PUBLIC LECTURE SERIES

Understanding the Formation and Evolution of Galaxies

Featuring Guest Speaker: Cameron Hummels

1
00:00:07,430 --> 00:00:04,550
welcome to the space telescope public

2
00:00:09,270 --> 00:00:07,440
lecture series tonight's talk

3
00:00:12,629 --> 00:00:09,280
understanding the formation and

4
00:00:15,350 --> 00:00:12,639
evolution of galaxies by cameron hummels

5
00:00:18,230 --> 00:00:15,360
of cal tech

6
00:00:20,950 --> 00:00:18,240
i'm dr frank summers your host and as

7
00:00:25,509 --> 00:00:20,960
always i want to thank our amazing tech

8
00:00:27,750 --> 00:00:25,519
team thomas marufu and grant justice

9
00:00:30,630 --> 00:00:27,760
our upcoming talks

10
00:00:33,110 --> 00:00:30,640
in july on july 5th

11
00:00:35,030 --> 00:00:33,120
we will have exoplanets orbital

12
00:00:37,030 --> 00:00:35,040
mechanics and

13
00:00:39,430 --> 00:00:37,040

the death star

14
00:00:41,830 --> 00:00:39,440
by mia boval of texas christian

15
00:00:44,229 --> 00:00:41,840
university actually she might change her

16
00:00:46,630 --> 00:00:44,239
topic by then this is just one she gave

17
00:00:48,470 --> 00:00:46,640
me as a placeholder we'll see what she

18
00:00:50,630 --> 00:00:48,480
actually comes up with but if she does

19
00:00:51,830 --> 00:00:50,640
do that it'll be it'll it'll be really

20
00:00:54,709 --> 00:00:51,840
cool

21
00:00:56,790 --> 00:00:54,719
on august 2nd we have the talk you've

22
00:00:58,869 --> 00:00:56,800
all been waiting for

23
00:01:01,910 --> 00:00:58,879
webb's first look

24
00:01:04,469 --> 00:01:01,920
images and spectra from nasa's newest

25
00:01:06,070 --> 00:01:04,479
great observatory alex lockwood from

26
00:01:07,030 --> 00:01:06,080
here at the space telescope science

27
00:01:09,190 --> 00:01:07,040
institute

28
00:01:11,270 --> 00:01:09,200
yes the james webb space telescope will

29
00:01:13,429 --> 00:01:11,280
be producing its it is currently

30
00:01:15,749 --> 00:01:13,439
producing its first images taking its

31
00:01:18,710 --> 00:01:15,759
first spectra you'll hear all about them

32
00:01:21,830 --> 00:01:18,720
on august 2nd okay here in the public

33
00:01:23,030 --> 00:01:21,840
lecture series on september 6th we have

34
00:01:25,429 --> 00:01:23,040
first light

35
00:01:29,030 --> 00:01:25,439
unveiling the properties of galaxies at

36
00:01:31,270 --> 00:01:29,040
cosmic dawn from guido robert sporsani

37
00:01:32,950 --> 00:01:31,280
at the university of california los

38
00:01:35,030 --> 00:01:32,960

angeles

39
00:01:38,590 --> 00:01:35,040
want to know about these things go to

40
00:01:43,190 --> 00:01:41,030
www.stsci dot

41
00:01:45,670 --> 00:01:43,200
public hyphen lectures

42
00:01:47,990 --> 00:01:45,680
or just look for space telescope public

43
00:01:50,550 --> 00:01:48,000
documentaries in your favorite uh search

44
00:01:53,030 --> 00:01:50,560
engine and you will find this page

45
00:01:55,910 --> 00:01:53,040
on the left you can see we have the

46
00:01:58,789 --> 00:01:55,920
links to our webcast both on the space

47
00:01:59,830 --> 00:01:58,799
telescope webcasting site as well as on

48
00:02:02,550 --> 00:01:59,840
youtube

49
00:02:04,069 --> 00:02:02,560
and on right we have a handy dandy

50
00:02:06,870 --> 00:02:04,079
little box where you can enter your

51
00:02:11,029 --> 00:02:06,880
email address push the subscribe button

52
00:02:13,110 --> 00:02:11,039
and you'll get our monthly emails

53
00:02:15,990 --> 00:02:13,120
also on the website we have of course

54
00:02:18,309 --> 00:02:16,000
links to our upcoming lectures as well

55
00:02:19,270 --> 00:02:18,319
as you can also look at our previous

56
00:02:20,630 --> 00:02:19,280
lectures

57
00:02:22,949 --> 00:02:20,640
and when you click on one of these

58
00:02:25,510 --> 00:02:22,959
lectures you get the full details

59
00:02:27,510 --> 00:02:25,520
including the description and if it's in

60
00:02:31,430 --> 00:02:27,520
the past you get a link to the space

61
00:02:33,670 --> 00:02:31,440
telescope webcast as well as the youtube

62
00:02:36,150 --> 00:02:33,680
recording of it

63
00:02:37,030 --> 00:02:36,160

for email the announcements as i said

64
00:02:40,150 --> 00:02:37,040
just

65
00:02:42,229 --> 00:02:40,160
uh sign up at our website uh you can

66
00:02:43,070 --> 00:02:42,239
also just subscribe to our youtube

67
00:02:46,070 --> 00:02:43,080
channel

68
00:02:47,830 --> 00:02:46,080
youtube.com slash hubble space telescope

69
00:02:50,070 --> 00:02:47,840
it's all one word

70
00:02:52,470 --> 00:02:50,080
um and when you subscribe you will get

71
00:02:54,390 --> 00:02:52,480
the notices of new videos and reminders

72
00:02:56,150 --> 00:02:54,400
of live events such as the one you're

73
00:02:57,830 --> 00:02:56,160
watching right now

74
00:02:59,910 --> 00:02:57,840
finally if you have comments or

75
00:03:04,120 --> 00:02:59,920
questions you can send them to the email

76
00:03:06,470 --> 00:03:04,130
address public lecture at stsci.edu

77
00:03:08,949 --> 00:03:06,480
[Music]

78
00:03:10,949 --> 00:03:08,959
for our social media we run the social

79
00:03:13,270 --> 00:03:10,959
media for the hubble space telescope for

80
00:03:15,750 --> 00:03:13,280
the web space telescope and another set

81
00:03:17,830 --> 00:03:15,760
of media for the space telescope science

82
00:03:20,390 --> 00:03:17,840
institute yes our social media team is a

83
00:03:22,790 --> 00:03:20,400
busy group uh they are on facebook

84
00:03:24,229 --> 00:03:22,800
they're on twitter on youtube and

85
00:03:26,869 --> 00:03:24,239
instagram

86
00:03:29,509 --> 00:03:26,879
in contrast i am not much of a social

87
00:03:31,750 --> 00:03:29,519
media person i'm not a busy busy person

88
00:03:34,229 --> 00:03:31,760

on this but if you want you can find me

89
00:03:36,789 --> 00:03:34,239
on facebook and twitter as dr frank

90
00:03:36,799 --> 00:03:42,470
our news from the universe for june 2022

91
00:03:49,030 --> 00:03:44,390
story tonight

92
00:03:49,750 --> 00:03:49,040
comet nuclei the largest of the small

93
00:03:51,830 --> 00:03:49,760
so

94
00:03:53,830 --> 00:03:51,840
when you think of a comet you should

95
00:03:56,229 --> 00:03:53,840
think of this

96
00:03:58,229 --> 00:03:56,239
however i know that i'm talking to the

97
00:04:00,630 --> 00:03:58,239
general public so when the general

98
00:04:03,270 --> 00:04:00,640
public thinks of a comet yeah they

99
00:04:04,869 --> 00:04:03,280
probably think of this

100
00:04:06,149 --> 00:04:04,879
it's going to crash it's going to hit

101
00:04:09,670 --> 00:04:06,159
the earth it's going to cause

102
00:04:10,869 --> 00:04:09,680
catastrophic planetary devastation

103
00:04:13,270 --> 00:04:10,879
um

104
00:04:15,589 --> 00:04:13,280
considering this has only happened once

105
00:04:17,509 --> 00:04:15,599
in the last 65 million years at least

106
00:04:18,550 --> 00:04:17,519
the planet to the planetary devastation

107
00:04:20,310 --> 00:04:18,560
phase

108
00:04:22,310 --> 00:04:20,320
it's probably not the first thing you

109
00:04:25,189 --> 00:04:22,320
should think of when you think of comets

110
00:04:27,030 --> 00:04:25,199
but hey it's what makes uh well it's

111
00:04:29,189 --> 00:04:27,040
what what hollywood likes because it's a

112
00:04:30,950 --> 00:04:29,199
it gives it a good plot line

113
00:04:34,629 --> 00:04:30,960

what you should be thinking of when you

114
00:04:36,469 --> 00:04:34,639
think of comets is this okay so this is

115
00:04:39,189 --> 00:04:36,479
comet hail bop

116
00:04:41,909 --> 00:04:39,199
um and you can see that it has a head to

117
00:04:44,390 --> 00:04:41,919
the comet and tails to the comet it

118
00:04:46,230 --> 00:04:44,400
actually has two different tails uh the

119
00:04:48,950 --> 00:04:46,240
dust tail which is pushed back by

120
00:04:51,350 --> 00:04:48,960
radiation pressure from the sun

121
00:04:54,070 --> 00:04:51,360
and the ion tail which is carried back

122
00:04:56,230 --> 00:04:54,080
by the magnetic fields in the

123
00:04:59,670 --> 00:04:56,240
solar wind so there are actually two

124
00:05:02,469 --> 00:04:59,680
tails to a comet um and the head you can

125
00:05:04,790 --> 00:05:02,479
see is pretty much fuzzy all right and

126
00:05:06,629 --> 00:05:04,800
that is what we call the coma

127
00:05:09,189 --> 00:05:06,639
and this is comet

128
00:05:12,550 --> 00:05:09,199
borisov observed by hubble and you can

129
00:05:14,390 --> 00:05:12,560
see by even with hubble's resolution

130
00:05:16,710 --> 00:05:14,400
you can still just see the fuzzy stuff

131
00:05:18,870 --> 00:05:16,720
okay this is way down deep inside that

132
00:05:20,950 --> 00:05:18,880
coma but it's still just fuzzy part of

133
00:05:23,749 --> 00:05:20,960
the coma all right

134
00:05:26,790 --> 00:05:23,759
in order to actually see what the comet

135
00:05:28,469 --> 00:05:26,800
really is the comet nucleus well you

136
00:05:30,710 --> 00:05:28,479
need to fly there

137
00:05:34,310 --> 00:05:30,720
this is from the giato mission

138
00:05:36,469 --> 00:05:34,320

in 1986 which flew past comet halley

139
00:05:38,550 --> 00:05:36,479
this is a wonderful picture of the

140
00:05:41,029 --> 00:05:38,560
nucleus of comet halley sometimes we

141
00:05:42,310 --> 00:05:41,039
call these giant snowballs

142
00:05:44,070 --> 00:05:42,320
and you can see that where the sun is

143
00:05:46,550 --> 00:05:44,080
hitting it on the left side

144
00:05:48,950 --> 00:05:46,560
uh the um

145
00:05:50,790 --> 00:05:48,960
the jets of material are evaporating

146
00:05:53,430 --> 00:05:50,800
away okay because the ices are

147
00:05:54,469 --> 00:05:53,440
sublimating and spraying away in these

148
00:05:57,270 --> 00:05:54,479
jets

149
00:05:59,909 --> 00:05:57,280
we have done this for several missions

150
00:06:01,189 --> 00:05:59,919
i have to say my favorite comet nucleus

151
00:06:04,830 --> 00:06:01,199
that we've seen

152
00:06:07,670 --> 00:06:04,840
uh is comet 67p cheerio mal

153
00:06:09,749 --> 00:06:07,680
gerasimenko which is only three miles

154
00:06:13,590 --> 00:06:09,759
across not very big

155
00:06:16,550 --> 00:06:13,600
but i like it because it's a contact

156
00:06:19,189 --> 00:06:16,560
binary all right you got two pieces and

157
00:06:21,350 --> 00:06:19,199
it earned it the nickname comet rubber

158
00:06:22,390 --> 00:06:21,360
ducky because it kind of looks like a

159
00:06:25,270 --> 00:06:22,400
rubber duck

160
00:06:27,510 --> 00:06:25,280
all right um so this montage was

161
00:06:30,230 --> 00:06:27,520
released a few years ago from somebody

162
00:06:33,350 --> 00:06:30,240
at nasa uh putting together all of the

163
00:06:35,189 --> 00:06:33,360

various um comets that we visited

164
00:06:37,590 --> 00:06:35,199
and you can see at least in this montage

165
00:06:39,670 --> 00:06:37,600
the biggest one here in the center

166
00:06:41,749 --> 00:06:39,680
is comet halley and that's only like

167
00:06:44,790 --> 00:06:41,759
nine miles across

168
00:06:46,350 --> 00:06:44,800
so now enter

169
00:06:50,629 --> 00:06:46,360
comet c

170
00:06:53,510 --> 00:06:50,639
2014 un271

171
00:06:56,070 --> 00:06:53,520
okay that's just the catalog name okay

172
00:06:59,270 --> 00:06:56,080
comments um are given names of their of

173
00:07:01,909 --> 00:06:59,280
their discoverers but really to

174
00:07:04,150 --> 00:07:01,919
their their catalog names are much more

175
00:07:07,029 --> 00:07:04,160
relevant for astronomy

176
00:07:09,909 --> 00:07:07,039
and so this comment was discovered in

177
00:07:11,749 --> 00:07:09,919
archival in archival images from the

178
00:07:14,150 --> 00:07:11,759
dark energy survey

179
00:07:16,390 --> 00:07:14,160
and what's really intriguing it was

180
00:07:17,749 --> 00:07:16,400
discovered when it was about 3 billion

181
00:07:19,670 --> 00:07:17,759
miles away

182
00:07:22,070 --> 00:07:19,680
and that's about the same distance as

183
00:07:23,990 --> 00:07:22,080
neptune is from the sun

184
00:07:26,790 --> 00:07:24,000
usually we don't see comets until they

185
00:07:28,870 --> 00:07:26,800
get inside the orbit of jupiter so this

186
00:07:32,070 --> 00:07:28,880
is way out there

187
00:07:34,870 --> 00:07:32,080
therefore it must be really big in order

188
00:07:36,629 --> 00:07:34,880

to be bright at such a large distance

189
00:07:38,790 --> 00:07:36,639
what we're looking at here are hubble

190
00:07:40,870 --> 00:07:38,800
observations and these came a little

191
00:07:43,270 --> 00:07:40,880
later when the comet had gotten to about

192
00:07:45,749 --> 00:07:43,280
2 billion miles away from the sun about

193
00:07:46,550 --> 00:07:45,759
the same distance as uranus is from the

194
00:07:48,950 --> 00:07:46,560
sun

195
00:07:50,150 --> 00:07:48,960
so this is you know this is a very

196
00:07:53,510 --> 00:07:50,160
bright comet

197
00:07:55,670 --> 00:07:53,520
but we also have improved our computer

198
00:07:56,869 --> 00:07:55,680
modeling all right so what they were

199
00:07:59,029 --> 00:07:56,879
able to do

200
00:08:02,710 --> 00:07:59,039
is take the hubble observation and from

201
00:08:05,670 --> 00:08:02,720
it create a model of the coma all that

202
00:08:08,150 --> 00:08:05,680
fuzzy gaseous stuff around the comet

203
00:08:10,230 --> 00:08:08,160
nucleus and then subtract that off from

204
00:08:12,629 --> 00:08:10,240
the observation to give us an

205
00:08:14,309 --> 00:08:12,639
approximation of what the emission from

206
00:08:16,869 --> 00:08:14,319
the nucleus looks like

207
00:08:19,350 --> 00:08:16,879
so this is an approximation due with

208
00:08:21,670 --> 00:08:19,360
computer modeling of the nucleus

209
00:08:23,830 --> 00:08:21,680
now is that big enough to be able to is

210
00:08:26,790 --> 00:08:23,840
that is that fine enough to be able to

211
00:08:28,790 --> 00:08:26,800
tell how big this nucleus is

212
00:08:31,110 --> 00:08:28,800
no actually not

213
00:08:33,350 --> 00:08:31,120

but if you combine it with radio

214
00:08:35,750 --> 00:08:33,360
telescope observations i believe these

215
00:08:38,389 --> 00:08:35,760
are from alma the atacama large

216
00:08:39,829 --> 00:08:38,399
millimeter array combine those

217
00:08:41,190 --> 00:08:39,839
observations with the hubble

218
00:08:42,709 --> 00:08:41,200
observations

219
00:08:46,070 --> 00:08:42,719
then you can get an estimate for the

220
00:08:49,430 --> 00:08:46,080
size of the nucleus and this they find

221
00:08:50,949 --> 00:08:49,440
is about 85 miles across

222
00:08:56,150 --> 00:08:50,959
so

223
00:09:00,150 --> 00:08:56,160
nucleuses all right and on the right we

224
00:09:02,710 --> 00:09:00,160
have uh c 2014 un-271

225
00:09:05,910 --> 00:09:02,720
uh in the middle you can see how bop was

226
00:09:06,790 --> 00:09:05,920
it uh expect uh estimated like 46 miles

227
00:09:09,430 --> 00:09:06,800
across

228
00:09:11,509 --> 00:09:09,440
um and on the left you see comet halley

229
00:09:13,509 --> 00:09:11,519
which this diagram says seven miles but

230
00:09:17,030 --> 00:09:13,519
everything i found online said nine

231
00:09:20,550 --> 00:09:17,040
miles so uh there's a discrepancy here

232
00:09:22,630 --> 00:09:20,560
and you may say 85 miles that's

233
00:09:27,350 --> 00:09:22,640
not that big still

234
00:09:30,310 --> 00:09:27,360
all right well it's big um it's actually

235
00:09:32,790 --> 00:09:30,320
bigger than the state of rhode island

236
00:09:35,110 --> 00:09:32,800
yes yes to scale that's the state of

237
00:09:37,590 --> 00:09:35,120
rhode island if you didn't know rhode

238
00:09:39,509 --> 00:09:37,600

island is only about 50 miles from top

239
00:09:41,990 --> 00:09:39,519
to bottom okay

240
00:09:45,350 --> 00:09:42,000
so we got comets that are bigger than

241
00:09:47,829 --> 00:09:45,360
the entire state of rhode island

242
00:09:50,389 --> 00:09:47,839
another important thing to do is make it

243
00:09:53,110 --> 00:09:50,399
a comparison of what

244
00:09:54,949 --> 00:09:53,120
uh what size comet you need to create

245
00:09:58,070 --> 00:09:54,959
that planetary devastation we talked

246
00:10:04,150 --> 00:09:58,080
about before okay so it says something

247
00:10:05,750 --> 00:10:04,160
about the size of uh comet c 2014 un271

248
00:10:09,110 --> 00:10:05,760
and it also says something about the

249
00:10:12,230 --> 00:10:09,120
size of rhode island okay um so it's

250
00:10:15,110 --> 00:10:12,240
looking at in that planetary devastation

251
00:10:17,110 --> 00:10:15,120
phase um there here's a little sign that

252
00:10:21,190 --> 00:10:17,120
says you must be this tall to cause

253
00:10:23,509 --> 00:10:21,200
planetary devastation uh the comet

254
00:10:27,110 --> 00:10:23,519
that uh the asteroid that hit in

255
00:10:29,190 --> 00:10:27,120
chixolube uh that caused that led to the

256
00:10:32,470 --> 00:10:29,200
downfall of the dinosaur 65 million

257
00:10:33,750 --> 00:10:32,480
years ago was about 10 to 15 kilometers

258
00:10:35,910 --> 00:10:33,760
across

259
00:10:38,630 --> 00:10:35,920
now that was an asteroid and asteroids

260
00:10:41,430 --> 00:10:38,640
are denser um and can have more mass per

261
00:10:43,829 --> 00:10:41,440
unit volume um some comets as we talked

262
00:10:46,949 --> 00:10:43,839
about as cameron just mentioned just are

263
00:10:48,150 --> 00:10:46,959

considered dirty snowballs and a little

264
00:10:51,110 --> 00:10:48,160
puffier

265
00:10:52,790 --> 00:10:51,120
less dense so we're not exactly sure how

266
00:10:55,190 --> 00:10:52,800
large of a comet you need to cause

267
00:10:57,509 --> 00:10:55,200
planetary devastation but

268
00:10:59,990 --> 00:10:57,519
here are it's this is the range of which

269
00:11:02,310 --> 00:11:00,000
they are and so these studies are

270
00:11:05,509 --> 00:11:02,320
important to understand just how big

271
00:11:07,030 --> 00:11:05,519
these comets can be um uh what was the

272
00:11:08,710 --> 00:11:07,040
initial

273
00:11:11,269 --> 00:11:08,720
distribution when the solar system

274
00:11:13,430 --> 00:11:11,279
formed four and a half billion years ago

275
00:11:15,509 --> 00:11:13,440
and it's a great collaboration using

276
00:11:17,750 --> 00:11:15,519
both the hubble space telescope and

277
00:11:20,389 --> 00:11:17,760
radio observatories on the ground to be

278
00:11:25,430 --> 00:11:20,399
able to measure these tiny tiny objects

279
00:11:31,750 --> 00:11:30,069
okay so our speaker tonight um i'm very

280
00:11:34,069 --> 00:11:31,760
happy to have him here

281
00:11:37,590 --> 00:11:34,079
you've already met him cameron hummels

282
00:11:41,590 --> 00:11:37,600
uh cameron uh got his phd at columbia

283
00:11:43,350 --> 00:11:41,600
university uh in new york city um and he

284
00:11:48,069 --> 00:11:43,360
has done post-docs at the university of

285
00:11:50,069 --> 00:11:48,079
arizona and is now at cal tech um as

286
00:11:53,030 --> 00:11:50,079
you'll see from him tonight he does

287
00:11:55,750 --> 00:11:53,040
galaxy formation simulations uh the kind

288
00:11:57,350 --> 00:11:55,760

of research i did 25 years ago

289
00:11:59,350 --> 00:11:57,360
when i was doing research before i

290
00:12:00,389 --> 00:11:59,360
turned my career to purely doing

291
00:12:02,790 --> 00:12:00,399
outreach

292
00:12:05,110 --> 00:12:02,800
but he also is working on not just the

293
00:12:06,550 --> 00:12:05,120
galaxy information but also the material

294
00:12:08,470 --> 00:12:06,560
around it what we call the circum

295
00:12:09,509 --> 00:12:08,480
galactic medium

296
00:12:11,750 --> 00:12:09,519
and it's one of the things that always

297
00:12:13,829 --> 00:12:11,760
intrigued me because i mean the visible

298
00:12:15,350 --> 00:12:13,839
galaxy is really kind of small and the

299
00:12:17,590 --> 00:12:15,360
material that's in falling because it

300
00:12:19,509 --> 00:12:17,600
never stops in falling is way out there

301
00:12:22,150 --> 00:12:19,519
and so he's doing really good uh

302
00:12:23,509 --> 00:12:22,160
simulations on that on visuals and

303
00:12:26,550 --> 00:12:23,519
understanding that

304
00:12:29,750 --> 00:12:26,560
he's also very much into doing outreach

305
00:12:31,910 --> 00:12:29,760
to the public uh while he was at uh

306
00:12:34,550 --> 00:12:31,920
columbia he served as the director of

307
00:12:36,470 --> 00:12:34,560
outreach um for columbia university and

308
00:12:38,069 --> 00:12:36,480
when he got to caltech he sort of

309
00:12:40,230 --> 00:12:38,079
created the position of director of

310
00:12:42,470 --> 00:12:40,240
outreach and put himself into it so i

311
00:12:46,230 --> 00:12:42,480
like people who appoint themselves uh

312
00:12:48,710 --> 00:12:46,240
head honcho on this uh he does a lot

313
00:12:51,030 --> 00:12:48,720

like we do public lecture series

314
00:12:53,269 --> 00:12:51,040
stuff he also does star gazing

315
00:12:55,910 --> 00:12:53,279
and he does astronomy on tap which will

316
00:12:58,060 --> 00:12:55,920
feature me as a payback for him doing my

317
00:13:00,870 --> 00:12:58,070
series i'm doing his series next week

318
00:13:02,790 --> 00:13:00,880
[Laughter]

319
00:13:04,829 --> 00:13:02,800
and i guess one last thing to say about

320
00:13:07,350 --> 00:13:04,839
him is he's heavily into

321
00:13:09,750 --> 00:13:07,360
outdoors um and

322
00:13:10,550 --> 00:13:09,760
in february which is what four months

323
00:13:12,629 --> 00:13:10,560
ago

324
00:13:14,550 --> 00:13:12,639
um he did

325
00:13:18,870 --> 00:13:14,560
170 miles

326
00:13:21,829 --> 00:13:18,880
across death valley in four days

327
00:13:23,910 --> 00:13:21,839
without any support he's not allowed to

328
00:13:26,069 --> 00:13:23,920
use roads he's not allowed to have food

329
00:13:27,990 --> 00:13:26,079
caches he's not allowed to have you know

330
00:13:31,110 --> 00:13:28,000
somebody come along and help him out and

331
00:13:33,590 --> 00:13:31,120
and do all stuff he had to do it solo as

332
00:13:37,670 --> 00:13:33,600
if he was the only person on earth and

333
00:13:39,189 --> 00:13:37,680
not only did he do it he set a record uh

334
00:13:41,750 --> 00:13:39,199
time so

335
00:13:43,990 --> 00:13:41,760
a man who has the endurance

336
00:13:45,910 --> 00:13:44,000
to get through anything even these

337
00:13:49,430 --> 00:13:45,920
technical glitches here

338
00:13:51,910 --> 00:13:49,440

ladies and gentlemen dr cameron hummels

339
00:13:54,710 --> 00:13:51,920
awesome thank you very much uh frank

340
00:13:57,750 --> 00:13:54,720
it's um it's my i'm really excited to be

341
00:13:59,910 --> 00:13:57,760
able to to talk to all of you about one

342
00:14:02,629 --> 00:13:59,920
of my passions which is uh galaxy

343
00:14:04,310 --> 00:14:02,639
evolution and hopefully i can convey

344
00:14:07,750 --> 00:14:04,320
some of what i find exciting to all of

345
00:14:10,150 --> 00:14:07,760
you in the next 45 minutes or so so uh

346
00:14:11,750 --> 00:14:10,160
thanks for this opportunity so as you're

347
00:14:13,509 --> 00:14:11,760
as you're seeing here this is a

348
00:14:15,350 --> 00:14:13,519
beautiful visualization of a

349
00:14:18,629 --> 00:14:15,360
supercomputing simulation done by my

350
00:14:22,790 --> 00:14:18,639
colleague dr nathan goldbaum at uc santa

351
00:14:25,829 --> 00:14:22,800
cruz um showcasing the evolution of a

352
00:14:28,550 --> 00:14:25,839
milky way like galaxy uh you can see a

353
00:14:30,870 --> 00:14:28,560
lot going on here it's for the most part

354
00:14:33,350 --> 00:14:30,880
all real scientific phenomena and

355
00:14:36,069 --> 00:14:33,360
realistic as to what one would see uh

356
00:14:37,750 --> 00:14:36,079
the one discrepancy is that time is

357
00:14:39,430 --> 00:14:37,760
passing really really quickly in this

358
00:14:41,590 --> 00:14:39,440
simulation relative to what it would be

359
00:14:43,189 --> 00:14:41,600
in reality about every second in the

360
00:14:45,829 --> 00:14:43,199
simulation is on the order of like 20

361
00:14:48,550 --> 00:14:45,839
million years passing so it's really

362
00:14:50,550 --> 00:14:48,560
evolving quite quickly but the white the

363
00:14:53,110 --> 00:14:50,560

white points represent individual stars

364
00:14:55,829 --> 00:14:53,120
the pink regions represent h2 regions

365
00:14:59,590 --> 00:14:55,839
that are ionized gas clouds surrounding

366
00:15:02,069 --> 00:14:59,600
uh supernovae and and um star-forming

367
00:15:04,150 --> 00:15:02,079
regions and this is yeah this is really

368
00:15:06,710 --> 00:15:04,160
a good representative

369
00:15:09,829 --> 00:15:06,720
like of what our milky way might look

370
00:15:12,389 --> 00:15:09,839
like as it evolves over time

371
00:15:15,590 --> 00:15:12,399
but let's start at the beginning uh

372
00:15:16,870 --> 00:15:15,600
before we get into galaxies per se and

373
00:15:18,470 --> 00:15:16,880
start with a little bit of history

374
00:15:20,310 --> 00:15:18,480
relative to what we've learned in the

375
00:15:21,910 --> 00:15:20,320
last you know few hundred years about

376
00:15:24,230 --> 00:15:21,920
galaxies and why we think we know what

377
00:15:26,470 --> 00:15:24,240
we know so first off i'll just give this

378
00:15:27,990 --> 00:15:26,480
general question to all of you guys

379
00:15:29,509 --> 00:15:28,000
what do we see when we look up in the

380
00:15:32,230 --> 00:15:29,519
night sky now this is normally when i

381
00:15:34,230 --> 00:15:32,240
ask people to shout out the responses uh

382
00:15:35,430 --> 00:15:34,240
but since i can't hear all of you i mean

383
00:15:37,189 --> 00:15:35,440
i guess i can look at the youtube

384
00:15:38,870 --> 00:15:37,199
comments but since i can't hear you i'm

385
00:15:40,870 --> 00:15:38,880
going to guess that you're shouting out

386
00:15:43,350 --> 00:15:40,880
things like

387
00:15:44,870 --> 00:15:43,360
uh stars stars are pretty obviously the

388
00:15:47,350 --> 00:15:44,880

things you see when you look up in the

389
00:15:49,670 --> 00:15:47,360
night sky also people might shout

390
00:15:51,910 --> 00:15:49,680
planets we see planets of course most of

391
00:15:53,670 --> 00:15:51,920
the planets the visible planets are are

392
00:15:56,150 --> 00:15:53,680
up in the early morning which is far too

393
00:15:58,389 --> 00:15:56,160
early for me right now um

394
00:16:02,069 --> 00:15:58,399
but we also see the milky way and

395
00:16:04,629 --> 00:16:02,079
hopefully you know i realize a large

396
00:16:06,230 --> 00:16:04,639
uh portion of the general population

397
00:16:09,269 --> 00:16:06,240
especially in western countries doesn't

398
00:16:11,430 --> 00:16:09,279
have the opportunity to go outside of a

399
00:16:12,949 --> 00:16:11,440
city and perhaps see from a dark sky

400
00:16:14,790 --> 00:16:12,959
site if you have the opportunity i

401
00:16:17,030 --> 00:16:14,800
highly recommend it and one of the

402
00:16:18,470 --> 00:16:17,040
things that's really majestic when you

403
00:16:20,470 --> 00:16:18,480
get in a dark sky site is the

404
00:16:23,189 --> 00:16:20,480
opportunity to see the milky way here

405
00:16:24,790 --> 00:16:23,199
you can see it uh kind of a glowing band

406
00:16:27,030 --> 00:16:24,800
across the sky this is from joshua tree

407
00:16:28,629 --> 00:16:27,040
national park near los angeles here this

408
00:16:32,230 --> 00:16:28,639
is a more representative view more

409
00:16:34,230 --> 00:16:32,240
all-sky view of that um and you can see

410
00:16:36,150 --> 00:16:34,240
that there's a lot of structure here but

411
00:16:38,949 --> 00:16:36,160
for the most part the name seems apt

412
00:16:40,790 --> 00:16:38,959
right the milky way looks like a band of

413
00:16:43,269 --> 00:16:40,800

milk across the sky

414
00:16:45,670 --> 00:16:43,279
um but make no mistake about it it's not

415
00:16:47,990 --> 00:16:45,680
milk it it's actually composed and this

416
00:16:50,629 --> 00:16:48,000
was understood reasonably early you know

417
00:16:52,629 --> 00:16:50,639
the last few hundred years that the band

418
00:16:55,670 --> 00:16:52,639
of light actually is composed of many

419
00:16:58,470 --> 00:16:55,680
many individual distant

420
00:17:01,269 --> 00:16:58,480
uh stars uh but because they're so far

421
00:17:02,550 --> 00:17:01,279
away and thus quite small on the sky and

422
00:17:05,590 --> 00:17:02,560
so numerous

423
00:17:07,270 --> 00:17:05,600
they they blend together into a band of

424
00:17:09,110 --> 00:17:07,280
light that looks like an extended light

425
00:17:10,069 --> 00:17:09,120
source like like milk

426
00:17:11,909 --> 00:17:10,079
and

427
00:17:13,829 --> 00:17:11,919
you can also see dark regions here these

428
00:17:16,630 --> 00:17:13,839
are dust lanes so it isn't that those

429
00:17:18,470 --> 00:17:16,640
regions are devoid of stars or starlight

430
00:17:20,069 --> 00:17:18,480
it's just that there's intervening dust

431
00:17:22,710 --> 00:17:20,079
that's absorbing the light between the

432
00:17:25,750 --> 00:17:22,720
background stars and us the viewer and

433
00:17:27,669 --> 00:17:25,760
gets absorbed along its way to us

434
00:17:29,270 --> 00:17:27,679
we also see this kind of behavior in

435
00:17:30,390 --> 00:17:29,280
other galaxies but i'm getting ahead of

436
00:17:32,070 --> 00:17:30,400
myself

437
00:17:34,789 --> 00:17:32,080
so this was an early representation

438
00:17:36,070 --> 00:17:34,799

before photographs of uh drawing because

439
00:17:37,350 --> 00:17:36,080
if you can't take a picture you do the

440
00:17:39,590 --> 00:17:37,360
best thing you you look through your

441
00:17:42,789 --> 00:17:39,600
telescope and you draw things of what

442
00:17:45,750 --> 00:17:42,799
our mil of the milky way uh looks like

443
00:17:47,510 --> 00:17:45,760
but more modern uh images like seen here

444
00:17:49,590 --> 00:17:47,520
on left by the gaia mission which has

445
00:17:51,830 --> 00:17:49,600
been operating for the last 10 10 or so

446
00:17:53,990 --> 00:17:51,840
years uh we can really see a lot of the

447
00:17:55,750 --> 00:17:54,000
structure in this and on it was

448
00:17:58,950 --> 00:17:55,760
understood quite early it was actually

449
00:18:02,070 --> 00:17:58,960
proposed by the philosopher emanuel kant

450
00:18:03,669 --> 00:18:02,080
um that the three-dimensional structure

451
00:18:05,510 --> 00:18:03,679
of our milky way is something like what

452
00:18:07,830 --> 00:18:05,520
you see on the right side where there's

453
00:18:10,470 --> 00:18:07,840
like a disc of material

454
00:18:12,789 --> 00:18:10,480
um with a with a bulge of material in

455
00:18:14,150 --> 00:18:12,799
the center and that we ourselves the the

456
00:18:16,470 --> 00:18:14,160
earth and the sun and the rest of the

457
00:18:18,789 --> 00:18:16,480
solar system are about halfway out in

458
00:18:20,070 --> 00:18:18,799
that disc and thus because we're present

459
00:18:22,789 --> 00:18:20,080
in the disc

460
00:18:24,630 --> 00:18:22,799
we we can't look down you know face on

461
00:18:26,950 --> 00:18:24,640
on the galaxy in the same way that we

462
00:18:30,789 --> 00:18:26,960
can in other galaxies but what we see is

463
00:18:32,710 --> 00:18:30,799

just this band of light across the sky

464
00:18:33,830 --> 00:18:32,720
and that three-dimensional structure has

465
00:18:36,230 --> 00:18:33,840
held up to

466
00:18:37,750 --> 00:18:36,240
to our observations of other galaxies

467
00:18:41,430 --> 00:18:37,760
and and seems

468
00:18:42,470 --> 00:18:41,440
seems like a reasonable representation

469
00:18:43,909 --> 00:18:42,480
okay so

470
00:18:45,350 --> 00:18:43,919
going back to the original question of

471
00:18:47,990 --> 00:18:45,360
what do we see when we look up in the

472
00:18:49,669 --> 00:18:48,000
night sky and tying in to what what uh

473
00:18:51,750 --> 00:18:49,679
frank was just discussing we see

474
00:18:53,510 --> 00:18:51,760
comments much like this comet that you

475
00:18:54,549 --> 00:18:53,520
can see here now

476
00:18:56,310 --> 00:18:54,559
um

477
00:18:57,830 --> 00:18:56,320
as you could tell from some of the

478
00:18:59,990 --> 00:18:57,840
naming schemes associated with the

479
00:19:02,630 --> 00:19:00,000
comets that frank was describing

480
00:19:04,630 --> 00:19:02,640
comets get named typically after the

481
00:19:06,870 --> 00:19:04,640
person who discovers them and so

482
00:19:09,590 --> 00:19:06,880
historically that was kind of a way that

483
00:19:11,590 --> 00:19:09,600
people could become famous by being the

484
00:19:13,510 --> 00:19:11,600
first to discover a comet and then

485
00:19:16,470 --> 00:19:13,520
having that comet named after themselves

486
00:19:18,390 --> 00:19:16,480
now in order to discover a comet like it

487
00:19:20,549 --> 00:19:18,400
has to be before other people have seen

488
00:19:23,110 --> 00:19:20,559

it by nature of you discovering it and

489
00:19:24,710 --> 00:19:23,120
and what that means is that it's not

490
00:19:26,070 --> 00:19:24,720
going to be big and bright because then

491
00:19:27,750 --> 00:19:26,080
it would be obvious and other people

492
00:19:29,590 --> 00:19:27,760
would have would have seen it probably

493
00:19:32,070 --> 00:19:29,600
before you so if you're going to be the

494
00:19:34,390 --> 00:19:32,080
first person to um

495
00:19:36,390 --> 00:19:34,400
identify a comet it's going to be very

496
00:19:37,990 --> 00:19:36,400
very faint in the outer solar system as

497
00:19:40,230 --> 00:19:38,000
it hasn't yet approached close enough to

498
00:19:42,789 --> 00:19:40,240
the sun to be bright um and it'll just

499
00:19:45,110 --> 00:19:42,799
be kind of a faint smudge that that

500
00:19:48,310 --> 00:19:45,120
isn't easily discernable by anyone but

501
00:19:50,470 --> 00:19:48,320
perhaps you now there was a comet hunter

502
00:19:52,390 --> 00:19:50,480
known as charles messier in the 18th

503
00:19:55,669 --> 00:19:52,400
century in france and he

504
00:19:56,470 --> 00:19:55,679
was determined to discover comets

505
00:19:57,990 --> 00:19:56,480
but

506
00:19:59,990 --> 00:19:58,000
it turns out that there are a lot of

507
00:20:01,909 --> 00:20:00,000
other things in the night sky that

508
00:20:03,909 --> 00:20:01,919
aren't uh

509
00:20:06,390 --> 00:20:03,919
comet like that aren't

510
00:20:08,549 --> 00:20:06,400
faint little blurry smudges on the sky

511
00:20:10,630 --> 00:20:08,559
that you can easily confuse with a comet

512
00:20:12,470 --> 00:20:10,640
the difference with a comet is uh it

513
00:20:15,029 --> 00:20:12,480

hasn't been seen in that location before

514
00:20:16,630 --> 00:20:15,039
and it will eventually move across the

515
00:20:18,310 --> 00:20:16,640
the sky relative to the background

516
00:20:20,390 --> 00:20:18,320
objects but these other objects that

517
00:20:23,750 --> 00:20:20,400
might be confused with a comet tend to

518
00:20:25,830 --> 00:20:23,760
stay put um and so essentially what's

519
00:20:27,909 --> 00:20:25,840
kind of ironic is that charles messier

520
00:20:30,390 --> 00:20:27,919
is not known for discovering comets he's

521
00:20:32,630 --> 00:20:30,400
known for identifying these non-comet

522
00:20:34,630 --> 00:20:32,640
objects that would be easily confused

523
00:20:35,909 --> 00:20:34,640
with being a comet

524
00:20:37,750 --> 00:20:35,919
and

525
00:20:40,149 --> 00:20:37,760
these sorts of objects are known as the

526
00:20:42,070 --> 00:20:40,159
messier list or the messier catalog and

527
00:20:43,830 --> 00:20:42,080
they're amongst the most beautiful and

528
00:20:45,909 --> 00:20:43,840
bright objects that you can see when you

529
00:20:48,149 --> 00:20:45,919
look through a telescope these are

530
00:20:50,470 --> 00:20:48,159
obviously modern images that are taken

531
00:20:52,070 --> 00:20:50,480
with modern technology but they reveal

532
00:20:53,350 --> 00:20:52,080
just some of the beauty associated with

533
00:20:55,590 --> 00:20:53,360
them so these are things like you may

534
00:20:58,870 --> 00:20:55,600
have heard of the orion nebula or the

535
00:21:01,350 --> 00:20:58,880
pleiades cluster or the hercules cluster

536
00:21:03,270 --> 00:21:01,360
or the ring nebula and and

537
00:21:05,190 --> 00:21:03,280
again if you have the opportunity to get

538
00:21:06,950 --> 00:21:05,200

to a dark sky-ish site and look through

539
00:21:08,310 --> 00:21:06,960
a telescope you'll probably be looking

540
00:21:10,070 --> 00:21:08,320
at one of these objects because they're

541
00:21:11,430 --> 00:21:10,080
really spectacular

542
00:21:13,350 --> 00:21:11,440
um

543
00:21:14,630 --> 00:21:13,360
so you can

544
00:21:16,390 --> 00:21:14,640
you can see from this kind of

545
00:21:18,070 --> 00:21:16,400
representative list there are 110

546
00:21:19,430 --> 00:21:18,080
different objects and you can see from

547
00:21:22,149 --> 00:21:19,440
the list that there are a variety of

548
00:21:24,070 --> 00:21:22,159
different kinds of things you can see

549
00:21:26,070 --> 00:21:24,080
some things that are very obviously

550
00:21:27,909 --> 00:21:26,080
star-like so this is the pleiades

551
00:21:30,149 --> 00:21:27,919
cluster you might also know it

552
00:21:32,230 --> 00:21:30,159
from the subaru logo because that's the

553
00:21:34,149 --> 00:21:32,240
japanese word for this this star cluster

554
00:21:35,270 --> 00:21:34,159
is subaru um

555
00:21:36,950 --> 00:21:35,280
but it

556
00:21:39,669 --> 00:21:36,960
it's a it's a star cluster and very

557
00:21:42,310 --> 00:21:39,679
obviously composed of individual stars

558
00:21:44,549 --> 00:21:42,320
similarly uh the ring nebula nebula is

559
00:21:45,669 --> 00:21:44,559
just a famous like a fancy word for

560
00:21:50,789 --> 00:21:45,679
cloud

561
00:21:52,630 --> 00:21:50,799
again associated with a star we can see

562
00:21:55,510 --> 00:21:52,640
individual stars present like the white

563
00:21:58,470 --> 00:21:55,520

dwarf in the center of this this nebula

564
00:21:59,830 --> 00:21:58,480
and and that cloud is glowing and it's

565
00:22:01,190 --> 00:21:59,840
associated with that but then there are

566
00:22:03,510 --> 00:22:01,200
these kind of

567
00:22:05,110 --> 00:22:03,520
at least 100 years ago or or a couple

568
00:22:07,510 --> 00:22:05,120
hundred years ago the there are these

569
00:22:10,230 --> 00:22:07,520
kind of cryptic objects called spiral

570
00:22:12,549 --> 00:22:10,240
nebulae and you can see that they it's a

571
00:22:14,070 --> 00:22:12,559
little bit harder to discern what these

572
00:22:16,070 --> 00:22:14,080
objects are they have some sort of

573
00:22:17,750 --> 00:22:16,080
spiral structure but you can definitely

574
00:22:19,909 --> 00:22:17,760
make out that they seem to be a little

575
00:22:21,750 --> 00:22:19,919
bit cloudy um

576
00:22:23,029 --> 00:22:21,760
and there you can see some stars that

577
00:22:24,950 --> 00:22:23,039
are present but it's unclear if those

578
00:22:28,149 --> 00:22:24,960
stars are associated with the object or

579
00:22:29,830 --> 00:22:28,159
their foreground stars or whatnot and so

580
00:22:32,710 --> 00:22:29,840
this is the great andromeda nebula

581
00:22:35,990 --> 00:22:32,720
messier object number 31 and what was

582
00:22:39,909 --> 00:22:36,000
unclear was are these objects

583
00:22:43,430 --> 00:22:39,919
uh nearby like stars in our own milky

584
00:22:44,149 --> 00:22:43,440
way galaxy or these distant objects that

585
00:22:46,310 --> 00:22:44,159
are

586
00:22:48,070 --> 00:22:46,320
they they call them potentially island

587
00:22:50,390 --> 00:22:48,080
universes which is to say

588
00:22:53,270 --> 00:22:50,400

uh objects much like our own milky way

589
00:22:55,029 --> 00:22:53,280
galaxy but much you know farther away

590
00:22:57,350 --> 00:22:55,039
and at the time we thought that for the

591
00:23:00,070 --> 00:22:57,360
most part the universe was like the

592
00:23:01,350 --> 00:23:00,080
milky way was the extent of the universe

593
00:23:03,669 --> 00:23:01,360
because that seems enormous i mean that

594
00:23:05,510 --> 00:23:03,679
is enormous right the the the extent of

595
00:23:09,110 --> 00:23:05,520
the milky way disc is

596
00:23:12,230 --> 00:23:09,120
is 30 000 light years away that's a huge

597
00:23:15,029 --> 00:23:12,240
distance right so um to think of things

598
00:23:19,110 --> 00:23:15,039
that were even beyond this at kind of

599
00:23:21,590 --> 00:23:19,120
unthinkable distance and themselves uh

600
00:23:23,110 --> 00:23:21,600
milky way-like structures was was almost

601
00:23:23,990 --> 00:23:23,120
unthinkable

602
00:23:25,430 --> 00:23:24,000
but

603
00:23:27,990 --> 00:23:25,440
this was uh

604
00:23:29,830 --> 00:23:28,000
this was essentially

605
00:23:32,710 --> 00:23:29,840
identified in this this thing called the

606
00:23:34,789 --> 00:23:32,720
great debate of 1920. so um you had an

607
00:23:37,909 --> 00:23:34,799
astronomer representing the idea that

608
00:23:40,310 --> 00:23:37,919
these are nearby objects within our own

609
00:23:42,310 --> 00:23:40,320
milky way and associated with individual

610
00:23:44,310 --> 00:23:42,320
clouds and quite small

611
00:23:46,630 --> 00:23:44,320
as in the size of like a solar system or

612
00:23:49,029 --> 00:23:46,640
maybe slightly larger than that or you

613
00:23:51,350 --> 00:23:49,039

had another person representing that

614
00:23:52,789 --> 00:23:51,360
these objects were island universes much

615
00:23:54,630 --> 00:23:52,799
like our own milky way and they were

616
00:23:57,510 --> 00:23:54,640
very far away and they were very very

617
00:23:59,990 --> 00:23:57,520
large and much like most debates whether

618
00:24:02,549 --> 00:24:00,000
they're philosophical or political or

619
00:24:04,789 --> 00:24:02,559
sometimes scientific there wasn't really

620
00:24:07,750 --> 00:24:04,799
a winner to this debate and it was

621
00:24:10,310 --> 00:24:07,760
unclear uh what what is the nature of

622
00:24:12,549 --> 00:24:10,320
these spiral nebulae

623
00:24:14,950 --> 00:24:12,559
and so time went on and people people

624
00:24:17,510 --> 00:24:14,960
were trying to identify how to

625
00:24:20,230 --> 00:24:17,520
how to resolve this this debate

626
00:24:22,390 --> 00:24:20,240
um and really the way to resolve it is

627
00:24:23,909 --> 00:24:22,400
to determine the distance to the spiral

628
00:24:26,070 --> 00:24:23,919
nebulae because if they're close by then

629
00:24:28,390 --> 00:24:26,080
they're small and if they're a long ways

630
00:24:29,830 --> 00:24:28,400
away then they're large

631
00:24:31,909 --> 00:24:29,840
but it turns out that determining

632
00:24:33,669 --> 00:24:31,919
distance to objects in space is actually

633
00:24:35,830 --> 00:24:33,679
really challenging i mean we get kind of

634
00:24:36,789 --> 00:24:35,840
spoiled right like when i walk along the

635
00:24:39,269 --> 00:24:36,799
street

636
00:24:41,269 --> 00:24:39,279
i can tell that something you know a

637
00:24:42,870 --> 00:24:41,279
sign post is 20 feet in front of me or

638
00:24:46,070 --> 00:24:42,880

if it's like a couple miles in front of

639
00:24:47,909 --> 00:24:46,080
me because how do we how do we have

640
00:24:49,830 --> 00:24:47,919
depth perception we have depth

641
00:24:51,669 --> 00:24:49,840
perception because we have two separate

642
00:24:53,350 --> 00:24:51,679
eyes

643
00:24:55,190 --> 00:24:53,360
we use something called the parallax

644
00:24:57,269 --> 00:24:55,200
method although nobody most people

645
00:24:59,110 --> 00:24:57,279
aren't familiar with this term but it's

646
00:25:01,029 --> 00:24:59,120
it's um it's the fact that we have two

647
00:25:03,590 --> 00:25:01,039
eyes from slightly different positions

648
00:25:05,590 --> 00:25:03,600
that that are both cameras that are

649
00:25:07,190 --> 00:25:05,600
looking at some distant object and we

650
00:25:09,029 --> 00:25:07,200
can kind of interpolate its distance

651
00:25:11,029 --> 00:25:09,039
from geometric means although it's all

652
00:25:13,190 --> 00:25:11,039
done internal to our head but i'm going

653
00:25:14,630 --> 00:25:13,200
to ask everyone it's kind of a goofy

654
00:25:16,630 --> 00:25:14,640
experiment but i think it's really

655
00:25:18,070 --> 00:25:16,640
illustrative uh so if you can follow

656
00:25:20,710 --> 00:25:18,080
along at home and do this i think it'll

657
00:25:23,190 --> 00:25:20,720
be helpful i want everyone to hold up a

658
00:25:25,750 --> 00:25:23,200
thumb in front of their head as goofy as

659
00:25:28,310 --> 00:25:25,760
it seems and then i want you to close

660
00:25:29,510 --> 00:25:28,320
one eye so like wink at it and look at

661
00:25:32,549 --> 00:25:29,520
your thumb

662
00:25:34,390 --> 00:25:32,559
and then uh switch so you're opening

663
00:25:36,470 --> 00:25:34,400

that eye and closing the other eye and

664
00:25:38,710 --> 00:25:36,480
just kind of go back and forth and what

665
00:25:40,470 --> 00:25:38,720
you'll notice is your thumb appears to

666
00:25:42,470 --> 00:25:40,480
change position relative to the

667
00:25:44,470 --> 00:25:42,480
background objects behind it

668
00:25:46,070 --> 00:25:44,480
that is essentially the parallax method

669
00:25:48,230 --> 00:25:46,080
for determining distance if you move

670
00:25:50,870 --> 00:25:48,240
your thumb closer and do this again your

671
00:25:53,029 --> 00:25:50,880
thumb will appear to move more relative

672
00:25:54,710 --> 00:25:53,039
to the background objects and

673
00:25:56,549 --> 00:25:54,720
essentially what we do to determine

674
00:25:57,990 --> 00:25:56,559
distances to objects in space rather

675
00:26:00,549 --> 00:25:58,000
than just your thumb in front of your

676
00:26:03,669 --> 00:26:00,559
head is to do the same thing with

677
00:26:05,830 --> 00:26:03,679
observations of nearby stars so on the

678
00:26:08,310 --> 00:26:05,840
bottom of this cartoon we have the earth

679
00:26:10,070 --> 00:26:08,320
in its orbit around the sun

680
00:26:11,830 --> 00:26:10,080
and on the right side we see where the

681
00:26:13,990 --> 00:26:11,840
earth is in january and then on the left

682
00:26:16,230 --> 00:26:14,000
side in six months later it's where we

683
00:26:18,070 --> 00:26:16,240
are in july now we're trying to observe

684
00:26:19,269 --> 00:26:18,080
this nearby star kind of in the middle

685
00:26:21,590 --> 00:26:19,279
of the screen

686
00:26:24,549 --> 00:26:21,600
and when we look up at it in january we

687
00:26:26,230 --> 00:26:24,559
see that the nearby star relative to the

688
00:26:28,549 --> 00:26:26,240

background stars here at the top of the

689
00:26:30,789 --> 00:26:28,559
screen puts it on the left side of those

690
00:26:33,269 --> 00:26:30,799
as we can see here on this left kind of

691
00:26:34,950 --> 00:26:33,279
inset panel here's our nearby star and

692
00:26:36,070 --> 00:26:34,960
it's on the left side but if we wait six

693
00:26:38,390 --> 00:26:36,080
months and then

694
00:26:40,710 --> 00:26:38,400
observe that same nearby star relative

695
00:26:42,310 --> 00:26:40,720
to those background stars we see now

696
00:26:44,230 --> 00:26:42,320
that it's on the right side of those

697
00:26:46,549 --> 00:26:44,240
stars simply due to

698
00:26:49,430 --> 00:26:46,559
our change in position over those six

699
00:26:51,909 --> 00:26:49,440
months as we orbit around the the sun

700
00:26:53,830 --> 00:26:51,919
and so you can you can see this exact

701
00:26:56,149 --> 00:26:53,840
same thing that we just did with our

702
00:26:58,230 --> 00:26:56,159
winking at our thumb to see its change

703
00:27:00,549 --> 00:26:58,240
in position this is how we determine the

704
00:27:02,950 --> 00:27:00,559
distance to stars um

705
00:27:05,110 --> 00:27:02,960
but it only works for stars that are

706
00:27:08,070 --> 00:27:05,120
reasonably close to us hundreds of

707
00:27:09,830 --> 00:27:08,080
parsecs although now with um with more

708
00:27:12,230 --> 00:27:09,840
sensitive missions like the gaia mission

709
00:27:14,230 --> 00:27:12,240
we can do this out to a few thousand

710
00:27:15,909 --> 00:27:14,240
light years away which has really opened

711
00:27:17,510 --> 00:27:15,919
up uh the precision with which we can

712
00:27:19,830 --> 00:27:17,520
measure distances but it's really the

713
00:27:22,070 --> 00:27:19,840

basis with which we we determine the

714
00:27:23,190 --> 00:27:22,080
distance to objects but it's it's far

715
00:27:25,590 --> 00:27:23,200
too it

716
00:27:26,710 --> 00:27:25,600
stars need to be much much closer to us

717
00:27:29,430 --> 00:27:26,720
um

718
00:27:30,950 --> 00:27:29,440
than was possible at the time when when

719
00:27:33,269 --> 00:27:30,960
uh when people wanted to do this a

720
00:27:36,070 --> 00:27:33,279
hundred years ago so determining

721
00:27:39,190 --> 00:27:36,080
distance to more distant objects in

722
00:27:41,430 --> 00:27:39,200
space uh was really helped a great deal

723
00:27:43,909 --> 00:27:41,440
by this scientist henrietta levitt this

724
00:27:46,789 --> 00:27:43,919
uh prominent astronomer at the harvard

725
00:27:48,789 --> 00:27:46,799
observatory in the uh in the early 20th

726
00:27:50,389 --> 00:27:48,799
century and she identified this

727
00:27:53,269 --> 00:27:50,399
ingenious method for determining

728
00:27:55,350 --> 00:27:53,279
distance she identified a special kind

729
00:27:57,430 --> 00:27:55,360
of star called a variable star not all

730
00:27:59,029 --> 00:27:57,440
stars are this it's some small subset of

731
00:28:00,630 --> 00:27:59,039
stars but there's there's a decent

732
00:28:02,789 --> 00:28:00,640
number of them in the sky

733
00:28:06,549 --> 00:28:02,799
and what happens is

734
00:28:08,870 --> 00:28:06,559
they change they pulsate in in in size

735
00:28:10,470 --> 00:28:08,880
and they change their brightness and so

736
00:28:12,230 --> 00:28:10,480
they'll go from being bright to being a

737
00:28:13,750 --> 00:28:12,240
little bit fainter to being bright to

738
00:28:16,789 --> 00:28:13,760

being a little bit fainter and there's a

739
00:28:19,029 --> 00:28:16,799
very set period over which this this

740
00:28:20,630 --> 00:28:19,039
oscillation takes place on the order of

741
00:28:22,149 --> 00:28:20,640
a few days it'll be bright and then a

742
00:28:23,590 --> 00:28:22,159
couple days later it gets faint and then

743
00:28:25,510 --> 00:28:23,600
a few days later it gets bright and so

744
00:28:27,190 --> 00:28:25,520
on and so forth and

745
00:28:28,470 --> 00:28:27,200
that in itself is kind of interesting

746
00:28:31,190 --> 00:28:28,480
but the thing that makes it a really

747
00:28:33,350 --> 00:28:31,200
useful technique is that

748
00:28:36,950 --> 00:28:33,360
the period over which that oscillation

749
00:28:39,110 --> 00:28:36,960
occurs is directly tied to the intrinsic

750
00:28:41,269 --> 00:28:39,120
brightness of the star

751
00:28:43,269 --> 00:28:41,279
um it's like it's like it prints out

752
00:28:45,510 --> 00:28:43,279
that it's a 100 watt light bulb or a

753
00:28:48,149 --> 00:28:45,520
1000 watt light bulb because essentially

754
00:28:49,350 --> 00:28:48,159
the problem all boils down to this if if

755
00:28:51,750 --> 00:28:49,360
i walk out

756
00:28:54,230 --> 00:28:51,760
uh out of my house at night time and i

757
00:28:55,430 --> 00:28:54,240
look across the street and i see a light

758
00:28:57,990 --> 00:28:55,440
there

759
00:28:59,830 --> 00:28:58,000
i can't easily tell if it's a firefly

760
00:29:01,510 --> 00:28:59,840
that's five feet in front of my face or

761
00:29:03,990 --> 00:29:01,520
if it's a spotlight that's two miles

762
00:29:06,950 --> 00:29:04,000
down the road that's pointed at me but

763
00:29:09,669 --> 00:29:06,960

with this method this this variable star

764
00:29:12,310 --> 00:29:09,679
if i can observe that that star pulsing

765
00:29:13,350 --> 00:29:12,320
then i know it's intrinsic brightness

766
00:29:15,510 --> 00:29:13,360
and by

767
00:29:17,750 --> 00:29:15,520
uh looking at its apparent brightness i

768
00:29:19,750 --> 00:29:17,760
can i can put those two things together

769
00:29:21,590 --> 00:29:19,760
and i can back out the distance to that

770
00:29:24,710 --> 00:29:21,600
actual object

771
00:29:26,149 --> 00:29:24,720
which is incredibly useful and so um a

772
00:29:28,870 --> 00:29:26,159
person with whom you're probably

773
00:29:30,310 --> 00:29:28,880
familiar uh dr edwin hubble who the

774
00:29:31,590 --> 00:29:30,320
hubble space telescope of course is

775
00:29:33,590 --> 00:29:31,600
named after

776
00:29:36,230 --> 00:29:33,600
employed this technique that henrietta

777
00:29:38,950 --> 00:29:36,240
leavitt had identified um with the mount

778
00:29:41,430 --> 00:29:38,960
wilson 100 inch telescope right here in

779
00:29:43,750 --> 00:29:41,440
our backyard outside of pasadena

780
00:29:45,350 --> 00:29:43,760
and uh at the time it was for about 40

781
00:29:48,389 --> 00:29:45,360
years it was the largest telescope in

782
00:29:51,590 --> 00:29:48,399
the world and he pointed this telescope

783
00:29:53,990 --> 00:29:51,600
at uh at the great spiral nebula in

784
00:29:56,870 --> 00:29:54,000
andromeda and he identified some stars

785
00:29:58,549 --> 00:29:56,880
associated with that nebula and he's

786
00:30:00,789 --> 00:29:58,559
found some of the stars were variable

787
00:30:03,430 --> 00:30:00,799
stars and thus he was able to determine

788
00:30:04,070 --> 00:30:03,440

the distance to the great spiral nebula

789
00:30:06,149 --> 00:30:04,080
in

790
00:30:07,510 --> 00:30:06,159
uh andromeda and he identified that it

791
00:30:09,269 --> 00:30:07,520
was two and a half million light years

792
00:30:11,269 --> 00:30:09,279
away which was an enormous distance i

793
00:30:13,269 --> 00:30:11,279
mean it is an enormous distance

794
00:30:15,430 --> 00:30:13,279
and what that told us is that really

795
00:30:18,310 --> 00:30:15,440
settled the great debate and it said

796
00:30:20,950 --> 00:30:18,320
these objects are large and distant in

797
00:30:22,630 --> 00:30:20,960
fact much much farther away than we ever

798
00:30:24,389 --> 00:30:22,640
really like i said it's kind of

799
00:30:26,470 --> 00:30:24,399
unthinkable at the time that these

800
00:30:29,110 --> 00:30:26,480
things are as far away as they are and

801
00:30:31,269 --> 00:30:29,120
that each of these indeed is much like

802
00:30:33,029 --> 00:30:31,279
our own milky way galaxy

803
00:30:35,750 --> 00:30:33,039
and so these were redubbed instead of

804
00:30:37,190 --> 00:30:35,760
spiral nebulae they were called galaxies

805
00:30:39,269 --> 00:30:37,200
and that was really kind of the birth of

806
00:30:41,510 --> 00:30:39,279
our understanding of galaxies about a

807
00:30:42,549 --> 00:30:41,520
hundred years ago so thank you edwin

808
00:30:44,710 --> 00:30:42,559
hubble

809
00:30:46,389 --> 00:30:44,720
for that wonderful contribution

810
00:30:48,549 --> 00:30:46,399
um

811
00:30:50,789 --> 00:30:48,559
and and just to continue a little bit on

812
00:30:52,789 --> 00:30:50,799
edwin hubble that wasn't the only thing

813
00:30:55,190 --> 00:30:52,799

that he's known for of course he's also

814
00:30:57,830 --> 00:30:55,200
known for identifying that those distant

815
00:31:00,230 --> 00:30:57,840
galaxies are actually traveling away

816
00:31:01,110 --> 00:31:00,240
from us this is a cartoon showing that

817
00:31:03,269 --> 00:31:01,120
um

818
00:31:04,389 --> 00:31:03,279
again this is us in the milky way kind

819
00:31:06,149 --> 00:31:04,399
of in the center

820
00:31:08,710 --> 00:31:06,159
of this plot although not necessarily

821
00:31:11,029 --> 00:31:08,720
the center of the universe and and he

822
00:31:12,950 --> 00:31:11,039
identified that each of these galaxies

823
00:31:14,789 --> 00:31:12,960
is traveling away from us

824
00:31:16,789 --> 00:31:14,799
um and the ones that are farther away

825
00:31:18,389 --> 00:31:16,799
from us are traveling faster away from

826
00:31:20,710 --> 00:31:18,399
us which is kind of

827
00:31:22,710 --> 00:31:20,720
weird like why is everybody running away

828
00:31:24,630 --> 00:31:22,720
but it turns out that there's a a pretty

829
00:31:25,830 --> 00:31:24,640
reasonable explanation for this and it's

830
00:31:28,789 --> 00:31:25,840
not that we're the center of the

831
00:31:32,470 --> 00:31:28,799
universe it's simply that the universe

832
00:31:33,590 --> 00:31:32,480
itself like space itself is expanding

833
00:31:35,590 --> 00:31:33,600
and so

834
00:31:37,110 --> 00:31:35,600
um it isn't that we're special here in

835
00:31:39,430 --> 00:31:37,120
the u in the center of the universe if

836
00:31:41,590 --> 00:31:39,440
you were at the in a gal in any of these

837
00:31:43,830 --> 00:31:41,600
galaxies you would observe all those

838
00:31:45,830 --> 00:31:43,840

other galaxies traveling away from you

839
00:31:48,310 --> 00:31:45,840
as well because it's the space that's

840
00:31:50,310 --> 00:31:48,320
expanding not that everything's like

841
00:31:51,430 --> 00:31:50,320
just moving within that space away from

842
00:31:53,190 --> 00:31:51,440
us

843
00:31:55,909 --> 00:31:53,200
and the example that oftentimes gets

844
00:31:58,470 --> 00:31:55,919
used for this is imagine you have uh

845
00:32:00,310 --> 00:31:58,480
you're you're baking a blueberry muffin

846
00:32:02,710 --> 00:32:00,320
in the oven now of course you have your

847
00:32:04,710 --> 00:32:02,720
dough and it's it's all runny and and

848
00:32:07,430 --> 00:32:04,720
doughy and it has little blueberries in

849
00:32:09,190 --> 00:32:07,440
it and when you put it in to the oven

850
00:32:11,590 --> 00:32:09,200
you turn up the heat the yeast that's

851
00:32:13,590 --> 00:32:11,600
present in that dough starts to expand

852
00:32:16,070 --> 00:32:13,600
causing the dough to expand much like

853
00:32:19,269 --> 00:32:16,080
here space is expanding so from the

854
00:32:23,430 --> 00:32:19,279
perspective of any blueberry in that

855
00:32:25,350 --> 00:32:23,440
that leavening blueberry muffin the uh

856
00:32:27,110 --> 00:32:25,360
the other blueberries are moving away

857
00:32:29,029 --> 00:32:27,120
from it not because they're they're

858
00:32:31,029 --> 00:32:29,039
actually moving away but because the the

859
00:32:33,509 --> 00:32:31,039
dough itself is expanding between them

860
00:32:36,230 --> 00:32:33,519
and the other blueberries so that's i

861
00:32:37,750 --> 00:32:36,240
think that's a pretty apt uh

862
00:32:39,509 --> 00:32:37,760
analogy that's that's good for

863
00:32:41,669 --> 00:32:39,519

visualizing what the heck is happening

864
00:32:43,190 --> 00:32:41,679
and that's not the only

865
00:32:45,190 --> 00:32:43,200
piece of evidence that we have for the

866
00:32:46,870 --> 00:32:45,200
big bang there are a number of different

867
00:32:48,789 --> 00:32:46,880
pieces but that was kind of the the

868
00:32:51,830 --> 00:32:48,799
first and

869
00:32:53,990 --> 00:32:51,840
and um and a very strong you know

870
00:32:55,590 --> 00:32:54,000
suggestion of what's going on and why

871
00:32:57,750 --> 00:32:55,600
why the universe behaves the way it

872
00:32:59,750 --> 00:32:57,760
seems to be behaving

873
00:33:01,590 --> 00:32:59,760
this is just a plot that was

874
00:33:04,149 --> 00:33:01,600
from edwin hubble's paper because it's

875
00:33:06,630 --> 00:33:04,159
nice to show actual scientific results

876
00:33:09,430 --> 00:33:06,640
on the x-axis this bottom line is the

877
00:33:11,430 --> 00:33:09,440
distance away that a galaxy is from us

878
00:33:13,190 --> 00:33:11,440
and on the y-axis it's the speed at

879
00:33:15,350 --> 00:33:13,200
which it's traveling away from us and

880
00:33:17,909 --> 00:33:15,360
all the individual dots are galaxies and

881
00:33:20,470 --> 00:33:17,919
you can see that as you go farther away

882
00:33:22,230 --> 00:33:20,480
from us the dra the the dots are higher

883
00:33:24,310 --> 00:33:22,240
up meaning that they're traveling faster

884
00:33:25,590 --> 00:33:24,320
away from us and this is kind of this is

885
00:33:27,110 --> 00:33:25,600
constraining

886
00:33:28,950 --> 00:33:27,120
the rate at which the universe is

887
00:33:30,549 --> 00:33:28,960
expanding called the the hubble

888
00:33:31,750 --> 00:33:30,559

expansion or the hubble constant

889
00:33:33,909 --> 00:33:31,760
everything gets named after hubble

890
00:33:36,549 --> 00:33:33,919
because he did so many contributions but

891
00:33:41,190 --> 00:33:36,559
it really is kind of worthwhile um and

892
00:33:43,350 --> 00:33:41,200
really transformed our idea of of space

893
00:33:45,590 --> 00:33:43,360
so that's that's how i mean i'm a big

894
00:33:48,230 --> 00:33:45,600
fan of edwin and that's how you get a

895
00:33:51,190 --> 00:33:48,240
space telescope named after you so um so

896
00:33:53,750 --> 00:33:51,200
good job good job edwin hubble okay

897
00:33:55,669 --> 00:33:53,760
so yeah here here we are the the hubble

898
00:33:57,669 --> 00:33:55,679
space telescope and the in the flesh

899
00:33:59,269 --> 00:33:57,679
hopefully long live the hubble space

900
00:34:01,750 --> 00:33:59,279
telescope i use it a lot for my research

901
00:34:04,070 --> 00:34:01,760
so um hopefully it will continue to

902
00:34:06,070 --> 00:34:04,080
operate for a long period in the future

903
00:34:07,830 --> 00:34:06,080
so a quick summary so far of the history

904
00:34:10,230 --> 00:34:07,840
of what this all is uh you know there's

905
00:34:11,750 --> 00:34:10,240
a lot of stuff in the sky including

906
00:34:13,990 --> 00:34:11,760
these smudges that were originally

907
00:34:15,829 --> 00:34:14,000
called spiral nebulae which we now

908
00:34:18,950 --> 00:34:15,839
understand are actually galaxies like

909
00:34:21,349 --> 00:34:18,960
our own milky way galaxy um the universe

910
00:34:23,109 --> 00:34:21,359
isn't is enormous you know we see these

911
00:34:24,869 --> 00:34:23,119
galaxies

912
00:34:26,790 --> 00:34:24,879
a long ways away from us and we see on

913
00:34:28,230 --> 00:34:26,800

the order of like 200 billion well we

914
00:34:30,310 --> 00:34:28,240
see on the order of 100 billion but we

915
00:34:32,310 --> 00:34:30,320
think that there's probably 200 plus

916
00:34:33,669 --> 00:34:32,320
billion of these objects in the sky and

917
00:34:35,109 --> 00:34:33,679
that the universe is expanding and

918
00:34:37,270 --> 00:34:35,119
getting even bigger with time and then

919
00:34:38,710 --> 00:34:37,280
yeah edwin hubble's pretty pretty cool

920
00:34:39,510 --> 00:34:38,720
dude

921
00:34:40,869 --> 00:34:39,520
okay

922
00:34:42,790 --> 00:34:40,879
so we've talked a lot about what

923
00:34:45,430 --> 00:34:42,800
galaxies you know

924
00:34:46,629 --> 00:34:45,440
what they aren't but what are they uh

925
00:34:48,470 --> 00:34:46,639
this is an image that you may be

926
00:34:50,629 --> 00:34:48,480
familiar with every

927
00:34:53,030 --> 00:34:50,639
apple macintosh computer had this as its

928
00:34:55,349 --> 00:34:53,040
background for a period in the past and

929
00:34:58,150 --> 00:34:55,359
it's kind of a an edited version of the

930
00:35:00,069 --> 00:34:58,160
andromeda galaxy they they took some

931
00:35:02,710 --> 00:35:00,079
artistic liberties in making this image

932
00:35:04,150 --> 00:35:02,720
but but nonetheless this is a galaxy and

933
00:35:05,990 --> 00:35:04,160
this is actually a proposed image of

934
00:35:08,470 --> 00:35:06,000
what our own milky way galaxy looks like

935
00:35:10,630 --> 00:35:08,480
if we were looking down on it you can

936
00:35:12,790 --> 00:35:10,640
probably make out this little label here

937
00:35:15,430 --> 00:35:12,800
for earth the earth and the sun and the

938
00:35:17,349 --> 00:35:15,440

solar system we uh we believe is about

939
00:35:19,510 --> 00:35:17,359
halfway out in the disc and it's in one

940
00:35:21,829 --> 00:35:19,520
of these spiral arms

941
00:35:24,630 --> 00:35:21,839
um we can talk more about why we believe

942
00:35:26,790 --> 00:35:24,640
that uh later on

943
00:35:29,910 --> 00:35:26,800
but what is a galaxy really it's just a

944
00:35:31,349 --> 00:35:29,920
collection of stars and gas so the the

945
00:35:33,910 --> 00:35:31,359
light that we see is coming from

946
00:35:35,589 --> 00:35:33,920
individual stars uh that as i said

947
00:35:37,430 --> 00:35:35,599
oftentimes blends together into that

948
00:35:40,870 --> 00:35:37,440
milky way band across the sky there's

949
00:35:42,310 --> 00:35:40,880
also dust that's present um

950
00:35:44,230 --> 00:35:42,320
and it's quite large you know there's

951
00:35:46,550 --> 00:35:44,240
there's like a hundred billion stars or

952
00:35:49,910 --> 00:35:46,560
so and it's around 100 000 light years

953
00:35:51,910 --> 00:35:49,920
across in terms of the disc itself

954
00:35:53,589 --> 00:35:51,920
but um

955
00:35:55,829 --> 00:35:53,599
you can obviously tell that there's some

956
00:35:57,589 --> 00:35:55,839
rotation and spin associated with this

957
00:35:59,510 --> 00:35:57,599
object just based on the spiral and that

958
00:36:01,270 --> 00:35:59,520
is true we we can measure the spin

959
00:36:03,270 --> 00:36:01,280
associated with our own galaxy as well

960
00:36:05,829 --> 00:36:03,280
as other distant galaxies

961
00:36:07,829 --> 00:36:05,839
and much like any rotating object there

962
00:36:09,829 --> 00:36:07,839
has to be a force that's holding it

963
00:36:11,670 --> 00:36:09,839

together if you get on a

964
00:36:14,150 --> 00:36:11,680
carousel or a merry-go-round and it

965
00:36:16,310 --> 00:36:14,160
starts going too fast you're gonna fly

966
00:36:18,230 --> 00:36:16,320
right off the side right so there has to

967
00:36:20,470 --> 00:36:18,240
be a force that's holding this together

968
00:36:23,030 --> 00:36:20,480
or else it'll just fling itself apart

969
00:36:25,270 --> 00:36:23,040
and that force is gravity

970
00:36:27,670 --> 00:36:25,280
so let's really quickly just talk about

971
00:36:29,430 --> 00:36:27,680
gravity since it's so important um

972
00:36:30,950 --> 00:36:29,440
gravity everyone has an idea of what

973
00:36:32,470 --> 00:36:30,960
gravity is it's the force that holds us

974
00:36:34,310 --> 00:36:32,480
to the earth but it holds us to the

975
00:36:35,829 --> 00:36:34,320
earth from regardless

976
00:36:38,470 --> 00:36:35,839
of where we're standing on the earth

977
00:36:40,790 --> 00:36:38,480
because it's an attractive force

978
00:36:42,470 --> 00:36:40,800
not only are we being pulled down to the

979
00:36:43,990 --> 00:36:42,480
earth but we're pulling back the earth

980
00:36:46,069 --> 00:36:44,000
is getting pulled back to each and every

981
00:36:49,030 --> 00:36:46,079
one of you although it's not a very high

982
00:36:51,030 --> 00:36:49,040
magnitude force because we ourselves

983
00:36:53,750 --> 00:36:51,040
don't have a lot of mass relative to the

984
00:36:55,430 --> 00:36:53,760
earth um but really gravity is just an

985
00:36:57,670 --> 00:36:55,440
attractive force that pulls any two

986
00:36:59,589 --> 00:36:57,680
objects that have mass towards each

987
00:37:01,750 --> 00:36:59,599
other and that mass increases as they

988
00:37:03,349 --> 00:37:01,760

get closer together and as those masses

989
00:37:05,670 --> 00:37:03,359
increase and that was identified by

990
00:37:07,750 --> 00:37:05,680
isaac newton around 400 years ago one of

991
00:37:09,670 --> 00:37:07,760
his major contributions to to the world

992
00:37:11,910 --> 00:37:09,680
of astronomy and physics

993
00:37:13,510 --> 00:37:11,920
so that's how gravity works so gravity

994
00:37:18,710 --> 00:37:13,520
is really the force that's holding

995
00:37:21,910 --> 00:37:19,990
so it's a gravitationally bound

996
00:37:24,390 --> 00:37:21,920
collection of stars and gas but it turns

997
00:37:26,390 --> 00:37:24,400
out if you count up all the stars and

998
00:37:28,790 --> 00:37:26,400
gas in a galaxy

999
00:37:31,430 --> 00:37:28,800
and figure out how uh quickly it's

1000
00:37:33,030 --> 00:37:31,440
rotating and how much gravity like mass

1001
00:37:35,430 --> 00:37:33,040
needs to be there to hold the galaxy

1002
00:37:37,510 --> 00:37:35,440
together it's not enough it's not enough

1003
00:37:39,430 --> 00:37:37,520
by a long shot it's like

1004
00:37:41,510 --> 00:37:39,440
some galaxies it's too low by a factor

1005
00:37:44,630 --> 00:37:41,520
of 10 some galaxies it's too low by a

1006
00:37:46,870 --> 00:37:44,640
factor of a thousand there's some unseen

1007
00:37:49,430 --> 00:37:46,880
mass that needs to be present to hold

1008
00:37:50,870 --> 00:37:49,440
the galaxy together at the rate at which

1009
00:37:52,310 --> 00:37:50,880
it's spinning or else it would fling

1010
00:37:55,750 --> 00:37:52,320
itself apart

1011
00:37:58,069 --> 00:37:55,760
and that unseen mass is referred to as

1012
00:38:00,390 --> 00:37:58,079
dark matter and that uh that discovery

1013
00:38:02,069 --> 00:38:00,400

was made uh largely by vera rubin

1014
00:38:03,990 --> 00:38:02,079
there's a new telescope coming out named

1015
00:38:07,750 --> 00:38:04,000
after vera rubin the vera rumen uh

1016
00:38:09,670 --> 00:38:07,760
telescope in chile and um

1017
00:38:11,990 --> 00:38:09,680
we see this in basically all the

1018
00:38:13,990 --> 00:38:12,000
galaxies out there that there's uh

1019
00:38:17,270 --> 00:38:14,000
there's not enough mass that's present

1020
00:38:19,910 --> 00:38:17,280
in in their visible components

1021
00:38:22,310 --> 00:38:19,920
to to hold them together which is why we

1022
00:38:23,510 --> 00:38:22,320
have to invoke this unseen mysterious

1023
00:38:29,589 --> 00:38:23,520
dark matter

1024
00:38:31,750 --> 00:38:29,599
now the kind of

1025
00:38:34,390 --> 00:38:31,760
paradigm is that dark matter is some

1026
00:38:36,790 --> 00:38:34,400
sort of subatomic particle like an

1027
00:38:38,870 --> 00:38:36,800
electron or a proton that happens to

1028
00:38:41,030 --> 00:38:38,880
weigh quite a bit but doesn't interact

1029
00:38:43,030 --> 00:38:41,040
through electromagnetic or nuclear

1030
00:38:45,109 --> 00:38:43,040
forces it only interacts gravitationally

1031
00:38:46,950 --> 00:38:45,119
but this hasn't yet been like confirmed

1032
00:38:48,470 --> 00:38:46,960
but it's super super hard to detect

1033
00:38:49,910 --> 00:38:48,480
these things because they only interact

1034
00:38:51,430 --> 00:38:49,920
gravitationally so

1035
00:38:52,950 --> 00:38:51,440
stay tuned hopefully that's a problem

1036
00:38:54,470 --> 00:38:52,960
that will be solved

1037
00:38:57,670 --> 00:38:54,480
in my lifetime

1038
00:38:58,790 --> 00:38:57,680

but it's it's definitely a hard problem

1039
00:39:01,430 --> 00:38:58,800
okay

1040
00:39:04,470 --> 00:39:01,440
so what do we know about galaxies from

1041
00:39:06,230 --> 00:39:04,480
observations here's a famous image that

1042
00:39:08,470 --> 00:39:06,240
people are probably familiar with called

1043
00:39:10,470 --> 00:39:08,480
the hubble ultra deep field um it was an

1044
00:39:13,190 --> 00:39:10,480
image taken of a

1045
00:39:16,230 --> 00:39:13,200
a very long exposure image taken of the

1046
00:39:18,470 --> 00:39:16,240
sky a small region of the sky and every

1047
00:39:21,589 --> 00:39:18,480
image in this particular i'm sorry every

1048
00:39:24,069 --> 00:39:21,599
object in this image is a galaxy and you

1049
00:39:26,470 --> 00:39:24,079
can see a huge diversity in the types of

1050
00:39:28,710 --> 00:39:26,480
galaxies that are present you see uh you

1051
00:39:30,790 --> 00:39:28,720
know this kind of whitish spiral galaxy

1052
00:39:33,270 --> 00:39:30,800
you see very blue objects you see very

1053
00:39:34,230 --> 00:39:33,280
red objects you see um

1054
00:39:35,990 --> 00:39:34,240
kind of

1055
00:39:37,670 --> 00:39:36,000
ellipses

1056
00:39:39,510 --> 00:39:37,680
kind of weird looking things this looks

1057
00:39:42,230 --> 00:39:39,520
a bit like tadpoles i mean there's

1058
00:39:45,109 --> 00:39:42,240
there's all kinds of stuff going on here

1059
00:39:47,349 --> 00:39:45,119
and so astronomers have come up with a

1060
00:39:49,349 --> 00:39:47,359
taxonomy to kind of break this down and

1061
00:39:51,829 --> 00:39:49,359
classify these into

1062
00:39:54,470 --> 00:39:51,839
into different types

1063
00:39:57,349 --> 00:39:54,480

so the main types there are two main

1064
00:39:59,190 --> 00:39:57,359
types that people really break it down

1065
00:40:01,109 --> 00:39:59,200
into and that is

1066
00:40:04,470 --> 00:40:01,119
red ellipticals you can see there's like

1067
00:40:06,470 --> 00:40:04,480
a reddish tinge to these these systems

1068
00:40:08,150 --> 00:40:06,480
and it's a it's an elliptical because it

1069
00:40:10,470 --> 00:40:08,160
looks like an ellipse now i tend to

1070
00:40:11,990 --> 00:40:10,480
think of things in food analogies

1071
00:40:14,309 --> 00:40:12,000
because i like food

1072
00:40:16,150 --> 00:40:14,319
so i think of these in terms of eggs it

1073
00:40:18,630 --> 00:40:16,160
looks kind of like a hard-boiled egg

1074
00:40:20,230 --> 00:40:18,640
it's just a single component

1075
00:40:22,069 --> 00:40:20,240
and keep in mind the glowing light that

1076
00:40:23,829 --> 00:40:22,079
we're seeing is starlight all that light

1077
00:40:25,829 --> 00:40:23,839
is stars that are very distant and

1078
00:40:27,990 --> 00:40:25,839
numerous and kind of blend together but

1079
00:40:30,470 --> 00:40:28,000
they make up this kind of elliptical

1080
00:40:33,030 --> 00:40:30,480
looking structure

1081
00:40:35,190 --> 00:40:33,040
similarly the other major type are blue

1082
00:40:38,470 --> 00:40:35,200
spirals much like the andromeda galaxy

1083
00:40:40,150 --> 00:40:38,480
is or the milky way is it has a bit more

1084
00:40:42,150 --> 00:40:40,160
structure to it there's the disc

1085
00:40:44,069 --> 00:40:42,160
component with the spiral structure and

1086
00:40:46,150 --> 00:40:44,079
then there's the bulge in the center

1087
00:40:48,069 --> 00:40:46,160
which is kind of like well again going

1088
00:40:49,990 --> 00:40:48,079

back to the egg analogy it's kind of

1089
00:40:51,670 --> 00:40:50,000
like the yolk in the center of a fried

1090
00:40:53,430 --> 00:40:51,680
egg so you've got your flat disky

1091
00:40:55,589 --> 00:40:53,440
component and then you've got your yoke

1092
00:40:58,870 --> 00:40:55,599
as the bulge in the center and again

1093
00:41:00,550 --> 00:40:58,880
that's all starlight um it's just stars

1094
00:41:03,510 --> 00:41:00,560
on different orbits that make up these

1095
00:41:06,630 --> 00:41:03,520
two like yoke and disk component or

1096
00:41:08,950 --> 00:41:06,640
bulge and disk component

1097
00:41:11,109 --> 00:41:08,960
and then there's kind of a catch-all

1098
00:41:12,710 --> 00:41:11,119
category that catches the things that

1099
00:41:15,030 --> 00:41:12,720
aren't red ellipticals and aren't blue

1100
00:41:17,030 --> 00:41:15,040
spirals and that is the irregular

1101
00:41:19,670 --> 00:41:17,040
galaxies and these are just all sorts of

1102
00:41:22,470 --> 00:41:19,680
morphological types all manner of weird

1103
00:41:24,230 --> 00:41:22,480
shapes they tend to be very blue and i

1104
00:41:26,069 --> 00:41:24,240
just refer to those as scrambled eggs

1105
00:41:27,670 --> 00:41:26,079
because they're just they're just a mess

1106
00:41:30,710 --> 00:41:27,680
and they just don't easily fit into

1107
00:41:33,270 --> 00:41:30,720
those two other categories

1108
00:41:34,870 --> 00:41:33,280
so you can see examples of this in the

1109
00:41:36,950 --> 00:41:34,880
hubble ultra deep field but we

1110
00:41:38,950 --> 00:41:36,960
definitely see this um these three

1111
00:41:41,349 --> 00:41:38,960
different types when we look up in the

1112
00:41:43,990 --> 00:41:41,359
sky at the like i said 100 billion or so

1113
00:41:45,589 --> 00:41:44,000

galaxies that have been identified

1114
00:41:47,750 --> 00:41:45,599
but what else do we know about galaxies

1115
00:41:49,589 --> 00:41:47,760
from observations we know you know you

1116
00:41:51,750 --> 00:41:49,599
might naively just think that galaxies

1117
00:41:53,510 --> 00:41:51,760
are randomly distributed distributed

1118
00:41:55,349 --> 00:41:53,520
through the sky but it turns out that

1119
00:41:57,349 --> 00:41:55,359
there's not there's actually structure

1120
00:41:59,030 --> 00:41:57,359
there and this is a nice movie that was

1121
00:42:00,710 --> 00:41:59,040
put together by the sloan digital sky

1122
00:42:02,470 --> 00:42:00,720
survey um

1123
00:42:05,190 --> 00:42:02,480
uh visualization team

1124
00:42:07,190 --> 00:42:05,200
showing the distribution of galaxies in

1125
00:42:09,190 --> 00:42:07,200
the sky now obviously we aren't able to

1126
00:42:11,750 --> 00:42:09,200
fly through galaxies at this speed this

1127
00:42:14,550 --> 00:42:11,760
is super luminal speed but you can see

1128
00:42:17,349 --> 00:42:14,560
but this is real data from from this

1129
00:42:19,510 --> 00:42:17,359
star survey uh and galactic survey and

1130
00:42:21,510 --> 00:42:19,520
you can see that galaxies are not

1131
00:42:23,109 --> 00:42:21,520
randomly distributed there's clumps like

1132
00:42:25,190 --> 00:42:23,119
this clump here

1133
00:42:27,430 --> 00:42:25,200
and then there's like kind of like

1134
00:42:30,069 --> 00:42:27,440
rope-like structures here's like a rope

1135
00:42:32,309 --> 00:42:30,079
of these things right across here and

1136
00:42:34,309 --> 00:42:32,319
where the ropes coincide then you get

1137
00:42:35,670 --> 00:42:34,319
nodes where there's a clump of material

1138
00:42:38,390 --> 00:42:35,680

and then there's voids kind of

1139
00:42:40,870 --> 00:42:38,400
separating these filaments and this is

1140
00:42:42,710 --> 00:42:40,880
what's known as the cosmic web because

1141
00:42:44,710 --> 00:42:42,720
it looks kind of like a spider web like

1142
00:42:47,589 --> 00:42:44,720
a 3d weird

1143
00:42:48,790 --> 00:42:47,599
you know drunk spider made this kind of

1144
00:42:51,430 --> 00:42:48,800
spiderweb

1145
00:42:53,829 --> 00:42:51,440
and it really describes the distribution

1146
00:42:56,309 --> 00:42:53,839
of galaxies and thus the distribution of

1147
00:42:58,630 --> 00:42:56,319
matter throughout the universe on very

1148
00:43:00,230 --> 00:42:58,640
large scales

1149
00:43:02,710 --> 00:43:00,240
yeah this visualization is really great

1150
00:43:04,550 --> 00:43:02,720
i love this um

1151
00:43:06,710 --> 00:43:04,560
so this is kind of a 2d flattening of

1152
00:43:08,630 --> 00:43:06,720
the results of that so each point is a

1153
00:43:10,630 --> 00:43:08,640
galaxy in the center is the earth and

1154
00:43:13,030 --> 00:43:10,640
the sun and we're looking out into the

1155
00:43:15,190 --> 00:43:13,040
universe and you can see that it has

1156
00:43:17,349 --> 00:43:15,200
this kind of web-like structure you see

1157
00:43:19,670 --> 00:43:17,359
filaments you see uh kind of some

1158
00:43:21,270 --> 00:43:19,680
two-dimensional flat sheets and then you

1159
00:43:23,349 --> 00:43:21,280
see where those filaments cross you see

1160
00:43:26,230 --> 00:43:23,359
clusters and that's really describing

1161
00:43:28,069 --> 00:43:26,240
the large-scale distribution of matter

1162
00:43:28,870 --> 00:43:28,079
throughout the universe

1163
00:43:31,829 --> 00:43:28,880

but

1164
00:43:33,750 --> 00:43:31,839
that's kind of weird right so um so what

1165
00:43:35,430 --> 00:43:33,760
do we know from galaxy about galaxies

1166
00:43:37,109 --> 00:43:35,440
from observations alone well we know

1167
00:43:38,630 --> 00:43:37,119
that these are groups of stars and gas

1168
00:43:39,750 --> 00:43:38,640
and dark matter they're gravitationally

1169
00:43:41,030 --> 00:43:39,760
bound

1170
00:43:42,470 --> 00:43:41,040
there's a bunch of these objects

1171
00:43:45,190 --> 00:43:42,480
throughout the universe there's this

1172
00:43:46,870 --> 00:43:45,200
huge population that's very diverse but

1173
00:43:48,950 --> 00:43:46,880
we can broadly break it down into

1174
00:43:50,870 --> 00:43:48,960
ellipticals and spirals and then finally

1175
00:43:53,670 --> 00:43:50,880
that has this weird web-like

1176
00:43:55,510 --> 00:43:53,680
distribution in space but of course the

1177
00:43:56,390 --> 00:43:55,520
the question that arises from this is

1178
00:43:57,990 --> 00:43:56,400
like

1179
00:44:01,109 --> 00:43:58,000
why right

1180
00:44:05,589 --> 00:44:01,119
and observations alone it's very hard to

1181
00:44:07,589 --> 00:44:05,599
answer why this is the way it is because

1182
00:44:10,470 --> 00:44:07,599
the time scales over which galaxies

1183
00:44:12,309 --> 00:44:10,480
change are very very slow

1184
00:44:13,910 --> 00:44:12,319
if you think about the earth and its

1185
00:44:15,589 --> 00:44:13,920
orbit around the sun

1186
00:44:16,870 --> 00:44:15,599
it takes a year for the earth to go

1187
00:44:18,950 --> 00:44:16,880
around the sun i mean that's how we

1188
00:44:19,829 --> 00:44:18,960

define a year right

1189
00:44:21,510 --> 00:44:19,839
um

1190
00:44:23,829 --> 00:44:21,520
but like the earth orbiting around the

1191
00:44:25,829 --> 00:44:23,839
sun our entire solar system composed of

1192
00:44:27,510 --> 00:44:25,839
the sun and the planets and the earth

1193
00:44:29,510 --> 00:44:27,520
and so on and so forth is orbiting

1194
00:44:30,950 --> 00:44:29,520
around the center of the milky way

1195
00:44:33,109 --> 00:44:30,960
galaxy

1196
00:44:36,550 --> 00:44:33,119
but instead of it taking a year to make

1197
00:44:38,790 --> 00:44:36,560
one full orbit it takes like roughly 250

1198
00:44:40,950 --> 00:44:38,800
million years it takes a very very long

1199
00:44:43,670 --> 00:44:40,960
period to make a full orbit and that

1200
00:44:45,270 --> 00:44:43,680
time scale is pretty representative of

1201
00:44:46,790 --> 00:44:45,280
the time scales associated with these

1202
00:44:49,270 --> 00:44:46,800
distant galaxies just because they're so

1203
00:44:50,710 --> 00:44:49,280
big and they're only moving so quickly

1204
00:44:53,670 --> 00:44:50,720
so you know

1205
00:44:55,750 --> 00:44:53,680
i can't see a galaxy

1206
00:44:58,230 --> 00:44:55,760
and and follow its evolution in real

1207
00:44:59,990 --> 00:44:58,240
time because i'm only going to live well

1208
00:45:01,349 --> 00:45:00,000
i i don't know i'm not going to live too

1209
00:45:03,670 --> 00:45:01,359
long if i spend that much time in the

1210
00:45:05,109 --> 00:45:03,680
desert but um i'm only going to live you

1211
00:45:07,670 --> 00:45:05,119
know humans only live on the order of

1212
00:45:09,430 --> 00:45:07,680
100 years if they're lucky right and

1213
00:45:11,349 --> 00:45:09,440

these things are changing over millions

1214
00:45:13,349 --> 00:45:11,359
or hundreds of million year time scale

1215
00:45:14,309 --> 00:45:13,359
so we just don't even have

1216
00:45:21,190 --> 00:45:14,319
the

1217
00:45:22,870 --> 00:45:21,200
very long time scales from just

1218
00:45:24,309 --> 00:45:22,880
observations alone so i don't know if

1219
00:45:26,950 --> 00:45:24,319
that galaxy is going to turn into that

1220
00:45:28,390 --> 00:45:26,960
galaxy at some other point in time just

1221
00:45:29,990 --> 00:45:28,400
because we don't have enough time to

1222
00:45:33,510 --> 00:45:30,000
watch it

1223
00:45:35,510 --> 00:45:33,520
enter in theory and simulations to to

1224
00:45:37,190 --> 00:45:35,520
better understand how

1225
00:45:40,390 --> 00:45:37,200
one galaxy might change to another

1226
00:45:44,230 --> 00:45:42,230
um so this is the stuff that i do in

1227
00:45:47,109 --> 00:45:44,240
terms of my research and many of my

1228
00:45:49,270 --> 00:45:47,119
colleagues uh do

1229
00:45:52,230 --> 00:45:49,280
and and and frank was involved in doing

1230
00:45:54,950 --> 00:45:52,240
as well um so how do we simulate

1231
00:45:56,630 --> 00:45:54,960
physical systems in general um i'm going

1232
00:45:57,990 --> 00:45:56,640
to apply this to astrophysics and

1233
00:45:59,430 --> 00:45:58,000
galaxies but

1234
00:46:01,829 --> 00:45:59,440
in general it's kind of like the

1235
00:46:03,589 --> 00:46:01,839
scientific method we write a computer

1236
00:46:05,750 --> 00:46:03,599
program that represents some sort of

1237
00:46:08,150 --> 00:46:05,760
virtual space inside of our computer

1238
00:46:10,309 --> 00:46:08,160

where we can like a sandbox where we can

1239
00:46:11,910 --> 00:46:10,319
monkey around inside the confines of

1240
00:46:13,589 --> 00:46:11,920
this virtual space

1241
00:46:17,190 --> 00:46:13,599
we include we'd like to include all

1242
00:46:18,550 --> 00:46:17,200
physics that we can uh but unfortunately

1243
00:46:20,230 --> 00:46:18,560
it would be computationally too

1244
00:46:22,069 --> 00:46:20,240
expensive and we wouldn't be able to

1245
00:46:23,829 --> 00:46:22,079
make much progress even running on the

1246
00:46:25,990 --> 00:46:23,839
fastest supercomputers that we have

1247
00:46:28,150 --> 00:46:26,000
access to so we only can include the

1248
00:46:29,990 --> 00:46:28,160
dominant physics that operates on these

1249
00:46:32,470 --> 00:46:30,000
sorts of scales now for these large

1250
00:46:34,230 --> 00:46:32,480
scales and astrophysics the main physics

1251
00:46:36,069 --> 00:46:34,240
that we want to include are our good

1252
00:46:37,750 --> 00:46:36,079
vend gravity that we already talked

1253
00:46:40,309 --> 00:46:37,760
about before because that really

1254
00:46:43,589 --> 00:46:40,319
dominates on large scales and fluid

1255
00:46:45,430 --> 00:46:43,599
dynamics fluids like how uh the seas you

1256
00:46:48,069 --> 00:46:45,440
know the currents in our oceans operate

1257
00:46:49,990 --> 00:46:48,079
but also how our atmosphere like gases

1258
00:46:52,950 --> 00:46:50,000
largely behave as fluids at high enough

1259
00:46:55,510 --> 00:46:52,960
density um so the planets have fluid

1260
00:46:57,829 --> 00:46:55,520
dynamics and the trifid nebula you know

1261
00:47:00,309 --> 00:46:57,839
other gas clouds throughout the universe

1262
00:47:02,150 --> 00:47:00,319
much of the universe can be approximated

1263
00:47:04,470 --> 00:47:02,160

by the fluid equations in the same

1264
00:47:07,670 --> 00:47:04,480
equations that approximate how water

1265
00:47:11,270 --> 00:47:09,670
then we create some sort of starting

1266
00:47:13,910 --> 00:47:11,280
point for our simulation some initial

1267
00:47:15,589 --> 00:47:13,920
condition initial distribution of matter

1268
00:47:17,589 --> 00:47:15,599
we run the simulation forward

1269
00:47:19,589 --> 00:47:17,599
accelerating time so it's faster than

1270
00:47:21,589 --> 00:47:19,599
real time so we can have like

1271
00:47:23,990 --> 00:47:21,599
you know instead of a second only a

1272
00:47:27,190 --> 00:47:24,000
second goes by a second p can be 100

1273
00:47:28,790 --> 00:47:27,200
years or a million years go by

1274
00:47:30,549 --> 00:47:28,800
and then we um

1275
00:47:32,230 --> 00:47:30,559
we do science with that we analyze the

1276
00:47:34,630 --> 00:47:32,240
results we compare with observations we

1277
00:47:36,069 --> 00:47:34,640
see how well we did and somehow that

1278
00:47:38,870 --> 00:47:36,079
yields some sort of scientific

1279
00:47:41,270 --> 00:47:38,880
understanding uh that might be better

1280
00:47:42,309 --> 00:47:41,280
than we had previous to the to this

1281
00:47:44,230 --> 00:47:42,319
happening

1282
00:47:45,109 --> 00:47:44,240
oops

1283
00:47:46,870 --> 00:47:45,119
so

1284
00:47:49,910 --> 00:47:46,880
let's uh let's

1285
00:47:53,270 --> 00:47:49,920
let's simulate galaxies using an initial

1286
00:47:55,750 --> 00:47:53,280
condition of just a really sim simple

1287
00:47:57,829 --> 00:47:55,760
distribution of material um we already

1288
00:48:00,230 --> 00:47:57,839

talked about this kind of schematic of a

1289
00:48:02,549 --> 00:48:00,240
milky way or a disc galaxy having a disc

1290
00:48:04,230 --> 00:48:02,559
component like a like a fried egg and

1291
00:48:06,309 --> 00:48:04,240
then having a bulge component like the

1292
00:48:08,950 --> 00:48:06,319
yolk part of a fried egg in the center

1293
00:48:11,510 --> 00:48:08,960
and and it all be stars let's just take

1294
00:48:13,990 --> 00:48:11,520
two galaxies and fling them into each

1295
00:48:16,309 --> 00:48:14,000
other that sounds fun just you know

1296
00:48:19,349 --> 00:48:16,319
cause mayhem and and see what see what

1297
00:48:21,430 --> 00:48:19,359
results now i'll just mention that the

1298
00:48:24,069 --> 00:48:21,440
visualization that i'm about to show was

1299
00:48:25,910 --> 00:48:24,079
done by our very own frank summers the

1300
00:48:28,230 --> 00:48:25,920
of course the host uh that that's

1301
00:48:30,069 --> 00:48:28,240
hosting me tonight and and it's one of

1302
00:48:31,670 --> 00:48:30,079
my favorite visualizations

1303
00:48:33,750 --> 00:48:31,680
so

1304
00:48:35,349 --> 00:48:33,760
we're we're taking these two simulations

1305
00:48:39,990 --> 00:48:35,359
we're flinging them together and then

1306
00:48:42,230 --> 00:48:40,000
periodically like now we're going to um

1307
00:48:44,390 --> 00:48:42,240
fade to an actual image taken with the

1308
00:48:45,670 --> 00:48:44,400
hubble space telescope of an irregular

1309
00:48:47,349 --> 00:48:45,680
galaxy

1310
00:48:49,430 --> 00:48:47,359
and you can see

1311
00:48:51,109 --> 00:48:49,440
that even though this is a reasonably

1312
00:48:53,430 --> 00:48:51,119
simple simulation we're going to rotate

1313
00:48:54,950 --> 00:48:53,440

the simulation around and then fade to

1314
00:48:57,030 --> 00:48:54,960
actual data taken with the hubble space

1315
00:48:59,670 --> 00:48:57,040
telescope and you can see obvious

1316
00:49:02,630 --> 00:48:59,680
similarities between the behavior in

1317
00:49:05,270 --> 00:49:02,640
this very simplistic simulation and

1318
00:49:08,230 --> 00:49:05,280
actual images of very complicated

1319
00:49:09,589 --> 00:49:08,240
galactic structures um

1320
00:49:11,430 --> 00:49:09,599
and it's really eye-opening because

1321
00:49:12,790 --> 00:49:11,440
before that you know you see these

1322
00:49:14,710 --> 00:49:12,800
irregular systems and you're like what

1323
00:49:16,309 --> 00:49:14,720
the heck are these weird shapes why they

1324
00:49:19,510 --> 00:49:16,319
have weird shapes why are they blue in

1325
00:49:22,790 --> 00:49:19,520
color um and yet these are reasonably

1326
00:49:24,790 --> 00:49:22,800
easily modeled by a very simple um two

1327
00:49:26,470 --> 00:49:24,800
galaxies slamming together that that

1328
00:49:28,950 --> 00:49:26,480
provides us a really good explanation of

1329
00:49:30,549 --> 00:49:28,960
how to form these these are just

1330
00:49:32,230 --> 00:49:30,559
galaxies that got too close to each

1331
00:49:34,069 --> 00:49:32,240
other they slammed into each other they

1332
00:49:35,910 --> 00:49:34,079
interacted when they interacted they

1333
00:49:37,270 --> 00:49:35,920
caused a new burst of star formation

1334
00:49:39,910 --> 00:49:37,280
that new burst of star formation

1335
00:49:41,510 --> 00:49:39,920
resulted in the kind of bluish color new

1336
00:49:43,349 --> 00:49:41,520
new stars tend to be dominated by the

1337
00:49:44,870 --> 00:49:43,359
most massive blue stars that are present

1338
00:49:46,710 --> 00:49:44,880

in those populations

1339
00:49:48,390 --> 00:49:46,720
and you end up with

1340
00:49:50,870 --> 00:49:48,400
with these an ex a really good

1341
00:49:53,510 --> 00:49:50,880
explanation for these blue irregular

1342
00:49:55,510 --> 00:49:53,520
galaxies that are that are so obvious

1343
00:49:58,230 --> 00:49:55,520
throughout the sky

1344
00:50:00,150 --> 00:49:58,240
so i i really love that for having this

1345
00:50:03,670 --> 00:50:00,160
beautiful direct comparison between

1346
00:50:05,829 --> 00:50:03,680
these uh a simple simulation and and

1347
00:50:07,270 --> 00:50:05,839
actual data that everyone is familiar

1348
00:50:08,069 --> 00:50:07,280
with

1349
00:50:10,309 --> 00:50:08,079
okay

1350
00:50:11,670 --> 00:50:10,319
so that was that was cool but let's move

1351
00:50:13,430 --> 00:50:11,680
to something a little bit more

1352
00:50:16,309 --> 00:50:13,440
complicated you know it'd be nice rather

1353
00:50:18,150 --> 00:50:16,319
than starting out with uh two

1354
00:50:19,990 --> 00:50:18,160
simulated galaxies where we've already

1355
00:50:22,309 --> 00:50:20,000
formed them well what about let's start

1356
00:50:23,910 --> 00:50:22,319
with nothing let's start with the the

1357
00:50:26,150 --> 00:50:23,920
beginning just after the big bang and

1358
00:50:27,510 --> 00:50:26,160
see if we can actually form galaxies

1359
00:50:28,309 --> 00:50:27,520
organically

1360
00:50:30,069 --> 00:50:28,319
um

1361
00:50:31,190 --> 00:50:30,079
so in order to do this we need to start

1362
00:50:33,510 --> 00:50:31,200
with initial conditions for our

1363
00:50:35,270 --> 00:50:33,520

simulation that were like the early

1364
00:50:37,510 --> 00:50:35,280
universe so what does the early universe

1365
00:50:40,150 --> 00:50:37,520
what did it look like well we have an

1366
00:50:42,390 --> 00:50:40,160
idea of this remember remember our idea

1367
00:50:44,069 --> 00:50:42,400
our cartoon version of what the universe

1368
00:50:45,829 --> 00:50:44,079
looks like with the milky way here and

1369
00:50:47,990 --> 00:50:45,839
all these galaxies traveling outward

1370
00:50:50,230 --> 00:50:48,000
away from us well if we go

1371
00:50:51,670 --> 00:50:50,240
back in time a little bit um you can

1372
00:50:53,910 --> 00:50:51,680
imagine the galaxies that are traveling

1373
00:50:55,270 --> 00:50:53,920
away from us are a little bit closer

1374
00:50:57,109 --> 00:50:55,280
because they've been traveling away from

1375
00:50:59,430 --> 00:50:57,119
us right and if you go back farther

1376
00:51:01,349 --> 00:50:59,440
they're going to be closer still and you

1377
00:51:03,430 --> 00:51:01,359
can keep going back until all the

1378
00:51:05,349 --> 00:51:03,440
galaxies are kind of piled on top of

1379
00:51:06,950 --> 00:51:05,359
each other and that's that's the big

1380
00:51:08,630 --> 00:51:06,960
bang for the most part i mean that's a

1381
00:51:11,270 --> 00:51:08,640
oversimplification but that's roughly

1382
00:51:14,230 --> 00:51:11,280
the idea to why we know that there was

1383
00:51:16,710 --> 00:51:14,240
some sort of origin time at which the

1384
00:51:18,549 --> 00:51:16,720
universe kind of began

1385
00:51:21,190 --> 00:51:18,559
this big bang moment

1386
00:51:23,030 --> 00:51:21,200
and it turns out we do have

1387
00:51:23,910 --> 00:51:23,040
some images

1388
00:51:26,309 --> 00:51:23,920

of

1389
00:51:28,630 --> 00:51:26,319
what's known as the light echo

1390
00:51:30,150 --> 00:51:28,640
of the big bang now these are not at the

1391
00:51:32,230 --> 00:51:30,160
moment of the big bang these are a few

1392
00:51:34,309 --> 00:51:32,240
hundred thousand years after but that's

1393
00:51:36,470 --> 00:51:34,319
a very short time scale relative to the

1394
00:51:38,230 --> 00:51:36,480
amount of time that's taken place since

1395
00:51:40,390 --> 00:51:38,240
the big bang which is a few billion

1396
00:51:42,069 --> 00:51:40,400
years um this is called the cosmic

1397
00:51:43,990 --> 00:51:42,079
microwave background you're probably

1398
00:51:45,589 --> 00:51:44,000
familiar with it if you've

1399
00:51:49,670 --> 00:51:45,599
read anything about astronomy or

1400
00:51:50,549 --> 00:51:49,680
cosmology in the last 50 years and

1401
00:51:55,270 --> 00:51:50,559
this

1402
00:51:57,589 --> 00:51:55,280
radiation and thus the distribution of

1403
00:52:00,390 --> 00:51:57,599
matter um very shortly after the big

1404
00:52:01,829 --> 00:52:00,400
bang took place and so in this um i

1405
00:52:03,670 --> 00:52:01,839
don't want to get too bogged down in the

1406
00:52:06,309 --> 00:52:03,680
details of this but in this the the red

1407
00:52:08,630 --> 00:52:06,319
regions are very high uh over densities

1408
00:52:10,630 --> 00:52:08,640
relative to the to the background level

1409
00:52:12,150 --> 00:52:10,640
of material and then the dark blue

1410
00:52:14,230 --> 00:52:12,160
regions are under densities where

1411
00:52:16,150 --> 00:52:14,240
there's less material relative to the

1412
00:52:18,309 --> 00:52:16,160
background

1413
00:52:20,870 --> 00:52:18,319

and if we plug this in this matter

1414
00:52:23,190 --> 00:52:20,880
distribution into our simulations as our

1415
00:52:25,030 --> 00:52:23,200
starting point for the simulations

1416
00:52:27,430 --> 00:52:25,040
um and run it forward we get something

1417
00:52:30,150 --> 00:52:27,440
like this this is a simulation that that

1418
00:52:32,870 --> 00:52:30,160
i ran a few years ago um

1419
00:52:34,150 --> 00:52:32,880
and it shows the distribution of

1420
00:52:36,069 --> 00:52:34,160
material

1421
00:52:37,750 --> 00:52:36,079
over the course of the of the of the

1422
00:52:40,069 --> 00:52:37,760
universe from just after the big bang to

1423
00:52:42,309 --> 00:52:40,079
present now you can see that this this

1424
00:52:44,950 --> 00:52:42,319
cube is very white because everything is

1425
00:52:46,950 --> 00:52:44,960
very uniform roughly uniform in the

1426
00:52:48,630 --> 00:52:46,960
early universe just perturbed by these

1427
00:52:51,030 --> 00:52:48,640
slight over densities and slight under

1428
00:52:53,270 --> 00:52:51,040
densities and then as we move forward in

1429
00:52:55,510 --> 00:52:53,280
time the over densities and under

1430
00:52:57,589 --> 00:52:55,520
densities start to be accentuated by

1431
00:52:59,910 --> 00:52:57,599
gravity remember

1432
00:53:01,829 --> 00:52:59,920
gravity uh gravity is an attractive

1433
00:53:03,589 --> 00:53:01,839
force so if you have a bunch of mass if

1434
00:53:06,790 --> 00:53:03,599
i have a bunch of mass i'm going to be

1435
00:53:08,630 --> 00:53:06,800
effective at pulling more mass into me

1436
00:53:10,309 --> 00:53:08,640
and it's kind of a rich gets richer kind

1437
00:53:11,829 --> 00:53:10,319
of game right because if i pull more

1438
00:53:14,630 --> 00:53:11,839

mass into me well then i'm more

1439
00:53:16,230 --> 00:53:14,640
effective at being able to having more

1440
00:53:18,470 --> 00:53:16,240
gravitational attraction and pulling

1441
00:53:19,910 --> 00:53:18,480
more mass into me so it's it's like a

1442
00:53:22,630 --> 00:53:19,920
snowball effect

1443
00:53:25,589 --> 00:53:22,640
and what ends up happening is you very

1444
00:53:27,510 --> 00:53:25,599
naturally create this

1445
00:53:30,549 --> 00:53:27,520
this distribution of matter that we saw

1446
00:53:33,750 --> 00:53:30,559
earlier this cosmic web of stuff where

1447
00:53:36,390 --> 00:53:33,760
those over densities seed gravitational

1448
00:53:37,430 --> 00:53:36,400
info of the surrounding material and you

1449
00:53:40,309 --> 00:53:37,440
form

1450
00:53:42,630 --> 00:53:40,319
clusters and sheets and filaments

1451
00:53:44,950 --> 00:53:42,640
describing the distribution of matter on

1452
00:53:46,309 --> 00:53:44,960
very large scales

1453
00:53:47,190 --> 00:53:46,319
um

1454
00:53:49,030 --> 00:53:47,200
and

1455
00:53:50,790 --> 00:53:49,040
you know that's awesome this this

1456
00:53:53,270 --> 00:53:50,800
doesn't even require fluid dynamics this

1457
00:53:54,790 --> 00:53:53,280
is just gravity and we can reproduce the

1458
00:53:56,950 --> 00:53:54,800
distribution of the cosmic web that

1459
00:53:59,030 --> 00:53:56,960
we're able to see in observations uh

1460
00:54:01,270 --> 00:53:59,040
like the ones that we we saw earlier

1461
00:54:02,470 --> 00:54:01,280
from the sloan digital sky survey

1462
00:54:04,150 --> 00:54:02,480
that we see the same sort of

1463
00:54:06,470 --> 00:54:04,160

distribution and it's a it's like a

1464
00:54:08,150 --> 00:54:06,480
wonderful explanation that could only be

1465
00:54:11,270 --> 00:54:08,160
revealed through

1466
00:54:13,270 --> 00:54:11,280
through simulations and theory uh

1467
00:54:14,549 --> 00:54:13,280
like the ones that i i showed now

1468
00:54:15,829 --> 00:54:14,559
there's additional

1469
00:54:18,710 --> 00:54:15,839
um

1470
00:54:20,630 --> 00:54:18,720
movies like this wonderful uh

1471
00:54:21,829 --> 00:54:20,640
visualization done by the illustrious

1472
00:54:23,829 --> 00:54:21,839
team

1473
00:54:25,190 --> 00:54:23,839
and collab uh mark vogelsberger and

1474
00:54:26,390 --> 00:54:25,200
collaborators

1475
00:54:29,030 --> 00:54:26,400
at um

1476
00:54:31,510 --> 00:54:29,040
at harvard and mit and and max planck

1477
00:54:32,630 --> 00:54:31,520
and a variety of other institutions um

1478
00:54:34,309 --> 00:54:32,640
showing

1479
00:54:36,950 --> 00:54:34,319
again you can see in dark purple this

1480
00:54:38,870 --> 00:54:36,960
kind of filamentary structure connecting

1481
00:54:41,589 --> 00:54:38,880
individu like connecting galaxies all

1482
00:54:43,829 --> 00:54:41,599
these little points are galaxies

1483
00:54:46,390 --> 00:54:43,839
these little yellow points are over

1484
00:54:48,789 --> 00:54:46,400
densities in the in the material in the

1485
00:54:50,789 --> 00:54:48,799
matter along these filaments and where

1486
00:54:51,589 --> 00:54:50,799
those filaments cross that's where you

1487
00:54:53,829 --> 00:54:51,599
have

1488
00:54:55,990 --> 00:54:53,839

galaxies and clusters of galaxies that

1489
00:54:57,990 --> 00:54:56,000
start to build up with time and i this

1490
00:54:59,349 --> 00:54:58,000
visualization is just incredible it's

1491
00:55:00,789 --> 00:54:59,359
like cinematic

1492
00:55:02,390 --> 00:55:00,799
um

1493
00:55:04,789 --> 00:55:02,400
in fact i wouldn't be surprised if frank

1494
00:55:07,910 --> 00:55:04,799
summers were involved with this so um

1495
00:55:09,829 --> 00:55:07,920
just really nice visualization of how

1496
00:55:11,910 --> 00:55:09,839
how the distribution of matter changes

1497
00:55:14,069 --> 00:55:11,920
over time and how you have these this

1498
00:55:17,910 --> 00:55:14,079
very cosmic web build up of material

1499
00:55:19,190 --> 00:55:17,920
simply by the presence of of gravity

1500
00:55:20,870 --> 00:55:19,200
much like we see here with the sloan

1501
00:55:24,390 --> 00:55:20,880
digital skieser

1502
00:55:27,270 --> 00:55:24,400
so um if we zoom in on

1503
00:55:28,870 --> 00:55:27,280
individual systems uh within those

1504
00:55:30,870 --> 00:55:28,880
filamentary structures this is another

1505
00:55:32,789 --> 00:55:30,880
simulation that i was involved with uh

1506
00:55:34,390 --> 00:55:32,799
the fire simulations that are pied by

1507
00:55:36,789 --> 00:55:34,400
phil hopkins here at caltech one of my

1508
00:55:38,470 --> 00:55:36,799
collaborators and

1509
00:55:39,829 --> 00:55:38,480
the left side is going to show you can

1510
00:55:42,230 --> 00:55:39,839
see that filamentary structure we're

1511
00:55:44,710 --> 00:55:42,240
going to zoom in on one galaxy in that

1512
00:55:46,710 --> 00:55:44,720
and watch its growth over time

1513
00:55:48,549 --> 00:55:46,720

and this white expanding circle

1514
00:55:50,870 --> 00:55:48,559
represents kind of the the sphere of

1515
00:55:53,270 --> 00:55:50,880
influence the kind of the gravitational

1516
00:55:55,030 --> 00:55:53,280
region over which that galaxy dominates

1517
00:55:56,309 --> 00:55:55,040
and you can see that it's growing over

1518
00:55:58,230 --> 00:55:56,319
time again

1519
00:56:00,150 --> 00:55:58,240
we're doing the entire evolution of the

1520
00:56:02,630 --> 00:56:00,160
universe here in like 30 seconds so this

1521
00:56:04,870 --> 00:56:02,640
is a very sped up version of the growth

1522
00:56:07,270 --> 00:56:04,880
of this galaxy but this is thought to be

1523
00:56:09,670 --> 00:56:07,280
a galaxy much like our own milky way

1524
00:56:10,789 --> 00:56:09,680
galaxy i'll play this again but you can

1525
00:56:12,870 --> 00:56:10,799
see this

1526
00:56:14,789 --> 00:56:12,880
this filament you can see lots of the

1527
00:56:17,670 --> 00:56:14,799
individual galaxies and essentially

1528
00:56:20,150 --> 00:56:17,680
they're falling into this galaxy over

1529
00:56:22,230 --> 00:56:20,160
time and this brings up what often

1530
00:56:23,829 --> 00:56:22,240
people refer to as this kind of morbid

1531
00:56:26,390 --> 00:56:23,839
analogy that

1532
00:56:27,670 --> 00:56:26,400
galaxies are cannibals they grow by

1533
00:56:30,630 --> 00:56:27,680
eating

1534
00:56:31,510 --> 00:56:30,640
neighboring galaxies that fall into

1535
00:56:33,109 --> 00:56:31,520
their

1536
00:56:35,589 --> 00:56:33,119
gravitational field and then they just

1537
00:56:38,390 --> 00:56:35,599
kind of consume them

1538
00:56:40,789 --> 00:56:38,400

and it's it's that's that's how it works

1539
00:56:43,270 --> 00:56:40,799
it's a it's the higher people refer to

1540
00:56:45,589 --> 00:56:43,280
it as a hierarchical construction of

1541
00:56:47,430 --> 00:56:45,599
galaxies you you have two small galaxies

1542
00:56:49,510 --> 00:56:47,440
they they fall together they grow into a

1543
00:56:51,990 --> 00:56:49,520
larger structure then those structures

1544
00:56:54,230 --> 00:56:52,000
fall into larger structures and and into

1545
00:56:57,589 --> 00:56:54,240
larger structures still and that's how

1546
00:56:59,430 --> 00:56:57,599
we see the remnants of galaxies in our

1547
00:57:00,390 --> 00:56:59,440
galaxy that have been slowly shredded

1548
00:57:07,589 --> 00:57:00,400
and

1549
00:57:09,670 --> 00:57:07,599
see this in in other galaxies

1550
00:57:11,430 --> 00:57:09,680
now if we take that same simulation from

1551
00:57:13,190 --> 00:57:11,440
the fire simulations

1552
00:57:16,549 --> 00:57:13,200
and we process it to make a

1553
00:57:18,470 --> 00:57:16,559
visualization that's more um

1554
00:57:20,470 --> 00:57:18,480
more

1555
00:57:23,750 --> 00:57:20,480
representative of what you'd see from

1556
00:57:26,309 --> 00:57:23,760
starlight and dust and gas this is what

1557
00:57:28,789 --> 00:57:26,319
it looks like as it evolves over time so

1558
00:57:31,190 --> 00:57:28,799
again this is a milky way like galaxy

1559
00:57:33,910 --> 00:57:31,200
that we've simulated in our computer

1560
00:57:36,390 --> 00:57:33,920
and you can see that it looks reasonably

1561
00:57:37,910 --> 00:57:36,400
realistic relative to a lot of the

1562
00:57:40,069 --> 00:57:37,920
observed galaxies that we see right now

1563
00:57:41,829 --> 00:57:40,079

we're flying through the disc plane of

1564
00:57:43,349 --> 00:57:41,839
the galaxy you can see there's a lot of

1565
00:57:46,150 --> 00:57:43,359
blue star light but then there's these

1566
00:57:48,710 --> 00:57:46,160
red patches those red patches are from

1567
00:57:50,549 --> 00:57:48,720
dust that's absorbing the the light

1568
00:57:53,109 --> 00:57:50,559
that's passing through it so

1569
00:57:54,630 --> 00:57:53,119
you you uh you see them kind of as a

1570
00:57:57,109 --> 00:57:54,640
void this can be a little bit

1571
00:57:59,270 --> 00:57:57,119
disorienting here as we're backing away

1572
00:58:00,230 --> 00:57:59,280
from this spiraling

1573
00:58:02,789 --> 00:58:00,240
um

1574
00:58:04,470 --> 00:58:02,799
kind of pulsing galaxy

1575
00:58:06,230 --> 00:58:04,480
but this is

1576
00:58:08,150 --> 00:58:06,240
this is kind of state of the art with

1577
00:58:10,470 --> 00:58:08,160
representative to how we're modeling

1578
00:58:11,910 --> 00:58:10,480
these systems and and how well we're

1579
00:58:13,910 --> 00:58:11,920
doing

1580
00:58:15,510 --> 00:58:13,920
in comparison to

1581
00:58:17,109 --> 00:58:15,520
to the systems that we see when we look

1582
00:58:19,190 --> 00:58:17,119
up with telescopes like the hubble space

1583
00:58:21,430 --> 00:58:19,200
telescope

1584
00:58:23,510 --> 00:58:21,440
um these are some stills from the fire

1585
00:58:25,670 --> 00:58:23,520
simulations and you can see these look

1586
00:58:27,190 --> 00:58:25,680
reasonably realistic

1587
00:58:29,589 --> 00:58:27,200
uh compared to

1588
00:58:32,470 --> 00:58:29,599

you know actual observations of actual

1589
00:58:34,150 --> 00:58:32,480
galaxies that we see in the sky now of

1590
00:58:35,990 --> 00:58:34,160
course that's not what we're doing we're

1591
00:58:37,910 --> 00:58:36,000
not just trying to reproduce and make

1592
00:58:40,150 --> 00:58:37,920
them look similar this isn't like movie

1593
00:58:41,430 --> 00:58:40,160
making here we're we're building these

1594
00:58:43,750 --> 00:58:41,440
galaxies

1595
00:58:45,430 --> 00:58:43,760
from first principles from computer

1596
00:58:46,710 --> 00:58:45,440
simulations where you code in all the

1597
00:58:49,510 --> 00:58:46,720
physics that you think is there we're

1598
00:58:51,030 --> 00:58:49,520
starting from these cosmic microwave

1599
00:58:53,109 --> 00:58:51,040
background initial conditions and

1600
00:58:55,030 --> 00:58:53,119
running them forward and

1601
00:58:56,710 --> 00:58:55,040
iterating by adding additional physics

1602
00:58:58,789 --> 00:58:56,720
here and additional physics there to

1603
00:59:01,190 --> 00:58:58,799
better understand how

1604
00:59:02,870 --> 00:59:01,200
how these galaxies are

1605
00:59:05,589 --> 00:59:02,880
matching what we see in the sky not just

1606
00:59:07,910 --> 00:59:05,599
by appearance not just by size and

1607
00:59:11,270 --> 00:59:07,920
structure and color but also by their

1608
00:59:12,069 --> 00:59:11,280
composition by their magnetic fields by

1609
00:59:14,630 --> 00:59:12,079
uh

1610
00:59:15,510 --> 00:59:14,640
the distribution by their temperatures

1611
00:59:17,270 --> 00:59:15,520
by

1612
00:59:18,950 --> 00:59:17,280
the types of stars that reside within

1613
00:59:21,190 --> 00:59:18,960

them all of these things to better

1614
00:59:22,950 --> 00:59:21,200
understand not just can we reproduce the

1615
00:59:24,950 --> 00:59:22,960
ones that we see in the sky but we

1616
00:59:27,190 --> 00:59:24,960
control all the knobs on these so we

1617
00:59:28,789 --> 00:59:27,200
know if i can re reproduce one that

1618
00:59:31,030 --> 00:59:28,799
looks like one in the sky then i can

1619
00:59:35,030 --> 00:59:31,040
look oh okay so the magnetic field

1620
00:59:36,789 --> 00:59:35,040
strength is this or um the distribution

1621
00:59:38,630 --> 00:59:36,799
of material or the metallicity that's

1622
00:59:41,190 --> 00:59:38,640
present in that galaxy is this when that

1623
00:59:43,190 --> 00:59:41,200
might not be so readily observable by

1624
00:59:44,950 --> 00:59:43,200
those galaxies just because they're

1625
00:59:47,349 --> 00:59:44,960
hundreds of thousands or hundreds of

1626
00:59:50,789 --> 00:59:47,359
millions of light years away from us and

1627
00:59:53,190 --> 00:59:50,799
not not easily um identified in that

1628
00:59:53,990 --> 00:59:53,200
that capacity

1629
00:59:56,230 --> 00:59:54,000
so

1630
00:59:58,309 --> 00:59:56,240
um and then lastly the last simulation

1631
01:00:00,390 --> 00:59:58,319
that i'd like to show is is close to

1632
01:00:02,230 --> 01:00:00,400
home because it's our own milky way

1633
01:00:04,549 --> 01:00:02,240
galaxy and what's going to happen to our

1634
01:00:05,510 --> 01:00:04,559
milky way galaxy in the next few billion

1635
01:00:06,309 --> 01:00:05,520
years

1636
01:00:07,910 --> 01:00:06,319
now

1637
01:00:10,789 --> 01:00:07,920
um

1638
01:00:13,829 --> 01:00:10,799

earlier i i kind of fibbed because this

1639
01:00:15,589 --> 01:00:13,839
simulation i said i said all galaxies

1640
01:00:17,589 --> 01:00:15,599
are traveling away from us but i kind of

1641
01:00:19,510 --> 01:00:17,599
lied there's one galaxy that is not

1642
01:00:21,829 --> 01:00:19,520
traveling away from us and it's our old

1643
01:00:23,829 --> 01:00:21,839
favorite the andromeda galaxy so we've

1644
01:00:25,829 --> 01:00:23,839
got the milky way up here and down here

1645
01:00:27,270 --> 01:00:25,839
we've got the andromeda galaxy

1646
01:00:29,109 --> 01:00:27,280
don't we don't worry so much about the

1647
01:00:30,950 --> 01:00:29,119
triangulum galaxy for the purposes of

1648
01:00:32,950 --> 01:00:30,960
this but the andromeda galaxy is

1649
01:00:35,510 --> 01:00:32,960
actually traveling towards us

1650
01:00:37,190 --> 01:00:35,520
and in a few billion years we're going

1651
01:00:39,750 --> 01:00:37,200
to merge with it the milky way will

1652
01:00:43,430 --> 01:00:39,760
merge with the andromeda galaxy and form

1653
01:00:45,589 --> 01:00:43,440
kind of a synthesize a new galaxy

1654
01:00:47,670 --> 01:00:45,599
and what's kind of ironic about this is

1655
01:00:49,109 --> 01:00:47,680
that the individual stars

1656
01:00:50,870 --> 01:00:49,119
in the galaxies

1657
01:00:52,390 --> 01:00:50,880
the problem there's very little

1658
01:00:54,390 --> 01:00:52,400
probability that they'll actually

1659
01:00:56,870 --> 01:00:54,400
collide it's just that these

1660
01:00:59,349 --> 01:00:56,880
the because most galaxies are mostly

1661
01:01:01,030 --> 01:00:59,359
empty space between the concentrations

1662
01:01:03,829 --> 01:01:01,040
of of matter that we call stars or

1663
01:01:06,150 --> 01:01:03,839

planets but um over time these things

1664
01:01:07,829 --> 01:01:06,160
will coalesce into a single structure

1665
01:01:10,870 --> 01:01:07,839
and because astronomers have a good

1666
01:01:12,309 --> 01:01:10,880
sense of humor the the resulting galaxy

1667
01:01:14,470 --> 01:01:12,319
that will happen in you know the next

1668
01:01:15,750 --> 01:01:14,480
five to eight billion years

1669
01:01:17,910 --> 01:01:15,760
because it's the combination of the

1670
01:01:21,109 --> 01:01:17,920
milky way and the andromeda galaxy we

1671
01:01:23,270 --> 01:01:21,119
refer to it as milk omada which i really

1672
01:01:27,190 --> 01:01:23,280
i really dig that should get that as my

1673
01:01:28,069 --> 01:01:27,200
license plate or something um anyway

1674
01:01:29,829 --> 01:01:28,079
so

1675
01:01:31,270 --> 01:01:29,839
kind of in summary based on this this

1676
01:01:33,829 --> 01:01:31,280
last section what do we know about

1677
01:01:35,750 --> 01:01:33,839
galaxies just from simulations alone

1678
01:01:37,430 --> 01:01:35,760
simulations can reproduce many of the

1679
01:01:39,829 --> 01:01:37,440
properties of galaxies i mean it's not

1680
01:01:42,870 --> 01:01:39,839
perfect we still have jobs we still have

1681
01:01:45,349 --> 01:01:42,880
a lot to understand about galaxies um

1682
01:01:47,510 --> 01:01:45,359
but they form from small over densities

1683
01:01:49,589 --> 01:01:47,520
in the early universe and gravity

1684
01:01:51,270 --> 01:01:49,599
accentuates these over densities and

1685
01:01:53,829 --> 01:01:51,280
causes them to be the seeds for these

1686
01:01:55,190 --> 01:01:53,839
these these galaxies that exist and then

1687
01:01:57,349 --> 01:01:55,200
slowly those galaxies kind of

1688
01:02:00,230 --> 01:01:57,359

cannibalize their neighbors and grow to

1689
01:02:02,470 --> 01:02:00,240
larger and larger structures by merging

1690
01:02:04,390 --> 01:02:02,480
um you can have spiral galaxies that

1691
01:02:06,230 --> 01:02:04,400
merge to make elliptical galaxies much

1692
01:02:08,470 --> 01:02:06,240
like the two spiral galaxies of the

1693
01:02:10,470 --> 01:02:08,480
milky way and andromeda merged to form

1694
01:02:12,230 --> 01:02:10,480
kind of an elliptical system the milk

1695
01:02:13,670 --> 01:02:12,240
armada system

1696
01:02:15,109 --> 01:02:13,680
and that will happen in the next you

1697
01:02:17,190 --> 01:02:15,119
know five to eight billion years so

1698
01:02:19,430 --> 01:02:17,200
don't don't sell your real estate this

1699
01:02:21,029 --> 01:02:19,440
isn't as dire as things like climate

1700
01:02:23,190 --> 01:02:21,039
change or

1701
01:02:25,510 --> 01:02:23,200
oh heck the the covid pandemic i don't

1702
01:02:27,829 --> 01:02:25,520
know but but uh this will happen we are

1703
01:02:29,750 --> 01:02:27,839
reas you know we are sure

1704
01:02:31,109 --> 01:02:29,760
we are traveling at each other the

1705
01:02:32,950 --> 01:02:31,119
gravitational fields from each other

1706
01:02:36,309 --> 01:02:32,960
will interact and we will merge but it

1707
01:02:37,589 --> 01:02:36,319
will be many billions of years from now

1708
01:02:39,109 --> 01:02:37,599
um

1709
01:02:40,470 --> 01:02:39,119
and then just the last thing that i want

1710
01:02:42,150 --> 01:02:40,480
to talk about is on what sort of

1711
01:02:44,390 --> 01:02:42,160
computers do we run our simulations it

1712
01:02:48,309 --> 01:02:44,400
is not in fact as you may have guessed

1713
01:02:50,150 --> 01:02:48,319

uh an old 8088 from uh decades past

1714
01:02:52,150 --> 01:02:50,160
these are super computers that we're

1715
01:02:53,910 --> 01:02:52,160
using um so

1716
01:02:56,309 --> 01:02:53,920
for those of you who have seen the

1717
01:02:57,750 --> 01:02:56,319
martian which is an excellent film young

1718
01:03:00,230 --> 01:02:57,760
donald glover

1719
01:03:02,789 --> 01:03:00,240
plays an astro dynamicist who works at

1720
01:03:05,589 --> 01:03:02,799
nasa the nasa jet propulsion laboratory

1721
01:03:08,069 --> 01:03:05,599
and he does a particular calculation on

1722
01:03:09,750 --> 01:03:08,079
a supercomputer called the nasa pleiades

1723
01:03:12,150 --> 01:03:09,760
supercomputer which i was on earlier

1724
01:03:14,470 --> 01:03:12,160
today this is a real supercomputer um it

1725
01:03:17,589 --> 01:03:14,480
exists in the in i think it's at ames up

1726
01:03:20,630 --> 01:03:17,599
in the bay area and

1727
01:03:22,549 --> 01:03:20,640
it it this they filmed on location it's

1728
01:03:25,430 --> 01:03:22,559
composed of i forget how many something

1729
01:03:28,390 --> 01:03:25,440
on the order of 50 000 cpus that are in

1730
01:03:30,549 --> 01:03:28,400
these big racks cooled very cool allow

1731
01:03:32,630 --> 01:03:30,559
them to process

1732
01:03:34,309 --> 01:03:32,640
so this is all accurate there are two

1733
01:03:36,309 --> 01:03:34,319
things that are not accurate about that

1734
01:03:39,349 --> 01:03:36,319
scene

1735
01:03:41,109 --> 01:03:39,359
one is you don't actually need to go to

1736
01:03:42,390 --> 01:03:41,119
the place to plug into the computer to

1737
01:03:44,230 --> 01:03:42,400
use it we have something called the

1738
01:03:46,630 --> 01:03:44,240

internet that allows you to connect to

1739
01:03:48,630 --> 01:03:46,640
remote computers from the from pretty

1740
01:03:50,549 --> 01:03:48,640
much any other computer connected to the

1741
01:03:52,470 --> 01:03:50,559
internet and so you can connect to this

1742
01:03:55,109 --> 01:03:52,480
the super computer from you know like i

1743
01:03:56,829 --> 01:03:55,119
said i was on it on my home computer

1744
01:03:59,349 --> 01:03:56,839
here earlier today doing some

1745
01:04:02,789 --> 01:03:59,359
computational uh work

1746
01:04:04,470 --> 01:04:02,799
um it's it's it's available if you if

1747
01:04:06,549 --> 01:04:04,480
you have a nasa grant or work for nasa

1748
01:04:08,230 --> 01:04:06,559
you can apply for time on this super

1749
01:04:10,150 --> 01:04:08,240
computer to do the calculations you need

1750
01:04:11,510 --> 01:04:10,160
to uh there are other computers that are

1751
01:04:13,029 --> 01:04:11,520
provided by the national science

1752
01:04:15,349 --> 01:04:13,039
foundation and so on and so forth and

1753
01:04:18,390 --> 01:04:15,359
you can apply for time to use them to do

1754
01:04:20,390 --> 01:04:18,400
your your bidding uh on whatever project

1755
01:04:22,309 --> 01:04:20,400
you need to work on

1756
01:04:24,150 --> 01:04:22,319
and the other thing that isn't entirely

1757
01:04:26,069 --> 01:04:24,160
accurate is it doesn't tell you at the

1758
01:04:28,710 --> 01:04:26,079
end that your calculations are correct

1759
01:04:30,789 --> 01:04:28,720
you have to kind of know yourself that

1760
01:04:33,349 --> 01:04:30,799
uh the results of your simulations are

1761
01:04:34,789 --> 01:04:33,359
correct or not they just it just it just

1762
01:04:36,870 --> 01:04:34,799
does the equations you have to figure

1763
01:04:38,870 --> 01:04:36,880

out if it's correct but other than that

1764
01:04:41,109 --> 01:04:38,880
uh the scene was was reasonably accurate

1765
01:04:42,390 --> 01:04:41,119
so good job 20th century fox and the

1766
01:04:44,470 --> 01:04:42,400
martian

1767
01:04:46,789 --> 01:04:44,480
um so anyway that kind of takes me to

1768
01:04:48,309 --> 01:04:46,799
the end of my presentation in summary

1769
01:04:49,750 --> 01:04:48,319
you know i covered a lot of stuff here

1770
01:04:51,430 --> 01:04:49,760
from the history

1771
01:04:53,190 --> 01:04:51,440
of galaxies to the observation of

1772
01:04:55,270 --> 01:04:53,200
galaxies to the simulations of galaxies

1773
01:04:58,150 --> 01:04:55,280
but kind of my bullet point uh

1774
01:04:59,750 --> 01:04:58,160
highlights are here and um there's a

1775
01:05:02,390 --> 01:04:59,760
bunch of visualizations you can see on

1776
01:05:04,390 --> 01:05:02,400
my website again i'm dr cameron hummels

1777
01:05:07,670 --> 01:05:04,400
i'm a researcher at caltech in the

1778
01:05:09,750 --> 01:05:07,680
astronomy department and um

1779
01:05:13,349 --> 01:05:09,760
and i'm happy to take questions but one

1780
01:05:15,349 --> 01:05:13,359
last plug as as frank mentioned i uh i

1781
01:05:18,069 --> 01:05:15,359
run the public education work in at

1782
01:05:20,390 --> 01:05:18,079
caltech astronomy and if you're ever in

1783
01:05:22,150 --> 01:05:20,400
the los angeles area or you live here uh

1784
01:05:25,430 --> 01:05:22,160
we have in-person events we had our

1785
01:05:26,789 --> 01:05:25,440
first in-person event last month um

1786
01:05:29,910 --> 01:05:26,799
and

1787
01:05:32,069 --> 01:05:29,920
month you can come to them it's open to

1788
01:05:33,990 --> 01:05:32,079

the public they're all suited for public

1789
01:05:35,750 --> 01:05:34,000
much like these this lecture series is

1790
01:05:38,150 --> 01:05:35,760
here we also have astronomy on tap that

1791
01:05:39,750 --> 01:05:38,160
takes place at a bar um we're doing one

1792
01:05:42,309 --> 01:05:39,760
this coming monday

1793
01:05:44,069 --> 01:05:42,319
and uh and as frank mentioned he's going

1794
01:05:45,990 --> 01:05:44,079
to be speaking at it

1795
01:05:47,990 --> 01:05:46,000
and so you can come drink a drink of

1796
01:05:49,510 --> 01:05:48,000
beer or whatever floats your boat and

1797
01:05:51,910 --> 01:05:49,520
hear about science and then there's

1798
01:05:54,069 --> 01:05:51,920
astronomy theme pub trivia and uh all of

1799
01:05:55,910 --> 01:05:54,079
our stuff is recorded and live streamed

1800
01:05:56,870 --> 01:05:55,920
on on youtube so you can check that out

1801
01:05:58,390 --> 01:05:56,880
too so

1802
01:06:01,349 --> 01:05:58,400
i'm happy to take questions thank you

1803
01:06:04,309 --> 01:06:01,359
much for your time and uh yeah galaxies

1804
01:06:07,510 --> 01:06:04,319
are awesome uh hubble's awesome and

1805
01:06:10,069 --> 01:06:07,520
stick with science it's great

1806
01:06:12,549 --> 01:06:10,079
i couldn't agree more cameron

1807
01:06:15,029 --> 01:06:12,559
uh science has been a fantastic career

1808
01:06:17,829 --> 01:06:15,039
for me i really enjoyed it and it looks

1809
01:06:20,470 --> 01:06:17,839
like you really enjoy yourself as well i

1810
01:06:22,309 --> 01:06:20,480
do i do it's true

1811
01:06:24,069 --> 01:06:22,319
all right so that was a great uh

1812
01:06:25,829 --> 01:06:24,079
overview of the

1813
01:06:28,230 --> 01:06:25,839

first the initial of getting out to the

1814
01:06:30,950 --> 01:06:28,240
scale of galaxies and then lots and lots

1815
01:06:33,670 --> 01:06:30,960
of information on uh how we understand

1816
01:06:35,270 --> 01:06:33,680
galaxies are the way they are i mean

1817
01:06:37,670 --> 01:06:35,280
that's kind of what we do in science we

1818
01:06:41,109 --> 01:06:37,680
go hey take a look at that

1819
01:06:43,270 --> 01:06:42,470
exactly

1820
01:06:45,750 --> 01:06:43,280
and

1821
01:06:49,349 --> 01:06:45,760
i just like to mention that um

1822
01:06:51,510 --> 01:06:49,359
you know simulations are sort of a third

1823
01:06:52,950 --> 01:06:51,520
branch of astronomy right uh we have

1824
01:06:54,470 --> 01:06:52,960
think of the theorists who are doing

1825
01:06:55,910 --> 01:06:54,480
equations and doing all that stuff we

1826
01:06:58,309 --> 01:06:55,920
think of the observers who are going out

1827
01:07:00,870 --> 01:06:58,319
to telescopes and and

1828
01:07:01,829 --> 01:07:00,880
observing but the connection between

1829
01:07:04,950 --> 01:07:01,839
theory

1830
01:07:07,829 --> 01:07:04,960
and observation is often the simulations

1831
01:07:09,910 --> 01:07:07,839
right um and i just wondering um your

1832
01:07:12,710 --> 01:07:09,920
perspective on that as somebody because

1833
01:07:14,549 --> 01:07:12,720
you got your phd about 20 years after i

1834
01:07:17,029 --> 01:07:14,559
got my phd so

1835
01:07:18,789 --> 01:07:17,039
how has that evolved in the in

1836
01:07:20,069 --> 01:07:18,799
over the course that's the thing so

1837
01:07:22,069 --> 01:07:20,079
that's a wonderful question and it's

1838
01:07:23,589 --> 01:07:22,079

really grown so i was actually i did my

1839
01:07:24,870 --> 01:07:23,599
undergraduate studies in computer

1840
01:07:27,510 --> 01:07:24,880
science i didn't actually study

1841
01:07:30,789 --> 01:07:27,520
astronomy until uh graduate school

1842
01:07:32,950 --> 01:07:30,799
explicitly and i think that really

1843
01:07:34,789 --> 01:07:32,960
in some ways prepared me for this uh a

1844
01:07:36,870 --> 01:07:34,799
bit more than people who who just

1845
01:07:37,829 --> 01:07:36,880
studied astronomy or physics but really

1846
01:07:39,109 --> 01:07:37,839
um

1847
01:07:40,549 --> 01:07:39,119
yeah i think you're absolutely right

1848
01:07:43,029 --> 01:07:40,559
that there's essentially three fields

1849
01:07:45,029 --> 01:07:43,039
now uh maybe even four if you count the

1850
01:07:47,029 --> 01:07:45,039
people who build instruments like the

1851
01:07:48,630 --> 01:07:47,039
people who build the cameras aboard the

1852
01:07:51,990 --> 01:07:48,640
hubble space telescope or the james webb

1853
01:07:53,829 --> 01:07:52,000
space telescope and and so you've got

1854
01:07:55,750 --> 01:07:53,839
yeah there has to be an interconnect

1855
01:07:57,349 --> 01:07:55,760
because there's only so much many of

1856
01:08:00,150 --> 01:07:57,359
these physical systems are so

1857
01:08:02,150 --> 01:08:00,160
complicated that it's very difficult to

1858
01:08:03,589 --> 01:08:02,160
turn to pencil and paper and go to first

1859
01:08:05,349 --> 01:08:03,599
principles and be able to make a lot of

1860
01:08:07,510 --> 01:08:05,359
progress in trying to reproduce a real

1861
01:08:09,990 --> 01:08:07,520
galaxy when you need millions or

1862
01:08:12,549 --> 01:08:10,000
billions of computations in order to to

1863
01:08:14,710 --> 01:08:12,559

follow its evolution so computers are

1864
01:08:15,990 --> 01:08:14,720
good for that but we can't rely entirely

1865
01:08:17,590 --> 01:08:16,000
on them we need to we need the pencil

1866
01:08:20,390 --> 01:08:17,600
and paper to boil it down to analytic

1867
01:08:22,149 --> 01:08:20,400
principles too so right i mean computers

1868
01:08:24,550 --> 01:08:22,159
can give you insights that you can then

1869
01:08:26,709 --> 01:08:24,560
further explore with the theory

1870
01:08:28,709 --> 01:08:26,719
and all this stuff it's just um it's

1871
01:08:30,709 --> 01:08:28,719
it's just wonderful to see how how it

1872
01:08:32,309 --> 01:08:30,719
has grown over the years

1873
01:08:34,870 --> 01:08:32,319
all right so let's bring in grant

1874
01:08:38,149 --> 01:08:34,880
justice we've had a good number of

1875
01:08:42,390 --> 01:08:38,159
people on our chat tonight uh grant you

1876
01:08:46,550 --> 01:08:45,189
absolutely cool shirt all right yeah

1877
01:08:48,550 --> 01:08:46,560
thanks

1878
01:08:50,709 --> 01:08:48,560
twinsies

1879
01:08:52,870 --> 01:08:50,719
we love the worm logo

1880
01:08:56,229 --> 01:08:52,880
i'm so very glad that nasa brought it

1881
01:08:58,070 --> 01:08:56,239
back all right so grant uh we've had uh

1882
01:09:00,309 --> 01:08:58,080
some some good conversation what

1883
01:09:03,349 --> 01:09:00,319
questions would you like to bring up for

1884
01:09:04,789 --> 01:09:03,359
him sure um first off and i actually

1885
01:09:06,390 --> 01:09:04,799
like this one because i'm interested to

1886
01:09:07,430 --> 01:09:06,400
hear what you have to say about this as

1887
01:09:10,470 --> 01:09:07,440
well

1888
01:09:12,470 --> 01:09:10,480

what is the bar in bar galaxies what

1889
01:09:14,229 --> 01:09:12,480
does it affect and why don't all

1890
01:09:15,590 --> 01:09:14,239
galaxies have them

1891
01:09:19,349 --> 01:09:15,600
oh that's great

1892
01:09:22,070 --> 01:09:19,359
i'll do my best to answer this question

1893
01:09:24,789 --> 01:09:22,080
the bar essentially okay so just to make

1894
01:09:26,870 --> 01:09:24,799
sure everyone understands what the

1895
01:09:29,990 --> 01:09:26,880
question is referring to we talked about

1896
01:09:31,829 --> 01:09:30,000
a taxonomy of galaxies being um spiral

1897
01:09:33,590 --> 01:09:31,839
galaxies and elliptical galaxies and

1898
01:09:36,309 --> 01:09:33,600
then the catch-all that was irregular

1899
01:09:39,030 --> 01:09:36,319
galaxies now spiral galaxies can be

1900
01:09:42,470 --> 01:09:39,040
further differentiated into barred

1901
01:09:44,950 --> 01:09:42,480
galaxies or non-barred galaxies and

1902
01:09:47,269 --> 01:09:44,960
essentially what that means the bar is a

1903
01:09:49,189 --> 01:09:47,279
dynamical component that's an extension

1904
01:09:51,110 --> 01:09:49,199
of the bulge in the center remember we

1905
01:09:51,829 --> 01:09:51,120
were talking about i made the the kind

1906
01:09:52,789 --> 01:09:51,839
of

1907
01:09:55,350 --> 01:09:52,799
callus

1908
01:09:57,189 --> 01:09:55,360
analog to a fried egg it would be as

1909
01:09:58,790 --> 01:09:57,199
though the yolk of the fried egg the

1910
01:10:01,430 --> 01:09:58,800
bulge of the fried egg were kind of

1911
01:10:03,350 --> 01:10:01,440
rectangular in shape it were extended

1912
01:10:06,790 --> 01:10:03,360
out into the disc and kind of

1913
01:10:09,910 --> 01:10:06,800

rectangular in it in a in a bar um that

1914
01:10:12,790 --> 01:10:09,920
is a dynamical effect that is caused

1915
01:10:15,510 --> 01:10:12,800
it's um it's definitely a an area of

1916
01:10:18,310 --> 01:10:15,520
research but it's caused by

1917
01:10:20,790 --> 01:10:18,320
stars being in a particular orbit um

1918
01:10:23,030 --> 01:10:20,800
that that that holds that bar over time

1919
01:10:24,630 --> 01:10:23,040
because remember all of these dynamic

1920
01:10:26,229 --> 01:10:24,640
all these components like the disk of

1921
01:10:28,790 --> 01:10:26,239
the the galaxy or the bulge of the

1922
01:10:30,630 --> 01:10:28,800
galaxy it's stars it's all individual

1923
01:10:32,630 --> 01:10:30,640
stars that that

1924
01:10:34,870 --> 01:10:32,640
are just

1925
01:10:37,350 --> 01:10:34,880
kind of decomposed into those

1926
01:10:39,430 --> 01:10:37,360
compositional structures morphological

1927
01:10:41,910 --> 01:10:39,440
structures and the bar is no different

1928
01:10:43,830 --> 01:10:41,920
so it's stars that that orbit in a

1929
01:10:45,110 --> 01:10:43,840
particular way to make those and i'm

1930
01:10:49,510 --> 01:10:45,120
trying to remember the thing that

1931
01:10:51,990 --> 01:10:49,520
actually causes the bar and i think

1932
01:10:54,950 --> 01:10:52,000
so is it is it the instabilities and and

1933
01:10:56,470 --> 01:10:54,960
the um oh what are those resonances

1934
01:10:58,149 --> 01:10:56,480
um

1935
01:11:01,270 --> 01:10:58,159
the lindblad residence the internet or

1936
01:11:02,870 --> 01:11:01,280
lindblad residences right yes so i mean

1937
01:11:04,790 --> 01:11:02,880
i remember that one of the first

1938
01:11:06,870 --> 01:11:04,800

computer simulations that just tried to

1939
01:11:08,470 --> 01:11:06,880
simulate a spiral galaxy

1940
01:11:10,149 --> 01:11:08,480
almost immediately developed a bar

1941
01:11:13,430 --> 01:11:10,159
instability right

1942
01:11:16,630 --> 01:11:13,440
so um it's it's a natural gravitational

1943
01:11:19,590 --> 01:11:16,640
formation that occurs in certain uh

1944
01:11:21,030 --> 01:11:19,600
setups but i'm trying to recall why

1945
01:11:23,110 --> 01:11:21,040
what causes the linblad because

1946
01:11:25,750 --> 01:11:23,120
obviously there are galaxies all right

1947
01:11:27,990 --> 01:11:25,760
quick call frank's

1948
01:11:30,630 --> 01:11:28,000
like the andromeda galaxy don't appear

1949
01:11:32,550 --> 01:11:30,640
to have a substantial bar i mean we see

1950
01:11:34,229 --> 01:11:32,560
systems like this the um

1951
01:11:36,310 --> 01:11:34,239
the pinwheel galaxy there's a bunch of

1952
01:11:38,630 --> 01:11:36,320
galaxies that you can see that it's more

1953
01:11:41,030 --> 01:11:38,640
like a sphere in the bulge in the center

1954
01:11:43,110 --> 01:11:41,040
as opposed to a bar and i forget

1955
01:11:44,870 --> 01:11:43,120
i forget because i don't do a lot of uh

1956
01:11:46,790 --> 01:11:44,880
galactic structure i do more hydro

1957
01:11:48,790 --> 01:11:46,800
modeling of why that's true but yeah

1958
01:11:50,709 --> 01:11:48,800
you're you're exactly right um

1959
01:11:52,709 --> 01:11:50,719
it's okay this is the caveat i give

1960
01:11:57,189 --> 01:11:52,719
people that's right i'm 30 years out of

1961
01:12:02,630 --> 01:11:59,830
there's such specificity to

1962
01:12:05,080 --> 01:12:02,640
what we study in astronomy that it's

1963
01:12:08,229 --> 01:12:05,090

difficult sometimes to ask

1964
01:12:08,229 --> 01:12:08,239
[Music]

1965
01:12:11,990 --> 01:12:10,229
okay all right and this is one again we

1966
01:12:13,910 --> 01:12:12,000
actually have a public lecture that we

1967
01:12:15,590 --> 01:12:13,920
did on this with brandon lawton and he

1968
01:12:17,510 --> 01:12:15,600
would go over the moon for this but i'm

1969
01:12:19,750 --> 01:12:17,520
asking you anyway

1970
01:12:21,669 --> 01:12:19,760
how empty are the empty regions in

1971
01:12:25,910 --> 01:12:21,679
between the filaments

1972
01:12:28,630 --> 01:12:25,920
and what's the average-ish size of them

1973
01:12:29,590 --> 01:12:28,640
ah that is that is that is excellent let

1974
01:12:32,390 --> 01:12:29,600
me see

1975
01:12:35,750 --> 01:12:34,070
obviously there's some diversity you

1976
01:12:38,630 --> 01:12:35,760
know there isn't just a set inter

1977
01:12:41,590 --> 01:12:38,640
interfilamentary uh distance between

1978
01:12:43,430 --> 01:12:41,600
objects or between these filaments um

1979
01:12:45,430 --> 01:12:43,440
but the voids people refer to them as

1980
01:12:48,630 --> 01:12:45,440
voids they tend to be quite empty

1981
01:12:50,630 --> 01:12:48,640
they're occasionally uh there is a field

1982
01:12:53,030 --> 01:12:50,640
a subfield of astronomy and galactic

1983
01:12:54,630 --> 01:12:53,040
astronomy that focuses on void galaxies

1984
01:12:56,390 --> 01:12:54,640
that is to say galaxies that find

1985
01:12:58,790 --> 01:12:56,400
themselves in these kind of

1986
01:13:00,870 --> 01:12:58,800
without any neighbors around to to

1987
01:13:02,790 --> 01:13:00,880
influence them either gravitationally or

1988
01:13:06,070 --> 01:13:02,800

radiationally

1989
01:13:07,590 --> 01:13:06,080
so some they definitely are there's a

1990
01:13:09,270 --> 01:13:07,600
significant deficit in the number of

1991
01:13:12,709 --> 01:13:09,280
galaxies in the amount of matter that's

1992
01:13:14,630 --> 01:13:12,719
in these void regions um

1993
01:13:16,149 --> 01:13:14,640
sometimes they're

1994
01:13:18,550 --> 01:13:16,159
you know it's a handful of galaxies

1995
01:13:21,669 --> 01:13:18,560
sometimes it's it's even less than that

1996
01:13:23,750 --> 01:13:21,679
but uh the size of the voids it's going

1997
01:13:25,590 --> 01:13:23,760
to vary but it's going to be on the on

1998
01:13:27,350 --> 01:13:25,600
the order of

1999
01:13:31,350 --> 01:13:27,360
i'd say like

2000
01:13:33,830 --> 01:13:31,360
20 to 100 megaparsecs which is

2001
01:13:36,390 --> 01:13:33,840
jargony

2002
01:13:42,470 --> 01:13:39,750
60 million to 300 million light years

2003
01:13:44,470 --> 01:13:42,480
across very very large regions in

2004
01:13:46,630 --> 01:13:44,480
between in between the clusters of

2005
01:13:48,310 --> 01:13:46,640
galaxies and clusters and

2006
01:13:50,790 --> 01:13:48,320
one of the things that i always liked

2007
01:13:53,270 --> 01:13:50,800
about watching the computer simulations

2008
01:13:54,790 --> 01:13:53,280
of these galaxy things everyone watches

2009
01:13:56,550 --> 01:13:54,800
the structure formation and your

2010
01:13:58,070 --> 01:13:56,560
formation of the filaments

2011
01:13:59,750 --> 01:13:58,080
i found that when i looked at them and i

2012
01:14:02,070 --> 01:13:59,760
just watched the voids the voids just

2013
01:14:04,229 --> 01:14:02,080

sort of expand over time and then

2014
01:14:06,550 --> 01:14:04,239
there's if you look at the empty regions

2015
01:14:09,189 --> 01:14:06,560
and not the the dense regions you really

2016
01:14:11,669 --> 01:14:09,199
get a a a similar perspective it's a

2017
01:14:14,790 --> 01:14:11,679
counter perspective that um has has a

2018
01:14:16,950 --> 01:14:14,800
lot of scientific insight in it

2019
01:14:18,630 --> 01:14:16,960
absolutely because that stuff is getting

2020
01:14:20,310 --> 01:14:18,640
flushed of its material as it's getting

2021
01:14:21,990 --> 01:14:20,320
evacuated and going into the dense

2022
01:14:23,750 --> 01:14:22,000
regions and yeah you see a similar

2023
01:14:25,110 --> 01:14:23,760
growth of those as well

2024
01:14:29,189 --> 01:14:25,120
excellent point

2025
01:14:32,470 --> 01:14:29,199
awesome cool next question all right uh

2026
01:14:34,950 --> 01:14:32,480
what makes a galaxy similar to our own

2027
01:14:37,590 --> 01:14:34,960
like what kind of observable differences

2028
01:14:40,950 --> 01:14:37,600
do you look for to identify it and say

2029
01:14:42,790 --> 01:14:40,960
oh that's like this one or that one

2030
01:14:44,550 --> 01:14:42,800
broadly speaking a lot of what i was

2031
01:14:48,870 --> 01:14:44,560
talking about when i was saying this

2032
01:14:51,030 --> 01:14:48,880
simulation is a milky way like galaxy um

2033
01:14:54,070 --> 01:14:51,040
is that it's a spiral

2034
01:14:57,189 --> 01:14:54,080
or a disc galaxy that's relatively well

2035
01:14:59,990 --> 01:14:57,199
evolved um that there isn't that there's

2036
01:15:02,390 --> 01:15:00,000
active star formation going off in it in

2037
01:15:05,750 --> 01:15:02,400
in the spiral arms much like we see in

2038
01:15:08,390 --> 01:15:05,760

our galaxy or the andromeda galaxy and

2039
01:15:10,950 --> 01:15:08,400
um that it tends to be at a certain mass

2040
01:15:13,430 --> 01:15:10,960
range as you can imagine uh there's a

2041
01:15:16,390 --> 01:15:13,440
huge range continuum in the masses of

2042
01:15:18,790 --> 01:15:16,400
galaxies that you see some are are very

2043
01:15:20,470 --> 01:15:18,800
small we call them dwarf galaxies dwarf

2044
01:15:22,550 --> 01:15:20,480
galaxies can be

2045
01:15:24,550 --> 01:15:22,560
on the order of a hundredth of the mass

2046
01:15:27,910 --> 01:15:24,560
of our milky way to

2047
01:15:31,189 --> 01:15:27,920
10 like 10 000 of the that mass then we

2048
01:15:32,790 --> 01:15:31,199
talk about ultra ultra light dwarfs or

2049
01:15:34,630 --> 01:15:32,800
ultra dwarfs that are even lower mass

2050
01:15:37,350 --> 01:15:34,640
than that um

2051
01:15:39,830 --> 01:15:37,360
so the milky way isn't the most massive

2052
01:15:42,070 --> 01:15:39,840
galaxy out there but it's it's on the

2053
01:15:44,390 --> 01:15:42,080
higher end it's it's considered a

2054
01:15:46,070 --> 01:15:44,400
giant-ish or i mean we refer to them as

2055
01:15:50,070 --> 01:15:46,080
normal because it's our galaxy so of

2056
01:15:51,910 --> 01:15:50,080
course it's normal of course but uh

2057
01:15:54,470 --> 01:15:51,920
something that's like a milky way galaxy

2058
01:15:58,229 --> 01:15:54,480
or milky way like i would refer to as a

2059
01:16:00,950 --> 01:15:58,239
a spiral galaxy or a disc galaxy that um

2060
01:16:03,189 --> 01:16:00,960
isn't actively engaged in a collision

2061
01:16:05,110 --> 01:16:03,199
with another one andromeda is a ways off

2062
01:16:07,270 --> 01:16:05,120
so we aren't yet engaged in it or else

2063
01:16:09,350 --> 01:16:07,280

it would look a lot like those irregular

2064
01:16:11,030 --> 01:16:09,360
those pesky irregulars that we showed

2065
01:16:13,270 --> 01:16:11,040
earlier um

2066
01:16:16,070 --> 01:16:13,280
and it it has on the order of

2067
01:16:18,390 --> 01:16:16,080
uh a trillion solar masses of material

2068
01:16:20,950 --> 01:16:18,400
plus or minus you know something on that

2069
01:16:22,790 --> 01:16:20,960
order so that's including its dark

2070
01:16:25,669 --> 01:16:22,800
matter as well as

2071
01:16:27,590 --> 01:16:25,679
as as the the visible matter the the gas

2072
01:16:29,270 --> 01:16:27,600
and the stars that are present in it

2073
01:16:32,070 --> 01:16:29,280
it's always so easy to talk about this

2074
01:16:33,990 --> 01:16:32,080
and just forget the scale of everything

2075
01:16:36,070 --> 01:16:34,000
there's a trillion you just throw around

2076
01:16:38,229 --> 01:16:36,080
yeah drop in the bucket it's fine

2077
01:16:40,550 --> 01:16:38,239
well yeah 10 to the 12th solar masses of

2078
01:16:42,709 --> 01:16:40,560
material is how we refer to it

2079
01:16:44,470 --> 01:16:42,719
or we'll just call it an all-star galaxy

2080
01:16:46,149 --> 01:16:44,480
right or an l-star game that's what

2081
01:16:48,790 --> 01:16:46,159
that's really getting into the jargon

2082
01:16:50,550 --> 01:16:48,800
yeah i'm not going to get into no no no

2083
01:16:51,530 --> 01:16:50,560
don't go there don't go there grant next

2084
01:16:53,669 --> 01:16:51,540
question come on quick

2085
01:16:58,550 --> 01:16:53,679
[Laughter]

2086
01:17:00,310 --> 01:16:58,560
um how do spiral galaxies stay spiral do

2087
01:17:02,470 --> 01:17:00,320
the filaments have like an angular

2088
01:17:03,510 --> 01:17:02,480

momentum that they have to maintain in

2089
01:17:06,550 --> 01:17:03,520
order to

2090
01:17:08,550 --> 01:17:06,560
maintain to keep cohesion

2091
01:17:10,070 --> 01:17:08,560
great these are well these are all great

2092
01:17:11,590 --> 01:17:10,080
questions so our online audience is

2093
01:17:13,750 --> 01:17:11,600
awesome yeah

2094
01:17:15,350 --> 01:17:13,760
people are on it so um

2095
01:17:17,350 --> 01:17:15,360
well for one

2096
01:17:19,990 --> 01:17:17,360
angular momentum tends to perpetuate

2097
01:17:22,229 --> 01:17:20,000
itself in the same way that uh if you

2098
01:17:23,830 --> 01:17:22,239
have a merry ground that's spinning and

2099
01:17:25,830 --> 01:17:23,840
without friction present if it's a

2100
01:17:27,990 --> 01:17:25,840
well-oiled merry-go-round it's gonna

2101
01:17:30,390 --> 01:17:28,000
keep spinning for a long period of time

2102
01:17:32,470 --> 01:17:30,400
the same thing goes for galaxies they're

2103
01:17:34,390 --> 01:17:32,480
rotating there are dissipative effects

2104
01:17:38,229 --> 01:17:34,400
but for the most part it wants to keep

2105
01:17:40,390 --> 01:17:38,239
going but as you say there's a torque um

2106
01:17:42,709 --> 01:17:40,400
for the most part galaxies as you could

2107
01:17:44,550 --> 01:17:42,719
see in the simulation where i showed it

2108
01:17:46,470 --> 01:17:44,560
kind of zooming in on the galaxy and

2109
01:17:48,550 --> 01:17:46,480
showing the galaxies the other galaxies

2110
01:17:51,430 --> 01:17:48,560
falling into it and it building up over

2111
01:17:54,229 --> 01:17:51,440
time each of those in-falling galaxies

2112
01:17:56,709 --> 01:17:54,239
is transferring torque to the to the

2113
01:17:59,030 --> 01:17:56,719

galaxy itself the one at the center and

2114
01:18:01,830 --> 01:17:59,040
so galaxies over time at least we think

2115
01:18:03,590 --> 01:18:01,840
from the computer simulations may change

2116
01:18:06,070 --> 01:18:03,600
the direction of their rotation

2117
01:18:07,669 --> 01:18:06,080
essentially the the axis of rotation so

2118
01:18:09,350 --> 01:18:07,679
it's kind of like you have a

2119
01:18:11,270 --> 01:18:09,360
merry-go-round that might be spinning

2120
01:18:12,790 --> 01:18:11,280
like this and then all of a sudden

2121
01:18:14,470 --> 01:18:12,800
another galaxy falls in from this

2122
01:18:16,950 --> 01:18:14,480
direction and all of a sudden it torques

2123
01:18:18,470 --> 01:18:16,960
everything and now you're now you're uh

2124
01:18:19,350 --> 01:18:18,480
now your merry ground is spinning like

2125
01:18:22,550 --> 01:18:19,360
this

2126
01:18:24,950 --> 01:18:22,560
and so over time um due to the info of

2127
01:18:26,950 --> 01:18:24,960
other other systems and other mass

2128
01:18:29,590 --> 01:18:26,960
sources into this it applies these

2129
01:18:31,990 --> 01:18:29,600
torques and kind of spins up the galaxy

2130
01:18:33,750 --> 01:18:32,000
to continue its rotation but yeah uh

2131
01:18:35,590 --> 01:18:33,760
torques from other objects falling in

2132
01:18:37,430 --> 01:18:35,600
along the filament seem to be the

2133
01:18:39,350 --> 01:18:37,440
perpetuation of angular momentum and

2134
01:18:40,790 --> 01:18:39,360
rotation in these systems and i'd like

2135
01:18:43,590 --> 01:18:40,800
to mention one thing here that people

2136
01:18:45,590 --> 01:18:43,600
don't often recognize is that the uh

2137
01:18:47,910 --> 01:18:45,600
spiral pattern as it

2138
01:18:49,750 --> 01:18:47,920

orbits around the milky way is moving at

2139
01:18:51,510 --> 01:18:49,760
a different speed than the stars within

2140
01:18:54,390 --> 01:18:51,520
it okay one of the important things to

2141
01:18:56,310 --> 01:18:54,400
note is that like our sun was probably

2142
01:18:57,990 --> 01:18:56,320
was born in a spiral arm but it moved

2143
01:19:00,229 --> 01:18:58,000
out and then moved into other spiral

2144
01:19:02,870 --> 01:19:00,239
arms and around so the spire the the

2145
01:19:04,870 --> 01:19:02,880
stars orbiting the in the milky way are

2146
01:19:06,470 --> 01:19:04,880
moving into the spiral arms and moving

2147
01:19:08,630 --> 01:19:06,480
out of those spiral arms and the spiral

2148
01:19:11,270 --> 01:19:08,640
arms have this pattern speed

2149
01:19:13,030 --> 01:19:11,280
that is different from the orbital speed

2150
01:19:14,470 --> 01:19:13,040
of the stars within it

2151
01:19:16,950 --> 01:19:14,480
and that's one thing that's always been

2152
01:19:19,669 --> 01:19:16,960
fascinating it's important to recognize

2153
01:19:21,350 --> 01:19:19,679
um because like our our

2154
01:19:22,390 --> 01:19:21,360
our star is four and a half billion

2155
01:19:25,270 --> 01:19:22,400
years old

2156
01:19:27,990 --> 01:19:25,280
and it's made about 18 rotations around

2157
01:19:31,270 --> 01:19:28,000
the milk center the milky way so it's

2158
01:19:33,430 --> 01:19:31,280
orbited 18 times and so there's a lot of

2159
01:19:36,630 --> 01:19:33,440
interactions that it does as it goes

2160
01:19:38,790 --> 01:19:36,640
into and out of these spiral arm regions

2161
01:19:41,350 --> 01:19:38,800
the the analogy that i like to use for

2162
01:19:43,830 --> 01:19:41,360
that is like when you say something out

2163
01:19:45,830 --> 01:19:43,840

of your mouth you're causing vibrations

2164
01:19:47,590 --> 01:19:45,840
with your vocal cords vocal cords that

2165
01:19:49,270 --> 01:19:47,600
are vibrating they're causing acoustic

2166
01:19:52,310 --> 01:19:49,280
waves but those are vibrations of the

2167
01:19:54,709 --> 01:19:52,320
atoms in the air around your around your

2168
01:19:56,630 --> 01:19:54,719
mouth and when someone else is standing

2169
01:19:58,790 --> 01:19:56,640
across the room and they feel those

2170
01:20:01,750 --> 01:19:58,800
vibrations in their eardrum it isn't

2171
01:20:03,350 --> 01:20:01,760
that the actual atoms that your vibrate

2172
01:20:04,950 --> 01:20:03,360
that you vibrated with your vocal cords

2173
01:20:07,270 --> 01:20:04,960
have traveled across the room and are

2174
01:20:10,550 --> 01:20:07,280
running into the person's eardrum it's

2175
01:20:13,350 --> 01:20:10,560
perpetuating that that that longitudinal

2176
01:20:15,030 --> 01:20:13,360
wave of basically a pressure wave

2177
01:20:16,310 --> 01:20:15,040
through the intervening medium and it's

2178
01:20:18,470 --> 01:20:16,320
the exact same thing that frank was

2179
01:20:20,550 --> 01:20:18,480
talking about uh there's this pressure

2180
01:20:22,709 --> 01:20:20,560
this spiral density pressure wave of

2181
01:20:24,950 --> 01:20:22,719
material in the disk and and we flow

2182
01:20:26,470 --> 01:20:24,960
through it the stars flow through it but

2183
01:20:27,430 --> 01:20:26,480
yeah

2184
01:20:29,110 --> 01:20:27,440
awesome

2185
01:20:29,910 --> 01:20:29,120
so that leads me directly into the next

2186
01:20:30,790 --> 01:20:29,920
one

2187
01:20:34,149 --> 01:20:30,800
um

2188
01:20:37,910 --> 01:20:34,159

when milk andromeda happens yes

2189
01:20:40,870 --> 01:20:37,920
by the way i do not like milk almond

2190
01:20:42,550 --> 01:20:40,880
oh i love it i'm not i'm i i i'm a

2191
01:20:43,590 --> 01:20:42,560
thumbs down on that term but anyways go

2192
01:20:45,990 --> 01:20:43,600
ahead

2193
01:20:47,910 --> 01:20:46,000
when the milky way and andromeda

2194
01:20:50,629 --> 01:20:47,920
eventually meet

2195
01:20:53,910 --> 01:20:50,639
uh is gravity really the only force that

2196
01:20:56,390 --> 01:20:53,920
is going to be affecting the

2197
01:20:59,990 --> 01:20:56,400
momentum of the galaxies like what other

2198
01:21:03,110 --> 01:21:00,000
forces can be exerted on those spiral

2199
01:21:06,310 --> 01:21:03,120
arms and those filaments

2200
01:21:07,830 --> 01:21:06,320
gravity will be the dominant one um

2201
01:21:10,870 --> 01:21:07,840
because

2202
01:21:13,350 --> 01:21:10,880
so for the most part the the forces that

2203
01:21:16,070 --> 01:21:13,360
dominate on these very very large scales

2204
01:21:17,510 --> 01:21:16,080
the galactic scale or larger than galaxy

2205
01:21:19,270 --> 01:21:17,520
scales

2206
01:21:23,590 --> 01:21:19,280
or gravity because it doesn't really

2207
01:21:26,390 --> 01:21:23,600
cancel out uh cancel out very well

2208
01:21:28,550 --> 01:21:26,400
you could imagine let's say a galaxy is

2209
01:21:31,189 --> 01:21:28,560
charged it has a net charge

2210
01:21:34,390 --> 01:21:31,199
um such that it repels other things of

2211
01:21:38,550 --> 01:21:36,629
the the problem with that is macroscopic

2212
01:21:40,790 --> 01:21:38,560
objects don't tend to remain charged

2213
01:21:43,110 --> 01:21:40,800

with a net charge for very long because

2214
01:21:44,790 --> 01:21:43,120
they effectively attract the things of

2215
01:21:47,430 --> 01:21:44,800
the opposite charge and it cancels it

2216
01:21:49,590 --> 01:21:47,440
out and so this this is true of of

2217
01:21:51,510 --> 01:21:49,600
macroscopic objects in space as well and

2218
01:21:53,910 --> 01:21:51,520
so you can't imagine that there will be

2219
01:21:55,830 --> 01:21:53,920
a i mean there may be some

2220
01:21:58,870 --> 01:21:55,840
some we we think that there are magnetic

2221
01:22:00,390 --> 01:21:58,880
fields we observe magnetic fields within

2222
01:22:01,990 --> 01:22:00,400
galaxies but the strength of those

2223
01:22:04,790 --> 01:22:02,000
magnetic fields are hundreds of

2224
01:22:07,189 --> 01:22:04,800
thousands of times less intense than our

2225
01:22:09,110 --> 01:22:07,199
sun or the earth so they're very very

2226
01:22:11,669 --> 01:22:09,120
weak they still do play a role in the

2227
01:22:12,709 --> 01:22:11,679
evolution on a sub like from subtle

2228
01:22:14,629 --> 01:22:12,719
effects

2229
01:22:17,189 --> 01:22:14,639
but they're not

2230
01:22:19,510 --> 01:22:17,199
they're not dramatic and they're not um

2231
01:22:22,629 --> 01:22:19,520
i mean they may alter the path and the

2232
01:22:25,110 --> 01:22:22,639
trajectory of gas of ionized gas plasma

2233
01:22:27,510 --> 01:22:25,120
that's charged um as it falls through

2234
01:22:29,590 --> 01:22:27,520
the galaxy but uh i guess that would

2235
01:22:31,590 --> 01:22:29,600
probably be the next thing that would be

2236
01:22:33,830 --> 01:22:31,600
an influencing thing i would say the the

2237
01:22:36,830 --> 01:22:33,840
main things that would influence kind of

2238
01:22:39,910 --> 01:22:36,840

the evolution of of the milky way

2239
01:22:41,750 --> 01:22:39,920
andromeda combined system would be

2240
01:22:44,229 --> 01:22:41,760
gravity

2241
01:22:45,830 --> 01:22:44,239
and then um the stars for the most part

2242
01:22:47,669 --> 01:22:45,840
are just going to be falling along their

2243
01:22:50,629 --> 01:22:47,679
gravitational trajectories based on the

2244
01:22:54,149 --> 01:22:50,639
distribution of mass and then the the

2245
01:22:56,629 --> 01:22:54,159
gas and the ionized plasma will follow

2246
01:22:59,270 --> 01:22:56,639
a modified direction because of a few

2247
01:23:00,950 --> 01:22:59,280
things magnetic fields um as well as

2248
01:23:03,350 --> 01:23:00,960
radiation if there's an intense

2249
01:23:05,270 --> 01:23:03,360
radiation field caused by a bunch of

2250
01:23:08,310 --> 01:23:05,280
stars that get formed and are pumping

2251
01:23:10,390 --> 01:23:08,320
out all kinds of light uh visible or uv

2252
01:23:12,470 --> 01:23:10,400
or x-ray that can also alter the

2253
01:23:14,229 --> 01:23:12,480
distribution of of mass in the form of

2254
01:23:15,669 --> 01:23:14,239
gas but for the most part those stars

2255
01:23:17,669 --> 01:23:15,679
the individual stars that have already

2256
01:23:19,030 --> 01:23:17,679
formed they're like little bbs little

2257
01:23:21,030 --> 01:23:19,040
bullets they're just going to fly

2258
01:23:23,189 --> 01:23:21,040
through and do their own thing according

2259
01:23:25,350 --> 01:23:23,199
to the gravitational potential that's

2260
01:23:28,629 --> 01:23:25,360
there that's reasonably well described

2261
01:23:29,669 --> 01:23:28,639
by newtonian newtonian dynamics

2262
01:23:30,709 --> 01:23:29,679
right

2263
01:23:32,950 --> 01:23:30,719

um and

2264
01:23:34,709 --> 01:23:32,960
and just to to clarify that the the

2265
01:23:36,790 --> 01:23:34,719
hydrodynamics of the gas clouds

2266
01:23:38,550 --> 01:23:36,800
colliding right because the stars will

2267
01:23:40,870 --> 01:23:38,560
pass straight through each other the gas

2268
01:23:43,590 --> 01:23:40,880
clouds will collide they'll shock heat

2269
01:23:45,669 --> 01:23:43,600
um we'll often create star formation

2270
01:23:47,270 --> 01:23:45,679
because that's what we see in starburst

2271
01:23:49,910 --> 01:23:47,280
galaxies as they're the results of

2272
01:23:52,629 --> 01:23:49,920
collisions so about on the largest

2273
01:23:56,070 --> 01:23:52,639
scales really gravity is just about it

2274
01:23:57,830 --> 01:23:56,080
yeah and and and to to to take off on a

2275
01:24:00,390 --> 01:23:57,840
little thing that that uh that frank

2276
01:24:01,750 --> 01:24:00,400
mentions there so oftentimes i say like

2277
01:24:04,149 --> 01:24:01,760
don't worry about it we've got bigger

2278
01:24:05,830 --> 01:24:04,159
problems which is definitely true

2279
01:24:07,669 --> 01:24:05,840
and and stars we don't have to worry

2280
01:24:10,149 --> 01:24:07,679
about like the earth slamming into a

2281
01:24:12,390 --> 01:24:10,159
star or slamming into a planet

2282
01:24:14,790 --> 01:24:12,400
um but something that we do need to

2283
01:24:17,030 --> 01:24:14,800
worry about is when the gas clouds that

2284
01:24:19,910 --> 01:24:17,040
are present in those galaxies slam into

2285
01:24:21,910 --> 01:24:19,920
each other as as frank suggests they're

2286
01:24:24,310 --> 01:24:21,920
going to shock heat and they're probably

2287
01:24:26,470 --> 01:24:24,320
going to induce a bunch of new stars to

2288
01:24:28,229 --> 01:24:26,480

be formed amongst those new stars there

2289
01:24:30,310 --> 01:24:28,239
will be massive enough stars that create

2290
01:24:33,030 --> 01:24:30,320
supernova and the supernova when they

2291
01:24:36,550 --> 01:24:33,040
explode will not be great for us here on

2292
01:24:39,030 --> 01:24:36,560
earth um so it won't be a really good

2293
01:24:41,590 --> 01:24:39,040
place to hang around in when that occurs

2294
01:24:43,430 --> 01:24:41,600
in five to eight billion years because

2295
01:24:45,350 --> 01:24:43,440
of the radiation field that's caused by

2296
01:24:47,590 --> 01:24:45,360
these exploding supernovae but on the

2297
01:24:50,790 --> 01:24:47,600
other hand like we've got other problems

2298
01:24:53,110 --> 01:24:50,800
to solve like our sun dying in that time

2299
01:24:55,030 --> 01:24:53,120
scale as well and and consuming the

2300
01:24:56,629 --> 01:24:55,040
earth so

2301
01:24:57,910 --> 01:24:56,639
a lot of the simulations have earth

2302
01:25:01,270 --> 01:24:57,920
being flung out to the edge of the

2303
01:25:04,229 --> 01:25:01,280
galaxy and being all out all alone way

2304
01:25:06,390 --> 01:25:04,239
away from everything you know hey

2305
01:25:08,629 --> 01:25:06,400
we could be either in

2306
01:25:11,750 --> 01:25:08,639
in the intense of star from ring region

2307
01:25:14,149 --> 01:25:11,760
and have supernovae or be out all alone

2308
01:25:16,550 --> 01:25:14,159
uh really really cold out at the end out

2309
01:25:19,430 --> 01:25:16,560
of the edge of the combined milky way

2310
01:25:21,910 --> 01:25:19,440
andromeda different flavors of bad news

2311
01:25:24,149 --> 01:25:21,920
yes okay yeah um we're getting time for

2312
01:25:25,510 --> 01:25:24,159
a couple more we got let's let's just do

2313
01:25:27,430 --> 01:25:25,520

one more i know we had a little bit of

2314
01:25:29,669 --> 01:25:27,440
technical problems so we're running a

2315
01:25:31,830 --> 01:25:29,679
little long but it's already 9 30 so

2316
01:25:35,510 --> 01:25:31,840
let's move let's get that

2317
01:25:37,270 --> 01:25:35,520
one killer question to really hit him

2318
01:25:39,030 --> 01:25:37,280
all right so

2319
01:25:40,550 --> 01:25:39,040
i like this one a lot and i usually try

2320
01:25:42,390 --> 01:25:40,560
to save this sort of a question for the

2321
01:25:45,910 --> 01:25:42,400
end of the program but

2322
01:25:48,149 --> 01:25:45,920
what was your moment that got you

2323
01:25:50,149 --> 01:25:48,159
involved not necessarily like it's your

2324
01:25:51,910 --> 01:25:50,159
job or what have you but what was your

2325
01:25:56,070 --> 01:25:51,920
defining moment

2326
01:26:00,310 --> 01:25:58,229
uh

2327
01:26:01,990 --> 01:26:00,320
i mean there have been a series i i

2328
01:26:04,229 --> 01:26:02,000
guess the the one

2329
01:26:06,709 --> 01:26:04,239
the one that most easily fits into this

2330
01:26:09,030 --> 01:26:06,719
into this argument is it's probably not

2331
01:26:11,910 --> 01:26:09,040
unlike many people's trajectory towards

2332
01:26:14,629 --> 01:26:11,920
getting into astronomy and space science

2333
01:26:17,030 --> 01:26:14,639
um i had the opportunity to look through

2334
01:26:19,110 --> 01:26:17,040
a telescope when i was like 11 through

2335
01:26:20,950 --> 01:26:19,120
uh at a there was an amateur group in a

2336
01:26:22,629 --> 01:26:20,960
parking lot in an elementary school that

2337
01:26:25,030 --> 01:26:22,639
was near my house and i got to see

2338
01:26:27,189 --> 01:26:25,040

saturn and it was super cool so that

2339
01:26:28,790 --> 01:26:27,199
that was definitely like pointing me in

2340
01:26:30,390 --> 01:26:28,800
that direction but as i said i studied

2341
01:26:32,070 --> 01:26:30,400
computer science as an undergrad and

2342
01:26:35,110 --> 01:26:32,080
only later switched towards

2343
01:26:36,470 --> 01:26:35,120
doing astronomy and astrophysics and

2344
01:26:38,149 --> 01:26:36,480
i don't know i mean

2345
01:26:40,070 --> 01:26:38,159
i just always knew that i wanted to do

2346
01:26:41,990 --> 01:26:40,080
science because i think it's it's one of

2347
01:26:44,149 --> 01:26:42,000
the most like interesting and and kind

2348
01:26:46,310 --> 01:26:44,159
of noble pursuits i'm getting some light

2349
01:26:48,550 --> 01:26:46,320
on me here noble pursuits that we can

2350
01:26:50,709 --> 01:26:48,560
have is to better understand the natural

2351
01:26:51,910 --> 01:26:50,719
world and our place in it and you know a

2352
01:26:53,590 --> 01:26:51,920
lot of people give me a hard time and

2353
01:26:55,030 --> 01:26:53,600
they say like well what are the

2354
01:26:56,470 --> 01:26:55,040
applications of this you know how can

2355
01:26:57,830 --> 01:26:56,480
you make money on this and it's like

2356
01:26:58,550 --> 01:26:57,840
well

2357
01:27:01,830 --> 01:26:58,560
the

2358
01:27:04,310 --> 01:27:01,840
you know

2359
01:27:06,310 --> 01:27:04,320
pure research going in lots of different

2360
01:27:08,149 --> 01:27:06,320
directions even without the direct

2361
01:27:09,669 --> 01:27:08,159
application towards you know this is

2362
01:27:11,030 --> 01:27:09,679
going to solve this problem or this is

2363
01:27:13,110 --> 01:27:11,040

going to solve this problem better

2364
01:27:14,950 --> 01:27:13,120
understanding the world around us is

2365
01:27:16,149 --> 01:27:14,960
incredibly important and takes us in

2366
01:27:18,629 --> 01:27:16,159
directions that we could never have

2367
01:27:20,709 --> 01:27:18,639
foreseen in the 19th century everyone

2368
01:27:22,629 --> 01:27:20,719
thought that the dominant technology was

2369
01:27:25,030 --> 01:27:22,639
going to be steam power and if you were

2370
01:27:27,350 --> 01:27:25,040
really worth your your gumption you'd go

2371
01:27:30,149 --> 01:27:27,360
out and do research in steam power but

2372
01:27:32,149 --> 01:27:30,159
it was it was a kind of a a nutty dude

2373
01:27:35,270 --> 01:27:32,159
named james clerk maxwell playing around

2374
01:27:37,669 --> 01:27:35,280
with magnets and prisms that figured out

2375
01:27:39,669 --> 01:27:37,679
the the the the theory of

2376
01:27:42,229 --> 01:27:39,679
electromagnetic uh

2377
01:27:44,390 --> 01:27:42,239
like interactions that's basically you

2378
01:27:46,149 --> 01:27:44,400
know if you'd asked people at that time

2379
01:27:47,750 --> 01:27:46,159
if he was doing something worthwhile a

2380
01:27:50,070 --> 01:27:47,760
lot of people would have said no he's

2381
01:27:52,870 --> 01:27:50,080
just wasting his time and yet

2382
01:27:54,950 --> 01:27:52,880
his work is the basis of all of 20th

2383
01:27:57,189 --> 01:27:54,960
century and 21st century technology in

2384
01:28:00,310 --> 01:27:57,199
terms of how currents run through

2385
01:28:03,350 --> 01:28:00,320
circuits how fiber optic cables work the

2386
01:28:05,110 --> 01:28:03,360
internet silicon uh you know uh

2387
01:28:06,790 --> 01:28:05,120
semiconductors all of this is based on

2388
01:28:09,030 --> 01:28:06,800

that work and it's just it's incredible

2389
01:28:11,430 --> 01:28:09,040
so i think i think i'm a huge proponent

2390
01:28:13,189 --> 01:28:11,440
in doing scientific research for the

2391
01:28:15,189 --> 01:28:13,199
point of better understanding the

2392
01:28:17,830 --> 01:28:15,199
natural world and the spin-offs will

2393
01:28:19,510 --> 01:28:17,840
come from it and and and it's impossible

2394
01:28:21,030 --> 01:28:19,520
to predict where that's going to be how

2395
01:28:22,550 --> 01:28:21,040
do you put a press on the government of

2396
01:28:24,470 --> 01:28:22,560
your species

2397
01:28:26,149 --> 01:28:24,480
what's that yeah

2398
01:28:28,709 --> 01:28:26,159
how do you put a price on the betterment

2399
01:28:30,870 --> 01:28:28,719
of your species exactly exactly and i

2400
01:28:33,350 --> 01:28:30,880
will i'll just i will just note that all

2401
01:28:35,030 --> 01:28:33,360
of computer technology is based upon the

2402
01:28:36,470 --> 01:28:35,040
josephson junction which we wouldn't

2403
01:28:38,070 --> 01:28:36,480
know about unless we did quantum

2404
01:28:40,709 --> 01:28:38,080
mechanics and when they were doing

2405
01:28:43,110 --> 01:28:40,719
quantum mechanics in the 40s

2406
01:28:45,350 --> 01:28:43,120
you never would have expected any

2407
01:28:47,510 --> 01:28:45,360
anything to come out of it okay it was

2408
01:28:50,149 --> 01:28:47,520
you know it's the kind of stuff so yes

2409
01:28:52,229 --> 01:28:50,159
basic research leads to

2410
01:28:55,590 --> 01:28:52,239
amazing results

2411
01:28:58,310 --> 01:28:55,600
not next year not next month not not 10

2412
01:29:01,110 --> 01:28:58,320
years from now but decades down the line

2413
01:29:03,270 --> 01:29:01,120

um and you know that's why basic

2414
01:29:04,229 --> 01:29:03,280
research we have to we have to continue

2415
01:29:06,470 --> 01:29:04,239
doing it

2416
01:29:08,629 --> 01:29:06,480
all right cameron that was fantastic i'm

2417
01:29:11,669 --> 01:29:08,639
sorry we didn't have time to do even

2418
01:29:13,430 --> 01:29:11,679
more questions um you can look through

2419
01:29:15,189 --> 01:29:13,440
the chat on youtube and see if there are

2420
01:29:16,550 --> 01:29:15,199
other ones that you'd like to answer

2421
01:29:17,830 --> 01:29:16,560
yeah um

2422
01:29:19,510 --> 01:29:17,840
next month

2423
01:29:22,629 --> 01:29:19,520
on july 5th

2424
01:29:25,510 --> 01:29:22,639
a mia bobo uh current title for her talk

2425
01:29:27,510 --> 01:29:25,520
exoplanets orbital mechanics and the

2426
01:29:29,110 --> 01:29:27,520
death star if you want to know what that

2427
01:29:31,750 --> 01:29:29,120
is all about