,310 --> 01:04:57,770
out all of these other theories that did

1334
01:05:02,350 --> 01:05:00,320
not include dark matter and so at the

1335
01:05:06,220 --> 01:05:02,360
moment the only theories that work are

1336
01:05:07,690 --> 01:05:06,230
the ones that include dark matter but

1337
01:05:18,040 --> 01:05:07,700
there's no way to actually detect it or

1338
01:05:21,250 --> 01:05:18,050

prove it it's just I have a question if

1339
01:05:22,720 --> 01:05:21,260
after the Big Bang all of this matter

1340
01:05:24,370 --> 01:05:22,730
which was this channel essentially

1341
01:05:26,590 --> 01:05:24,380
particles gradually accreted into

1342
01:05:28,570 --> 01:05:26,600
planets and Suns and galaxies and galaxy

1343
01:05:30,190 --> 01:05:28,580
clusters and if dark matter is really

1344
01:05:31,960 --> 01:05:30,200
little particles that we can't see

1345
01:05:33,550 --> 01:05:31,970
shouldn't it have done the same thing

1346
01:05:35,970 --> 01:05:33,560
and shouldn't it be concentrated in all

1347
01:05:38,530 --> 01:05:35,980
the galaxies and stars

1348
01:05:40,450 --> 01:05:38,540
why is it in between the galaxies is not

1349
01:05:43,930 --> 01:05:40,460
in the galaxies the question is about

1350
01:05:47,620 --> 01:05:43,940
how the dark matter is is distributed

1351
01:05:49,300 --> 01:05:47,630
throughout the universe and and I can

1352
01:05:51,880 --> 01:05:49,310
let you know that the dark matter is

1353
01:05:54,370 --> 01:05:51,890
actually clustered at the Centers of the

1354
01:05:56,470 --> 01:05:54,380
galaxies and scientists believe that the

1355
01:05:58,750 --> 01:05:56,480
density of the dark matter at the center

1356
01:06:01,360 --> 01:05:58,760
of a galaxy is much higher than the

1357
01:06:04,450 --> 01:06:01,370
density at the outskirts of the galaxy

1358
01:06:08,990 --> 01:06:04,460
when we do simulations of dark matter

1359
01:06:11,510 --> 01:06:09,000
with a computer we get these beautiful

1360
01:06:13,760 --> 01:06:11,520
clustering of the dark matter in what we

1361
01:06:17,000 --> 01:06:13,770
call a big cosmic web and where we would

1362
01:06:20,809 --> 01:06:17,010
expect to see a galaxy there's this high

1363
01:06:23,480 --> 01:06:20,819

density of dark matter and you can trace

1364
01:06:24,500 --> 01:06:23,490
it along where you expect to see the

1365
01:06:29,900 --> 01:06:24,510
luminous matter

1366
01:06:32,690 --> 01:06:29,910
into the center of these dense dark

1367
01:06:34,280 --> 01:06:32,700
matter areas okay thank you and one

1368
01:06:36,140 --> 01:06:34,290
other little anecdote is it true that

1369
01:06:37,910 --> 01:06:36,150
when they discovered that the Hubble

1370
01:06:39,890 --> 01:06:37,920
constant was wrong and the universe was

1371
01:06:42,829 --> 01:06:39,900
accelerating that there was a headline

1372
01:06:49,579 --> 01:06:42,839
that said Hubble double universe in

1373
01:06:51,890 --> 01:06:49,589
trouble there should have been okay so

1374
01:06:54,380 --> 01:06:51,900
Derek on YouTube asked if dark matter

1375
01:06:57,650 --> 01:06:54,390
has an electrical charge we know enough

1376
01:06:59,420 --> 01:06:57,660
about it to say that we do so dark an

1377
01:07:03,349 --> 01:06:59,430
electrical charge comes from the

1378
01:07:05,690 --> 01:07:03,359
electromagnetic interaction and so right

1379
01:07:08,510 --> 01:07:05,700
now our best guess for dark matter is

1380
01:07:11,240 --> 01:07:08,520
that it does not interact at all through

1381
01:07:14,329 --> 01:07:11,250
the electromagnetic interaction so it

1382
01:07:16,789 --> 01:07:14,339
has no electric charge in fact we think

1383
01:07:19,280 --> 01:07:16,799
the dark matter only interacts

1384
01:07:21,559 --> 01:07:19,290
gravitationally it doesn't interact in

1385
01:07:25,430 --> 01:07:21,569
any other way that's what we think right

1386
01:07:29,390 --> 01:07:25,440
now so no no magnetic charge no

1387
01:07:31,130 --> 01:07:29,400
electrical charge just gravity and was

1388
01:07:33,049 --> 01:07:31,140

that question sorry about that matter or

1389
01:07:35,150 --> 01:07:33,059
definition it was about dark matter

1390
01:07:40,579 --> 01:07:35,160
whether the dark matter has the charge

1391
01:07:44,809 --> 01:07:40,589
yeah hi hi so um my questions about the

1392
01:07:47,690 --> 01:07:44,819
big rip if everything is oh my god if

1393
01:07:50,359 --> 01:07:47,700
everything is ripping apart and the

1394
01:07:53,599 --> 01:07:50,369
atoms get ripped apart wouldn't that

1395
01:07:55,160 --> 01:07:53,609
create energy that would then bring it

1396
01:07:59,510 --> 01:07:55,170
all together and we would have like a

1397
01:08:04,609 --> 01:07:59,520
big suck and then another big bang and

1398
01:08:06,890 --> 01:08:04,619
they just start all over again so a

1399
01:08:09,020 --> 01:08:06,900
question is wouldn't a big rip create

1400
01:08:14,390 --> 01:08:09,030
energy that might start everything all

1401
01:08:17,209 --> 01:08:14,400
over again and I I said well I can't

1402
01:08:19,669 --> 01:08:17,219
visualize an expanding universe into

1403
01:08:21,740 --> 01:08:19,679
something it's just the equations I can

1404
01:08:22,249 --> 01:08:21,750
tell you that the problem there is that

1405
01:08:24,200 --> 01:08:22,259
once

1406
01:08:25,849 --> 01:08:24,210
we get to this big rip our equations

1407
01:08:28,309 --> 01:08:25,859
don't work very well anymore

1408
01:08:30,319 --> 01:08:28,319
so I don't have an intuition from the

1409
01:08:35,059 --> 01:08:30,329
equations that tell me what's going to

1410
01:08:37,549 --> 01:08:35,069
happen after that so I don't know yeah

1411
01:08:41,920 --> 01:08:37,559
what happens after the big rip you get

1412
01:08:44,079 --> 01:08:41,930
me to say oh I don't know we don't know

1413
01:08:46,999 --> 01:08:44,089

[Laughter]

1414
01:08:48,859 --> 01:08:47,009
and it's that way at the beginning of

1415
01:08:50,990 --> 01:08:48,869
the universe as well as the end right we

1416
01:08:52,579 --> 01:08:51,000
don't that's right at the at the time of

1417
01:08:54,589 --> 01:08:52,589
the Big Bang our equations don't work

1418
01:08:56,689 --> 01:08:54,599
very well and it's only after the Big

1419
01:08:59,599 --> 01:08:56,699
Bang that the equations start to work so

1420
01:09:02,779 --> 01:08:59,609
there's still there's still work we have

1421
01:09:06,039 --> 01:09:02,789
to do and don't forget we did start this

1422
01:09:08,029 --> 01:09:06,049
talk by saying that 95% of the universe

1423
01:09:10,519 --> 01:09:08,039
cosmologists people who study the

1424
01:09:12,919 --> 01:09:10,529
universe don't understand so we stood in

1425
01:09:15,200 --> 01:09:12,929
front of several hundred people and said

1426
01:09:18,919 --> 01:09:15,210
we don't understand 95% of what we do in

1427
01:09:21,319 --> 01:09:18,929
our job and they're ok with that there's

1428
01:09:24,950 --> 01:09:21,329
time for a couple more questions go

1429
01:09:28,549 --> 01:09:24,960
ahead I just had a question I just just

1430
01:09:31,249 --> 01:09:28,559
had a question on accion's what in your

1431
01:09:33,529 --> 01:09:31,259
view is like the hypothetical particle

1432
01:09:38,149 --> 01:09:33,539
that dark matter dark energy consists of

1433
01:09:40,399 --> 01:09:38,159
like neutral Eno's wimps or what what

1434
01:09:45,339 --> 01:09:40,409
could if you could expand on that thanks

1435
01:09:54,379 --> 01:09:48,200
see you asked what do we think dark

1436
01:09:56,870 --> 01:09:54,389
matter is and right now the theorists on

1437
01:10:01,830 --> 01:09:56,880
this are somewhat unconstrained by the

1438
01:10:07,870 --> 01:10:06,400

have any Dark Matter theorists here so

1439
01:10:09,400 --> 01:10:07,880
what it means is there's a lot of

1440
01:10:10,270 --> 01:10:09,410
theories and you mentioned a few there's

1441
01:10:13,990 --> 01:10:10,280
accion's

1442
01:10:15,970 --> 01:10:14,000
there's wimps we're pretty clever at

1443
01:10:19,420 --> 01:10:15,980
naming things there's another one called

1444
01:10:21,520 --> 01:10:19,430
macho's I'm more partial to that than

1445
01:10:24,610 --> 01:10:21,530
the wimps I guess but these are all

1446
01:10:27,760 --> 01:10:24,620
different theories of what the dark

1447
01:10:29,350 --> 01:10:27,770
matter particle is and in fact the one

1448
01:10:32,320 --> 01:10:29,360
that's been pretty well ruled out as the

1449
01:10:35,350 --> 01:10:32,330
macho's unfortunately but what we're

1450
01:10:37,960 --> 01:10:35,360
doing with the gravitational lensing

1451
01:10:40,240 --> 01:10:37,970
experiments is we're starting to rule

1452
01:10:43,330 --> 01:10:40,250
out what I call different classes of

1453
01:10:46,060 --> 01:10:43,340
models and because they behave somewhat

1454
01:10:48,040 --> 01:10:46,070
differently and when we get better and

1455
01:10:50,470 --> 01:10:48,050
better David we can rule out different

1456
01:10:52,120 --> 01:10:50,480
classes of dark matter particles but

1457
01:10:53,950 --> 01:10:52,130
there's still a lot of possibilities

1458
01:10:57,070 --> 01:10:53,960
left and that's why we need to do these

1459
01:11:00,430 --> 01:10:57,080
experiments like LSST euclid and w first

1460
01:11:03,070 --> 01:11:00,440
in the future all right future NASA

1461
01:11:05,200 --> 01:11:03,080
intern you get to have our last question

1462
01:11:07,810 --> 01:11:05,210
of the night okay so I had another

1463
01:11:09,760 --> 01:11:07,820

question you said that I will answering

1464
01:11:12,580 --> 01:11:09,770
your previous question you said that

1465
01:11:14,470 --> 01:11:12,590
dark matter concentrates at the Centers

1466
01:11:16,840 --> 01:11:14,480
of galaxies would that have any relation

1467
01:11:18,700 --> 01:11:16,850
to black holes because black holes are

1468
01:11:25,050 --> 01:11:18,710
theorized from what I've heard to have

1469
01:11:41,050 --> 01:11:34,210
now we have two interns yeah come on

1470
01:11:43,720 --> 01:11:41,060
down so the question was is the dark

1471
01:11:46,690 --> 01:11:43,730
matter at the center of galaxies related

1472
01:11:48,760 --> 01:11:46,700
to the black holes at the center of

1473
01:11:51,760 --> 01:11:48,770
galaxies and so black holes are

1474
01:11:55,360 --> 01:11:51,770
something very different to dark matter

1475
01:11:57,970 --> 01:11:55,370
black holes what come about when when

1476
01:12:01,140 --> 01:11:57,980
stars very massive stars reach the end

1477
01:12:04,390 --> 01:12:01,150
of their lives and then there's some

1478
01:12:06,160 --> 01:12:04,400
coalescing of black holes at the center

1479
01:12:08,290 --> 01:12:06,170
of galaxies to make these supermassive

1480
01:12:12,760 --> 01:12:08,300
black holes and we can measure the mass

1481
01:12:14,830 --> 01:12:12,770
of these black holes actually and and as

1482
01:12:16,990 --> 01:12:14,840
was very helpfully mentioned they they

1483
01:12:19,420 --> 01:12:17,000
have a finite mass that an infinite sort

1484
01:12:22,540 --> 01:12:19,430
of density and so the light can't escape

1485
01:12:24,820 --> 01:12:22,550
from that mass and so they're unrelated

1486
01:12:27,340 --> 01:12:24,830
to the dark matter in the center of

1487
01:12:29,290 --> 01:12:27,350
those galaxies all right thank you so

1488
01:12:33,640 --> 01:12:29,300

they're dark matter but they're not dark

1489
01:12:36,520 --> 01:12:33,650
matter so all right well that's all the

1490
01:12:38,979 --> 01:12:36,530
time we have for this and we can we can

1491
01:12:40,930 --> 01:12:38,989
have some for a while after the show and

1492
01:12:42,510 --> 01:12:40,940
we come on up and we can continue this

1493
01:12:45,190 --> 01:12:42,520
discussion but for our audience at home

1494
01:12:46,479 --> 01:12:45,200
thanks for joining us thanks to everyone

1495
01:12:55,100 --> 01:12:46,489
for being here thank you again to our

1496
01:13:01,450 --> 01:12:57,160
please join us

1497
01:13:03,610 --> 01:13:01,460
all about how we use the International

1498
01:13:04,960 --> 01:13:03,620
Space Station to study our home planet