PUBLIC LECTURE SERIES

The Darkest Secrets of the Universe

Featuring Guest Speaker:
Raja Guhathakurta

1
00:00:05,269 --> 00:00:03,830
welcome to the space telescope public

2
00:00:08,150 --> 00:00:05,279
lecture series

3
00:00:09,030 --> 00:00:08,160
tonight's talk the darkest secrets of

4
00:00:14,150 --> 00:00:09,040
the universe

5
00:00:18,230 --> 00:00:16,150
this i'm dr frank summers of the space

6
00:00:20,950 --> 00:00:18,240
telescope science institute

7
00:00:21,670 --> 00:00:20,960
and um as we have so told you in past

8
00:00:23,670 --> 00:00:21,680
months the

9
00:00:25,189 --> 00:00:23,680
space telescope public ledger series

10
00:00:27,830 --> 00:00:25,199
will be online only

11
00:00:29,669 --> 00:00:27,840
until further notice thanks to our

12
00:00:30,950 --> 00:00:29,679
amazing tech team that helps us get it

13
00:00:34,549 --> 00:00:30,960

out there online

14
00:00:37,990 --> 00:00:34,559
thomas marufu and grant justice

15
00:00:41,110 --> 00:00:38,000
our upcoming talks include in february

16
00:00:42,869 --> 00:00:41,120
the milky way versus andromeda when

17
00:00:45,910 --> 00:00:42,879
galaxies collide

18
00:00:47,830 --> 00:00:45,920
it's a titanic battle for supremacy in

19
00:00:51,029 --> 00:00:47,840
the local group of galaxies

20
00:00:53,510 --> 00:00:51,039
who will win tune in next

21
00:00:55,990 --> 00:00:53,520
month uh laura pritchard will discuss

22
00:00:59,830 --> 00:00:56,000
that and reveal the answers

23
00:01:01,830 --> 00:00:59,840
in march uh tom brown head of the hubble

24
00:01:04,789 --> 00:01:01,840
mission office here at space telescope

25
00:01:06,630 --> 00:01:04,799
will give a wonderful overview talk

26
00:01:09,510 --> 00:01:06,640
called the hubble space telescope

27
00:01:11,109 --> 00:01:09,520
from cosmological conflict to alien

28
00:01:14,149 --> 00:01:11,119
atmospheres

29
00:01:16,310 --> 00:01:14,159
and in april we have a special guest

30
00:01:17,270 --> 00:01:16,320
author christopher wanzek will come and

31
00:01:19,990 --> 00:01:17,280
talk to us about

32
00:01:20,870 --> 00:01:20,000
space farers how humans will settle the

33
00:01:24,310 --> 00:01:20,880
moon

34
00:01:26,469 --> 00:01:24,320
mars and beyond we have talks scheduled

35
00:01:28,149 --> 00:01:26,479
throughout the year and if you want to

36
00:01:30,710 --> 00:01:28,159
find out about them

37
00:01:31,710 --> 00:01:30,720
you can go to our website if you just

38
00:01:34,469 --> 00:01:31,720

type in

39
00:01:37,749 --> 00:01:34,479
sdsci.edu public hyphen

40
00:01:39,830 --> 00:01:37,759
lectures you'll find this webpage

41
00:01:41,670 --> 00:01:39,840
and in the lower left you can see the

42
00:01:44,069 --> 00:01:41,680
links to our webcasts

43
00:01:44,789 --> 00:01:44,079
both on the space telescope webcasting

44
00:01:48,069 --> 00:01:44,799
page

45
00:01:50,230 --> 00:01:48,079
and our youtube playlist if you would

46
00:01:52,069 --> 00:01:50,240
like to be reminded monthly about it

47
00:01:54,149 --> 00:01:52,079
in the lower right you can see how to

48
00:01:57,510 --> 00:01:54,159
subscribe to our email

49
00:02:00,550 --> 00:01:57,520
list and you'll get two emails

50
00:02:03,030 --> 00:02:00,560
each month also on our website we have

51
00:02:05,749 --> 00:02:03,040
the list of the upcoming lectures

52
00:02:06,870 --> 00:02:05,759
and if you click on the read more about

53
00:02:09,990 --> 00:02:06,880
every lecture

54
00:02:13,190 --> 00:02:10,000
you will find out about the description

55
00:02:15,110 --> 00:02:13,200
on author information as well as

56
00:02:16,630 --> 00:02:15,120
after the lecture is finished links to

57
00:02:21,270 --> 00:02:16,640
the sdsci webcast

58
00:02:23,750 --> 00:02:21,280
as well as the youtube recording of it

59
00:02:25,510 --> 00:02:23,760
our email the announcements you can sign

60
00:02:28,070 --> 00:02:25,520
up at the website

61
00:02:28,790 --> 00:02:28,080
uh you can also subscribe to our youtube

62
00:02:32,630 --> 00:02:28,800
channel

63
00:02:35,830 --> 00:02:32,640

youtube.com hubble space telescope okay

64
00:02:36,949 --> 00:02:35,840
um that when if you subscribe you'll get

65
00:02:39,990 --> 00:02:36,959
new video notices

66
00:02:42,150 --> 00:02:40,000
and reminders of live events

67
00:02:43,509 --> 00:02:42,160
if you have comments or questions you

68
00:02:47,150 --> 00:02:43,519
can send them to us

69
00:02:49,750 --> 00:02:47,160
via the email address public lecture

70
00:02:52,229 --> 00:02:49,760
stsci.edu

71
00:02:52,869 --> 00:02:52,239
if you want other information about

72
00:02:54,949 --> 00:02:52,879
hubble

73
00:02:56,949 --> 00:02:54,959
or the james webb space telescope or the

74
00:03:00,229 --> 00:02:56,959
space telescope science institute

75
00:03:02,309 --> 00:03:00,239
you can follow us on facebook on twitter

76
00:03:04,309 --> 00:03:02,319
uh our youtube channels both for hubble

77
00:03:07,910 --> 00:03:04,319
and for and for web um

78
00:03:09,110 --> 00:03:07,920
and on instagram myself i do a tiny bit

79
00:03:11,670 --> 00:03:09,120
of social media

80
00:03:13,509 --> 00:03:11,680
on facebook and on twitter if you want

81
00:03:15,750 --> 00:03:13,519
to hear what's up with me

82
00:03:18,149 --> 00:03:15,760
but what's usually up with me is this

83
00:03:20,830 --> 00:03:18,159
part of the program where i give you

84
00:03:23,110 --> 00:03:20,840
the news from the universe for january

85
00:03:26,149 --> 00:03:23,120
2021

86
00:03:29,110 --> 00:03:26,159
and our first story tonight the

87
00:03:29,430 --> 00:03:29,120
darkest sky you ever thought about you

88
00:03:31,270 --> 00:03:29,440

know

89
00:03:33,589 --> 00:03:31,280
getting out if you want to see the stars

90
00:03:36,710 --> 00:03:33,599
you've got to get out to a dark sky

91
00:03:38,390 --> 00:03:36,720
well i was in new york city and worked

92
00:03:39,910 --> 00:03:38,400
at the hayden planetarium the american

93
00:03:42,789 --> 00:03:39,920
museum of natural history

94
00:03:44,550 --> 00:03:42,799
and we used to do stargazing parties in

95
00:03:47,670 --> 00:03:44,560
central park

96
00:03:49,509 --> 00:03:47,680
this image here is uh from urban scopes

97
00:03:52,309 --> 00:03:49,519
and you can see they're actually using

98
00:03:54,470 --> 00:03:52,319
telescopes in new york city

99
00:03:56,070 --> 00:03:54,480
uh which you generally don't recommend

100
00:03:58,070 --> 00:03:56,080
because of all the light pollution with

101
00:03:59,910 --> 00:03:58,080
all those bright lights of the city

102
00:04:01,270 --> 00:03:59,920
you really can't see many stars matter

103
00:04:03,509 --> 00:04:01,280
of fact in this picture there are

104
00:04:05,030 --> 00:04:03,519
zero stars in the background although i

105
00:04:05,830 --> 00:04:05,040
will tell you that having done it in

106
00:04:07,990 --> 00:04:05,840
central park

107
00:04:09,910 --> 00:04:08,000
you can see a smattering of stars and

108
00:04:12,630 --> 00:04:09,920
sun and and the planets

109
00:04:15,110 --> 00:04:12,640
and the moon for that but if you really

110
00:04:17,189 --> 00:04:15,120
want to get a dark sky

111
00:04:19,430 --> 00:04:17,199
i would suggest going to a national park

112
00:04:21,349 --> 00:04:19,440
like yosemite okay

113
00:04:22,469 --> 00:04:21,359

when my family took a vacation to

114
00:04:25,830 --> 00:04:22,479
yosemite

115
00:04:27,590 --> 00:04:25,840
oh gosh it's coming out 15 years ago

116
00:04:29,110 --> 00:04:27,600
i took my son out into the middle of

117
00:04:31,909 --> 00:04:29,120
yosemite valley and we

118
00:04:33,830 --> 00:04:31,919
looked up and we saw one of the darkest

119
00:04:35,990 --> 00:04:33,840
guys we'd ever seen

120
00:04:37,670 --> 00:04:36,000
we saw so many stars that i as a

121
00:04:39,270 --> 00:04:37,680
professional astronomer

122
00:04:41,110 --> 00:04:39,280
couldn't make sense of them because

123
00:04:43,749 --> 00:04:41,120
there were too many of them

124
00:04:45,350 --> 00:04:43,759
there were so many stars so getting out

125
00:04:47,590 --> 00:04:45,360
to like national parks will give you a

126
00:04:51,030 --> 00:04:47,600
really good dark sky

127
00:04:51,590 --> 00:04:51,040
but even the darkest sky on earth isn't

128
00:04:54,790 --> 00:04:51,600
really

129
00:04:55,590 --> 00:04:54,800
fully dark and one of the reasons is

130
00:04:58,230 --> 00:04:55,600
because

131
00:05:00,230 --> 00:04:58,240
of something called the zodiacal light

132
00:05:04,070 --> 00:05:00,240
now this is shown in this diagram

133
00:05:06,310 --> 00:05:04,080
here okay so this band on the right here

134
00:05:07,909 --> 00:05:06,320
this is the milky way this is the band

135
00:05:09,029 --> 00:05:07,919
of the milky way that goes across the

136
00:05:11,350 --> 00:05:09,039
sky

137
00:05:13,350 --> 00:05:11,360
but this other band this bright light

138
00:05:16,629 --> 00:05:13,360

over here on the left

139
00:05:17,350 --> 00:05:16,639
that is the zodiacal light now what this

140
00:05:20,230 --> 00:05:17,360
really is

141
00:05:20,790 --> 00:05:20,240
is dust in the plane of our solar system

142
00:05:22,469 --> 00:05:20,800
okay

143
00:05:24,950 --> 00:05:22,479
the planets are all in a plane and

144
00:05:26,790 --> 00:05:24,960
there's bits of dust within that plane

145
00:05:28,629 --> 00:05:26,800
that scatter some of the light from the

146
00:05:31,830 --> 00:05:28,639
sun so

147
00:05:34,230 --> 00:05:31,840
we on earth being embedded in

148
00:05:35,110 --> 00:05:34,240
that milky way in that solar system

149
00:05:36,870 --> 00:05:35,120
plane

150
00:05:38,950 --> 00:05:36,880
are always going to be looking a little

151
00:05:42,230 --> 00:05:38,960
bit through that zodiacal

152
00:05:45,110 --> 00:05:42,240
dust so our dark knights

153
00:05:46,710 --> 00:05:45,120
aren't as dark as they really could be

154
00:05:47,430 --> 00:05:46,720
how are we going to find out how dark

155
00:05:51,110 --> 00:05:47,440
the nice guy

156
00:05:53,510 --> 00:05:51,120
really really really really is well

157
00:05:54,629 --> 00:05:53,520
we need to get outside the solar system

158
00:05:56,710 --> 00:05:54,639
fortunately

159
00:05:59,029 --> 00:05:56,720
we happen to have a space mission that

160
00:06:01,430 --> 00:05:59,039
has got has done just that

161
00:06:03,909 --> 00:06:01,440
this is an artist's depiction of the new

162
00:06:05,909 --> 00:06:03,919
horizons spacecraft craft

163
00:06:07,670 --> 00:06:05,919

and if you remember new horizons went

164
00:06:10,390 --> 00:06:07,680
out and visited the pluto

165
00:06:12,870 --> 00:06:10,400
karen system and it also went past a

166
00:06:16,070 --> 00:06:12,880
kuiper belt object called erikoff

167
00:06:16,950 --> 00:06:16,080
and uh it's now out you know 40 50 a.u

168
00:06:21,749 --> 00:06:16,960
outside

169
00:06:24,390 --> 00:06:21,759
almost all of that sodium dust

170
00:06:26,790 --> 00:06:24,400
so what the what the experiment they did

171
00:06:29,430 --> 00:06:26,800
was using new horizons

172
00:06:30,230 --> 00:06:29,440
to measure the darkness of the night sky

173
00:06:33,350 --> 00:06:30,240
the true

174
00:06:36,469 --> 00:06:33,360
darkness of the night sky and what they

175
00:06:38,950 --> 00:06:36,479
found is that when you measure

176
00:06:40,070 --> 00:06:38,960
the deepest darkest black that new

177
00:06:43,670 --> 00:06:40,080
horizons

178
00:06:46,629 --> 00:06:43,680
gets out there um and you consider

179
00:06:48,390 --> 00:06:46,639
what hubble has seen like if you take

180
00:06:49,270 --> 00:06:48,400
all the galaxies this is an image of the

181
00:06:51,350 --> 00:06:49,280
ultra deep field

182
00:06:52,309 --> 00:06:51,360
you take all the the light that that

183
00:06:54,309 --> 00:06:52,319
hubble has seen

184
00:06:56,070 --> 00:06:54,319
and you add them up and then you look

185
00:06:58,710 --> 00:06:56,080
for you say what's missing

186
00:06:59,510 --> 00:06:58,720
okay um the brightness of the night sky

187
00:07:01,110 --> 00:06:59,520
the absolute

188
00:07:02,870 --> 00:07:01,120

final brightness of the night sky the

189
00:07:06,150 --> 00:07:02,880
what we call the optical sky

190
00:07:09,189 --> 00:07:06,160
background is about twice as bright

191
00:07:11,990 --> 00:07:09,199
as all the stuff that hubble sees so

192
00:07:14,550 --> 00:07:12,000
the idea being that there are unresolved

193
00:07:17,830 --> 00:07:14,560
galaxies galaxies that hubble can't see

194
00:07:19,589 --> 00:07:17,840
too small too faint just too spread out

195
00:07:21,909 --> 00:07:19,599
that hubble can't see them

196
00:07:23,029 --> 00:07:21,919
and the light the combined light from

197
00:07:25,430 --> 00:07:23,039
all those

198
00:07:27,189 --> 00:07:25,440
is about equal to the light from all the

199
00:07:29,830 --> 00:07:27,199
stuff that it can see

200
00:07:30,550 --> 00:07:29,840
so maybe like half of the galaxies out

201
00:07:32,870 --> 00:07:30,560
in the universe

202
00:07:34,870 --> 00:07:32,880
are stuff hubble can't see and that

203
00:07:36,469 --> 00:07:34,880
actually contrasts against a previous

204
00:07:38,790 --> 00:07:36,479
estimate that was done with simulations

205
00:07:41,990 --> 00:07:38,800
that said oh no no hubble only sees 10

206
00:07:43,589 --> 00:07:42,000
of the light in the universe actually um

207
00:07:45,909 --> 00:07:43,599
what the new horizons measurement seems

208
00:07:48,550 --> 00:07:45,919
to be that hubble sees about 50

209
00:07:49,830 --> 00:07:48,560
of the light in the universe so with new

210
00:07:52,629 --> 00:07:49,840
horizons being

211
00:07:53,350 --> 00:07:52,639
outside of the main part of the solar

212
00:07:55,350 --> 00:07:53,360
system

213
00:07:56,950 --> 00:07:55,360

we're actually able to able to level the

214
00:08:00,309 --> 00:07:56,960
true black level

215
00:08:04,150 --> 00:08:02,469
our second story for you tonight is

216
00:08:07,589 --> 00:08:04,160
called the fading glory

217
00:08:10,150 --> 00:08:07,599
of the stingray nebula now this

218
00:08:10,869 --> 00:08:10,160
is the stingray nebula and it sort of

219
00:08:12,869 --> 00:08:10,879
gets this

220
00:08:14,950 --> 00:08:12,879
uh it sort of kind of looks like a

221
00:08:16,950 --> 00:08:14,960
stingray um but it has nothing to do

222
00:08:19,990 --> 00:08:16,960
with actual an actual stingray

223
00:08:21,830 --> 00:08:20,000
it is a planetary nebula which also

224
00:08:24,869 --> 00:08:21,840
actually has nothing to do with planets

225
00:08:26,950 --> 00:08:24,879
all right so planetary nebula were a

226
00:08:28,230 --> 00:08:26,960
category created by people who said hey

227
00:08:28,869 --> 00:08:28,240
they look round they look sort of like

228
00:08:30,950 --> 00:08:28,879
planets

229
00:08:32,230 --> 00:08:30,960
we'll call them a planetary nebula they

230
00:08:34,709 --> 00:08:32,240
have nothing to do with planets it's

231
00:08:37,829 --> 00:08:34,719
actually a dying star

232
00:08:41,350 --> 00:08:37,839
this star here in the center

233
00:08:43,829 --> 00:08:41,360
is a star at the end of its life and

234
00:08:45,269 --> 00:08:43,839
it's blowing off its outer layers okay

235
00:08:46,310 --> 00:08:45,279
it's gone through its hydrogen and

236
00:08:48,870 --> 00:08:46,320
helium fusion

237
00:08:49,509 --> 00:08:48,880
um and it's blowing off its outer layers

238
00:08:51,990 --> 00:08:49,519

this

239
00:08:52,870 --> 00:08:52,000
gas that you see around it is gas that

240
00:08:55,590 --> 00:08:52,880
have been

241
00:08:56,630 --> 00:08:55,600
ejected from the star during its death

242
00:08:58,150 --> 00:08:56,640
and that star

243
00:09:00,630 --> 00:08:58,160
is really really bright and really

244
00:09:03,829 --> 00:09:00,640
really hot and is illuminating

245
00:09:05,670 --> 00:09:03,839
and ionizing the gases around it but

246
00:09:08,070 --> 00:09:05,680
this is the way the stingray nebula

247
00:09:09,990 --> 00:09:08,080
looked in 1996

248
00:09:11,750 --> 00:09:10,000
and hubble has taken more than one image

249
00:09:14,790 --> 00:09:11,760
of the stingray nebula

250
00:09:19,190 --> 00:09:14,800
and by the time it got to 2016

251
00:09:26,949 --> 00:09:22,630
yeah that's interesting it went from

252
00:09:29,829 --> 00:09:26,959
really bright in in 1996 to really dim

253
00:09:31,670 --> 00:09:29,839
in 2016 much dimmer matter of fact

254
00:09:33,590 --> 00:09:31,680
here's an animated gif of it

255
00:09:35,430 --> 00:09:33,600
and you can see the stingray nebula

256
00:09:38,550 --> 00:09:35,440
slowly fading

257
00:09:41,590 --> 00:09:38,560
over 20 years what's

258
00:09:44,870 --> 00:09:41,600
going on here i mean we just don't

259
00:09:48,310 --> 00:09:44,880
see things like this fade that quickly

260
00:09:49,030 --> 00:09:48,320
all right so here's uh the 1996 on the

261
00:09:52,389 --> 00:09:49,040
left

262
00:09:54,630 --> 00:09:52,399
2016 on the right so this is

263
00:09:56,310 --> 00:09:54,640

this is really kind of an unprecedented

264
00:09:59,190 --> 00:09:56,320
change in the light admitted

265
00:10:00,470 --> 00:09:59,200
and this is hot nitrogen hydrogen and

266
00:10:02,949 --> 00:10:00,480
oxygen emission

267
00:10:04,550 --> 00:10:02,959
and these lines are ionized by that

268
00:10:07,590 --> 00:10:04,560
central star

269
00:10:10,470 --> 00:10:07,600
so in particular the oxygen emission

270
00:10:13,269 --> 00:10:10,480
has dropped by a factor of a thousand

271
00:10:16,310 --> 00:10:13,279
over the course of 20 years

272
00:10:21,910 --> 00:10:16,320
this means that the central star

273
00:10:25,590 --> 00:10:21,920
which has a phone number of sao244567

274
00:10:27,590 --> 00:10:25,600
is decreasing its ionizing output

275
00:10:30,389 --> 00:10:27,600
the gases are still there they're just

276
00:10:33,269 --> 00:10:30,399
not being ionized by that central star

277
00:10:33,910 --> 00:10:33,279
so they aren't glowing as much and the

278
00:10:36,389 --> 00:10:33,920
idea

279
00:10:38,470 --> 00:10:36,399
is that the central star was really

280
00:10:41,829 --> 00:10:38,480
bright in in 1996

281
00:10:42,150 --> 00:10:41,839
but it has expanded and when you expand

282
00:10:47,350 --> 00:10:42,160
you

283
00:10:49,509 --> 00:10:47,360
ionizing radiation

284
00:10:52,310 --> 00:10:49,519
right matter of fact observations from

285
00:10:54,230 --> 00:10:52,320
1971 to 2002

286
00:10:56,389 --> 00:10:54,240
showed that the temperature of this star

287
00:10:59,430 --> 00:10:56,399
actually increased by a factor of

288
00:11:00,310 --> 00:10:59,440

two and a half during that time so over

289
00:11:02,150 --> 00:11:00,320
30 years

290
00:11:03,350 --> 00:11:02,160
its temperature increased by a factor of

291
00:11:06,550 --> 00:11:03,360
two and a half

292
00:11:08,550 --> 00:11:06,560
and now it appears to be cooling again

293
00:11:09,670 --> 00:11:08,560
uh one of the research main researchers

294
00:11:12,710 --> 00:11:09,680
on this surmised

295
00:11:13,750 --> 00:11:12,720
that perhaps there was a brief flash of

296
00:11:18,069 --> 00:11:13,760
helium

297
00:11:20,389 --> 00:11:18,079
around the core of the star

298
00:11:21,110 --> 00:11:20,399
so the idea would be that that the star

299
00:11:23,750 --> 00:11:21,120
collapsed

300
00:11:25,430 --> 00:11:23,760
in ignited a little bit of helium helium

301
00:11:28,470 --> 00:11:25,440
fusion around the core

302
00:11:30,949 --> 00:11:28,480
that a helium fusion caused it to

303
00:11:33,190 --> 00:11:30,959
to brighten and get hot high temperature

304
00:11:36,470 --> 00:11:33,200
it made a lot of ionizing radiation

305
00:11:37,590 --> 00:11:36,480
but it also caused it to expand and then

306
00:11:40,069 --> 00:11:37,600
cool

307
00:11:42,069 --> 00:11:40,079
and the really crazy thing about this as

308
00:11:45,350 --> 00:11:42,079
this is all happened on a time scale

309
00:11:47,670 --> 00:11:45,360
of about 50 years i mean when when we

310
00:11:50,629 --> 00:11:47,680
think of astronomy we don't think of

311
00:11:52,710 --> 00:11:50,639
you know nebulae like this ex changing

312
00:11:55,670 --> 00:11:52,720
over the time scale of 50 years

313
00:11:55,990 --> 00:11:55,680

this is a very brief event and it's

314
00:11:58,150 --> 00:11:56,000
really

315
00:11:59,030 --> 00:11:58,160
cool we'll be studying it and we'll be

316
00:12:01,030 --> 00:11:59,040
watching it

317
00:12:02,550 --> 00:12:01,040
because if it continues to fade at the

318
00:12:05,190 --> 00:12:02,560
way it is matter of fact

319
00:12:06,150 --> 00:12:05,200
the stingray nebula will barely be

320
00:12:09,110 --> 00:12:06,160
detectable

321
00:12:10,230 --> 00:12:09,120
in another couple of decades so stay

322
00:12:15,829 --> 00:12:10,240
tuned to see how

323
00:12:22,550 --> 00:12:19,030
and now we go to our speaker tonight

324
00:12:23,910 --> 00:12:22,560
um our speaker tonight um is raja gujata

325
00:12:27,190 --> 00:12:23,920
kurta

326
00:12:29,990 --> 00:12:27,200
and he is the a professor

327
00:12:31,030 --> 00:12:30,000
and the department chair and astronomy

328
00:12:33,190 --> 00:12:31,040
and after physics

329
00:12:34,790 --> 00:12:33,200
at the university of california santa

330
00:12:36,629 --> 00:12:34,800
cruz

331
00:12:38,389 --> 00:12:36,639
i'm told that i'm only allowed to say

332
00:12:38,949 --> 00:12:38,399
condolences on him being department

333
00:12:42,150 --> 00:12:38,959
chair

334
00:12:42,550 --> 00:12:42,160
because that is actually quite true you

335
00:12:44,069 --> 00:12:42,560
end up

336
00:12:45,910 --> 00:12:44,079
having to do an awful lot of work as

337
00:12:48,230 --> 00:12:45,920
department chair and it interrupts the

338
00:12:50,230 --> 00:12:48,240

flow of your research and raja has been

339
00:12:53,110 --> 00:12:50,240
an amazing researcher

340
00:12:54,310 --> 00:12:53,120
ah gosh we first met in the early 90s at

341
00:12:56,230 --> 00:12:54,320
princeton

342
00:12:58,230 --> 00:12:56,240
um uh when we went there and he was

343
00:13:00,870 --> 00:12:58,240
doing some marvelous stuff there

344
00:13:01,590 --> 00:13:00,880
he's worked on all sorts of things a lot

345
00:13:03,910 --> 00:13:01,600
most of them

346
00:13:05,030 --> 00:13:03,920
are concerning galaxies uh he's worked

347
00:13:07,750 --> 00:13:05,040
on various large

348
00:13:09,990 --> 00:13:07,760
surveys he's worked on especially the

349
00:13:12,870 --> 00:13:10,000
andromeda galaxy doing surveys of

350
00:13:13,430 --> 00:13:12,880
looking deep into the andromeda galaxies

351
00:13:17,350 --> 00:13:13,440
um

352
00:13:19,190 --> 00:13:17,360
know one of the people that i always

353
00:13:19,990 --> 00:13:19,200
listen to at conferences because i know

354
00:13:21,670 --> 00:13:20,000
that when he does

355
00:13:23,990 --> 00:13:21,680
it he's going to do it right and he's

356
00:13:26,069 --> 00:13:24,000
going to explain it well

357
00:13:27,350 --> 00:13:26,079
he's received numerous awards including

358
00:13:30,790 --> 00:13:27,360
a hubble fellowship

359
00:13:34,470 --> 00:13:30,800
an alfred sloan research fellowship um

360
00:13:39,350 --> 00:13:34,480
and the beverly sackler lecturer

361
00:13:40,870 --> 00:13:39,360
award um and so raja's been you know

362
00:13:42,470 --> 00:13:40,880
somebody that i've looked to for you

363
00:13:45,189 --> 00:13:42,480

know for well it's almost

364
00:13:46,710 --> 00:13:45,199
for 30 years now uh he got i didn't

365
00:13:47,990 --> 00:13:46,720
mention where he got his degrees he got

366
00:13:50,949 --> 00:13:48,000
his bachelor's uh

367
00:13:52,389 --> 00:13:50,959
from xavier's college in kolkata in

368
00:13:54,629 --> 00:13:52,399
india

369
00:13:56,069 --> 00:13:54,639
and he got his phd at princeton

370
00:13:58,949 --> 00:13:56,079
university

371
00:13:59,750 --> 00:13:58,959
uh one thing to tell about him is that

372
00:14:03,509 --> 00:13:59,760
actually

373
00:14:05,269 --> 00:14:03,519
despite all the success um astronomy was

374
00:14:08,150 --> 00:14:05,279
his plan b

375
00:14:09,350 --> 00:14:08,160
when raja wanted to was thinking about

376
00:14:10,069 --> 00:14:09,360
what he was going to be in life he

377
00:14:12,870 --> 00:14:10,079
wanted to be an

378
00:14:14,550 --> 00:14:12,880
artist i understand he is a quite an

379
00:14:16,550 --> 00:14:14,560
accomplished painter

380
00:14:17,670 --> 00:14:16,560
and he can tell you more about that but

381
00:14:24,949 --> 00:14:17,680
ladies and gentlemen

382
00:14:28,230 --> 00:14:27,030
thank you so much frank for that kind

383
00:14:31,990 --> 00:14:28,240
introduction

384
00:14:33,990 --> 00:14:32,000
uh it's a real pleasure to be

385
00:14:36,150 --> 00:14:34,000
giving this public lecture this is going

386
00:14:38,470 --> 00:14:36,160
to be my largest

387
00:14:40,550 --> 00:14:38,480
in terms of audience largest public

388
00:14:45,269 --> 00:14:40,560

lecture it's an online lecture

389
00:14:47,990 --> 00:14:45,279
and i'm really privileged to be

390
00:14:49,829 --> 00:14:48,000
a speaker in this series the space

391
00:14:50,230 --> 00:14:49,839
telescope science institute feels like

392
00:14:52,550 --> 00:14:50,240
home

393
00:14:54,310 --> 00:14:52,560
i was an employee of the space telescope

394
00:14:58,470 --> 00:14:54,320
science institute

395
00:15:01,750 --> 00:14:58,480
it was 20 27 years ago

396
00:15:03,590 --> 00:15:01,760
and um also i was happy to see that the

397
00:15:05,030 --> 00:15:03,600
following speakers in the series laura

398
00:15:06,710 --> 00:15:05,040
pritchard was my

399
00:15:08,150 --> 00:15:06,720
student when she was an undergraduate

400
00:15:09,269 --> 00:15:08,160
and a master's student she did her

401
00:15:10,870 --> 00:15:09,279
research with me

402
00:15:12,310 --> 00:15:10,880
and tom brown has been a longtime

403
00:15:14,949 --> 00:15:12,320
collaborator

404
00:15:15,750 --> 00:15:14,959
so i'm going to speak about the darkest

405
00:15:19,189 --> 00:15:15,760
secrets

406
00:15:20,710 --> 00:15:19,199
of the universe i in addition to being

407
00:15:23,910 --> 00:15:20,720
at santa cruz for

408
00:15:26,310 --> 00:15:23,920
now coming up on uh 27 years

409
00:15:28,470 --> 00:15:26,320
i was five years ago i was visiting

410
00:15:29,990 --> 00:15:28,480
faculty at google's headquarters in

411
00:15:32,949 --> 00:15:30,000
mountain view where they've

412
00:15:34,550 --> 00:15:32,959
really helped me with my educational

413
00:15:37,350 --> 00:15:34,560

projects you know bringing

414
00:15:38,629 --> 00:15:37,360
stem research to high school students i

415
00:15:40,230 --> 00:15:38,639
won't say much about that

416
00:15:41,749 --> 00:15:40,240
in my talk but if you're interested

417
00:15:45,269 --> 00:15:41,759
please ask questions

418
00:15:48,870 --> 00:15:45,279
all right so i'm going to

419
00:15:51,990 --> 00:15:48,880
plunge right in and focus on certain

420
00:15:53,910 --> 00:15:52,000
aspects of the of the universe

421
00:15:55,670 --> 00:15:53,920
certain dark secrets there are many dark

422
00:15:59,829 --> 00:15:55,680
secrets i'll focus on

423
00:16:02,550 --> 00:15:59,839
a few of them in particular i want to

424
00:16:05,509 --> 00:16:02,560
talk about galaxies because they are

425
00:16:08,069 --> 00:16:05,519
basic building blocks of the cosmos

426
00:16:09,189 --> 00:16:08,079
in the same way that atoms are basic

427
00:16:13,189 --> 00:16:09,199
building blocks

428
00:16:17,430 --> 00:16:16,629
what atoms are to matter galaxies are to

429
00:16:20,629 --> 00:16:17,440
the universe

430
00:16:22,389 --> 00:16:20,639
and here's what i mean by this atoms are

431
00:16:23,269 --> 00:16:22,399
not the smallest building blocks of

432
00:16:26,069 --> 00:16:23,279
matter

433
00:16:27,030 --> 00:16:26,079
clearly atoms can be broken up into

434
00:16:31,110 --> 00:16:27,040
smaller

435
00:16:33,350 --> 00:16:31,120
into

436
00:16:36,790 --> 00:16:33,360
protons neutrons electrons protons and

437
00:16:38,470 --> 00:16:36,800
neutrons can be broken up further

438
00:16:39,990 --> 00:16:38,480

and you know of course you can have

439
00:16:41,430 --> 00:16:40,000
larger building blocks than atoms you

440
00:16:43,030 --> 00:16:41,440
can have molecules which is something

441
00:16:44,710 --> 00:16:43,040
we'll talk about in a minute you can

442
00:16:45,749 --> 00:16:44,720
have you know brick and mortar you can

443
00:16:48,389 --> 00:16:45,759
have

444
00:16:49,590 --> 00:16:48,399
concrete bars that you know metal rods

445
00:16:52,230 --> 00:16:49,600
that make up buildings

446
00:16:54,629 --> 00:16:52,240
in the same way galaxies are not the

447
00:16:56,310 --> 00:16:54,639
smallest nor the

448
00:16:57,829 --> 00:16:56,320
largest building blocks of the cosmos

449
00:16:59,030 --> 00:16:57,839
you know clearly stars and planets are

450
00:17:01,509 --> 00:16:59,040
smaller building blocks

451
00:17:03,189 --> 00:17:01,519
and clusters of galaxies and super

452
00:17:06,150 --> 00:17:03,199
clusters are bigger structures

453
00:17:07,510 --> 00:17:06,160
however atoms are super important to

454
00:17:10,630 --> 00:17:07,520
matter because

455
00:17:12,150 --> 00:17:10,640
our understanding of atoms led to some

456
00:17:15,110 --> 00:17:12,160
of the biggest revolutions

457
00:17:17,590 --> 00:17:15,120
in physics understanding the you know

458
00:17:20,710 --> 00:17:17,600
understanding sort of the

459
00:17:22,870 --> 00:17:20,720
very fabric of matter itself

460
00:17:24,309 --> 00:17:22,880
made huge progress human beings made

461
00:17:25,510 --> 00:17:24,319
huge progress in our understanding of

462
00:17:28,150 --> 00:17:25,520
matter itself

463
00:17:30,150 --> 00:17:28,160

when we understood the nature of atoms

464
00:17:31,750 --> 00:17:30,160
this was the birth of quantum mechanics

465
00:17:33,350 --> 00:17:31,760
in the same way i will argue that

466
00:17:34,549 --> 00:17:33,360
galaxies are really important even

467
00:17:35,510 --> 00:17:34,559
though they are not the biggest nor

468
00:17:37,510 --> 00:17:35,520
smallest

469
00:17:39,190 --> 00:17:37,520
they're the most important because if it

470
00:17:42,549 --> 00:17:39,200
weren't for the fact that

471
00:17:45,990 --> 00:17:42,559
you and i and frank and thomas

472
00:17:49,590 --> 00:17:46,000
and grant the fact that we are live in

473
00:17:51,190 --> 00:17:49,600
a galaxy makes us who we are

474
00:17:53,270 --> 00:17:51,200
the fact that we live not just in a

475
00:17:56,230 --> 00:17:53,280
galaxy we live in a large

476
00:17:57,190 --> 00:17:56,240
dark matter dominated galaxy is really

477
00:17:59,510 --> 00:17:57,200
what

478
00:18:00,710 --> 00:17:59,520
makes complex life here on earth

479
00:18:02,310 --> 00:18:00,720
possible

480
00:18:05,430 --> 00:18:02,320
let me illustrate this with my next

481
00:18:05,830 --> 00:18:05,440
slide i like to open with a picture of

482
00:18:08,310 --> 00:18:05,840
my

483
00:18:10,390 --> 00:18:08,320
son lounging on the carpet you know

484
00:18:13,590 --> 00:18:10,400
there he is

485
00:18:16,390 --> 00:18:13,600
i didn't promise he'd be human

486
00:18:17,669 --> 00:18:16,400
so there's an example of canine life and

487
00:18:19,990 --> 00:18:17,679
let me show you two other

488
00:18:21,750 --> 00:18:20,000

examples of life there's a particular

489
00:18:23,669 --> 00:18:21,760
form of life that's been

490
00:18:25,190 --> 00:18:23,679
really capturing our attention more than

491
00:18:27,430 --> 00:18:25,200
just our attention of late

492
00:18:29,270 --> 00:18:27,440
and that's the coronavirus and there's a

493
00:18:31,350 --> 00:18:29,280
picture of a human being

494
00:18:33,350 --> 00:18:31,360
so three forms of life right there in

495
00:18:34,310 --> 00:18:33,360
one picture you have two in the inset

496
00:18:36,870 --> 00:18:34,320
one in the main

497
00:18:39,510 --> 00:18:36,880
picture and the story i'm about to tell

498
00:18:42,549 --> 00:18:39,520
you applies to all forms of life

499
00:18:45,909 --> 00:18:42,559
mammals viruses

500
00:18:49,110 --> 00:18:45,919
and everything in between

501
00:18:52,950 --> 00:18:49,120
the complexity richness

502
00:18:57,669 --> 00:18:52,960
and diversity of form and function

503
00:19:00,789 --> 00:18:57,679
of life on earth as we know it

504
00:19:04,230 --> 00:19:00,799
is directly

505
00:19:06,630 --> 00:19:04,240
caused by the fact that

506
00:19:08,549 --> 00:19:06,640
life is made up of complex molecules

507
00:19:11,990 --> 00:19:08,559
living things are made up of complex

508
00:19:13,270 --> 00:19:12,000
molecules if the molecules you had to

509
00:19:15,830 --> 00:19:13,280
build life were simple

510
00:19:18,230 --> 00:19:15,840
like carbon dioxide or water you would

511
00:19:19,350 --> 00:19:18,240
not get this range of diversity richness

512
00:19:21,430 --> 00:19:19,360
or complexity

513
00:19:23,430 --> 00:19:21,440

so here's an example a graphical

514
00:19:24,230 --> 00:19:23,440
representation of a complex molecule

515
00:19:26,150 --> 00:19:24,240
this is

516
00:19:28,029 --> 00:19:26,160
representation of a protein molecule but

517
00:19:30,549 --> 00:19:28,039
of course

518
00:19:32,150 --> 00:19:30,559
deoxyribonucleic acid dna is a very

519
00:19:34,230 --> 00:19:32,160
important complex molecule

520
00:19:35,270 --> 00:19:34,240
for the structure of basic structure of

521
00:19:37,350 --> 00:19:35,280
life and

522
00:19:39,190 --> 00:19:37,360
in this representation every colored

523
00:19:41,270 --> 00:19:39,200
sphere represents a different kind of

524
00:19:42,870 --> 00:19:41,280
atom in the periodic table

525
00:19:46,630 --> 00:19:42,880
so you know you might have carbon

526
00:19:49,430 --> 00:19:46,640
nitrogen oxygen hydrogen helium

527
00:19:50,310 --> 00:19:49,440
these are of course important elements

528
00:19:52,870 --> 00:19:50,320
in these

529
00:19:54,870 --> 00:19:52,880
organic molecules and you know why is it

530
00:19:56,710 --> 00:19:54,880
that it's carbon nitrogen oxygen why not

531
00:19:58,950 --> 00:19:56,720
hydrogen hydrogen is a very common

532
00:20:01,350 --> 00:19:58,960
element why why isn't it so important

533
00:20:03,350 --> 00:20:01,360
hydrogen is important but not nearly as

534
00:20:06,470 --> 00:20:03,360
important as these more complex

535
00:20:08,390 --> 00:20:06,480
heavy atoms it's really cn and o that

536
00:20:09,590 --> 00:20:08,400
are really important carbon nitrogen and

537
00:20:11,510 --> 00:20:09,600
oxygen these are

538
00:20:12,950 --> 00:20:11,520

elements that are present in abundance

539
00:20:15,270 --> 00:20:12,960
here on earth

540
00:20:16,149 --> 00:20:15,280
why am i talking about cn and oh why not

541
00:20:19,669 --> 00:20:16,159
hydrogen

542
00:20:23,270 --> 00:20:19,679
form

543
00:20:25,110 --> 00:20:23,280
one chemical bond so it can be at the

544
00:20:25,990 --> 00:20:25,120
periphery of these large molecules but

545
00:20:30,630 --> 00:20:26,000
it can't be a

546
00:20:33,990 --> 00:20:30,640
these complex molecules

547
00:20:36,870 --> 00:20:34,000
so it's like a one armed atom that

548
00:20:37,430 --> 00:20:36,880
can form hold one hand of the hand of

549
00:20:41,110 --> 00:20:37,440
another

550
00:20:43,750 --> 00:20:41,120
atom helium is a two electron

551
00:20:45,270 --> 00:20:43,760
atom it can it has two hands but it

552
00:20:45,750 --> 00:20:45,280
doesn't like to hold hands with anyone

553
00:20:48,789 --> 00:20:45,760
it's an

554
00:20:49,430 --> 00:20:48,799
inert atom so really lithium beryllium

555
00:20:52,070 --> 00:20:49,440
boron

556
00:20:52,470 --> 00:20:52,080
carbon carbon has six electrons nitrogen

557
00:20:55,029 --> 00:20:52,480
seven

558
00:20:55,669 --> 00:20:55,039
oxygen eight these elements are

559
00:20:57,510 --> 00:20:55,679
important

560
00:20:59,510 --> 00:20:57,520
if we want to understand the origin of

561
00:21:00,710 --> 00:20:59,520
life origin of complex life

562
00:21:02,789 --> 00:21:00,720
and of course these elements are very

563
00:21:04,870 --> 00:21:02,799

common here on earth you know those of

564
00:21:07,669 --> 00:21:04,880
us who are listening to this talk

565
00:21:09,590 --> 00:21:07,679
uh live and indeed those who are going

566
00:21:11,909 --> 00:21:09,600
to listen to this asynchronously

567
00:21:13,590 --> 00:21:11,919
are all breathing in or breathing out

568
00:21:15,350 --> 00:21:13,600
these elements right there's nitrogen

569
00:21:17,029 --> 00:21:15,360
and oxygen in the air we breathe

570
00:21:18,630 --> 00:21:17,039
there's carbon dioxide in the air we

571
00:21:20,789 --> 00:21:18,640
breathe out you know you know

572
00:21:22,390 --> 00:21:20,799
if you went to a barbecue recently you

573
00:21:23,750 --> 00:21:22,400
know you enjoyed the benefits of carbon

574
00:21:25,190 --> 00:21:23,760
if you're wearing a diamond ring

575
00:21:27,110 --> 00:21:25,200
uh you know good for you you're enjoying

576
00:21:29,669 --> 00:21:27,120
the benefits of carbon you know

577
00:21:31,830 --> 00:21:29,679
water in the oceans contain oxygen these

578
00:21:35,350 --> 00:21:31,840
elements are common here on earth

579
00:21:36,470 --> 00:21:35,360
now they're also common in the sun the

580
00:21:38,390 --> 00:21:36,480
sun contains

581
00:21:39,669 --> 00:21:38,400
all of these elements and more in fact

582
00:21:41,430 --> 00:21:39,679
pretty much every element in the

583
00:21:42,230 --> 00:21:41,440
periodic table that's been discovered

584
00:21:45,110 --> 00:21:42,240
here on earth

585
00:21:46,789 --> 00:21:45,120
it's also present in the sun and uh so

586
00:21:49,029 --> 00:21:46,799
it's natural to ask the question

587
00:21:50,149 --> 00:21:49,039
whether the sun's nuclear fusion

588
00:21:52,149 --> 00:21:50,159

reactions

589
00:21:53,909 --> 00:21:52,159
converting hydrogen to helium whether

590
00:21:56,950 --> 00:21:53,919
that fusion reaction

591
00:21:57,669 --> 00:21:56,960
went further and created elements that

592
00:22:00,549 --> 00:21:57,679
we see

593
00:22:01,830 --> 00:22:00,559
and know about in the periodic table so

594
00:22:04,149 --> 00:22:01,840
did the sun

595
00:22:06,149 --> 00:22:04,159
produce these large complex atoms

596
00:22:08,950 --> 00:22:06,159
through nuclear fusion reactions

597
00:22:09,669 --> 00:22:08,960
in its core the simple answer to this

598
00:22:13,350 --> 00:22:09,679
question

599
00:22:15,110 --> 00:22:13,360
is no and this may not come as a

600
00:22:17,669 --> 00:22:15,120
surprise to many of you

601
00:22:19,190 --> 00:22:17,679
but the elements present on earth the

602
00:22:22,789 --> 00:22:19,200
elements

603
00:22:24,950 --> 00:22:22,799
present in the sun were inherited by

604
00:22:25,750 --> 00:22:24,960
these two entities they were inherited

605
00:22:28,390 --> 00:22:25,760
from

606
00:22:29,029 --> 00:22:28,400
the large cloud of gas and dust that the

607
00:22:31,510 --> 00:22:29,039
sun

608
00:22:32,710 --> 00:22:31,520
the earth and the rest of the planets

609
00:22:36,789 --> 00:22:32,720
formed out of

610
00:22:38,310 --> 00:22:36,799
in other words our inheritance consisted

611
00:22:40,149 --> 00:22:38,320
of these wonderful elements in the

612
00:22:42,149 --> 00:22:40,159
periodic table these life-bearing

613
00:22:45,430 --> 00:22:42,159

elements in the periodic table

614
00:22:48,549 --> 00:22:45,440
so of course as a scientist we can't be

615
00:22:50,710 --> 00:22:48,559
we can't stop our search

616
00:22:52,230 --> 00:22:50,720
just at the word inheritance we want to

617
00:22:56,630 --> 00:22:52,240
understand

618
00:22:59,350 --> 00:22:56,640
how or why our ancestors

619
00:23:01,110 --> 00:22:59,360
gave these resources to us the resources

620
00:23:03,990 --> 00:23:01,120
of these wonderful elements

621
00:23:05,350 --> 00:23:04,000
how did they come to be on the earth

622
00:23:05,990 --> 00:23:05,360
well how do they come to be in the

623
00:23:07,750 --> 00:23:06,000
nebula

624
00:23:09,750 --> 00:23:07,760
out of which the sun and earth were

625
00:23:12,070 --> 00:23:09,760
formed well

626
00:23:13,110 --> 00:23:12,080
they came to me in the nebula because of

627
00:23:16,549 --> 00:23:13,120
the sun's

628
00:23:17,510 --> 00:23:16,559
ancestral stars stars that lived and

629
00:23:19,830 --> 00:23:17,520
died

630
00:23:21,590 --> 00:23:19,840
before the sun was even born before the

631
00:23:22,390 --> 00:23:21,600
sun and planets of the solar system were

632
00:23:23,830 --> 00:23:22,400
even born

633
00:23:26,710 --> 00:23:23,840
there were stars like the one in this

634
00:23:30,390 --> 00:23:26,720
picture that

635
00:23:33,350 --> 00:23:30,400
lived and died and produced the elements

636
00:23:35,110 --> 00:23:33,360
that we are you and i are made of now

637
00:23:37,830 --> 00:23:35,120
there are many stars in this picture

638
00:23:38,950 --> 00:23:37,840

and the colors of this particular field

639
00:23:40,149 --> 00:23:38,960
of stars

640
00:23:41,990 --> 00:23:40,159
the colors of the stars in this

641
00:23:43,350 --> 00:23:42,000
particular field reflect something about

642
00:23:45,110 --> 00:23:43,360
their temperature

643
00:23:46,470 --> 00:23:45,120
if you can see my cursor you'll see this

644
00:23:50,470 --> 00:23:46,480
very red star

645
00:23:52,549 --> 00:23:50,480
in the lower left in contrast to a very

646
00:23:53,990 --> 00:23:52,559
blue or bluish white star this one up

647
00:23:56,950 --> 00:23:54,000
here or this one up here

648
00:23:57,590 --> 00:23:56,960
the red stars are much cooler than the

649
00:23:59,590 --> 00:23:57,600
sun

650
00:24:01,350 --> 00:23:59,600
cooler only in a temperature sense the

651
00:24:02,390 --> 00:24:01,360
sun after all is the coolest star in the

652
00:24:04,789 --> 00:24:02,400
whole universe

653
00:24:05,510 --> 00:24:04,799
but these are lower temperature stars i

654
00:24:07,909 --> 00:24:05,520
should say the

655
00:24:08,950 --> 00:24:07,919
red stars and the bluish white stars are

656
00:24:11,350 --> 00:24:08,960
much hotter

657
00:24:12,710 --> 00:24:11,360
stars much higher temperature tens of

658
00:24:16,149 --> 00:24:12,720
thousands of kelvin

659
00:24:19,510 --> 00:24:16,159
on the surface it's these hot stars

660
00:24:21,350 --> 00:24:19,520
that are vigorously

661
00:24:22,549 --> 00:24:21,360
undergoing nuclear fusion reaction in

662
00:24:24,549 --> 00:24:22,559
their centers

663
00:24:25,750 --> 00:24:24,559

much more vigorously than the sun much

664
00:24:27,990 --> 00:24:25,760
more rapidly

665
00:24:29,110 --> 00:24:28,000
so that's one kind of way in which

666
00:24:30,470 --> 00:24:29,120
they're different from the sun

667
00:24:32,870 --> 00:24:30,480
much more vigorous than their nuclear

668
00:24:33,750 --> 00:24:32,880
fusion reaction that vigor translates to

669
00:24:35,909 --> 00:24:33,760
two things

670
00:24:38,870 --> 00:24:35,919
they're able to go through the fusion

671
00:24:40,390 --> 00:24:38,880
reactions much more rapidly than the sun

672
00:24:42,230 --> 00:24:40,400
the sun is going to take 10 billion

673
00:24:44,470 --> 00:24:42,240
years before it produces carbon nitrogen

674
00:24:46,310 --> 00:24:44,480
oxygen it hasn't produced any yet

675
00:24:47,590 --> 00:24:46,320
these stars in less than a million years

676
00:24:48,950 --> 00:24:47,600
the most massive of them

677
00:24:50,950 --> 00:24:48,960
in a million or less than a million

678
00:24:51,590 --> 00:24:50,960
years they can go through and produce

679
00:24:54,310 --> 00:24:51,600
the first

680
00:24:56,789 --> 00:24:54,320
26 elements in the periodic table of

681
00:25:00,149 --> 00:24:56,799
elements the 26th element being iron

682
00:25:04,149 --> 00:25:00,159
fe it can produce those elements

683
00:25:07,669 --> 00:25:04,159
the remarkable thing about these massive

684
00:25:10,950 --> 00:25:07,679
white bluish white massive stars

685
00:25:12,390 --> 00:25:10,960
is they end their lives in spectacular

686
00:25:16,950 --> 00:25:12,400
explosions

687
00:25:17,430 --> 00:25:16,960
of the periodic table are produced

688
00:25:20,230 --> 00:25:17,440

through

689
00:25:21,750 --> 00:25:20,240
neutron bombardment but the wonderful

690
00:25:24,070 --> 00:25:21,760
thing about these explosions

691
00:25:25,830 --> 00:25:24,080
is the elements that were cooked inside

692
00:25:28,070 --> 00:25:25,840
of star through nuclear fusion reactions

693
00:25:29,909 --> 00:25:28,080
are now released to the surroundings so

694
00:25:30,870 --> 00:25:29,919
that the next generation of the stars

695
00:25:33,269 --> 00:25:30,880
can benefit

696
00:25:35,029 --> 00:25:33,279
from what was cooked inside a previous

697
00:25:36,630 --> 00:25:35,039
generation

698
00:25:38,070 --> 00:25:36,640
the story is a little more complicated

699
00:25:40,390 --> 00:25:38,080
than this because

700
00:25:42,149 --> 00:25:40,400
you know you can imagine that yes we

701
00:25:43,830 --> 00:25:42,159
needed to be part of a family of stars

702
00:25:44,230 --> 00:25:43,840
there needed to be other stars exploding

703
00:25:46,470 --> 00:25:44,240
around

704
00:25:47,510 --> 00:25:46,480
us for us to be born out of their ashes

705
00:25:50,950 --> 00:25:47,520
we needed to be

706
00:25:53,269 --> 00:25:50,960
made of stardust but the story is a

707
00:25:54,789 --> 00:25:53,279
little more complicated right so

708
00:25:56,950 --> 00:25:54,799
we needed to be part of a family of

709
00:25:57,669 --> 00:25:56,960
stars family of stars is what we call a

710
00:25:59,830 --> 00:25:57,679
galaxy

711
00:26:01,590 --> 00:25:59,840
but we really need it to be part of a

712
00:26:03,750 --> 00:26:01,600
large galaxy like this one

713
00:26:05,029 --> 00:26:03,760

right this is not our own galaxy this is

714
00:26:06,789 --> 00:26:05,039
a neighbor galaxy

715
00:26:08,630 --> 00:26:06,799
but our milky way galaxy is a large

716
00:26:09,510 --> 00:26:08,640
galaxy just like the galaxy in this

717
00:26:11,590 --> 00:26:09,520
picture

718
00:26:13,190 --> 00:26:11,600
you know and i say large i don't just

719
00:26:15,430 --> 00:26:13,200
mean large in size

720
00:26:17,430 --> 00:26:15,440
i mean it needed to be part of a massive

721
00:26:18,149 --> 00:26:17,440
galaxy a galaxy that contains a lot of

722
00:26:22,390 --> 00:26:18,159
mass

723
00:26:24,230 --> 00:26:22,400
matter the reason why we needed to be

724
00:26:26,549 --> 00:26:24,240
part of a massive galaxy

725
00:26:27,830 --> 00:26:26,559
is because these explosions are so

726
00:26:31,750 --> 00:26:27,840
energetic

727
00:26:34,870 --> 00:26:31,760
that without the gravitational anchor

728
00:26:37,510 --> 00:26:34,880
of a massive host galaxy

729
00:26:39,269 --> 00:26:37,520
the material would have blown right out

730
00:26:41,830 --> 00:26:39,279
of the milky way

731
00:26:42,710 --> 00:26:41,840
and not benefited the next generation of

732
00:26:44,710 --> 00:26:42,720
stars

733
00:26:46,310 --> 00:26:44,720
so we'd be made of the stuff that's

734
00:26:49,110 --> 00:26:46,320
already in our galaxy

735
00:26:51,430 --> 00:26:49,120
not the blown out material enriched

736
00:26:53,029 --> 00:26:51,440
material from previous generations so

737
00:26:55,269 --> 00:26:53,039
the fact that we are stardust in the

738
00:26:56,870 --> 00:26:55,279

world of crosby stills nation young we

739
00:27:00,710 --> 00:26:56,880
are stardust we are golden right

740
00:27:02,230 --> 00:27:00,720
we are that because not just because we

741
00:27:03,990 --> 00:27:02,240
are part of a family of stars but

742
00:27:05,510 --> 00:27:04,000
because we are part of a family of stars

743
00:27:09,669 --> 00:27:05,520
that has so much dark matter

744
00:27:12,310 --> 00:27:09,679
that say that it's able to hold in the

745
00:27:13,909 --> 00:27:12,320
explosion of massive stars now the young

746
00:27:15,029 --> 00:27:13,919
people among you are wondering who

747
00:27:17,430 --> 00:27:15,039
crosby stills

748
00:27:18,230 --> 00:27:17,440
nash and young are they are not a law

749
00:27:19,990 --> 00:27:18,240
firm

750
00:27:21,350 --> 00:27:20,000
they're a rock group they performed at

751
00:27:23,510 --> 00:27:21,360
woodstock and

752
00:27:25,110 --> 00:27:23,520
neil young's girlfriend at the time joni

753
00:27:28,470 --> 00:27:25,120
mitchell

754
00:27:30,310 --> 00:27:28,480
wrote the lyrics to this song now

755
00:27:31,510 --> 00:27:30,320
i said this is a picture of a massive

756
00:27:35,350 --> 00:27:31,520
galaxy

757
00:27:37,190 --> 00:27:35,360
we don't have

758
00:27:39,110 --> 00:27:37,200
a long enough selfie stick to take a

759
00:27:40,950 --> 00:27:39,120
picture of the milky way like this

760
00:27:43,110 --> 00:27:40,960
so what we have to do instead is we have

761
00:27:46,230 --> 00:27:43,120
to look out of our window

762
00:27:48,470 --> 00:27:46,240
and see a neighbor's

763
00:27:50,630 --> 00:27:48,480

house we can't see our own house because

764
00:27:53,350 --> 00:27:50,640
we've been stuck inside it forever

765
00:27:55,029 --> 00:27:53,360
if this were the milky way we don't live

766
00:27:58,070 --> 00:27:55,039
in downtown milky way

767
00:27:58,630 --> 00:27:58,080
we don't live in rural milky way we sort

768
00:28:01,110 --> 00:27:58,640
of live

769
00:28:03,269 --> 00:28:01,120
in suburbia had this been an image of

770
00:28:07,190 --> 00:28:03,279
the milky way we would be about there

771
00:28:08,870 --> 00:28:07,200
we live about 25 000

772
00:28:10,549 --> 00:28:08,880
light years from the center of the milky

773
00:28:12,789 --> 00:28:10,559
way this whole picture

774
00:28:15,110 --> 00:28:12,799
is about a hundred thousand light years

775
00:28:18,230 --> 00:28:15,120
across

776
00:28:18,789 --> 00:28:18,240
you know 25 000 years of light travel

777
00:28:21,269 --> 00:28:18,799
time

778
00:28:23,190 --> 00:28:21,279
from the center of the milky way to our

779
00:28:25,110 --> 00:28:23,200
solar system's location

780
00:28:26,630 --> 00:28:25,120
you know if if this were the milky way

781
00:28:28,389 --> 00:28:26,640
and i tried to show you a picture of the

782
00:28:29,110 --> 00:28:28,399
solar system it would be smaller than a

783
00:28:31,029 --> 00:28:29,120
pixel

784
00:28:32,870 --> 00:28:31,039
our solar system would be so small just

785
00:28:35,909 --> 00:28:32,880
to give you a sense of scale

786
00:28:39,350 --> 00:28:35,919
light travels across our solar system

787
00:28:41,750 --> 00:28:39,360
in about a day it travels from the sun

788
00:28:44,549 --> 00:28:41,760

to the earth in about eight minutes

789
00:28:45,510 --> 00:28:44,559
from the moon to the earth in about a

790
00:28:47,430 --> 00:28:45,520
second

791
00:28:49,110 --> 00:28:47,440
light travels around the world seven

792
00:28:51,590 --> 00:28:49,120
times in one second

793
00:28:54,470 --> 00:28:51,600
traveling at that speed light takes a

794
00:28:56,950 --> 00:28:54,480
hundred thousand years to get across

795
00:28:58,870 --> 00:28:56,960
this section of the andromeda galaxy the

796
00:29:01,190 --> 00:28:58,880
section that's shown in this picture

797
00:29:03,029 --> 00:29:01,200
i say this section because i'll tell you

798
00:29:04,870 --> 00:29:03,039
in a minute how the andromeda galaxy is

799
00:29:07,110 --> 00:29:04,880
much bigger than this rectangle than

800
00:29:09,430 --> 00:29:07,120
this red rectangle can hold

801
00:29:11,430 --> 00:29:09,440
now this is of course not our home

802
00:29:13,590 --> 00:29:11,440
galaxy it's the andromeda galaxy we have

803
00:29:15,110 --> 00:29:13,600
a very strange view of our own galaxy

804
00:29:17,269 --> 00:29:15,120
it's like trying to look at your own

805
00:29:19,669 --> 00:29:17,279
face without a mirror you can squint you

806
00:29:22,389 --> 00:29:19,679
can see a part of your nose perhaps

807
00:29:23,830 --> 00:29:22,399
you can see your own spectacles you know

808
00:29:25,350 --> 00:29:23,840
you might see your

809
00:29:27,110 --> 00:29:25,360
you know bit of mustache if you have a

810
00:29:28,710 --> 00:29:27,120
lot of you know a lot of that

811
00:29:31,029 --> 00:29:28,720
but you really have to squint to see

812
00:29:34,149 --> 00:29:31,039
your own face in the same way

813
00:29:37,430 --> 00:29:34,159

we have a very strange view of our own

814
00:29:39,750 --> 00:29:37,440
galaxy our milky way galaxy

815
00:29:41,830 --> 00:29:39,760
looks like this from our perspective you

816
00:29:44,870 --> 00:29:41,840
know this band of light across the

817
00:29:46,870 --> 00:29:44,880
bottom band of light and gas and dust

818
00:29:48,710 --> 00:29:46,880
this was imaged by one of my friends

819
00:29:49,830 --> 00:29:48,720
john rockman at castle air school in

820
00:29:52,310 --> 00:29:49,840
palo alto

821
00:29:54,149 --> 00:29:52,320
and he took not one image but a series

822
00:29:55,029 --> 00:29:54,159
of wide-angle images i'm going to remove

823
00:29:59,190 --> 00:29:55,039
the label

824
00:30:02,070 --> 00:29:59,200
and play this time lapse for you as

825
00:30:03,990 --> 00:30:02,080
the sun sets the sky gets darker as the

826
00:30:07,510 --> 00:30:04,000
earth's rotation

827
00:30:10,470 --> 00:30:07,520
takes place the milky way appears

828
00:30:11,110 --> 00:30:10,480
to sweep across the sky you see

829
00:30:15,190 --> 00:30:11,120
lightning

830
00:30:17,590 --> 00:30:15,200
shooting stars clouds the fluttering of

831
00:30:19,430 --> 00:30:17,600
tree leaves of the tree and the breeze

832
00:30:21,029 --> 00:30:19,440
i'll play this one more time for you

833
00:30:23,350 --> 00:30:21,039
at the beginning of this movie the sky

834
00:30:25,350 --> 00:30:23,360
is still getting dark after sunset

835
00:30:27,510 --> 00:30:25,360
but slowly the sky gets darker and we

836
00:30:30,070 --> 00:30:27,520
see our grand home the milky way

837
00:30:30,870 --> 00:30:30,080
frisbee shaped milky way that's viewed

838
00:30:33,750 --> 00:30:30,880

from our

839
00:30:35,269 --> 00:30:33,760
perspective within that frisbee we are

840
00:30:37,430 --> 00:30:35,279
in the plane of the milky way which is

841
00:30:40,149 --> 00:30:37,440
why it looks like a band of light

842
00:30:41,590 --> 00:30:40,159
a line of light across the sky in fact

843
00:30:44,789 --> 00:30:41,600
the word milky

844
00:30:47,110 --> 00:30:44,799
way via lactair uh

845
00:30:48,870 --> 00:30:47,120
comes from the appearance of our milky

846
00:30:49,510 --> 00:30:48,880
way you know the band of light across

847
00:30:51,029 --> 00:30:49,520
the sky

848
00:30:53,830 --> 00:30:51,039
but i just wanted to point out that the

849
00:30:55,350 --> 00:30:53,840
word galaxy the word galaxy is related

850
00:30:58,389 --> 00:30:55,360
to the greek word for milk

851
00:31:00,870 --> 00:30:58,399
galacto lacto so we've named

852
00:31:02,710 --> 00:31:00,880
our every galaxy after the appearance of

853
00:31:05,590 --> 00:31:02,720
our own after the milky appearance

854
00:31:07,350 --> 00:31:05,600
of our own you know there we go so

855
00:31:09,909 --> 00:31:07,360
that's our milky way

856
00:31:10,630 --> 00:31:09,919
now you know for a long time you know

857
00:31:13,350 --> 00:31:10,640
going back

858
00:31:15,350 --> 00:31:13,360
hundreds of years people speculated

859
00:31:16,950 --> 00:31:15,360
about the nature of these things we now

860
00:31:18,950 --> 00:31:16,960
call galaxies

861
00:31:20,070 --> 00:31:18,960
this goes back to a very famous

862
00:31:24,230 --> 00:31:20,080
philosopher

863
00:31:28,470 --> 00:31:24,240

emmanuel kant who coined the term

864
00:31:29,750 --> 00:31:28,480
island universe in 1755. we're talking

865
00:31:33,110 --> 00:31:29,760
about

866
00:31:35,029 --> 00:31:33,120
you know a quarter of a millennium ago

867
00:31:37,990 --> 00:31:35,039
250 years ago

868
00:31:39,269 --> 00:31:38,000
um kant posted this selfie at some point

869
00:31:42,149 --> 00:31:39,279
around that time

870
00:31:43,350 --> 00:31:42,159
and this is a quote from him you know

871
00:31:47,029 --> 00:31:43,360
about

872
00:31:50,310 --> 00:31:47,039
how he pondered the nature of

873
00:31:53,590 --> 00:31:50,320
these islands of light

874
00:31:59,190 --> 00:31:56,549
kant lived in a very small town in what

875
00:32:01,909 --> 00:31:59,200
was then prussia

876
00:32:03,830 --> 00:32:01,919
koenigsberg i forget the new name for it

877
00:32:05,029 --> 00:32:03,840
it's in russia now i forget the new name

878
00:32:07,430 --> 00:32:05,039
of koenigsberg i've

879
00:32:08,950 --> 00:32:07,440
i've looked it up before i was once

880
00:32:10,389 --> 00:32:08,960
giving a talk and there was a person in

881
00:32:12,230 --> 00:32:10,399
the audience who was from that town

882
00:32:14,630 --> 00:32:12,240
that's the only other person i've

883
00:32:16,710 --> 00:32:14,640
come across from koenigsberg prussia

884
00:32:19,669 --> 00:32:16,720
what was called koenigsberg pressure

885
00:32:21,269 --> 00:32:19,679
now kant of course deflected this

886
00:32:23,669 --> 00:32:21,279
wonderful term

887
00:32:25,750 --> 00:32:23,679
um when he was given credit for uh the

888
00:32:27,509 --> 00:32:25,760

term island universe he said no no this

889
00:32:28,630 --> 00:32:27,519
term came from other people it came from

890
00:32:30,870 --> 00:32:28,640
people before me

891
00:32:31,909 --> 00:32:30,880
he credited this to thomas wright and

892
00:32:34,710 --> 00:32:31,919
william herschel

893
00:32:35,190 --> 00:32:34,720
but most people credit can't with the

894
00:32:38,470 --> 00:32:35,200
term

895
00:32:41,509 --> 00:32:38,480
island universe so this was really

896
00:32:41,750 --> 00:32:41,519
a philosopher's view of how the universe

897
00:32:46,470 --> 00:32:41,760
is

898
00:32:49,750 --> 00:32:46,480
important

899
00:32:51,029 --> 00:32:49,760
um sort of discussion about the nature

900
00:32:53,269 --> 00:32:51,039
of the universe and

901
00:32:56,870 --> 00:32:53,279
kant is a you know i would argue one of

902
00:32:58,789 --> 00:32:56,880
the most famous philosophers of all time

903
00:33:01,190 --> 00:32:58,799
certainly the most famous philosopher to

904
00:33:04,070 --> 00:33:01,200
ever come out of koenigsberg pressure

905
00:33:05,190 --> 00:33:04,080
but the sad thing is he applied for a

906
00:33:07,590 --> 00:33:05,200
faculty position

907
00:33:09,350 --> 00:33:07,600
in the philosophy department of the

908
00:33:11,269 --> 00:33:09,360
university of konigsberg

909
00:33:12,950 --> 00:33:11,279
and for the first first time he applied

910
00:33:14,470 --> 00:33:12,960
they turned him down you know imagine

911
00:33:15,430 --> 00:33:14,480
that they turned him down the university

912
00:33:17,029 --> 00:33:15,440
really blew it

913
00:33:19,110 --> 00:33:17,039

it turns out he applied a second time

914
00:33:19,750 --> 00:33:19,120
and he got the job but it makes me feel

915
00:33:22,230 --> 00:33:19,760
very bad

916
00:33:23,190 --> 00:33:22,240
as a faculty member especially now as

917
00:33:25,590 --> 00:33:23,200
department chairs

918
00:33:26,470 --> 00:33:25,600
i'm hiring new faculty makes all of us

919
00:33:30,149 --> 00:33:26,480
faculty feel

920
00:33:32,230 --> 00:33:30,159
really uh guilty that here we were we

921
00:33:33,269 --> 00:33:32,240
were given faculty positions at uc santa

922
00:33:35,990 --> 00:33:33,279
cruz or

923
00:33:38,149 --> 00:33:36,000
wherever we are but this great

924
00:33:39,830 --> 00:33:38,159
philosopher the greatest of all time was

925
00:33:41,110 --> 00:33:39,840
turned down for a faculty position the

926
00:33:43,269 --> 00:33:41,120
first time around

927
00:33:45,830 --> 00:33:43,279
and one of my colleagues speculated that

928
00:33:47,590 --> 00:33:45,840
you know when you hire a faculty person

929
00:33:49,269 --> 00:33:47,600
you have to not just put aside money for

930
00:33:51,430 --> 00:33:49,279
their salary you have to put aside money

931
00:33:53,669 --> 00:33:51,440
for them to do research so they're given

932
00:33:54,470 --> 00:33:53,679
startup grants you know startup packages

933
00:33:56,549 --> 00:33:54,480
that

934
00:33:58,789 --> 00:33:56,559
with which you an astronomer might go

935
00:34:00,310 --> 00:33:58,799
off and either build a telescope or buy

936
00:34:02,470 --> 00:34:00,320
into a telescope project

937
00:34:03,669 --> 00:34:02,480
a physicist might set up a lab a chemist

938
00:34:06,230 --> 00:34:03,679

might set up a lab

939
00:34:08,149 --> 00:34:06,240
if you're a theoretical physicist your

940
00:34:10,069 --> 00:34:08,159
startup funds can be limited because all

941
00:34:13,909 --> 00:34:10,079
you need to buy are a desk

942
00:34:16,149 --> 00:34:13,919
a chair a notepad a pencil

943
00:34:17,750 --> 00:34:16,159
and a wastebasket if you're a

944
00:34:19,589 --> 00:34:17,760
philosopher you don't even need the

945
00:34:24,710 --> 00:34:19,599
waste basket

946
00:34:27,829 --> 00:34:24,720
anyway moving on kant's work

947
00:34:29,990 --> 00:34:27,839
was largely forgotten for

948
00:34:32,869 --> 00:34:30,000
almost 100 years after his death you

949
00:34:34,710 --> 00:34:32,879
know so he died in 1804

950
00:34:38,389 --> 00:34:34,720
in the early 1900s in the beginning of

951
00:34:44,069 --> 00:34:42,470
the notion of island universes started

952
00:34:48,470 --> 00:34:44,079
to resurface

953
00:34:52,389 --> 00:34:48,480
through the work of two astronomers

954
00:34:56,470 --> 00:34:52,399
sharply and curtis curtis and sharply

955
00:35:00,150 --> 00:34:56,480
curtis was of the opinion that these

956
00:35:02,069 --> 00:35:00,160
islands of light were

957
00:35:03,589 --> 00:35:02,079
galaxies just like the milky way you

958
00:35:05,829 --> 00:35:03,599
know the milky way is a galaxy

959
00:35:07,670 --> 00:35:05,839
these little islands are just distant

960
00:35:09,190 --> 00:35:07,680
galaxies that look like tiny

961
00:35:12,790 --> 00:35:09,200
islands but they're actually as big as

962
00:35:15,430 --> 00:35:12,800
the milky way and shapley said no

963
00:35:15,990 --> 00:35:15,440

those things are inside our milky way

964
00:35:18,630 --> 00:35:16,000
galaxy

965
00:35:20,870 --> 00:35:18,640
those nebulae those island universes

966
00:35:21,829 --> 00:35:20,880
that can't talk about are within our

967
00:35:25,589 --> 00:35:21,839
milky way

968
00:35:28,390 --> 00:35:25,599
inside

969
00:35:30,069 --> 00:35:28,400
um so there was this big debate in the

970
00:35:32,630 --> 00:35:30,079
early 1900s

971
00:35:33,190 --> 00:35:32,640
curtis turns out was right he was right

972
00:35:35,670 --> 00:35:33,200
that those

973
00:35:37,030 --> 00:35:35,680
nebulae that can't refer to as alien

974
00:35:38,870 --> 00:35:37,040
universes were really

975
00:35:40,870 --> 00:35:38,880
uh are the galaxies like the milky way

976
00:35:43,030 --> 00:35:40,880
sharply got it wrong shapley had

977
00:35:43,990 --> 00:35:43,040
made a mistake um you know not not

978
00:35:46,310 --> 00:35:44,000
through any

979
00:35:47,349 --> 00:35:46,320
fault of his but had misestimated the

980
00:35:49,990 --> 00:35:47,359
distances to

981
00:35:51,349 --> 00:35:50,000
globular clusters so we had an incorrect

982
00:35:53,589 --> 00:35:51,359
notion about

983
00:35:55,109 --> 00:35:53,599
how big our milky way was now time

984
00:35:56,630 --> 00:35:55,119
magazine got this

985
00:35:58,230 --> 00:35:56,640
completely reversed and they put the

986
00:36:00,150 --> 00:35:58,240
wrong person on the cover of time

987
00:36:02,069 --> 00:36:00,160
magazine they put harlow shapley

988
00:36:04,470 --> 00:36:02,079

on the cover harvard's hollow sharply it

989
00:36:07,030 --> 00:36:04,480
says on the cover of time magazine

990
00:36:08,550 --> 00:36:07,040
and um of course you know they're not

991
00:36:10,069 --> 00:36:08,560
going to put a second astronomer on the

992
00:36:13,430 --> 00:36:10,079
cover in the next issue

993
00:36:15,910 --> 00:36:13,440
so to poke fun at themselves uh they

994
00:36:18,230 --> 00:36:15,920
a few months later they had this issue

995
00:36:20,630 --> 00:36:18,240
of time magazine a much more

996
00:36:21,430 --> 00:36:20,640
typical time magazine cover where they

997
00:36:24,870 --> 00:36:21,440
had um

998
00:36:28,870 --> 00:36:24,880
an entertainer gene harlow on the cover

999
00:36:31,430 --> 00:36:28,880
now notice her last name harlow

1000
00:36:32,150 --> 00:36:31,440
written right there under her picture is

1001
00:36:34,470 --> 00:36:32,160
the same

1002
00:36:35,349 --> 00:36:34,480
as his first name harlow so they were

1003
00:36:38,230 --> 00:36:35,359
sort of poking

1004
00:36:39,670 --> 00:36:38,240
fun at their own mistake and apparently

1005
00:36:42,630 --> 00:36:39,680
inside the magazine

1006
00:36:43,670 --> 00:36:42,640
they referred to her as the shapely

1007
00:36:46,550 --> 00:36:43,680
harlow

1008
00:36:47,750 --> 00:36:46,560
which was a direct play on words on the

1009
00:36:50,470 --> 00:36:47,760
name of harlow

1010
00:36:50,950 --> 00:36:50,480
sharply anyway this story was told to be

1011
00:36:54,630 --> 00:36:50,960
my

1012
00:36:56,230 --> 00:36:54,640
rich god i don't know how he knew about

1013
00:36:58,230 --> 00:36:56,240

the story but i actually looked up these

1014
00:37:00,550 --> 00:36:58,240
covers and found them online

1015
00:37:01,430 --> 00:37:00,560
so back to thinking about island

1016
00:37:05,910 --> 00:37:01,440
universes

1017
00:37:08,150 --> 00:37:05,920
this debate got rejuvenated in the 1900s

1018
00:37:10,390 --> 00:37:08,160
and it remained open as to how much

1019
00:37:11,829 --> 00:37:10,400
empty space there is between galaxies

1020
00:37:13,670 --> 00:37:11,839
now that you've established that these

1021
00:37:15,349 --> 00:37:13,680
island universes are indeed islands

1022
00:37:17,829 --> 00:37:15,359
how much ocean is there between these

1023
00:37:20,150 --> 00:37:17,839
islands so this is a question that

1024
00:37:21,190 --> 00:37:20,160
my group and i got very interested in

1025
00:37:24,390 --> 00:37:21,200
over the years

1026
00:37:25,589 --> 00:37:24,400
and here's a picture we took my students

1027
00:37:28,069 --> 00:37:25,599
and i took

1028
00:37:29,670 --> 00:37:28,079
of the andromeda galaxy so this is

1029
00:37:31,190 --> 00:37:29,680
really at that time it was the first

1030
00:37:34,390 --> 00:37:31,200
digital mosaic

1031
00:37:35,670 --> 00:37:34,400
of the andromeda galaxy the mosaic was

1032
00:37:38,630 --> 00:37:35,680
stitched by my

1033
00:37:39,349 --> 00:37:38,640
students um andreas berlind and phil

1034
00:37:41,109 --> 00:37:39,359
choi

1035
00:37:42,550 --> 00:37:41,119
and shimakura choudhury and i did the

1036
00:37:44,390 --> 00:37:42,560
original observations these are four

1037
00:37:45,910 --> 00:37:44,400
images of the andromeda galaxy

1038
00:37:47,430 --> 00:37:45,920

at four different contrast levels you

1039
00:37:48,950 --> 00:37:47,440
see the highest contrast on the right

1040
00:37:50,310 --> 00:37:48,960
lowest contrast on the left

1041
00:37:52,150 --> 00:37:50,320
and if you look closely you can see one

1042
00:37:54,870 --> 00:37:52,160
of the companions of andromeda

1043
00:37:55,589 --> 00:37:54,880
m32 another companion peeking in from

1044
00:37:58,470 --> 00:37:55,599
the left

1045
00:37:59,030 --> 00:37:58,480
as we go to higher contrast ngc 205 uh

1046
00:38:01,589 --> 00:37:59,040
here's

1047
00:38:02,950 --> 00:38:01,599
another image of andromeda this one's

1048
00:38:06,150 --> 00:38:02,960
taken by robert gendler

1049
00:38:08,069 --> 00:38:06,160
beautiful image this time of andromeda

1050
00:38:09,589 --> 00:38:08,079
in a different orientation and two of

1051
00:38:11,670 --> 00:38:09,599
its satellite galaxies two small

1052
00:38:14,950 --> 00:38:11,680
galaxies that are being cannibalized

1053
00:38:15,349 --> 00:38:14,960
by andromeda now for my research our

1054
00:38:19,349 --> 00:38:15,359
group

1055
00:38:22,150 --> 00:38:19,359
uses his privileged to use

1056
00:38:22,790 --> 00:38:22,160
the keck telescope on the sacred

1057
00:38:27,430 --> 00:38:22,800
mountain

1058
00:38:31,270 --> 00:38:27,440
of mauna kea on the big island of hawaii

1059
00:38:33,670 --> 00:38:31,280
this is a sacred mountain to

1060
00:38:35,430 --> 00:38:33,680
many generations of people who lived on

1061
00:38:35,990 --> 00:38:35,440
the island who have looked up to the

1062
00:38:39,430 --> 00:38:36,000
skies

1063
00:38:41,270 --> 00:38:39,440

for inspiration and worshiped the gods

1064
00:38:43,589 --> 00:38:41,280
and we astronomers are very privileged

1065
00:38:45,990 --> 00:38:43,599
to have use of that

1066
00:38:47,750 --> 00:38:46,000
mountaintop to use modern telescopes to

1067
00:38:50,950 --> 00:38:47,760
continue the search for

1068
00:38:51,270 --> 00:38:50,960
our place in the universe so this photo

1069
00:38:53,109 --> 00:38:51,280
of

1070
00:38:55,109 --> 00:38:53,119
the mauna kea summit with the two keck

1071
00:38:56,230 --> 00:38:55,119
telescopes was taken by lori hatch on a

1072
00:38:58,790 --> 00:38:56,240
beautiful

1073
00:39:00,710 --> 00:38:58,800
big island sunset and you have andromeda

1074
00:39:03,670 --> 00:39:00,720
and its two satellites

1075
00:39:05,510 --> 00:39:03,680
in the background of this image we also

1076
00:39:06,790 --> 00:39:05,520
use the hubble space telescope my

1077
00:39:08,150 --> 00:39:06,800
collaborators and i have

1078
00:39:10,230 --> 00:39:08,160
used the hubble space telescope

1079
00:39:12,710 --> 00:39:10,240
extensively to study

1080
00:39:14,150 --> 00:39:12,720
the andromeda galaxy if you could see

1081
00:39:16,950 --> 00:39:14,160
the andromeda galaxy

1082
00:39:19,349 --> 00:39:16,960
with powerful binoculars you'd see that

1083
00:39:21,910 --> 00:39:19,359
it's actually more extended

1084
00:39:23,349 --> 00:39:21,920
in apparent extent than the full moon

1085
00:39:25,270 --> 00:39:23,359
there's the full moon to scale

1086
00:39:26,390 --> 00:39:25,280
the andromeda galaxy the full moon is

1087
00:39:28,390 --> 00:39:26,400
half a degree across

1088
00:39:29,510 --> 00:39:28,400

this portion of the andromeda galaxy is

1089
00:39:32,230 --> 00:39:29,520
a few degrees

1090
00:39:33,829 --> 00:39:32,240
across at least along the long axis and

1091
00:39:36,550 --> 00:39:33,839
about half a degree across

1092
00:39:37,270 --> 00:39:36,560
along the short axis of this ellipse

1093
00:39:39,589 --> 00:39:37,280
this

1094
00:39:40,950 --> 00:39:39,599
white outline that you typically draw

1095
00:39:44,069 --> 00:39:40,960
around a crime scene

1096
00:39:45,510 --> 00:39:44,079
this white outline is not the chalk mark

1097
00:39:48,069 --> 00:39:45,520
of a crime scene but it's the

1098
00:39:49,829 --> 00:39:48,079
region of the andromeda galaxy in which

1099
00:39:52,390 --> 00:39:49,839
a modern digital

1100
00:39:54,069 --> 00:39:52,400
mosaic was constructed i mentioned the

1101
00:39:55,030 --> 00:39:54,079
first digital mosaic of my students and

1102
00:39:59,270 --> 00:39:55,040
i made with

1103
00:40:01,030 --> 00:39:59,280
57 images this one we used 3 000 images

1104
00:40:03,030 --> 00:40:01,040
with the hubble space telescope

1105
00:40:05,190 --> 00:40:03,040
a project called the panchromatic hubble

1106
00:40:07,030 --> 00:40:05,200
andromeda treasury led by

1107
00:40:08,790 --> 00:40:07,040
my wonderful colleague julian del canton

1108
00:40:11,109 --> 00:40:08,800
at the university of washington

1109
00:40:12,390 --> 00:40:11,119
and our group at ucsc used the cat

1110
00:40:14,470 --> 00:40:12,400
telescope that you saw in the last

1111
00:40:17,589 --> 00:40:14,480
picture to take spectrostars

1112
00:40:19,030 --> 00:40:17,599
now in the next few years

1113
00:40:21,109 --> 00:40:19,040

there's going to be another wonderful

1114
00:40:23,910 --> 00:40:21,119
telescope put out by nasa

1115
00:40:24,870 --> 00:40:23,920
it's called the nancy grace roman space

1116
00:40:29,109 --> 00:40:24,880
telescope

1117
00:40:31,430 --> 00:40:29,119
and it will have the imaging capability

1118
00:40:32,470 --> 00:40:31,440
of more than a hundred hubble space

1119
00:40:35,670 --> 00:40:32,480
telescopes

1120
00:40:37,109 --> 00:40:35,680
what took three thousand images to cover

1121
00:40:40,069 --> 00:40:37,119
with hubble

1122
00:40:41,589 --> 00:40:40,079
what's shown in this blue outline here

1123
00:40:43,589 --> 00:40:41,599
will be covered with

1124
00:40:45,670 --> 00:40:43,599
two or three pointings with the nancy

1125
00:40:47,829 --> 00:40:45,680
grace ramen telescope

1126
00:40:49,030 --> 00:40:47,839
so it's going to be a supremely powerful

1127
00:40:51,750 --> 00:40:49,040
telescope

1128
00:40:53,910 --> 00:40:51,760
in terms of how much area it can cover

1129
00:40:56,710 --> 00:40:53,920
at one shot so i can't wait

1130
00:40:58,950 --> 00:40:56,720
to see this come to and the the the

1131
00:41:00,230 --> 00:40:58,960
footprint of a single pointing with the

1132
00:41:03,510 --> 00:41:00,240
roman telescope

1133
00:41:06,550 --> 00:41:03,520
is shown in in in the form of these

1134
00:41:07,190 --> 00:41:06,560
small squares one two three multiplied

1135
00:41:11,190 --> 00:41:07,200
by six

1136
00:41:11,750 --> 00:41:11,200
these 18 uh mosaic 18 element mosaic

1137
00:41:13,589 --> 00:41:11,760
camera

1138
00:41:15,430 --> 00:41:13,599

is what the roman space telescope will

1139
00:41:16,390 --> 00:41:15,440
use that's a grace roman space telescope

1140
00:41:19,750 --> 00:41:16,400
will use

1141
00:41:21,190 --> 00:41:19,760
now i will zoom in on the hubble image

1142
00:41:21,670 --> 00:41:21,200
the hubble mosaic because the nancy

1143
00:41:23,910 --> 00:41:21,680
grace

1144
00:41:24,950 --> 00:41:23,920
roman telescope hasn't been launched yet

1145
00:41:27,030 --> 00:41:24,960
it's not yet in orbit

1146
00:41:28,230 --> 00:41:27,040
so i'll show you an image taken with the

1147
00:41:29,109 --> 00:41:28,240
hubble space telescope we're going to

1148
00:41:30,710 --> 00:41:29,119
zoom in

1149
00:41:32,710 --> 00:41:30,720
so those of you who are watching this at

1150
00:41:35,750 --> 00:41:32,720
home please fasten your seat belts

1151
00:41:37,670 --> 00:41:35,760
as we zoom in i'm going to remove the

1152
00:41:40,950 --> 00:41:37,680
label so you can focus on the image

1153
00:41:41,990 --> 00:41:40,960
and not on the label and what we're

1154
00:41:44,309 --> 00:41:42,000
going to see

1155
00:41:46,790 --> 00:41:44,319
is this is the arc of the milky way

1156
00:41:49,109 --> 00:41:46,800
galaxy with gas and dust the dark back

1157
00:41:50,630 --> 00:41:49,119
bands are dust there's andromeda two and

1158
00:41:51,750 --> 00:41:50,640
a half million light years away and

1159
00:41:53,190 --> 00:41:51,760
we're going to zoom in we're going to

1160
00:41:54,870 --> 00:41:53,200
zoom in a long way

1161
00:41:56,550 --> 00:41:54,880
so you can see a lot of the details of

1162
00:41:58,710 --> 00:41:56,560
andromeda and it's two satellites you

1163
00:42:01,349 --> 00:41:58,720

just saw the two satellites go by there

1164
00:42:01,990 --> 00:42:01,359
we're going to zoom in so much that

1165
00:42:06,230 --> 00:42:02,000
you'll be able

1166
00:42:08,230 --> 00:42:06,240
to see individual stars

1167
00:42:10,150 --> 00:42:08,240
imaged with the hubble space telescope

1168
00:42:11,109 --> 00:42:10,160
individual stars that have different

1169
00:42:13,430 --> 00:42:11,119
colors

1170
00:42:14,710 --> 00:42:13,440
some are very hot and they look bluish

1171
00:42:18,150 --> 00:42:14,720
white in this image

1172
00:42:19,030 --> 00:42:18,160
some are very cool they look reddish or

1173
00:42:21,910 --> 00:42:19,040
orange

1174
00:42:24,630 --> 00:42:21,920
in this picture and you even see these

1175
00:42:26,550 --> 00:42:24,640
dark bands of gas and dust

1176
00:42:28,870 --> 00:42:26,560
just like you see in the milky way

1177
00:42:31,190 --> 00:42:28,880
pictures like this convince us that the

1178
00:42:33,190 --> 00:42:31,200
detailed structure of andromeda

1179
00:42:34,390 --> 00:42:33,200
is no different from the detailed

1180
00:42:37,670 --> 00:42:34,400
structure of our own

1181
00:42:40,470 --> 00:42:37,680
milky way galaxy so

1182
00:42:42,309 --> 00:42:40,480
my group has used this these images to

1183
00:42:44,950 --> 00:42:42,319
carry out very detailed studies

1184
00:42:46,390 --> 00:42:44,960
of the andromeda galaxy one of the

1185
00:42:49,750 --> 00:42:46,400
things i just talked about

1186
00:42:51,990 --> 00:42:49,760
is galaxies cannibalize each other

1187
00:42:53,910 --> 00:42:52,000
andromeda is swallowing

1188
00:42:56,150 --> 00:42:53,920

two of its satellites so let's look at

1189
00:42:58,550 --> 00:42:56,160
what galaxy collisions

1190
00:42:59,349 --> 00:42:58,560
or cannibalism looks like galaxy

1191
00:43:01,430 --> 00:42:59,359
cannibalism

1192
00:43:04,790 --> 00:43:01,440
lasts for a very long time a single

1193
00:43:07,109 --> 00:43:04,800
snack lasts for a billion years

1194
00:43:09,589 --> 00:43:07,119
or a few billion years so i'm going to

1195
00:43:12,309 --> 00:43:09,599
speed this up with computer simulations

1196
00:43:13,670 --> 00:43:12,319
of galaxy collisions compared to actual

1197
00:43:16,390 --> 00:43:13,680
snapshots

1198
00:43:17,430 --> 00:43:16,400
of galaxies different pairs of galaxies

1199
00:43:19,670 --> 00:43:17,440
caught in the act

1200
00:43:21,510 --> 00:43:19,680
of cannibalism so again i'm going to

1201
00:43:24,870 --> 00:43:21,520
remove my label so you can focus

1202
00:43:25,750 --> 00:43:24,880
on the video itself and here are two

1203
00:43:32,309 --> 00:43:25,760
galaxies

1204
00:43:33,670 --> 00:43:32,319
as they come together we stop the

1205
00:43:36,309 --> 00:43:33,680
computer simulation

1206
00:43:37,270 --> 00:43:36,319
and here are two real disc galaxies that

1207
00:43:39,750 --> 00:43:37,280
are about

1208
00:43:40,550 --> 00:43:39,760
to collide we go back to the computer

1209
00:43:42,710 --> 00:43:40,560
simulation

1210
00:43:44,870 --> 00:43:42,720
their mutual gravity draws them ever

1211
00:43:46,630 --> 00:43:44,880
closer and they start to intersect the

1212
00:43:47,829 --> 00:43:46,640
two galaxies are actually intersecting

1213
00:43:50,550 --> 00:43:47,839

each other at this point

1214
00:43:52,309 --> 00:43:50,560
the way we can tell they're intersecting

1215
00:43:54,550 --> 00:43:52,319
these two model galaxies if we change

1216
00:43:56,309 --> 00:43:54,560
our perspective you stop the simulation

1217
00:43:58,069 --> 00:43:56,319
change our perspective here are two real

1218
00:43:59,990 --> 00:43:58,079
galaxies that are intersecting

1219
00:44:01,990 --> 00:44:00,000
different pair than the first two the

1220
00:44:03,750 --> 00:44:02,000
two galaxies computer simulated galaxies

1221
00:44:05,109 --> 00:44:03,760
start to stretch each other out through

1222
00:44:07,190 --> 00:44:05,119
their differential gravity

1223
00:44:08,230 --> 00:44:07,200
tidal forces stop the computer

1224
00:44:10,150 --> 00:44:08,240
simulation here

1225
00:44:11,670 --> 00:44:10,160
are two real galaxies that are further

1226
00:44:13,270 --> 00:44:11,680
along in the collision process that are

1227
00:44:15,750 --> 00:44:13,280
stretching each other out

1228
00:44:17,349 --> 00:44:15,760
the main bodies of the simulated galaxy

1229
00:44:20,550 --> 00:44:17,359
start to fall back together again

1230
00:44:22,710 --> 00:44:20,560
again due to their gravity and right

1231
00:44:24,390 --> 00:44:22,720
before the two main bodies merge we stop

1232
00:44:27,030 --> 00:44:24,400
the computer simulation

1233
00:44:27,430 --> 00:44:27,040
change our perspective one more time and

1234
00:44:30,870 --> 00:44:27,440
here

1235
00:44:31,589 --> 00:44:30,880
are very far along in the collision

1236
00:44:33,510 --> 00:44:31,599
process

1237
00:44:35,750 --> 00:44:33,520
the two main bodies of the galaxies now

1238
00:44:35,990 --> 00:44:35,760

merge the black holes at their centers

1239
00:44:39,109 --> 00:44:36,000
will

1240
00:44:40,790 --> 00:44:39,119
ultimately merge produce gravitational

1241
00:44:42,790 --> 00:44:40,800
waves which i'll talk about in a minute

1242
00:44:44,550 --> 00:44:42,800
but we stop the computer simulation and

1243
00:44:46,470 --> 00:44:44,560
pause one last time

1244
00:44:48,390 --> 00:44:46,480
to show you a final pair of galaxies

1245
00:44:50,150 --> 00:44:48,400
that are very far along the atoms for

1246
00:44:52,630 --> 00:44:50,160
peace galaxy very far along

1247
00:44:54,150 --> 00:44:52,640
in the collision process so galaxy

1248
00:44:56,470 --> 00:44:54,160
collisions are common

1249
00:44:58,309 --> 00:44:56,480
they are spectacular as you can see here

1250
00:45:02,230 --> 00:44:58,319
both from computer simulations

1251
00:45:04,390 --> 00:45:02,240
and from actual

1252
00:45:05,910 --> 00:45:04,400
images of colliding galaxies and if

1253
00:45:09,030 --> 00:45:05,920
you're wondering you know

1254
00:45:11,829 --> 00:45:09,040
that's all good why do we care we care

1255
00:45:15,990 --> 00:45:14,470
the milky way and andromeda galaxies are

1256
00:45:18,150 --> 00:45:16,000
going to collide in the future

1257
00:45:19,670 --> 00:45:18,160
and i'm going to again remove the label

1258
00:45:22,069 --> 00:45:19,680
and show you a wonderful set of

1259
00:45:24,150 --> 00:45:22,079
simulations carried out by john dubinsky

1260
00:45:26,390 --> 00:45:24,160
and collaborators at the university of

1261
00:45:27,750 --> 00:45:26,400
toronto and the canadian institute for

1262
00:45:31,030 --> 00:45:27,760
theoretical astronomy

1263
00:45:32,230 --> 00:45:31,040

the future sky you know this is a image

1264
00:45:34,550 --> 00:45:32,240
of the milky way

1265
00:45:37,190 --> 00:45:34,560
that's viewed from the sun and there's

1266
00:45:38,950 --> 00:45:37,200
andromeda coming through

1267
00:45:41,030 --> 00:45:38,960
as we go forward in time so it's really

1268
00:45:44,550 --> 00:45:41,040
about the future sky and this is

1269
00:45:47,270 --> 00:45:44,560
um john dobinski and john camille farah

1270
00:45:48,390 --> 00:45:47,280
from you toronto and ceta who put this

1271
00:45:49,750 --> 00:45:48,400
together

1272
00:45:51,829 --> 00:45:49,760
look what happens to the andromeda

1273
00:45:54,790 --> 00:45:51,839
galaxy as it swings through

1274
00:45:55,430 --> 00:45:54,800
it comes close it in one of its close

1275
00:45:58,710 --> 00:45:55,440
passage

1276
00:46:01,510 --> 00:45:58,720
we slow down so that you can really see

1277
00:46:05,510 --> 00:46:01,520
how spectacular its disruption is you'll

1278
00:46:09,190 --> 00:46:08,790
it gets ripped apart from a frisbee

1279
00:46:13,910 --> 00:46:09,200
shape

1280
00:46:15,910 --> 00:46:13,920
doing the same thing to the milky way

1281
00:46:17,270 --> 00:46:15,920
and in fact the sun is plunging in and

1282
00:46:18,630 --> 00:46:17,280
out of the milky way because the sun has

1283
00:46:20,309 --> 00:46:18,640
been perturbed in its orbit

1284
00:46:22,790 --> 00:46:20,319
that's why it looks like now you see me

1285
00:46:24,390 --> 00:46:22,800
now you don't it's because the sun

1286
00:46:26,470 --> 00:46:24,400
has been perturbed into a highly

1287
00:46:27,109 --> 00:46:26,480
eccentric orbit from its nearly circular

1288
00:46:29,750 --> 00:46:27,119

orbit

1289
00:46:31,109 --> 00:46:29,760
and in good time in a few billion years

1290
00:46:34,630 --> 00:46:31,119
the two galaxies

1291
00:46:37,430 --> 00:46:34,640
merge to form one galaxy okay so this is

1292
00:46:38,950 --> 00:46:37,440
a perspective from the sun of this

1293
00:46:40,309 --> 00:46:38,960
wonderful simulation of the milky way

1294
00:46:43,589 --> 00:46:40,319
andromeda collision

1295
00:46:44,309 --> 00:46:43,599
now i have to say that our group at uc

1296
00:46:45,990 --> 00:46:44,319
santa cruz

1297
00:46:48,309 --> 00:46:46,000
worked closely with a group at the space

1298
00:46:51,510 --> 00:46:48,319
telescope led by roland van der marrell

1299
00:46:53,030 --> 00:46:51,520
and really in um

1300
00:46:56,309 --> 00:46:53,040
before we started our work with the

1301
00:46:57,910 --> 00:46:56,319
group at um at space telescope in 2005

1302
00:46:59,670 --> 00:46:57,920
our group at santa cruz working with a

1303
00:47:00,630 --> 00:46:59,680
group at university of virginia group at

1304
00:47:03,349 --> 00:47:00,640
ucla

1305
00:47:05,589 --> 00:47:03,359
we jointly discovered that the milk that

1306
00:47:06,390 --> 00:47:05,599
the andromeda galaxy is about five times

1307
00:47:08,630 --> 00:47:06,400
bigger than p

1308
00:47:11,030 --> 00:47:08,640
people had previously given it credit

1309
00:47:12,390 --> 00:47:11,040
for instead of being a hundred thousand

1310
00:47:14,870 --> 00:47:12,400
light years across

1311
00:47:15,910 --> 00:47:14,880
we found that the andromeda galaxy is at

1312
00:47:18,550 --> 00:47:15,920
least

1313
00:47:19,910 --> 00:47:18,560

500 000 light years across so imagine

1314
00:47:21,270 --> 00:47:19,920
this you know you wake up one morning

1315
00:47:22,470 --> 00:47:21,280
you find out you're five times bigger

1316
00:47:23,670 --> 00:47:22,480
than you previously thought

1317
00:47:25,750 --> 00:47:23,680
but you're going to bump into things

1318
00:47:28,630 --> 00:47:25,760
you're going to bump into things and

1319
00:47:29,430 --> 00:47:28,640
um so galaxy collisions become even more

1320
00:47:31,829 --> 00:47:29,440
of a

1321
00:47:33,829 --> 00:47:31,839
thing if uh if galaxies are bigger than

1322
00:47:36,630 --> 00:47:33,839
people previously thought

1323
00:47:38,390 --> 00:47:36,640
another discovery we made not in 2005

1324
00:47:40,470 --> 00:47:38,400
now but fast forward to 2012

1325
00:47:42,230 --> 00:47:40,480
seven years later working with a group

1326
00:47:42,790 --> 00:47:42,240
at space telescope led by roland van de

1327
00:47:45,030 --> 00:47:42,800
mero

1328
00:47:46,790 --> 00:47:45,040
and collaborators we discovered that not

1329
00:47:48,230 --> 00:47:46,800
only is the andromeda galaxy much bigger

1330
00:47:51,430 --> 00:47:48,240
than we previously thought

1331
00:47:52,150 --> 00:47:51,440
it's heading straight for us you know as

1332
00:47:56,390 --> 00:47:52,160
the

1333
00:47:57,750 --> 00:47:56,400
joke goes people wondered why andromeda

1334
00:47:59,990 --> 00:47:57,760
was getting bigger and bigger and then

1335
00:48:00,950 --> 00:48:00,000
it hit us um and robert is heading

1336
00:48:03,990 --> 00:48:00,960
straight for us

1337
00:48:06,309 --> 00:48:04,000
and uh in with that discovery uh

1338
00:48:08,390 --> 00:48:06,319

came a nasa press release where they put

1339
00:48:09,589 --> 00:48:08,400
this video together the future milky way

1340
00:48:11,270 --> 00:48:09,599
andromeda

1341
00:48:12,870 --> 00:48:11,280
galactic collision again here's the

1342
00:48:13,349 --> 00:48:12,880
milky way the band of light of the milky

1343
00:48:14,950 --> 00:48:13,359
way

1344
00:48:16,390 --> 00:48:14,960
andromeda two and a half million light

1345
00:48:17,349 --> 00:48:16,400
years away and let's look at what our

1346
00:48:20,309 --> 00:48:17,359
future holds

1347
00:48:21,990 --> 00:48:20,319
i'll play this movie for you what our

1348
00:48:23,589 --> 00:48:22,000
movie holds is a much bigger andromeda

1349
00:48:24,870 --> 00:48:23,599
galaxy as it approaches us in two

1350
00:48:27,990 --> 00:48:24,880
billion years

1351
00:48:31,910 --> 00:48:28,000
galaxies

1352
00:48:33,589 --> 00:48:31,920
collide and soon there's such a

1353
00:48:37,030 --> 00:48:33,599
spectacular collision

1354
00:48:38,630 --> 00:48:37,040
that there are fireworks in the sky and

1355
00:48:40,309 --> 00:48:38,640
you know i'm fairly sure we've stopped

1356
00:48:41,670 --> 00:48:40,319
celebrating the fourth of july because

1357
00:48:42,150 --> 00:48:41,680
we'll have permanent fireworks in the

1358
00:48:43,670 --> 00:48:42,160
sky

1359
00:48:45,270 --> 00:48:43,680
and in seven billion years the two

1360
00:48:48,309 --> 00:48:45,280
galaxies have completely

1361
00:48:50,069 --> 00:48:48,319
merged to form one galaxy where there

1362
00:48:52,150 --> 00:48:50,079
used to be two the one galaxy that's

1363
00:48:53,349 --> 00:48:52,160

going to be called milkometer milky way

1364
00:48:55,670 --> 00:48:53,359
andromeda

1365
00:48:57,109 --> 00:48:55,680
now uh what is amazing is in seven

1366
00:48:58,950 --> 00:48:57,119
billion years

1367
00:49:00,950 --> 00:48:58,960
whatever these rocks are made of in the

1368
00:49:01,270 --> 00:49:00,960
foreground hillside haven't weathered it

1369
00:49:03,670 --> 00:49:01,280
for

1370
00:49:04,790 --> 00:49:03,680
in seven billion years so you know get a

1371
00:49:06,069 --> 00:49:04,800
hold of these rocks they're they're

1372
00:49:07,589 --> 00:49:06,079
wonderful things

1373
00:49:09,829 --> 00:49:07,599
um that's the one piece of the

1374
00:49:11,990 --> 00:49:09,839
simulation that i guess went a little

1375
00:49:13,750 --> 00:49:12,000
wrong now of course a lot is going to

1376
00:49:15,349 --> 00:49:13,760
happen in seven billion years so that's

1377
00:49:16,950 --> 00:49:15,359
a lot's gonna happen and much less than

1378
00:49:19,750 --> 00:49:16,960
that you know this pandemic is a

1379
00:49:21,910 --> 00:49:19,760
reminder of the fragility of human life

1380
00:49:23,190 --> 00:49:21,920
fragility of human life in the face of

1381
00:49:25,990 --> 00:49:23,200
disease you know

1382
00:49:26,630 --> 00:49:26,000
diseases caused by viruses degenerative

1383
00:49:33,349 --> 00:49:26,640
diseases

1384
00:49:35,270 --> 00:49:33,359
war and violence here on earth sadly uh

1385
00:49:36,710 --> 00:49:35,280
that's another thing we have to overcome

1386
00:49:39,270 --> 00:49:36,720
you know that's on time scales that are

1387
00:49:41,990 --> 00:49:39,280
much less than seven billion years

1388
00:49:42,870 --> 00:49:42,000

like disease we have to there's old age

1389
00:49:46,390 --> 00:49:42,880
you know

1390
00:49:48,710 --> 00:49:46,400
that we have to understand and conquer

1391
00:49:49,750 --> 00:49:48,720
um these are things that we really have

1392
00:49:51,349 --> 00:49:49,760
to get past

1393
00:49:53,270 --> 00:49:51,359
if we have to live long enough to

1394
00:49:56,150 --> 00:49:53,280
understand the future and

1395
00:49:56,870 --> 00:49:56,160
not understand witness the future

1396
00:49:57,910 --> 00:49:56,880
collision

1397
00:49:59,670 --> 00:49:57,920
there's another thing that's going to

1398
00:50:01,510 --> 00:49:59,680
happen which is the sun is going to

1399
00:50:03,829 --> 00:50:01,520
bloat up into a

1400
00:50:05,910 --> 00:50:03,839
a very large star we're going to become

1401
00:50:08,630 --> 00:50:05,920
a red giant engulf the earth

1402
00:50:09,270 --> 00:50:08,640
so we not only have to survive all these

1403
00:50:11,270 --> 00:50:09,280
things

1404
00:50:12,870 --> 00:50:11,280
we actually have to travel outwards in

1405
00:50:14,630 --> 00:50:12,880
the solar system

1406
00:50:16,069 --> 00:50:14,640
mars is probably too close we have to

1407
00:50:18,470 --> 00:50:16,079
get to one of the moons of the

1408
00:50:20,069 --> 00:50:18,480
gas giants you know saturn or jupiter

1409
00:50:21,670 --> 00:50:20,079
and watch this wonderful milky way

1410
00:50:23,670 --> 00:50:21,680
andromeda collision

1411
00:50:25,670 --> 00:50:23,680
um so that you know we can only watch it

1412
00:50:25,990 --> 00:50:25,680
if we can watch the sun bloat up from a

1413
00:50:29,109 --> 00:50:26,000

safe

1414
00:50:30,950 --> 00:50:29,119
distance and then outlive that and

1415
00:50:32,630 --> 00:50:30,960
watch the milky way andromeda collision

1416
00:50:34,870 --> 00:50:32,640
seven billion years from now so a lot to

1417
00:50:36,790 --> 00:50:34,880
think about for the future

1418
00:50:38,150 --> 00:50:36,800
okay um i do want to take you on a

1419
00:50:38,790 --> 00:50:38,160
little journey through the milky way to

1420
00:50:40,710 --> 00:50:38,800
get your

1421
00:50:42,230 --> 00:50:40,720
give you a sense of what space around us

1422
00:50:43,829 --> 00:50:42,240
looks like i'm still talking about

1423
00:50:45,430 --> 00:50:43,839
galaxies and their structure

1424
00:50:47,109 --> 00:50:45,440
this is a wonderful video that brent

1425
00:50:48,390 --> 00:50:47,119
tully uh my

1426
00:50:50,390 --> 00:50:48,400
astronomer colleague at the university

1427
00:50:51,349 --> 00:50:50,400
of hawaii and his and his collaborators

1428
00:50:52,950 --> 00:50:51,359
put together

1429
00:50:54,710 --> 00:50:52,960
this is flying through the milky way

1430
00:50:56,230 --> 00:50:54,720
into intergalactic space

1431
00:50:58,710 --> 00:50:56,240
i'm going to remove the label and if you

1432
00:50:59,829 --> 00:50:58,720
see this the orion nebula the three

1433
00:51:02,069 --> 00:50:59,839
stars

1434
00:51:03,990 --> 00:51:02,079
the sword of orion the other star some

1435
00:51:04,790 --> 00:51:04,000
of the other stars in iran the shoulders

1436
00:51:06,790 --> 00:51:04,800
etc

1437
00:51:08,790 --> 00:51:06,800
and as we zoom in you'll see that orion

1438
00:51:09,750 --> 00:51:08,800

is the stars in orion are not really at

1439
00:51:11,510 --> 00:51:09,760
one distance from us

1440
00:51:13,270 --> 00:51:11,520
as we zoom in towards it the

1441
00:51:15,510 --> 00:51:13,280
constellation loses its shape

1442
00:51:18,230 --> 00:51:15,520
you can see that the sword of orion is

1443
00:51:20,069 --> 00:51:18,240
not really one star it's a nebulae

1444
00:51:22,150 --> 00:51:20,079
it's a nebula of gas and dust out of

1445
00:51:23,589 --> 00:51:22,160
which new stars are born

1446
00:51:25,430 --> 00:51:23,599
you can see the band of light in the

1447
00:51:26,950 --> 00:51:25,440
milky way this wonderful video was put

1448
00:51:29,430 --> 00:51:26,960
together by taking actual

1449
00:51:31,349 --> 00:51:29,440
images astronomical images but putting

1450
00:51:33,270 --> 00:51:31,359
them at appropriate distances and then

1451
00:51:33,910 --> 00:51:33,280
taking this virtual journey through them

1452
00:51:37,270 --> 00:51:33,920
there's the

1453
00:51:39,109 --> 00:51:37,280
horsehead nebula and orion and

1454
00:51:40,470 --> 00:51:39,119
you know this is the milky way we're

1455
00:51:41,589 --> 00:51:40,480
going to go through an exploded star

1456
00:51:44,390 --> 00:51:41,599
this is this

1457
00:51:46,069 --> 00:51:44,400
pink pinkish white blob that's uh

1458
00:51:48,870 --> 00:51:46,079
getting bigger and bigger and

1459
00:51:50,309 --> 00:51:48,880
coming to the center of our screen

1460
00:51:52,950 --> 00:51:50,319
that's an exploded star

1461
00:51:55,349 --> 00:51:52,960
in our own galaxy we're going to go

1462
00:51:58,470 --> 00:51:55,359
through that

1463
00:51:59,030 --> 00:51:58,480

and as we do this we get to say get a

1464
00:52:01,030 --> 00:51:59,040
sense

1465
00:52:03,349 --> 00:52:01,040
of the structure of our own milky way

1466
00:52:06,470 --> 00:52:03,359
galaxy so you're going to see an image

1467
00:52:09,510 --> 00:52:06,480
soon of our own

1468
00:52:11,270 --> 00:52:09,520
milky way galaxy taken from a great

1469
00:52:12,630 --> 00:52:11,280
height so you can see the frisbee and

1470
00:52:13,750 --> 00:52:12,640
the shape of the frisbee and you're

1471
00:52:15,670 --> 00:52:13,760
wondering you know

1472
00:52:17,910 --> 00:52:15,680
how did brent tully get such a long

1473
00:52:19,670 --> 00:52:17,920
selfie stick how did he manage to take

1474
00:52:20,470 --> 00:52:19,680
this picture of the milky way taken from

1475
00:52:23,030 --> 00:52:20,480
the outside

1476
00:52:24,549 --> 00:52:23,040
you know this view right here where the

1477
00:52:26,230 --> 00:52:24,559
milky way

1478
00:52:28,630 --> 00:52:26,240
clearly looks like a frisbee because we

1479
00:52:30,790 --> 00:52:28,640
are so far away from it now that we can

1480
00:52:31,750 --> 00:52:30,800
get that perspective and the answer is

1481
00:52:34,390 --> 00:52:31,760
simple

1482
00:52:35,990 --> 00:52:34,400
brent has another galaxy playing the

1483
00:52:37,349 --> 00:52:36,000
role of the milky way this is not really

1484
00:52:40,630 --> 00:52:37,359
an image of the milky way it's an

1485
00:52:41,190 --> 00:52:40,640
actor playing the milky way on in this

1486
00:52:42,870 --> 00:52:41,200
video

1487
00:52:44,549 --> 00:52:42,880
now those two galaxies that came by

1488
00:52:46,230 --> 00:52:44,559

those other two galaxies that came by

1489
00:52:47,750 --> 00:52:46,240
those are real images of those companion

1490
00:52:49,430 --> 00:52:47,760
galaxies of the milky way

1491
00:52:50,950 --> 00:52:49,440
um you know in a second you'll see

1492
00:52:53,430 --> 00:52:50,960
andromeda coming in from the

1493
00:52:56,230 --> 00:52:53,440
uh upper right there's andromeda and its

1494
00:52:57,430 --> 00:52:56,240
companion there's the triangulum galaxy

1495
00:52:59,030 --> 00:52:57,440
we're going to go through an exploded

1496
00:53:00,549 --> 00:52:59,040
star and triangulum so you can see that

1497
00:53:02,950 --> 00:53:00,559
the milky way and

1498
00:53:04,390 --> 00:53:02,960
you know lives near other galaxies uh

1499
00:53:06,309 --> 00:53:04,400
each of these galaxies

1500
00:53:08,069 --> 00:53:06,319
you know if there are some that are

1501
00:53:09,030 --> 00:53:08,079
bigger than the milky way andromeda is

1502
00:53:10,710 --> 00:53:09,040
somewhat bigger

1503
00:53:12,470 --> 00:53:10,720
some are smaller triangulum is smaller

1504
00:53:14,950 --> 00:53:12,480
than the milky way you know

1505
00:53:16,309 --> 00:53:14,960
but you know 100 000 500 000 light years

1506
00:53:18,309 --> 00:53:16,319
across is quite typical

1507
00:53:21,030 --> 00:53:18,319
even for these tiny little specks in the

1508
00:53:23,190 --> 00:53:21,040
distance each of those is a galaxy

1509
00:53:24,390 --> 00:53:23,200
each of those has lots of stars and i

1510
00:53:26,150 --> 00:53:24,400
you know should have said this but the

1511
00:53:29,349 --> 00:53:26,160
milky way galaxy has about a

1512
00:53:32,390 --> 00:53:29,359
hundred billion stars you know one with

1513
00:53:33,910 --> 00:53:32,400

11 zeros after it but if that isn't bad

1514
00:53:35,910 --> 00:53:33,920
enough it contains

1515
00:53:37,750 --> 00:53:35,920
more dark matter more mass in the form

1516
00:53:39,430 --> 00:53:37,760
of dark matter than it does in stars

1517
00:53:40,470 --> 00:53:39,440
almost 10 times as much mass in dark

1518
00:53:42,790 --> 00:53:40,480
matter than it does

1519
00:53:44,390 --> 00:53:42,800
in stars and you know as you're seeing

1520
00:53:45,910 --> 00:53:44,400
this you're seeing a collection of

1521
00:53:47,349 --> 00:53:45,920
galaxies in the distance that's the

1522
00:53:48,790 --> 00:53:47,359
virgo cluster of galaxy

1523
00:53:50,390 --> 00:53:48,800
this is something that my colleagues and

1524
00:53:51,109 --> 00:53:50,400
my students and i are studying in great

1525
00:53:54,069 --> 00:53:51,119
detail

1526
00:53:56,790 --> 00:53:54,079
and there's a particularly monstrous

1527
00:53:58,390 --> 00:53:56,800
monstrous in terms of size uh galaxy at

1528
00:54:00,390 --> 00:53:58,400
the center of the virgo cluster that's a

1529
00:54:02,630 --> 00:54:00,400
result of many galactic collisions

1530
00:54:04,230 --> 00:54:02,640
and that's the messier 87 galaxy we're

1531
00:54:06,630 --> 00:54:04,240
going to crash land

1532
00:54:09,510 --> 00:54:06,640
into that galaxy to end this piece of

1533
00:54:12,230 --> 00:54:09,520
our virtual journey there's messier

1534
00:54:13,510 --> 00:54:12,240
m87 messier 87 that's a super massive

1535
00:54:15,670 --> 00:54:13,520
black hole at its center

1536
00:54:17,270 --> 00:54:15,680
a few billion solar masses and its

1537
00:54:20,390 --> 00:54:17,280
gravity has gathered

1538
00:54:22,630 --> 00:54:20,400

light around it stars around it sorry

1539
00:54:24,630 --> 00:54:22,640
that's what that brightening is and if

1540
00:54:26,470 --> 00:54:24,640
you look closely you'll see this bluish

1541
00:54:28,549 --> 00:54:26,480
white jet off to the left

1542
00:54:30,150 --> 00:54:28,559
um this we think this jet is from

1543
00:54:32,069 --> 00:54:30,160
material that's swirling around the

1544
00:54:33,990 --> 00:54:32,079
black hole and it's being squirted out

1545
00:54:35,270 --> 00:54:34,000
i'll show you that in the next animation

1546
00:54:38,309 --> 00:54:35,280
this is that same

1547
00:54:39,589 --> 00:54:38,319
same messier 87 galaxy

1548
00:54:41,829 --> 00:54:39,599
this time we're going to zoom into the

1549
00:54:44,230 --> 00:54:41,839
super massive black hole near the center

1550
00:54:45,670 --> 00:54:44,240
and because telescopes most telescopes

1551
00:54:46,630 --> 00:54:45,680
don't have the resolution to show that

1552
00:54:48,150 --> 00:54:46,640
kind of detail

1553
00:54:50,470 --> 00:54:48,160
we're going to resort to sort of an

1554
00:54:52,870 --> 00:54:50,480
artist's rendering of what's going on

1555
00:54:53,990 --> 00:54:52,880
at the center so we're going to zoom in

1556
00:54:57,109 --> 00:54:54,000
these little blobs

1557
00:54:59,750 --> 00:54:57,119
around our star clusters uh that are

1558
00:55:01,349 --> 00:54:59,760
orbiting m87 but as we zoom in as i said

1559
00:55:02,069 --> 00:55:01,359
you know this particular telescope loses

1560
00:55:04,230 --> 00:55:02,079
resolution

1561
00:55:05,750 --> 00:55:04,240
so we're sort of relying on an artist's

1562
00:55:06,470 --> 00:55:05,760
rendering of what's going on near the

1563
00:55:09,670 --> 00:55:06,480

center

1564
00:55:11,829 --> 00:55:09,680
believe is a supermassive black hole

1565
00:55:12,630 --> 00:55:11,839
with swirling material that's heated up

1566
00:55:17,190 --> 00:55:12,640
by the

1567
00:55:19,750 --> 00:55:17,200
and that's squirting out this

1568
00:55:21,670 --> 00:55:19,760
jet that you see going off like that now

1569
00:55:24,150 --> 00:55:21,680
this supermassive black hole

1570
00:55:26,630 --> 00:55:24,160
this very supermassive black hole at the

1571
00:55:29,270 --> 00:55:26,640
center of m87 was recently

1572
00:55:31,030 --> 00:55:29,280
the subject of a portrait a bunch of

1573
00:55:31,750 --> 00:55:31,040
radio telescopes got together and

1574
00:55:34,150 --> 00:55:31,760
decided

1575
00:55:35,589 --> 00:55:34,160
we would take a picture of this

1576
00:55:37,270 --> 00:55:35,599
supermassive black hole this happened

1577
00:55:39,670 --> 00:55:37,280
about two years ago

1578
00:55:42,069 --> 00:55:39,680
this is in a way it's an image of the

1579
00:55:44,309 --> 00:55:42,079
black hole but it's really a silhouette

1580
00:55:45,670 --> 00:55:44,319
of the black hole what happens is radio

1581
00:55:48,470 --> 00:55:45,680
waves that are

1582
00:55:49,510 --> 00:55:48,480
emanating from behind the black hole

1583
00:55:51,910 --> 00:55:49,520
beyond the black hole

1584
00:55:52,950 --> 00:55:51,920
they're getting bent by the gravity of

1585
00:55:55,270 --> 00:55:52,960
the black hole

1586
00:55:56,549 --> 00:55:55,280
all around to produce this ring this

1587
00:55:59,430 --> 00:55:56,559
partial einstein ring

1588
00:56:01,030 --> 00:55:59,440

this was this image was wonderful it was

1589
00:56:03,670 --> 00:56:01,040
really the first

1590
00:56:04,549 --> 00:56:03,680
real image of a black hole imaged with

1591
00:56:07,030 --> 00:56:04,559
the so-called

1592
00:56:08,470 --> 00:56:07,040
event horizon telescope it's not a

1593
00:56:10,549 --> 00:56:08,480
single telescope it's actually an

1594
00:56:12,150 --> 00:56:10,559
array of telescopes the largest array of

1595
00:56:13,829 --> 00:56:12,160
radio telescopes on earth

1596
00:56:15,990 --> 00:56:13,839
i can safely say that because these

1597
00:56:17,750 --> 00:56:16,000
telescopes are all over the earth so

1598
00:56:19,910 --> 00:56:17,760
you can have larger telescope arrays but

1599
00:56:21,910 --> 00:56:19,920
they wouldn't be earthbound anymore

1600
00:56:23,430 --> 00:56:21,920
anyway this wonderful image was taken

1601
00:56:26,789 --> 00:56:23,440
with this telescope

1602
00:56:28,230 --> 00:56:26,799
now the bending of light by gravity

1603
00:56:30,069 --> 00:56:28,240
of the black hole is what you're seeing

1604
00:56:32,470 --> 00:56:30,079
here light is bending around

1605
00:56:33,910 --> 00:56:32,480
the black hole to produce this apparent

1606
00:56:35,589 --> 00:56:33,920
ring

1607
00:56:37,190 --> 00:56:35,599
light can be bent by gravity in even

1608
00:56:39,270 --> 00:56:37,200
more spectacular ways

1609
00:56:40,630 --> 00:56:39,280
here's the light of distant galaxies

1610
00:56:43,589 --> 00:56:40,640
being bent

1611
00:56:45,349 --> 00:56:43,599
by the gravity of these two yellowish

1612
00:56:48,230 --> 00:56:45,359
white galaxies there these are

1613
00:56:49,270 --> 00:56:48,240

two galaxies in a cluster and they're

1614
00:56:51,109 --> 00:56:49,280
bending the light

1615
00:56:53,030 --> 00:56:51,119
of these background bluish white

1616
00:56:53,750 --> 00:56:53,040
galaxies you see the smile of the smiley

1617
00:57:02,150 --> 00:56:53,760
face

1618
00:57:02,950 --> 00:57:02,160
this gravitational light bending of

1619
00:57:04,789 --> 00:57:02,960
course

1620
00:57:06,870 --> 00:57:04,799
was a prediction of einstein's general

1621
00:57:08,789 --> 00:57:06,880
relativity and what i'm going to do at

1622
00:57:09,910 --> 00:57:08,799
this point in my talk is make a brief

1623
00:57:11,829 --> 00:57:09,920
pause

1624
00:57:13,589 --> 00:57:11,839
to reflect on something i've been

1625
00:57:14,870 --> 00:57:13,599
talking about the grandeur of the

1626
00:57:17,910 --> 00:57:14,880
universe

1627
00:57:21,510 --> 00:57:17,920
about the study of

1628
00:57:24,950 --> 00:57:21,520
universe cosmology astronomy space

1629
00:57:25,990 --> 00:57:24,960
stars galaxies and i would say i've

1630
00:57:27,510 --> 00:57:26,000
already talked about

1631
00:57:29,030 --> 00:57:27,520
the privilege of using the keck

1632
00:57:31,829 --> 00:57:29,040
telescope on mauna kea

1633
00:57:33,990 --> 00:57:31,839
i say it's a privilege to be paid a

1634
00:57:35,589 --> 00:57:34,000
salary to go off and study something as

1635
00:57:37,430 --> 00:57:35,599
beautiful as the universe

1636
00:57:38,789 --> 00:57:37,440
i feel completely privileged utterly

1637
00:57:41,750 --> 00:57:38,799
privileged to do that

1638
00:57:43,670 --> 00:57:41,760

and it's easy to look back over my 35

1639
00:57:45,430 --> 00:57:43,680
years of being an astronomer

1640
00:57:47,430 --> 00:57:45,440
and say that the most wonderful thing

1641
00:57:48,950 --> 00:57:47,440
about my career was getting to study

1642
00:57:51,030 --> 00:57:48,960
these wonderful

1643
00:57:52,630 --> 00:57:51,040
aspects these grand questions in the

1644
00:57:53,910 --> 00:57:52,640
universe some of the biggest questions

1645
00:57:55,349 --> 00:57:53,920
literally some of the biggest questions

1646
00:57:57,670 --> 00:57:55,359
humanity can ask

1647
00:57:59,670 --> 00:57:57,680
but as i look back it's really not the

1648
00:58:00,630 --> 00:57:59,680
grand questions that stick out the most

1649
00:58:03,990 --> 00:58:00,640
in my mind

1650
00:58:05,510 --> 00:58:04,000
it's the amazing people individuals

1651
00:58:08,710 --> 00:58:05,520
human beings

1652
00:58:10,230 --> 00:58:08,720
whose own stories have touched my own

1653
00:58:12,150 --> 00:58:10,240
and i want to spend a few minutes

1654
00:58:14,710 --> 00:58:12,160
acknowledging them because i wouldn't be

1655
00:58:17,510 --> 00:58:14,720
here without them

1656
00:58:19,270 --> 00:58:17,520
i want to acknowledge the person whose

1657
00:58:20,870 --> 00:58:19,280
theory predicted that light should be

1658
00:58:22,710 --> 00:58:20,880
bent by gravity and that's

1659
00:58:25,349 --> 00:58:22,720
albert einstein you see him on the left

1660
00:58:27,190 --> 00:58:25,359
there it's a photograph taken in 1912

1661
00:58:29,510 --> 00:58:27,200
around the time general relativity had

1662
00:58:31,190 --> 00:58:29,520
just been published and was very famous

1663
00:58:33,589 --> 00:58:31,200

as a theory that predicted that light

1664
00:58:37,270 --> 00:58:33,599
should be bent by gravity

1665
00:58:39,030 --> 00:58:37,280
1912 was also the year

1666
00:58:40,150 --> 00:58:39,040
when albert einstein's one of his

1667
00:58:41,349 --> 00:58:40,160
closest collaborators called

1668
00:58:41,990 --> 00:58:41,359
schwarzschild who you see with the

1669
00:58:44,470 --> 00:58:42,000
impressive

1670
00:58:46,150 --> 00:58:44,480
facial hair in the upper right couch

1671
00:58:47,910 --> 00:58:46,160
schwarzschild was the first person to

1672
00:58:50,470 --> 00:58:47,920
solve einstein's equations of general

1673
00:58:52,230 --> 00:58:50,480
relativity in exact form so carl is

1674
00:58:53,510 --> 00:58:52,240
shown here in this picture because he

1675
00:58:55,270 --> 00:58:53,520
gave

1676
00:58:57,030 --> 00:58:55,280
rise to the notion that if you have a

1677
00:58:59,190 --> 00:58:57,040
point mass and you solve einstein's

1678
00:59:01,349 --> 00:58:59,200
equations of general relativity

1679
00:59:02,789 --> 00:59:01,359
you can get the notion of a black hole

1680
00:59:05,190 --> 00:59:02,799
okay so

1681
00:59:06,470 --> 00:59:05,200
called schwarzschild's name is attached

1682
00:59:08,470 --> 00:59:06,480
to the event horizon of a black hole

1683
00:59:10,710 --> 00:59:08,480
it's called the schwarzschild radius

1684
00:59:13,030 --> 00:59:10,720
but the short shield had an important

1685
00:59:14,470 --> 00:59:13,040
year in 1912 because their son martin

1686
00:59:17,190 --> 00:59:14,480
was born that year this is a

1687
00:59:18,549 --> 00:59:17,200
photograph of martin schwarchel taken

1688
00:59:20,870 --> 00:59:18,559

you know when he was

1689
00:59:22,230 --> 00:59:20,880
a professor at princeton so martin

1690
00:59:24,230 --> 00:59:22,240
shortshield

1691
00:59:26,390 --> 00:59:24,240
uh lost his father very early couch

1692
00:59:29,510 --> 00:59:26,400
watching died when he was in his

1693
00:59:32,710 --> 00:59:29,520
early 30s he died during world war one

1694
00:59:35,430 --> 00:59:32,720
martin um um

1695
00:59:35,910 --> 00:59:35,440
was visited by albert einstein martin

1696
00:59:37,990 --> 00:59:35,920
and his

1697
00:59:39,349 --> 00:59:38,000
family his mom uh they were visited by

1698
00:59:40,789 --> 00:59:39,359
albert einstein because

1699
00:59:42,309 --> 00:59:40,799
you know einstein had lost one of his

1700
00:59:44,069 --> 00:59:42,319
closest collaborators so martin

1701
00:59:47,190 --> 00:59:44,079
remembers albert einstein

1702
00:59:48,950 --> 00:59:47,200
uh when he was a child and martin came

1703
00:59:51,910 --> 00:59:48,960
to princeton university

1704
00:59:53,829 --> 00:59:51,920
the institute for advanced study they

1705
00:59:56,150 --> 00:59:53,839
reconnected in princeton

1706
00:59:57,910 --> 00:59:56,160
my connection to the soul pieces martin

1707
00:59:59,750 --> 00:59:57,920
schwartzel was an emeritus professor at

1708
01:00:00,630 --> 00:59:59,760
princeton university in the astrophysics

1709
01:00:02,549 --> 01:00:00,640
department

1710
01:00:04,069 --> 01:00:02,559
and he was one of my mentors when i went

1711
01:00:06,230 --> 01:00:04,079
to princeton

1712
01:00:07,589 --> 01:00:06,240
i got excellent advice about research

1713
01:00:09,109 --> 01:00:07,599

from him he was a mentor to many

1714
01:00:11,430 --> 01:00:09,119
students not just me

1715
01:00:13,430 --> 01:00:11,440
and so because he knew albert einstein

1716
01:00:15,510 --> 01:00:13,440
he is my one degree of separation from

1717
01:00:18,230 --> 01:00:15,520
albert einstein

1718
01:00:19,589 --> 01:00:18,240
as a student and later a postdoc at

1719
01:00:22,789 --> 01:00:19,599
princeton i met

1720
01:00:25,190 --> 01:00:22,799
freeman dyson john wheeler

1721
01:00:26,789 --> 01:00:25,200
and lyman spitzer i'm in with an

1722
01:00:28,230 --> 01:00:26,799
emeritus professor in our department all

1723
01:00:29,750 --> 01:00:28,240
four of them had met einstein new

1724
01:00:32,069 --> 01:00:29,760
einstein when he was

1725
01:00:33,829 --> 01:00:32,079
a professor at the institute for

1726
01:00:36,150 --> 01:00:33,839
advanced study so i have not one but

1727
01:00:38,390 --> 01:00:36,160
four one degrees of separation to albert

1728
01:00:41,829 --> 01:00:38,400
einstein thanks to martin

1729
01:00:43,750 --> 01:00:41,839
freeman john wheeler and lyman lyman

1730
01:00:46,950 --> 01:00:43,760
spitzer

1731
01:00:48,710 --> 01:00:46,960
now here's another person uh with whom i

1732
01:00:49,430 --> 01:00:48,720
feel one degree of separation stephen

1733
01:00:52,390 --> 01:00:49,440
hawking

1734
01:00:54,309 --> 01:00:52,400
whose excellent work explained how

1735
01:00:56,309 --> 01:00:54,319
radiation can actually

1736
01:00:57,910 --> 01:00:56,319
escape from a black hole not just a

1737
01:00:59,430 --> 01:00:57,920
one-way street things can escape from a

1738
01:01:01,270 --> 01:00:59,440

black hole hawking radiation

1739
01:01:02,710 --> 01:01:01,280
i had the privilege of going to one of

1740
01:01:04,069 --> 01:01:02,720
stephen hawking's talk right here in

1741
01:01:07,030 --> 01:01:04,079
santa clara where i live in

1742
01:01:08,390 --> 01:01:07,040
in santa clara county and california and

1743
01:01:10,470 --> 01:01:08,400
this connection was again through one

1744
01:01:11,270 --> 01:01:10,480
degree of separation my ucsc colleague

1745
01:01:13,750 --> 01:01:11,280
doug lynn

1746
01:01:14,630 --> 01:01:13,760
was a colleague of stephen hawkings in

1747
01:01:17,190 --> 01:01:14,640
cambridge

1748
01:01:19,430 --> 01:01:17,200
and doug got an invitation to stephen

1749
01:01:19,990 --> 01:01:19,440
hawking's talk so i got to listen to him

1750
01:01:21,589 --> 01:01:20,000
in person

1751
01:01:23,030 --> 01:01:21,599
we breathed in the same oxygen and

1752
01:01:27,510 --> 01:01:23,040
nitrogen breathed out the same

1753
01:01:29,589 --> 01:01:27,520
carbon dioxide in the same room um

1754
01:01:31,109 --> 01:01:29,599
there were people who touched me even

1755
01:01:36,870 --> 01:01:31,119
more

1756
01:01:37,990 --> 01:01:36,880
very reuben or the four i showed earlier

1757
01:01:41,030 --> 01:01:38,000
very ruben the discoverer

1758
01:01:43,349 --> 01:01:41,040
of dark matter and galaxies was actively

1759
01:01:45,510 --> 01:01:43,359
searching for dark matter in galaxies

1760
01:01:48,150 --> 01:01:45,520
when i was a starting graduate student

1761
01:01:49,589 --> 01:01:48,160
and she was an amazing mentor kind

1762
01:01:50,950 --> 01:01:49,599
gentle soul

1763
01:01:53,349 --> 01:01:50,960

i was a starting graduate student

1764
01:01:56,390 --> 01:01:53,359
studying the rotation curves of galaxies

1765
01:01:58,230 --> 01:01:56,400
in the virgo cluster and vera was really

1766
01:02:00,069 --> 01:01:58,240
kind took me under a wing and she was

1767
01:02:02,150 --> 01:02:00,079
she was doing her own studies but

1768
01:02:03,750 --> 01:02:02,160
uh really made me feel at home in in the

1769
01:02:05,990 --> 01:02:03,760
field of astronomy

1770
01:02:07,510 --> 01:02:06,000
uh subramanyam chandrasekhar imaged in

1771
01:02:10,630 --> 01:02:07,520
the middle he was a

1772
01:02:11,510 --> 01:02:10,640
famous famous astronomer who uh went

1773
01:02:14,549 --> 01:02:11,520
from india

1774
01:02:17,270 --> 01:02:14,559
to the uk first on his uh

1775
01:02:18,390 --> 01:02:17,280
voyage in the ship he worked out the

1776
01:02:20,069 --> 01:02:18,400
physics of

1777
01:02:21,910 --> 01:02:20,079
what later came to be known as neutron

1778
01:02:24,710 --> 01:02:21,920
stars um

1779
01:02:26,470 --> 01:02:24,720
went on to a illustrious career at the

1780
01:02:28,710 --> 01:02:26,480
university of chicago

1781
01:02:30,230 --> 01:02:28,720
illustrious beyond belief he had he got

1782
01:02:32,390 --> 01:02:30,240
the nobel prize

1783
01:02:34,549 --> 01:02:32,400
but even well before he got this nobel

1784
01:02:37,750 --> 01:02:34,559
prize he had phd students

1785
01:02:40,630 --> 01:02:37,760
in physics chemistry and mathematics

1786
01:02:43,270 --> 01:02:40,640
he was a polymath he was able to advise

1787
01:02:47,670 --> 01:02:43,280
phd thesis in all three subjects

1788
01:02:50,870 --> 01:02:47,680

one of his astronomy phds guido monk

1789
01:02:52,630 --> 01:02:50,880
went on to a faculty position at rice

1790
01:02:55,510 --> 01:02:52,640
university

1791
01:02:57,829 --> 01:02:55,520
guido had phd students at rice one of

1792
01:02:58,789 --> 01:02:57,839
his phd students very illustrious phd

1793
01:03:01,670 --> 01:02:58,799
student

1794
01:03:03,829 --> 01:03:01,680
jim gunn went on to become a professor

1795
01:03:08,069 --> 01:03:03,839
first at caltech then at princeton

1796
01:03:11,109 --> 01:03:08,079
and i was one of jim's phd students

1797
01:03:14,710 --> 01:03:11,119
so chandrasekhar is my great great

1798
01:03:15,430 --> 01:03:14,720
grand thesis advisor i had the privilege

1799
01:03:18,390 --> 01:03:15,440
of meeting him

1800
01:03:19,990 --> 01:03:18,400
in princeton i had lunch with him um

1801
01:03:20,870 --> 01:03:20,000
grad students and i had lunch with him

1802
01:03:23,430 --> 01:03:20,880
and again

1803
01:03:25,109 --> 01:03:23,440
it's these people whose journeys whose

1804
01:03:27,829 --> 01:03:25,119
amazing minds

1805
01:03:29,829 --> 01:03:27,839
um have left a bigger impression on me

1806
01:03:31,670 --> 01:03:29,839
than anything i've studied in astronomy

1807
01:03:32,549 --> 01:03:31,680
finally mother teresa this is an oil

1808
01:03:33,910 --> 01:03:32,559
painting that i

1809
01:03:35,750 --> 01:03:33,920
it's very close to my heart an oil

1810
01:03:38,870 --> 01:03:35,760
painting i did of mother teresa

1811
01:03:40,950 --> 01:03:38,880
in 2007 10 years after her death

1812
01:03:43,510 --> 01:03:40,960
she's someone i met for all of 10

1813
01:03:45,910 --> 01:03:43,520

seconds no words exchanged but

1814
01:03:46,549 --> 01:03:45,920
met her one one on one for about 10

1815
01:03:48,789 --> 01:03:46,559
seconds

1816
01:03:50,630 --> 01:03:48,799
in uh in one of her orphanages in

1817
01:03:53,829 --> 01:03:50,640
calcutta

1818
01:03:55,829 --> 01:03:53,839
so with this let me come back and close

1819
01:03:57,109 --> 01:03:55,839
up my science story

1820
01:03:59,109 --> 01:03:57,119
i've been talking about the darkest

1821
01:04:02,069 --> 01:03:59,119
secrets of the universe what one of the

1822
01:04:03,270 --> 01:04:02,079
universe's darkest secrets was sort of

1823
01:04:05,990 --> 01:04:03,280
reserved

1824
01:04:06,950 --> 01:04:06,000
held in suspension for us for the

1825
01:04:11,270 --> 01:04:06,960
longest time

1826
01:04:16,069 --> 01:04:11,280
it's only in 2015 that the first

1827
01:04:19,190 --> 01:04:16,079
detection of ripples of gravitation

1828
01:04:20,950 --> 01:04:19,200
through the universe 2015 a hundred

1829
01:04:23,190 --> 01:04:20,960
years after einstein predicted

1830
01:04:25,270 --> 01:04:23,200
gravitational waves in 1915 they were

1831
01:04:27,990 --> 01:04:25,280
finally detected why did it

1832
01:04:29,910 --> 01:04:28,000
take so long it took so long because it

1833
01:04:34,950 --> 01:04:29,920
takes

1834
01:04:38,829 --> 01:04:34,960
immense precision hard work

1835
01:04:41,510 --> 01:04:38,839
years of years of hard work

1836
01:04:43,589 --> 01:04:41,520
self-belief and

1837
01:04:44,950 --> 01:04:43,599
what i'm reminded of i'm a huge sports

1838
01:04:48,230 --> 01:04:44,960

fan what i'm reminded of

1839
01:04:53,670 --> 01:04:48,240
is this man over here precision

1840
01:04:56,870 --> 01:04:55,670
he is someone's this is steph curry he's

1841
01:04:59,510 --> 01:04:56,880
risen above

1842
01:05:01,109 --> 01:04:59,520
the sport he's risen about his team the

1843
01:05:03,270 --> 01:05:01,119
golden state warriors risen above the

1844
01:05:05,190 --> 01:05:03,280
sport of basketball

1845
01:05:06,309 --> 01:05:05,200
risen above sports altogether in the

1846
01:05:08,789 --> 01:05:06,319
same way

1847
01:05:10,630 --> 01:05:08,799
this discovery of gravitational waves

1848
01:05:12,470 --> 01:05:10,640
while it was part of science was bigger

1849
01:05:14,309 --> 01:05:12,480
than science itself

1850
01:05:16,069 --> 01:05:14,319
what i mean by that is people who never

1851
01:05:17,349 --> 01:05:16,079
pay attention to science or rarely pay

1852
01:05:20,230 --> 01:05:17,359
attention to science

1853
01:05:21,190 --> 01:05:20,240
got up and took notice of the universe's

1854
01:05:23,990 --> 01:05:21,200
vibrations

1855
01:05:24,549 --> 01:05:24,000
being heard by us dark secrets being

1856
01:05:27,670 --> 01:05:24,559
heard

1857
01:05:31,829 --> 01:05:27,680
not seen by humanity

1858
01:05:33,670 --> 01:05:31,839
it took very fancy apparatus like this

1859
01:05:35,270 --> 01:05:33,680
ligo the laser interferometric

1860
01:05:36,390 --> 01:05:35,280
gravitational observatory this is a

1861
01:05:39,029 --> 01:05:36,400
schematic

1862
01:05:41,670 --> 01:05:39,039
this is an aerial view i won't go into

1863
01:05:44,789 --> 01:05:41,680

the details of it except to say

1864
01:05:47,670 --> 01:05:44,799
this was the magic moment in 2015

1865
01:05:48,230 --> 01:05:47,680
where the first chirp gravitational

1866
01:05:50,069 --> 01:05:48,240
chirp

1867
01:05:53,190 --> 01:05:50,079
due to the merger of two black holes was

1868
01:05:55,910 --> 01:05:53,200
heard in the two bottom panels

1869
01:05:57,270 --> 01:05:55,920
are theoretical predictions and the two

1870
01:05:59,670 --> 01:05:57,280
upper panels

1871
01:06:00,950 --> 01:05:59,680
are the signals signals received in

1872
01:06:03,990 --> 01:06:00,960
hanford washington

1873
01:06:05,589 --> 01:06:04,000
and livingston louisiana received within

1874
01:06:07,670 --> 01:06:05,599
a short while of each other because it

1875
01:06:09,029 --> 01:06:07,680
was finite light travel time between the

1876
01:06:11,270 --> 01:06:09,039
two

1877
01:06:12,309 --> 01:06:11,280
locations and this really was the first

1878
01:06:15,349 --> 01:06:12,319
detection

1879
01:06:17,910 --> 01:06:15,359
of gravity waves and it's the first time

1880
01:06:19,670 --> 01:06:17,920
humanity was hearing not just seeing the

1881
01:06:22,789 --> 01:06:19,680
universe

1882
01:06:25,750 --> 01:06:22,799
it's an incredibly subtle

1883
01:06:27,589 --> 01:06:25,760
signal um the signal of this

1884
01:06:31,029 --> 01:06:27,599
gravitational

1885
01:06:34,230 --> 01:06:31,039
um oscillation you know the entire

1886
01:06:37,670 --> 01:06:34,240
four kilometer baseline its length

1887
01:06:40,950 --> 01:06:37,680
changed by an amount that's 100

1888
01:06:43,510 --> 01:06:40,960

the diameter of a proton

1889
01:06:44,870 --> 01:06:43,520
again the four kilometer baseline of the

1890
01:06:47,029 --> 01:06:44,880
ligo array

1891
01:06:49,510 --> 01:06:47,039
oscillated by with an amplitude that's

1892
01:06:50,549 --> 01:06:49,520
100 the diameter not of an atom but of a

1893
01:06:52,309 --> 01:06:50,559
proton

1894
01:06:54,230 --> 01:06:52,319
in other words the distance between us

1895
01:06:56,549 --> 01:06:54,240
and alpha centauri

1896
01:06:57,829 --> 01:06:56,559
oscillated by an amount that's the

1897
01:07:00,309 --> 01:06:57,839
breadth of human hair

1898
01:07:01,910 --> 01:07:00,319
it's an incredibly subtle measurement

1899
01:07:03,589 --> 01:07:01,920
it's remarkable to

1900
01:07:05,589 --> 01:07:03,599
the wonderful engineers and scientists

1901
01:07:09,349 --> 01:07:05,599
who made this possible

1902
01:07:11,029 --> 01:07:09,359
um in 2017 two years later you know

1903
01:07:12,870 --> 01:07:11,039
one of my colleagues at uc santa cruz

1904
01:07:13,990 --> 01:07:12,880
and indeed other astronomers around the

1905
01:07:16,470 --> 01:07:14,000
world

1906
01:07:18,069 --> 01:07:16,480
not only heard a chirp this time this

1907
01:07:20,230 --> 01:07:18,079
time it was a chirp due to two emerging

1908
01:07:21,109 --> 01:07:20,240
neutron stars the kind chandrasekhar had

1909
01:07:23,270 --> 01:07:21,119
studied

1910
01:07:24,549 --> 01:07:23,280
but they also saw the flash of light

1911
01:07:26,309 --> 01:07:24,559
they not only heard the chirp of the

1912
01:07:28,309 --> 01:07:26,319
bird they saw the proverbial bird fly

1913
01:07:30,630 --> 01:07:28,319

away so they were able to connect

1914
01:07:31,910 --> 01:07:30,640
the sense of hearing or sensing of

1915
01:07:33,990 --> 01:07:31,920
gravitational waves to

1916
01:07:35,270 --> 01:07:34,000
electromagnetic radiation another

1917
01:07:36,950 --> 01:07:35,280
miracle moment

1918
01:07:38,710 --> 01:07:36,960
now i've been talking about galaxies and

1919
01:07:41,990 --> 01:07:38,720
black holes a lot in this

1920
01:07:43,270 --> 01:07:42,000
very last segment of my talk i want to

1921
01:07:45,750 --> 01:07:43,280
leave you with

1922
01:07:47,430 --> 01:07:45,760
how galaxies came into being i hope i've

1923
01:07:49,510 --> 01:07:47,440
convinced you that you know we living

1924
01:07:51,190 --> 01:07:49,520
things rely on complex molecules

1925
01:07:53,510 --> 01:07:51,200
these complex molecules have to be

1926
01:07:55,910 --> 01:07:53,520
synthesized from stardust

1927
01:07:57,270 --> 01:07:55,920
stardust only happens if you're part of

1928
01:07:59,349 --> 01:07:57,280
a massive galaxy

1929
01:08:00,870 --> 01:07:59,359
so we owe our existence to the fact that

1930
01:08:02,710 --> 01:08:00,880
we live in a massive galaxy

1931
01:08:04,630 --> 01:08:02,720
but where did galaxies come from and the

1932
01:08:07,910 --> 01:08:04,640
answer will take us to the earliest

1933
01:08:09,589 --> 01:08:07,920
moments in the history of the universe

1934
01:08:11,910 --> 01:08:09,599
it'll actually take us back to something

1935
01:08:13,990 --> 01:08:11,920
called quantum fluctuations

1936
01:08:15,670 --> 01:08:14,000
in the early universe now if you're

1937
01:08:17,910 --> 01:08:15,680
wondering what quantum fluctuations

1938
01:08:19,510 --> 01:08:17,920

are don't worry i'm not about to give

1939
01:08:20,870 --> 01:08:19,520
you a lesson in quantum mechanics for

1940
01:08:21,430 --> 01:08:20,880
one thing i couldn't give you that

1941
01:08:22,870 --> 01:08:21,440
lesson

1942
01:08:24,789 --> 01:08:22,880
my knowledge of quantum mechanics isn't

1943
01:08:25,590 --> 01:08:24,799
good enough to do that but what i will

1944
01:08:28,550 --> 01:08:25,600
give you

1945
01:08:29,829 --> 01:08:28,560
is a description of an experiment called

1946
01:08:32,950 --> 01:08:29,839
the schrodinger's

1947
01:08:34,709 --> 01:08:32,960
cat experiment now this was a duncan

1948
01:08:37,189 --> 01:08:34,719
experiment a thought experiment that

1949
01:08:38,950 --> 01:08:37,199
schrolinger thought up he said you know

1950
01:08:40,789 --> 01:08:38,960
the quantum

1951
01:08:42,870 --> 01:08:40,799
uncertainty which was you know very

1952
01:08:44,470 --> 01:08:42,880
popular uh about 100

1953
01:08:46,070 --> 01:08:44,480
you know came into popularity a little

1954
01:08:47,349 --> 01:08:46,080
over 100 years ago

1955
01:08:50,550 --> 01:08:47,359
surely that was one of the drivers of

1956
01:08:53,910 --> 01:08:50,560
this heisenberg boar

1957
01:08:55,590 --> 01:08:53,920
they said you know the world of atoms

1958
01:08:57,749 --> 01:08:55,600
microscopic world of atoms is governed

1959
01:08:59,669 --> 01:08:57,759
by chance you know a probability

1960
01:09:02,070 --> 01:08:59,679
if you put radioactive material like you

1961
01:09:04,870 --> 01:09:02,080
see in this test tube here

1962
01:09:06,390 --> 01:09:04,880
there's a 50 chance that one alpha

1963
01:09:06,709 --> 01:09:06,400

particle will be emitted in the next

1964
01:09:09,349 --> 01:09:06,719
hour

1965
01:09:10,149 --> 01:09:09,359
50 chance so if you set it up in a box

1966
01:09:11,910 --> 01:09:10,159
like this

1967
01:09:13,269 --> 01:09:11,920
there's a 50 chance that an alpha

1968
01:09:15,430 --> 01:09:13,279
particle will go

1969
01:09:16,709 --> 01:09:15,440
and the geiger counter is set up so that

1970
01:09:18,070 --> 01:09:16,719
instead of beeping

1971
01:09:20,149 --> 01:09:18,080
there'll be a hammer that'll fall on a

1972
01:09:21,590 --> 01:09:20,159
bottle of cyanide that'll kill the poor

1973
01:09:25,910 --> 01:09:21,600
cat that you put in the box

1974
01:09:27,749 --> 01:09:25,920
but there's also a 50 chance that the

1975
01:09:29,590 --> 01:09:27,759
alpha particle won't be emitted the cat

1976
01:09:31,749 --> 01:09:29,600
will be alive so

1977
01:09:33,829 --> 01:09:31,759
this is a thought experiment saying that

1978
01:09:34,709 --> 01:09:33,839
if you set it up such that there's a 50

1979
01:09:36,550 --> 01:09:34,719
probability

1980
01:09:38,390 --> 01:09:36,560
and you set up say a thousand boxes with

1981
01:09:41,510 --> 01:09:38,400
a thousand each with a cat inside

1982
01:09:45,189 --> 01:09:41,520
you couldn't predict beforehand which

1983
01:09:47,269 --> 01:09:45,199
of these is going to be

1984
01:09:48,630 --> 01:09:47,279
the live cat box which of these are

1985
01:09:49,749 --> 01:09:48,640
going to be dead cat boxes which of

1986
01:09:51,829 --> 01:09:49,759
these are going to end up

1987
01:09:54,149 --> 01:09:51,839
like this versus like this you cannot

1988
01:09:57,270 --> 01:09:54,159

predict so the so the uncertainty

1989
01:10:00,390 --> 01:09:57,280
in the nature of quantum

1990
01:10:00,870 --> 01:10:00,400
physics translates to the macroscopic

1991
01:10:04,229 --> 01:10:00,880
world

1992
01:10:05,830 --> 01:10:04,239
of the cat and the cat's owner now

1993
01:10:07,590 --> 01:10:05,840
remember this experiment was a thought

1994
01:10:09,590 --> 01:10:07,600
experiment no animals were harmed in the

1995
01:10:11,830 --> 01:10:09,600
making of this experiment

1996
01:10:13,510 --> 01:10:11,840
however this experiment was never

1997
01:10:13,990 --> 01:10:13,520
carried out that's why no animals were

1998
01:10:15,830 --> 01:10:14,000
harmed

1999
01:10:17,350 --> 01:10:15,840
the universe went ahead and carried out

2000
01:10:19,430 --> 01:10:17,360
its own version

2001
01:10:21,110 --> 01:10:19,440
of the schrodinger cat experiment

2002
01:10:23,189 --> 01:10:21,120
shortly after the big bang there were

2003
01:10:24,630 --> 01:10:23,199
quantum fluctuations you see a timeline

2004
01:10:26,709 --> 01:10:24,640
of the universe on the x-axis

2005
01:10:28,390 --> 01:10:26,719
shortly after the big bang there were

2006
01:10:30,709 --> 01:10:28,400
quantum fluctuations

2007
01:10:32,790 --> 01:10:30,719
that got blown up just just like the

2008
01:10:34,790 --> 01:10:32,800
geiger counter takes the alpha particle

2009
01:10:36,390 --> 01:10:34,800
and creates a macroscopic signal

2010
01:10:37,990 --> 01:10:36,400
in the form of a beep or a falling

2011
01:10:39,669 --> 01:10:38,000
hammer the

2012
01:10:42,390 --> 01:10:39,679
inflation a very rapid period of

2013
01:10:45,430 --> 01:10:42,400

expansion shortly after the big bang

2014
01:10:47,830 --> 01:10:45,440
makes this transition from microscopic

2015
01:10:50,470 --> 01:10:47,840
quantum fluctuations to macroscopic

2016
01:10:52,870 --> 01:10:50,480
fluctuations in the fabric of space-time

2017
01:10:53,750 --> 01:10:52,880
gravity then takes over and makes the

2018
01:10:55,510 --> 01:10:53,760
rich richer

2019
01:10:57,990 --> 01:10:55,520
poor poorer over time to produce

2020
01:11:01,669 --> 01:10:58,000
galaxies the way that happens

2021
01:11:04,790 --> 01:11:01,679
is really over a long period of time

2022
01:11:05,510 --> 01:11:04,800
but this schrodinger scat experiment

2023
01:11:08,870 --> 01:11:05,520
that

2024
01:11:11,990 --> 01:11:08,880
is not hypothetical

2025
01:11:14,470 --> 01:11:12,000
we can now see the afterglow in the

2026
01:11:16,870 --> 01:11:14,480
afterglow of the big bang we can see the

2027
01:11:17,830 --> 01:11:16,880
imprint of these tiny quantum

2028
01:11:19,430 --> 01:11:17,840
fluctuations

2029
01:11:20,870 --> 01:11:19,440
and i'm going to play this movie so you

2030
01:11:22,870 --> 01:11:20,880
can see this

2031
01:11:24,070 --> 01:11:22,880
globe that you see this sphere that you

2032
01:11:27,110 --> 01:11:24,080
see spinning

2033
01:11:27,830 --> 01:11:27,120
is an actual map a radio map microwave

2034
01:11:29,910 --> 01:11:27,840
map

2035
01:11:30,950 --> 01:11:29,920
off the afterglow from the big bang and

2036
01:11:33,350 --> 01:11:30,960
you can see

2037
01:11:34,630 --> 01:11:33,360
that it's not uniformly um it's not

2038
01:11:35,830 --> 01:11:34,640

uniformly the same temperature there are

2039
01:11:39,350 --> 01:11:35,840
tiny fluctuations

2040
01:11:42,550 --> 01:11:39,360
it's these fluctuations that um

2041
01:11:45,030 --> 01:11:42,560
started out as the seeds of galaxies

2042
01:11:46,870 --> 01:11:45,040
gravity then took over you see the tiny

2043
01:11:49,669 --> 01:11:46,880
fluctuations early on

2044
01:11:50,070 --> 01:11:49,679
but gravity acts on them you'll see that

2045
01:11:53,189 --> 01:11:50,080
the

2046
01:11:53,990 --> 01:11:53,199
tiny up fluctuations get even richer and

2047
01:11:55,910 --> 01:11:54,000
richer over time

2048
01:11:57,430 --> 01:11:55,920
the tiny down fluctuations the parts

2049
01:12:00,070 --> 01:11:57,440
that were poorer than average

2050
01:12:00,630 --> 01:12:00,080
get completely emptied out and over a

2051
01:12:02,790 --> 01:12:00,640
period

2052
01:12:04,229 --> 01:12:02,800
of a long time over billions of years

2053
01:12:07,270 --> 01:12:04,239
you see time counting up

2054
01:12:09,270 --> 01:12:07,280
on the on the

2055
01:12:10,790 --> 01:12:09,280
upper right that's time in billions of

2056
01:12:12,070 --> 01:12:10,800
years giga years billions of years

2057
01:12:15,590 --> 01:12:12,080
that's a quarter of a billion

2058
01:12:19,590 --> 01:12:15,600
yes and the scale bar at the bottom 500

2059
01:12:22,709 --> 01:12:19,600
kiloparsecs that's about

2060
01:12:24,790 --> 01:12:22,719
one and a half million

2061
01:12:26,709 --> 01:12:24,800
light years that's what that scale bar

2062
01:12:28,229 --> 01:12:26,719
is so a little smaller than the under

2063
01:12:30,550 --> 01:12:28,239

about half the andromeda milky way

2064
01:12:32,709 --> 01:12:30,560
distance what you're seeing form here

2065
01:12:33,669 --> 01:12:32,719
is through the moderated gravity of dark

2066
01:12:37,110 --> 01:12:33,679
matter

2067
01:12:38,870 --> 01:12:37,120
collision you've seen the formation of a

2068
01:12:41,430 --> 01:12:38,880
galaxy like the milky way

2069
01:12:43,510 --> 01:12:41,440
so i know i'm i've been speaking for a

2070
01:12:44,310 --> 01:12:43,520
long time so let me wrap up my story by

2071
01:12:45,830 --> 01:12:44,320
saying

2072
01:12:47,990 --> 01:12:45,840
here's an image of the afterglow from

2073
01:12:50,550 --> 01:12:48,000
the big bang in it you can see

2074
01:12:51,189 --> 01:12:50,560
you know hot spots and cold spots the in

2075
01:12:58,310 --> 01:12:51,199
the

2076
01:13:01,590 --> 01:12:58,320
you can be sure

2077
01:13:02,790 --> 01:13:01,600
that this would have led to a an infant

2078
01:13:04,630 --> 01:13:02,800
galaxy

2079
01:13:07,350 --> 01:13:04,640
whose cannibalism over time would have

2080
01:13:09,669 --> 01:13:07,360
produced a massive galaxy

2081
01:13:11,990 --> 01:13:09,679
within which there were wonderful fields

2082
01:13:14,550 --> 01:13:12,000
of stars some of which exploded

2083
01:13:16,070 --> 01:13:14,560
and produced wonderful elements during

2084
01:13:17,110 --> 01:13:16,080
the lifetimes of these stars disperse

2085
01:13:20,229 --> 01:13:17,120
these elements

2086
01:13:22,550 --> 01:13:20,239
so that complex elements could get into

2087
01:13:23,510 --> 01:13:22,560
stars and planets next generation stars

2088
01:13:25,189 --> 01:13:23,520

and planets

2089
01:13:26,950 --> 01:13:25,199
on which there were complex molecules

2090
01:13:30,070 --> 01:13:26,960
and wonderful life forms

2091
01:13:31,110 --> 01:13:30,080
that's my daughter and son and thank you

2092
01:13:32,470 --> 01:13:31,120
ladies and gentlemen

2093
01:13:37,110 --> 01:13:32,480
um it's been a wonderful journey thank

2094
01:13:44,229 --> 01:13:40,630
all right thank you raja that was um

2095
01:13:46,470 --> 01:13:44,239
quite the tour of the universe

2096
01:13:48,550 --> 01:13:46,480
uh you there's there's there's barely a

2097
01:13:51,669 --> 01:13:48,560
scale you didn't touch in that

2098
01:13:54,149 --> 01:13:51,679
and uh i think it asked one of our um

2099
01:13:54,950 --> 01:13:54,159
we had a great audience on on youtube

2100
01:13:56,709 --> 01:13:54,960
and one of them

2101
01:13:58,950 --> 01:13:56,719
you know like you covered so many things

2102
01:13:59,510 --> 01:13:58,960
and it was like do you have a favorite

2103
01:14:02,310 --> 01:13:59,520
amongst

2104
01:14:02,950 --> 01:14:02,320
all of those variety of scales that you

2105
01:14:05,350 --> 01:14:02,960
covered or

2106
01:14:06,709 --> 01:14:05,360
favorite celestial body amongst all of

2107
01:14:07,669 --> 01:14:06,719
them they were it was one of the

2108
01:14:10,229 --> 01:14:07,679
questions

2109
01:14:11,510 --> 01:14:10,239
okay i'm going to maybe i'll stop

2110
01:14:12,229 --> 01:14:11,520
sharing my screen while i answer

2111
01:14:15,510 --> 01:14:12,239
questions

2112
01:14:17,110 --> 01:14:15,520
sure um i like to say that the andromeda

2113
01:14:18,790 --> 01:14:17,120

galaxy is my favorite galaxy in the

2114
01:14:20,229 --> 01:14:18,800
whole world and that's a joke of course

2115
01:14:22,470 --> 01:14:20,239
because it's not in the world

2116
01:14:23,430 --> 01:14:22,480
um but uh if i had to pick one favorite

2117
01:14:25,189 --> 01:14:23,440
thing

2118
01:14:27,510 --> 01:14:25,199
every time i see the andromeda galaxy it

2119
01:14:29,030 --> 01:14:27,520
feels like home that's right

2120
01:14:30,470 --> 01:14:29,040
was it was one of those lunches at the

2121
01:14:31,990 --> 01:14:30,480
institute for advanced study when you

2122
01:14:34,630 --> 01:14:32,000
unfurled the uh

2123
01:14:36,390 --> 01:14:34,640
six foot long poster it was a nine foot

2124
01:14:39,110 --> 01:14:36,400
a three foot by nine foot poster i still

2125
01:14:40,709 --> 01:14:39,120
have that in my office

2126
01:14:42,550 --> 01:14:40,719
i do remember that that was that was

2127
01:14:44,390 --> 01:14:42,560
quite the moment all right

2128
01:14:46,070 --> 01:14:44,400
so um i've been monitoring some of the

2129
01:14:47,910 --> 01:14:46,080
questions but grant justice has been

2130
01:14:50,070 --> 01:14:47,920
monitoring a little bit better than i am

2131
01:14:51,669 --> 01:14:50,080
so grant why don't you turn on your

2132
01:14:55,189 --> 01:14:51,679
video and join us and help

2133
01:14:57,430 --> 01:14:55,199
moderate the questions absolutely

2134
01:14:58,630 --> 01:14:57,440
thank you frank you've got your nasa

2135
01:15:01,910 --> 01:14:58,640
pajamas on today

2136
01:15:04,550 --> 01:15:01,920
i do yeah gotta bring back the old

2137
01:15:08,630 --> 01:15:07,430
all right so um yeah our chat has been

2138
01:15:11,430 --> 01:15:08,640

quite active

2139
01:15:13,030 --> 01:15:11,440
thank you for the phenomenal talk

2140
01:15:16,229 --> 01:15:13,040
everyone's been

2141
01:15:18,470 --> 01:15:16,239
as excited as we have been about this so

2142
01:15:19,910 --> 01:15:18,480
um frank already got the first question

2143
01:15:22,950 --> 01:15:19,920
that i wrote down because

2144
01:15:25,390 --> 01:15:22,960
grapevines think alike so um

2145
01:15:26,709 --> 01:15:25,400
another one is uh what will happen to

2146
01:15:31,830 --> 01:15:26,719
m33

2147
01:15:35,270 --> 01:15:33,910
that's a wonderful question wonderful

2148
01:15:36,790 --> 01:15:35,280
question and it's something we're

2149
01:15:40,630 --> 01:15:36,800
researching right now

2150
01:15:41,910 --> 01:15:40,640
um i won't have an answer for you for a

2151
01:15:43,030 --> 01:15:41,920
few more years

2152
01:15:44,790 --> 01:15:43,040
but one of the things we're trying to

2153
01:15:45,669 --> 01:15:44,800
measure right now with the hubble space

2154
01:15:47,030 --> 01:15:45,679
telescope

2155
01:15:48,870 --> 01:15:47,040
is we're trying to measure the lateral

2156
01:15:51,189 --> 01:15:48,880
motion of m33

2157
01:15:52,390 --> 01:15:51,199
you know we know it's line of sight

2158
01:15:55,669 --> 01:15:52,400
motion if you think of

2159
01:15:57,750 --> 01:15:55,679
x y and z as three axes if the plane of

2160
01:16:00,229 --> 01:15:57,760
the sky is x and y

2161
01:16:02,550 --> 01:16:00,239
we know the z component of n33 is motion

2162
01:16:03,830 --> 01:16:02,560
we know it's moving towards us at 180

2163
01:16:05,590 --> 01:16:03,840

kilometers per second it's moving

2164
01:16:06,950 --> 01:16:05,600
towards the sun at that speed

2165
01:16:08,709 --> 01:16:06,960
and ramadan is moving towards it's at

2166
01:16:12,630 --> 01:16:08,719
300 kilometers per second

2167
01:16:15,750 --> 01:16:12,640
uh so we can see that m33

2168
01:16:17,189 --> 01:16:15,760
is both further away than andromeda but

2169
01:16:19,110 --> 01:16:17,199
also coming towards us

2170
01:16:20,470 --> 01:16:19,120
more slowly than andromeda so they're

2171
01:16:22,470 --> 01:16:20,480
going to separate

2172
01:16:24,550 --> 01:16:22,480
in time what we don't know at all about

2173
01:16:27,590 --> 01:16:24,560
m33 is how fast it's moving in

2174
01:16:28,470 --> 01:16:27,600
x and y and that's something we're

2175
01:16:31,030 --> 01:16:28,480
trying to measure

2176
01:16:33,669 --> 01:16:31,040
right now with repeat measurements with

2177
01:16:35,189 --> 01:16:33,679
hubble it's like watching

2178
01:16:36,790 --> 01:16:35,199
if you take an image with hubble and you

2179
01:16:39,669 --> 01:16:36,800
take another image 10 years

2180
01:16:41,110 --> 01:16:39,679
later you can see a slight creep in the

2181
01:16:42,790 --> 01:16:41,120
stars relative to the background

2182
01:16:45,430 --> 01:16:42,800
wallpaper of distant galaxies

2183
01:16:46,550 --> 01:16:45,440
it's like watching an insect crawl very

2184
01:16:48,630 --> 01:16:46,560
slowly across

2185
01:16:49,990 --> 01:16:48,640
the wallpaper on your wall if you have

2186
01:16:51,910 --> 01:16:50,000
pattern wallpaper

2187
01:16:53,270 --> 01:16:51,920
you can see it if your wall is painted a

2188
01:16:54,870 --> 01:16:53,280

flat white it's very hard to see it

2189
01:16:56,790 --> 01:16:54,880
so we're using the background galaxies

2190
01:16:57,750 --> 01:16:56,800
that are behind frank right now in his

2191
01:16:59,990 --> 01:16:57,760
virtual screen

2192
01:17:01,590 --> 01:17:00,000
we're using those background galaxies as

2193
01:17:03,350 --> 01:17:01,600
the cosmic wallpaper against which to

2194
01:17:05,910 --> 01:17:03,360
measure the motion of

2195
01:17:07,350 --> 01:17:05,920
stars now it's a very subtle notion it's

2196
01:17:07,830 --> 01:17:07,360
like watching human hair grow on the

2197
01:17:10,550 --> 01:17:07,840
moon

2198
01:17:11,510 --> 01:17:10,560
that's that's how subtle it is but

2199
01:17:17,270 --> 01:17:11,520
measurable

2200
01:17:17,990 --> 01:17:17,280
i think was the 2012 press release we

2201
01:17:21,350 --> 01:17:18,000
did on

2202
01:17:22,070 --> 01:17:21,360
the milky way andromeda one um gertina

2203
01:17:24,790 --> 01:17:22,080
besla

2204
01:17:26,870 --> 01:17:24,800
uh and roland van demar did simulations

2205
01:17:28,070 --> 01:17:26,880
that they included m33

2206
01:17:30,390 --> 01:17:28,080
but you're telling me that they really

2207
01:17:32,390 --> 01:17:30,400
didn't have good um full spatial motion

2208
01:17:34,390 --> 01:17:32,400
for m33 at that time

2209
01:17:35,750 --> 01:17:34,400
because correct their simulations in

2210
01:17:38,709 --> 01:17:35,760
their suite of simulations

2211
01:17:39,990 --> 01:17:38,719
about 20 percent of the time m-33 became

2212
01:17:43,750 --> 01:17:40,000
part of the

2213
01:17:44,149 --> 01:17:43,760

resulting collision no that's exactly

2214
01:17:46,390 --> 01:17:44,159
right

2215
01:17:47,910 --> 01:17:46,400
um and uh you know those simulations

2216
01:17:51,590 --> 01:17:47,920
were fantastic uh

2217
01:17:55,030 --> 01:17:53,110
routine is part of the team that's

2218
01:17:56,950 --> 01:17:55,040
trying to measure the lateral motion of

2219
01:17:58,630 --> 01:17:56,960
m33 for exactly these reasons we can

2220
01:18:01,990 --> 01:17:58,640
print it down then

2221
01:18:04,470 --> 01:18:02,000
in addition to the milky way andromeda

2222
01:18:06,790 --> 01:18:04,480
collision there's also the question of

2223
01:18:08,149 --> 01:18:06,800
what has m33 been up to in the past you

2224
01:18:10,149 --> 01:18:08,159
know if you know which way it's going

2225
01:18:12,070 --> 01:18:10,159
now you can tell where it's come from

2226
01:18:13,830 --> 01:18:12,080
and where it's going to be in the future

2227
01:18:16,870 --> 01:18:13,840
so we want to understand a little bit

2228
01:18:19,110 --> 01:18:16,880
about um whether m33 has been

2229
01:18:20,709 --> 01:18:19,120
a good child or a bad child a good

2230
01:18:21,590 --> 01:18:20,719
galaxy or a bad galaxy in terms of what

2231
01:18:24,870 --> 01:18:21,600
neighborhood it's been

2232
01:18:25,990 --> 01:18:24,880
in in the past okay grant another

2233
01:18:27,910 --> 01:18:26,000
question

2234
01:18:29,510 --> 01:18:27,920
sure um i'll take just a second and

2235
01:18:31,030 --> 01:18:29,520
address this one because we always get

2236
01:18:32,390 --> 01:18:31,040
this every week in the chat about a

2237
01:18:35,110 --> 01:18:32,400
million times

2238
01:18:36,390 --> 01:18:35,120

we have a couple of public lectures on

2239
01:18:38,550 --> 01:18:36,400
dark matter

2240
01:18:41,270 --> 01:18:38,560
um i would suggest checking those out

2241
01:18:44,950 --> 01:18:41,280
through the playlist for public lectures

2242
01:18:46,790 --> 01:18:44,960
um we we know we have many questions and

2243
01:18:48,709 --> 01:18:46,800
many answers but we also do them every

2244
01:18:50,470 --> 01:18:48,719
week so i would recommend checking out

2245
01:18:51,990 --> 01:18:50,480
some of those previous programs for

2246
01:18:55,110 --> 01:18:52,000
those because we go into depth that we

2247
01:18:56,709 --> 01:18:55,120
won't be able to go into now

2248
01:18:58,470 --> 01:18:56,719
several questions on the nature of dark

2249
01:19:01,750 --> 01:18:58,480
matter and dark energy today

2250
01:19:03,990 --> 01:19:01,760
yeah which won't bother you with raja

2251
01:19:05,110 --> 01:19:04,000
yeah we love the interest but we've done

2252
01:19:06,470 --> 01:19:05,120
it a couple times and we will

2253
01:19:08,790 --> 01:19:06,480
undoubtedly do it again

2254
01:19:12,070 --> 01:19:08,800
so um i will say one thing though about

2255
01:19:14,790 --> 01:19:12,080
dark matter and dark energy

2256
01:19:16,580 --> 01:19:14,800
dark matter sucks but dark energy is

2257
01:19:20,470 --> 01:19:16,590
truly repulsive

2258
01:19:21,830 --> 01:19:20,480
[Laughter]

2259
01:19:23,830 --> 01:19:21,840
observable but that doesn't mean you

2260
01:19:25,430 --> 01:19:23,840
have to like it like

2261
01:19:26,350 --> 01:19:25,440
no i literally mean it sucks since

2262
01:19:29,030 --> 01:19:26,360
gravity sucks

2263
01:19:31,189 --> 01:19:29,040

[Laughter]

2264
01:19:32,790 --> 01:19:31,199
all right so here's one that i like and

2265
01:19:36,390 --> 01:19:32,800
um we can talk about this

2266
01:19:39,830 --> 01:19:36,400
is how will jwst

2267
01:19:42,229 --> 01:19:39,840
slash roman impact the way that you are

2268
01:19:44,470 --> 01:19:42,239
doing your studies or what kind of new

2269
01:19:46,790 --> 01:19:44,480
observations or data

2270
01:19:48,390 --> 01:19:46,800
might you get that can further your

2271
01:19:50,709 --> 01:19:48,400
research

2272
01:19:52,149 --> 01:19:50,719
that's an excellent question um you know

2273
01:19:55,430 --> 01:19:52,159
the first round of

2274
01:19:56,630 --> 01:19:55,440
proposals uh to use the james webb space

2275
01:19:58,070 --> 01:19:56,640
telescope has

2276
01:19:59,910 --> 01:19:58,080
already gone in there was an early

2277
01:20:02,149 --> 01:19:59,920
release science observations that are

2278
01:20:04,390 --> 01:20:02,159
have already been approved but the cycle

2279
01:20:07,830 --> 01:20:04,400
one of the proposals happened

2280
01:20:10,629 --> 01:20:07,840
late last year i'm on

2281
01:20:12,229 --> 01:20:10,639
six of those teams a couple of them are

2282
01:20:16,629 --> 01:20:12,239
to study

2283
01:20:19,669 --> 01:20:16,639
the details of andromeda

2284
01:20:21,030 --> 01:20:19,679
one of those is to study very detailed

2285
01:20:24,470 --> 01:20:21,040
star formation

2286
01:20:26,709 --> 01:20:24,480
in the triangulum galaxy m33

2287
01:20:28,310 --> 01:20:26,719
some of them are one of them is to study

2288
01:20:29,430 --> 01:20:28,320

detail dark matter substructure in

2289
01:20:32,629 --> 01:20:29,440
distant galaxies

2290
01:20:34,390 --> 01:20:32,639
so jwst is you know like

2291
01:20:35,910 --> 01:20:34,400
any piece of modern technology and this

2292
01:20:36,629 --> 01:20:35,920
is a spectacular piece of modern

2293
01:20:38,310 --> 01:20:36,639
technology

2294
01:20:42,310 --> 01:20:38,320
it's really going to advance the field

2295
01:20:45,750 --> 01:20:44,229
and the roman space telescope you

2296
01:20:48,950 --> 01:20:45,760
mentioned in um

2297
01:20:51,510 --> 01:20:48,960
in discussing andromeda that being a

2298
01:20:54,310 --> 01:20:51,520
survey instrument it's going to get

2299
01:20:54,709 --> 01:20:54,320
you know 100 what is 320 million pixels

2300
01:20:57,830 --> 01:20:54,719
per

2301
01:20:58,709 --> 01:20:57,840
image at hubble resolution so this is

2302
01:21:01,189 --> 01:20:58,719
going to

2303
01:21:02,470 --> 01:21:01,199
you know allow us to gain a tremendous

2304
01:21:04,390 --> 01:21:02,480
amount of data

2305
01:21:06,550 --> 01:21:04,400
relatively quickly that and it's all

2306
01:21:09,830 --> 01:21:06,560
going to be non-proprietary so

2307
01:21:12,950 --> 01:21:09,840
it'll be open to the entire astronomical

2308
01:21:15,110 --> 01:21:12,960
community to go at that data

2309
01:21:16,390 --> 01:21:15,120
and you know really it's it's good it's

2310
01:21:19,910 --> 01:21:16,400
gonna

2311
01:21:22,070 --> 01:21:19,920
computers warm at night how about that

2312
01:21:23,830 --> 01:21:22,080
processing and analyzing it i think

2313
01:21:25,110 --> 01:21:23,840

roman will be fantastic not just for

2314
01:21:26,870 --> 01:21:25,120
andromeda and triangular it'll be

2315
01:21:29,030 --> 01:21:26,880
fantastic for the virgo cluster

2316
01:21:30,950 --> 01:21:29,040
i'm particularly excited about studying

2317
01:21:31,990 --> 01:21:30,960
star clusters globular star clusters in

2318
01:21:36,229 --> 01:21:32,000
virgo that's

2319
01:21:38,149 --> 01:21:36,239
going to be an amazing roman application

2320
01:21:39,669 --> 01:21:38,159
very much so and between the new

2321
01:21:42,310 --> 01:21:39,679
observations and

2322
01:21:44,229 --> 01:21:42,320
the double-blind studies that we do now

2323
01:21:46,470 --> 01:21:44,239
for science proposals and whatnot

2324
01:21:48,070 --> 01:21:46,480
like the merits coming from the actual

2325
01:21:49,750 --> 01:21:48,080
science themselves and not where people

2326
01:21:51,110 --> 01:21:49,760
come from or their universities or the

2327
01:21:51,990 --> 01:21:51,120
background and that sort of thing in

2328
01:21:54,629 --> 01:21:52,000
addition to

2329
01:21:56,070 --> 01:21:54,639
a lot of the new information especially

2330
01:21:57,510 --> 01:21:56,080
the larger breadth

2331
01:21:59,990 --> 01:21:57,520
of infrared light that we'll be able to

2332
01:22:01,750 --> 01:22:00,000
see with jwst coming so soon like

2333
01:22:04,310 --> 01:22:01,760
there's a lot of potential for us to

2334
01:22:07,669 --> 01:22:04,320
delve a lot deeper

2335
01:22:09,750 --> 01:22:07,679
especially into emissions and uh

2336
01:22:12,229 --> 01:22:09,760
like atmospheres for exoplanets but for

2337
01:22:13,669 --> 01:22:12,239
black holes there's definitely a lot

2338
01:22:17,910 --> 01:22:13,679

more spectrum that you're going to be

2339
01:22:21,270 --> 01:22:19,590
grant i do want to pick up on one thing

2340
01:22:22,709 --> 01:22:21,280
you just said which is

2341
01:22:25,030 --> 01:22:22,719
something that space telescope's been

2342
01:22:27,910 --> 01:22:25,040
such a leader in which is

2343
01:22:28,550 --> 01:22:27,920
this double-blind process of being fair

2344
01:22:31,990 --> 01:22:28,560
in

2345
01:22:34,149 --> 01:22:32,000
it's really been a

2346
01:22:36,709 --> 01:22:34,159
leader in science for this it's to say

2347
01:22:39,030 --> 01:22:36,719
that the power of your storytelling

2348
01:22:40,550 --> 01:22:39,040
in that proposal is what should get you

2349
01:22:42,550 --> 01:22:40,560
telescope time

2350
01:22:44,149 --> 01:22:42,560
not where you've been for the last 25

2351
01:22:46,390 --> 01:22:44,159
years or what institution you

2352
01:22:48,550 --> 01:22:46,400
are or aren't at whether you're male or

2353
01:22:49,910 --> 01:22:48,560
female what the color of your skin is

2354
01:22:51,910 --> 01:22:49,920
none of these things should matter the

2355
01:22:52,550 --> 01:22:51,920
power of your storytelling divorced from

2356
01:22:53,910 --> 01:22:52,560
your name

2357
01:22:55,669 --> 01:22:53,920
divorced from all other personal

2358
01:22:56,790 --> 01:22:55,679
identity is what should get you

2359
01:22:57,510 --> 01:22:56,800
telescope time and that's been a

2360
01:23:00,950 --> 01:22:57,520
wonderful

2361
01:23:02,950 --> 01:23:00,960
led i just want to applaud that

2362
01:23:04,229 --> 01:23:02,960
and i will note that nasa has adopted

2363
01:23:06,229 --> 01:23:04,239

that for all of their

2364
01:23:07,750 --> 01:23:06,239
uh peer review systems now going forward

2365
01:23:10,149 --> 01:23:07,760
so that's wonderful

2366
01:23:11,590 --> 01:23:10,159
it's great that it was a great it's a

2367
01:23:13,189 --> 01:23:11,600
great advancement

2368
01:23:16,149 --> 01:23:13,199
we should all be judged by the content

2369
01:23:19,669 --> 01:23:18,229
all right so i think i've got one last

2370
01:23:19,990 --> 01:23:19,679
question i'm getting a couple in the

2371
01:23:22,790 --> 01:23:20,000
chat

2372
01:23:24,470 --> 01:23:22,800
here and i feel like that's a reasonable

2373
01:23:26,950 --> 01:23:24,480
reasonable place to wrap up

2374
01:23:27,669 --> 01:23:26,960
okay is that okay or do we have time for

2375
01:23:30,550 --> 01:23:27,679
a couple more

2376
01:23:31,750 --> 01:23:30,560
we got at least one more let's okay so

2377
01:23:34,149 --> 01:23:31,760
um

2378
01:23:36,229 --> 01:23:34,159
oh here's a good personal one how do the

2379
01:23:37,270 --> 01:23:36,239
telescopes in chile compare with the

2380
01:23:46,149 --> 01:23:37,280
telescopes

2381
01:23:48,390 --> 01:23:46,159
these mountain tops of course and

2382
01:23:49,990 --> 01:23:48,400
there are many mountain tops in chile as

2383
01:23:51,270 --> 01:23:50,000
well many mountain tops in hawaii i

2384
01:23:54,470 --> 01:23:51,280
suppose there's

2385
01:23:55,510 --> 01:23:54,480
haleakala as well as mauna kea houses

2386
01:23:57,990 --> 01:23:55,520
telescopes

2387
01:23:58,629 --> 01:23:58,000
um i've i've been privileged enough to

2388
01:24:02,149 --> 01:23:58,639

use

2389
01:24:05,189 --> 01:24:02,159
two mountain tops in chile tololo

2390
01:24:08,390 --> 01:24:05,199
and and las campanas

2391
01:24:11,350 --> 01:24:08,400
and they are different

2392
01:24:13,990 --> 01:24:11,360
in the sense that in one case you're

2393
01:24:15,110 --> 01:24:14,000
surrounded by the ocean

2394
01:24:17,270 --> 01:24:15,120
when you're on mauna kea you're

2395
01:24:18,870 --> 01:24:17,280
surrounded by the ocean and i would have

2396
01:24:22,709 --> 01:24:18,880
to say that the

2397
01:24:25,750 --> 01:24:22,719
laminar flow of air over mauna kea

2398
01:24:27,350 --> 01:24:25,760
is in my experience unparalleled

2399
01:24:30,870 --> 01:24:27,360
uh compared to the other observatories

2400
01:24:33,270 --> 01:24:30,880
i've been to chile

2401
01:24:35,350 --> 01:24:33,280
tololo in particular is about the

2402
01:24:36,550 --> 01:24:35,360
darkest place i've ever been in i

2403
01:24:40,950 --> 01:24:36,560
remember

2404
01:24:42,790 --> 01:24:40,960
walking out during a night moon had set

2405
01:24:45,030 --> 01:24:42,800
i was walking from one observatory to

2406
01:24:46,950 --> 01:24:45,040
the other and

2407
01:24:48,870 --> 01:24:46,960
people told me if you look carefully you

2408
01:24:52,229 --> 01:24:48,880
can see your own shadow cast by

2409
01:24:55,270 --> 01:24:52,239
jupiter it's no

2410
01:24:56,470 --> 01:24:55,280
so each observatory you know the dryness

2411
01:24:59,669 --> 01:24:56,480
the clear skies

2412
01:25:01,750 --> 01:24:59,679
of chile spectacular the darkness

2413
01:25:03,510 --> 01:25:01,760

spectacular sadly these things are

2414
01:25:05,430 --> 01:25:03,520
changing with time as human civilization

2415
01:25:06,790 --> 01:25:05,440
encroaches more and more into the

2416
01:25:09,430 --> 01:25:06,800
into the pristine environment these

2417
01:25:12,390 --> 01:25:09,440
things are changing all the time

2418
01:25:13,590 --> 01:25:12,400
any budding uh young astronomers or new

2419
01:25:15,669 --> 01:25:13,600
telescope

2420
01:25:16,950 --> 01:25:15,679
users i always say like be careful of

2421
01:25:18,950 --> 01:25:16,960
your light pollution because you don't

2422
01:25:20,310 --> 01:25:18,960
think about it but like

2423
01:25:21,830 --> 01:25:20,320
if you're in the middle of a city it

2424
01:25:24,950 --> 01:25:21,840
doesn't matter how good your telescope

2425
01:25:27,990 --> 01:25:24,960
is to a certain point like

2426
01:25:30,790 --> 01:25:28,000
yeah location location location okay

2427
01:25:31,189 --> 01:25:30,800
so any last one any last questions for

2428
01:25:35,270 --> 01:25:31,199
us

2429
01:25:36,950 --> 01:25:35,280
grant um i'm seeing a few but most of

2430
01:25:39,910 --> 01:25:36,960
them still talking about

2431
01:25:40,390 --> 01:25:39,920
uh either galaxy collision or dark

2432
01:25:42,229 --> 01:25:40,400
matter

2433
01:25:44,149 --> 01:25:42,239
there was there was one i i see here all

2434
01:25:45,910 --> 01:25:44,159
right okay so they wanted to correlate

2435
01:25:48,709 --> 01:25:45,920
two of the things you talked about

2436
01:25:51,189 --> 01:25:48,719
um the milky way andromeda collision and

2437
01:25:53,750 --> 01:25:51,199
the detection of gravitational waves

2438
01:25:55,030 --> 01:25:53,760

would we expect that the collision of

2439
01:26:00,070 --> 01:25:55,040
galaxies

2440
01:26:03,750 --> 01:26:01,750
they do create gravitational waves of

2441
01:26:05,189 --> 01:26:03,760
course any kind of change like that but

2442
01:26:07,430 --> 01:26:05,199
it's not detectable

2443
01:26:09,669 --> 01:26:07,440
in the foreseeable future you need

2444
01:26:12,229 --> 01:26:09,679
things to be much more compact

2445
01:26:13,669 --> 01:26:12,239
and much more intense the gravitational

2446
01:26:14,950 --> 01:26:13,679
field has to be much more intense you

2447
01:26:16,950 --> 01:26:14,960
really need supermassive

2448
01:26:19,030 --> 01:26:16,960
you need black holes or neutron stars

2449
01:26:20,790 --> 01:26:19,040
colliding with current technology and

2450
01:26:24,070 --> 01:26:20,800
for the foreseeable future

2451
01:26:25,350 --> 01:26:24,080
the the gravity waves produced by galaxy

2452
01:26:27,350 --> 01:26:25,360
collisions

2453
01:26:28,870 --> 01:26:27,360
just by the entire bodies of galaxies

2454
01:26:30,470 --> 01:26:28,880
colliding is way too weak

2455
01:26:32,310 --> 01:26:30,480
the black holes at their centers of

2456
01:26:33,910 --> 01:26:32,320
course are likely to emerge and that

2457
01:26:35,910 --> 01:26:33,920
will lead to gravity waves so

2458
01:26:37,750 --> 01:26:35,920
yes there's a link through that

2459
01:26:39,270 --> 01:26:37,760
mechanism but since the

2460
01:26:41,350 --> 01:26:39,280
collision itself isn't going to happen

2461
01:26:41,830 --> 01:26:41,360
for like four billion years and then you

2462
01:26:43,270 --> 01:26:41,840
know

2463
01:26:45,030 --> 01:26:43,280

getting those black holes together it'll

2464
01:26:47,350 --> 01:26:45,040
take another few billion years

2465
01:26:49,270 --> 01:26:47,360
uh we're unlikely or even even our

2466
01:26:51,430 --> 01:26:49,280
graduate students are unlikely to still

2467
01:26:52,629 --> 01:26:51,440
be astronomers at that time

2468
01:26:53,990 --> 01:26:52,639
on the other hand we have a lot of time

2469
01:26:56,470 --> 01:26:54,000
to build this brand new technology

2470
01:27:02,310 --> 01:27:00,149
true all right well thank you grant

2471
01:27:04,229 --> 01:27:02,320
uh for monitoring it was an incredibly

2472
01:27:05,110 --> 01:27:04,239
active chat thank you to all of our

2473
01:27:07,430 --> 01:27:05,120
watchers

2474
01:27:09,750 --> 01:27:07,440
for making that chat so active and most

2475
01:27:13,510 --> 01:27:09,760
of all thank you to raja for

2476
01:27:15,350 --> 01:27:13,520
a wonderful talk a wide ranging talk

2477
01:27:16,950 --> 01:27:15,360
if you want to know more about the milky

2478
01:27:19,750 --> 01:27:16,960
way andromeda collision

2479
01:27:21,830 --> 01:27:19,760
well then join us on february 2nd

2480
01:27:23,510 --> 01:27:21,840
groundhog day when laura pritchard from

2481
01:27:25,669 --> 01:27:23,520
the space telescope science institute

2482
01:27:28,149 --> 01:27:25,679
will give a complete talk about that and

2483
01:27:28,950 --> 01:27:28,159
she'll go into all sorts of details on

2484
01:27:31,750 --> 01:27:28,960
that

2485
01:27:32,950 --> 01:27:31,760
so thank you all for coming tonight and