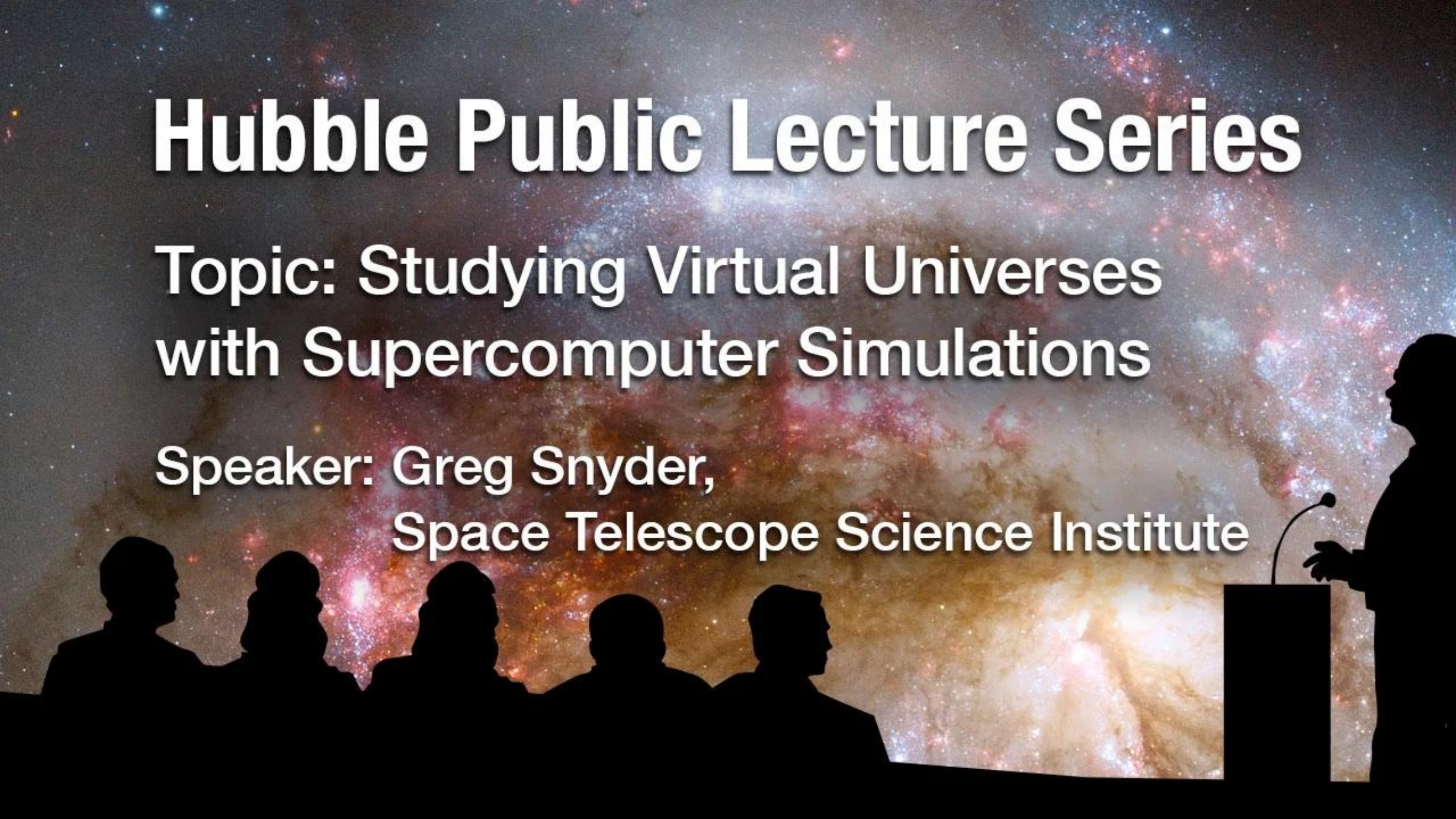
Hubble Public Lecture Series
Topic: Studying Virtual Universes with Supercomputer Simulations
Speaker: Greg Snyder,
Space Telescope Science Institute

1
00:00:02,750 --> 00:00:01,340
good evening ladies and gentlemen and

2
00:00:06,889 --> 00:00:02,760
welcome to the Hubble Space Telescope

3
00:00:09,379 --> 00:00:06,899
public lecture series as all as I hope

4
00:00:11,000 --> 00:00:09,389
to be always every month although as you

5
00:00:13,339 --> 00:00:11,010
know this year I've been on a lot of

6
00:00:17,269 --> 00:00:13,349
travel I am your host dr. Frank summers

7
00:00:19,880 --> 00:00:17,279
of the office of public outreach if you

8
00:00:21,200 --> 00:00:19,890
did not get one on your way in over on

9
00:00:23,330 --> 00:00:21,210
the table you can get one on your way

10
00:00:26,060 --> 00:00:23,340
out we have our beautiful Hubble picture

11
00:00:29,240 --> 00:00:26,070
lithographs and tonight is an oldie but

12
00:00:34,130 --> 00:00:29,250
a goodie one of one of the favorites

13
00:00:35,510 --> 00:00:34,140

from 2009 the butterfly nebula now I

14
00:00:37,639 --> 00:00:35,520
will actually tell you the truth this

15
00:00:40,670 --> 00:00:37,649
isn't really the butterfly nebula it's

16
00:00:42,200 --> 00:00:40,680
the bug nebula but in our press release

17
00:00:44,660 --> 00:00:42,210
we said hey it looks a lot like a

18
00:00:46,819 --> 00:00:44,670
butterfly the press called it the

19
00:00:49,220 --> 00:00:46,829
butterfly nebula and the name is stuck

20
00:00:51,590 --> 00:00:49,230
so this is something that got renamed by

21
00:00:53,330 --> 00:00:51,600
a press release if you want to know more

22
00:00:54,979 --> 00:00:53,340
than just trivia about it if you want to

23
00:00:57,279 --> 00:00:54,989
know some science about it turn it over

24
00:01:00,709 --> 00:00:57,289
on the back and we have approximately

25
00:01:02,119 --> 00:01:00,719
330 words because I write some of these

26
00:01:03,860 --> 00:01:02,129
and when I'm giving it as a Frank you

27
00:01:06,500 --> 00:01:03,870
have 330 words and that's all you have

28
00:01:10,340 --> 00:01:06,510
to write on the back and information

29
00:01:13,520 --> 00:01:10,350
about it grab one on the way out our

30
00:01:16,100 --> 00:01:13,530
talk tonight Greg Snyder studying

31
00:01:19,030 --> 00:01:16,110
virtual universes with supercomputer

32
00:01:23,179 --> 00:01:19,040
simulations this is gonna be a high-tech

33
00:01:27,289 --> 00:01:23,189
extravaganza and he gave me his his

34
00:01:29,870 --> 00:01:27,299
keynote file had 700 megabytes of visual

35
00:01:32,030 --> 00:01:29,880
goodness in it so I'm expecting some

36
00:01:33,920 --> 00:01:32,040
really cool movies because hey if you do

37
00:01:36,319 --> 00:01:33,930
simulations you got to do the cool

38
00:01:37,819 --> 00:01:36,329

movies got to attract attention but

39
00:01:39,440 --> 00:01:37,829
there's also fantastic science because

40
00:01:43,819 --> 00:01:39,450
I've seen some of the results from this

41
00:01:46,600 --> 00:01:43,829
this this work upcoming now next month

42
00:01:49,010 --> 00:01:46,610
we are voting on the first Tuesday right

43
00:01:50,569 --> 00:01:49,020
everyone shake your head yes at least

44
00:01:52,609 --> 00:01:50,579
those who are at least at our 18 and a

45
00:01:54,440 --> 00:01:52,619
voting age in a retro if you're not

46
00:01:56,630 --> 00:01:54,450
registered go gout and get registered I

47
00:01:58,730 --> 00:01:56,640
don't care which party you vote for or

48
00:02:00,550 --> 00:01:58,740
who a candidate you vote for just get

49
00:02:04,459 --> 00:02:00,560
out and exercise your democratic right

50
00:02:06,170 --> 00:02:04,469
and vote on November 4th then remember

51
00:02:08,749 --> 00:02:06,180
you have your little I voted sticker

52
00:02:10,420 --> 00:02:08,759
well maybe we'll get I went to astronomy

53
00:02:12,470 --> 00:02:10,430
lecture stickers for the next weekend

54
00:02:15,080 --> 00:02:12,480
because we're going to have

55
00:02:17,300 --> 00:02:15,090
Cammi and kelskiy talking a telegram

56
00:02:19,490 --> 00:02:17,310
from the early universe and let me tell

57
00:02:21,619 --> 00:02:19,500
you folks this is one of the world

58
00:02:24,440 --> 00:02:21,629
experts on the Cosmic Microwave

59
00:02:26,390 --> 00:02:24,450
Background the remnant radiation from

60
00:02:29,630 --> 00:02:26,400
the Big Bang comes from half a million

61
00:02:31,970 --> 00:02:29,640
years after the Big Bang mark I worked

62
00:02:38,180 --> 00:02:31,980
with him Oh

63
00:02:40,640 --> 00:02:38,190

much too long ago 1997 1997-98 up at

64
00:02:43,430 --> 00:02:40,650
Columbia University I worked with him

65
00:02:45,050 --> 00:02:43,440
there he's fantastic he went out to

66
00:02:48,920 --> 00:02:45,060
Caltech and fortunately we got him back

67
00:02:50,990 --> 00:02:48,930
here to Johns Hopkins expert on this

68
00:02:53,830 --> 00:02:51,000
thing if you want to know that all the

69
00:02:59,240 --> 00:02:53,840
the the true nitty gritty he's the one

70
00:03:01,250 --> 00:02:59,250
December 2nd Joshua peak has volunteered

71
00:03:02,839 --> 00:03:01,260
to give that one but he didn't give me a

72
00:03:05,539 --> 00:03:02,849
title he just said he's talking about

73
00:03:07,940 --> 00:03:05,549
the is M which in astronomy is M is

74
00:03:11,809 --> 00:03:07,950
short for interstellar medium the gas

75
00:03:13,910 --> 00:03:11,819
the diffuse gas in between the stars he

76
00:03:16,160 --> 00:03:13,920
said he gave this talk in Princeton and

77
00:03:18,050 --> 00:03:16,170
it was an award-winning talk so I'm

78
00:03:20,089 --> 00:03:18,060
expecting it to be wonderful even if

79
00:03:20,740 --> 00:03:20,099
though I don't know quite all the

80
00:03:23,720 --> 00:03:20,750
details

81
00:03:27,620 --> 00:03:23,730
finally in January we will also have

82
00:03:29,839 --> 00:03:27,630
another second Tuesday because the

83
00:03:33,229 --> 00:03:29,849
auditorium is going to get retrofitted

84
00:03:35,349 --> 00:03:33,239
over the holidays well so what I'm told

85
00:03:39,050 --> 00:03:35,359
is we're going to have new carpets and

86
00:03:41,150 --> 00:03:39,060
new chairs I'm looking up in the corner

87
00:03:43,069 --> 00:03:41,160
and I noticed some some chairs up there

88
00:03:44,960 --> 00:03:43,079

that aren't like the others and I'm

89
00:03:46,490 --> 00:03:44,970
wondering if those are prototypes as for

90
00:03:48,500 --> 00:03:46,500
what the chairs in this auditorium might

91
00:03:50,750 --> 00:03:48,510
look like when you come in in January

92
00:03:52,909 --> 00:03:50,760
but when I was trying to schedule this

93
00:03:55,430 --> 00:03:52,919
on the calendar the auditorium was

94
00:03:59,119 --> 00:03:55,440
blacked out for two weeks and they said

95
00:04:00,650 --> 00:03:59,129
push push the PLS back one week so that

96
00:04:03,170 --> 00:04:00,660
they can make sure the auditorium is

97
00:04:06,020 --> 00:04:03,180
pristine and beautiful for you so

98
00:04:08,809 --> 00:04:06,030
January 13th will have a fascinating

99
00:04:12,020 --> 00:04:08,819
topic by some amazing astronomer who I

100
00:04:15,140 --> 00:04:12,030
will hook into and and and twist arms

101
00:04:16,939 --> 00:04:15,150
etc in the next month or two okay all

102
00:04:18,740 --> 00:04:16,949
right if you want to find out who that

103
00:04:21,969 --> 00:04:18,750
person is that I get the art gets the

104
00:04:24,879 --> 00:04:21,979
arm twisting you can go to our website

105
00:04:27,339 --> 00:04:24,889
here's our goal income site or goat

106
00:04:29,770 --> 00:04:27,349
or if you just search for Hubble public

107
00:04:31,300 --> 00:04:29,780
lecture you should find this page it has

108
00:04:35,850 --> 00:04:31,310
a list of the next three upcoming

109
00:04:39,279 --> 00:04:35,860
lectures as well as the archive back to

110
00:04:42,429 --> 00:04:39,289
2005 nine years of wonderful astronomy

111
00:04:44,679 --> 00:04:42,439
talks this link down here is also the

112
00:04:47,080 --> 00:04:44,689
one to go to our web casting our

113
00:04:50,320 --> 00:04:47,090

wonderful web casting team has web cast

114
00:04:53,110 --> 00:04:50,330
almost all of the talks back to dating

115
00:04:56,770 --> 00:04:53,120
back to 2005

116
00:04:58,360 --> 00:04:56,780
let's see email if you want a once a

117
00:05:00,339 --> 00:04:58,370
month or so announcement of what's

118
00:05:02,409 --> 00:05:00,349
coming just sign up on finding your

119
00:05:06,580 --> 00:05:02,419
email address we have a good record of

120
00:05:09,520 --> 00:05:06,590
no spam if you want to contact us send

121
00:05:12,040 --> 00:05:09,530
an email to public lecture at STScI edu

122
00:05:14,170 --> 00:05:12,050
you can give us a comment ask a question

123
00:05:15,760 --> 00:05:14,180
or it's a great way to sign up for the

124
00:05:18,459 --> 00:05:15,770
announcements because we'll already have

125
00:05:20,800 --> 00:05:18,469
your email address let's see for those

126
00:05:23,320 --> 00:05:20,810
who do social media we have facebook we

127
00:05:27,610 --> 00:05:23,330
have twitter we have Google+ we have

128
00:05:29,110 --> 00:05:27,620
Pinterest we may have other things that

129
00:05:30,399 --> 00:05:29,120
I don't know about Instagram or things

130
00:05:33,790 --> 00:05:30,409
like that

131
00:05:35,800 --> 00:05:33,800
I do Facebook and Google+ and Twitter a

132
00:05:39,279 --> 00:05:35,810
little every now and then and people

133
00:05:41,050 --> 00:05:39,289
sometimes want to follow me I don't do

134
00:05:45,999 --> 00:05:41,060
it that much so you're not gonna get a

135
00:05:47,320 --> 00:05:46,009
lot but hey I'm there just to keep up

136
00:05:49,480 --> 00:05:47,330
keep it up

137
00:05:51,820 --> 00:05:49,490
the observatory tonight is not going to

138
00:05:53,619 --> 00:05:51,830

happen unless you like to look through a

139
00:05:56,079 --> 00:05:53,629
telescope at raindrops you're not going

140
00:05:58,209 --> 00:05:56,089
to see much tonight so unfortunately

141
00:06:00,670 --> 00:05:58,219
have to come back Maryland space grant

142
00:06:02,709 --> 00:06:00,680
observatory does have open houses with

143
00:06:04,930 --> 00:06:02,719
their telescope every Friday night if

144
00:06:07,619 --> 00:06:04,940
you go to their website MD dot space

145
00:06:10,869 --> 00:06:07,629
grant org you can find their observatory

146
00:06:13,779 --> 00:06:10,879
listed and they will tell you when their

147
00:06:18,070 --> 00:06:13,789
next open observing night is going to be

148
00:06:19,390 --> 00:06:18,080
okay all right so now my favorite part

149
00:06:22,529 --> 00:06:19,400
time of the evening news from the

150
00:06:26,249 --> 00:06:22,539
universe for October 2014

151
00:06:30,730 --> 00:06:26,259
our first story tonight hidden by a

152
00:06:34,149 --> 00:06:30,740
supernova well this is a story about the

153
00:06:36,579 --> 00:06:34,159
galaxy Messier 81 and this is a

154
00:06:37,469 --> 00:06:36,589
beautiful picture of this spiral galaxy

155
00:06:38,879 --> 00:06:37,479
from Hubble

156
00:06:40,920 --> 00:06:38,889
all right you can see it's got a

157
00:06:42,659 --> 00:06:40,930
relatively large bulge it's got a

158
00:06:45,360 --> 00:06:42,669
somewhat circular feature around here

159
00:06:49,769 --> 00:06:45,370
with the spiral arms tailing off around

160
00:06:52,260 --> 00:06:49,779
it now there was a supernova in Messier

161
00:06:55,980 --> 00:06:52,270
81 Messier 81 it's actually relatively

162
00:06:58,290 --> 00:06:55,990
close by okay it's only tens of millions

163
00:07:01,950 --> 00:06:58,300

of light years away so it's relatively

164
00:07:06,029 --> 00:07:01,960
nearby and we saw a supernova back in

165
00:07:09,239 --> 00:07:06,039
1993 here's the image ground-based image

166
00:07:11,969 --> 00:07:09,249
from the Canada France Hawaii telescope

167
00:07:13,890 --> 00:07:11,979
see fht before the supernova went off

168
00:07:19,649 --> 00:07:13,900
and you see that bright spot there that

169
00:07:22,469 --> 00:07:19,659
is the supernova 1993 J and so you can

170
00:07:25,559 --> 00:07:22,479
see that the supernovae are extremely

171
00:07:28,230 --> 00:07:25,569
bright they can be seen galaxies tens of

172
00:07:30,659 --> 00:07:28,240
millions of light years away really cool

173
00:07:36,269 --> 00:07:30,669
that makes a supernova study of all

174
00:07:40,409 --> 00:07:36,279
across the local universe now 1993 J is

175
00:07:42,389 --> 00:07:40,419
a type 2b supernova and I'm not going to

176
00:07:45,749 --> 00:07:42,399
explain that in great detail just it's a

177
00:07:49,920 --> 00:07:45,759
massive star and the presence or not

178
00:07:52,649 --> 00:07:49,930
presence of hydrogen lines etc is is

179
00:07:55,469 --> 00:07:52,659
noted in its spectrum so the idea is

180
00:07:57,600 --> 00:07:55,479
that you have two massive stars orbiting

181
00:08:01,649 --> 00:07:57,610
around each other that they are a binary

182
00:08:04,019 --> 00:08:01,659
star one of them evolves to become a

183
00:08:06,409 --> 00:08:04,029
giant star which that happens at the end

184
00:08:10,249 --> 00:08:06,419
of the lives of a massive star and

185
00:08:13,019 --> 00:08:10,259
material it flows off of the giant of

186
00:08:16,110 --> 00:08:13,029
the more massive one the one that

187
00:08:18,860 --> 00:08:16,120
evolves first on to the other one That

188
00:08:23,369 --> 00:08:18,870

star then goes supernova explodes and

189
00:08:24,959 --> 00:08:23,379
when and leaving behind a supernova

190
00:08:28,739 --> 00:08:24,969
remnant that eventually will fade away

191
00:08:31,889 --> 00:08:28,749
but also the material fed onto this

192
00:08:33,719 --> 00:08:31,899
other companion star rejuvenates the

193
00:08:36,689 --> 00:08:33,729
star it adds more hydrogen to its

194
00:08:38,879 --> 00:08:36,699
envelope allows it to get bigger and

195
00:08:43,500 --> 00:08:38,889
more and brighter and sort of

196
00:08:44,759 --> 00:08:43,510
rejuvenates that star missus I want to

197
00:08:46,400 --> 00:08:44,769
say it's like a blue straggler but you

198
00:08:50,300 --> 00:08:46,410
guys don't know what a blue striker is

199
00:08:52,820 --> 00:08:50,310
it's where by adding new material on

200
00:08:56,840 --> 00:08:52,830
the star it gives it a new lease on life

201
00:09:00,620 --> 00:08:56,850
for a little bit longer so seeing 1993 J

202
00:09:04,250 --> 00:09:00,630
as as a supernova explosion and from its

203
00:09:08,540 --> 00:09:04,260
spectrum determining that it's a type 2b

204
00:09:14,650 --> 00:09:08,550
and this is our idea of what a type 2b

205
00:09:18,800 --> 00:09:14,660
should be so the question is is there a

206
00:09:21,410 --> 00:09:18,810
rejuvenated bright blue star left in the

207
00:09:23,570 --> 00:09:21,420
wake of the supernova how are we gonna

208
00:09:26,120 --> 00:09:23,580
tell well the thing I didn't tell you

209
00:09:27,470 --> 00:09:26,130
about is that Hubble image is twenty two

210
00:09:30,350 --> 00:09:27,480
thousand six hundred and twenty pixels

211
00:09:34,060 --> 00:09:30,360
by fifteen thousand two hundred pixels

212
00:09:38,300 --> 00:09:34,070
or three hundred and eighty four

213
00:09:41,690 --> 00:09:38,310

megapixels that's a lot of galaxies okay

214
00:09:44,360 --> 00:09:41,700
that's a lot of resolution so much

215
00:09:48,440 --> 00:09:44,370
resolution that we can go back in there

216
00:09:51,769 --> 00:09:48,450
and start searching for the leftover

217
00:09:54,860 --> 00:09:51,779
star now for the past twenty years

218
00:09:57,320 --> 00:09:54,870
the supernova explosion the remnant the

219
00:10:00,730 --> 00:09:57,330
the gas blown off in that supernova

220
00:10:03,560 --> 00:10:00,740
explosion has been too bright but

221
00:10:05,960 --> 00:10:03,570
recently we were able to look in with

222
00:10:08,690 --> 00:10:05,970
Hubble and can you pick out the

223
00:10:10,520 --> 00:10:08,700
supernova you shouldn't be able to

224
00:10:14,210 --> 00:10:10,530
because that's faded away but you know

225
00:10:18,140 --> 00:10:14,220
it's somewhere in here alright alright

226
00:10:22,640 --> 00:10:18,150
and we're I in one of these blue dots in

227
00:10:27,190 --> 00:10:22,650
here is supposed to be the blue star of

228
00:10:32,050 --> 00:10:27,200
the companion ok this is the first time

229
00:10:35,960 --> 00:10:32,060
that they have been able to identify the

230
00:10:38,570 --> 00:10:35,970
companion star left over from a type 2b

231
00:10:40,310 --> 00:10:38,580
supernova alright that idea that I that

232
00:10:42,770 --> 00:10:40,320
cartoon that I showed you has been our

233
00:10:47,120 --> 00:10:42,780
theoretical model of how these type two

234
00:10:49,220 --> 00:10:47,130
bees must happen but this is of now we

235
00:10:52,430 --> 00:10:49,230
have confirmation in that yes there is a

236
00:10:55,430 --> 00:10:52,440
bright big blue star left over in the

237
00:10:57,079 --> 00:10:55,440
wake of supernova 1993 J it has just

238
00:11:00,560 --> 00:10:57,089

been hidden within a supernova explosion

239
00:11:02,200 --> 00:11:00,570
for the past twenty years that's kind of

240
00:11:05,900 --> 00:11:02,210
cool

241
00:11:09,200 --> 00:11:05,910
next we have signing up to Mars but in

242
00:11:11,389 --> 00:11:09,210
the fall not the spring which is a

243
00:11:14,150 --> 00:11:11,399
convoluted title because I wanted to get

244
00:11:18,199 --> 00:11:14,160
the word siding and spring in there you

245
00:11:20,810 --> 00:11:18,209
guys remember yes we have comet siding

246
00:11:24,380 --> 00:11:20,820
spring I told you about this a few

247
00:11:26,060 --> 00:11:24,390
months ago okay and I haven't mentioned

248
00:11:27,650 --> 00:11:26,070
it since because well I'll tell you why

249
00:11:30,620 --> 00:11:27,660
I haven't mentioned it since all right

250
00:11:34,850 --> 00:11:30,630
so this is a wonderful picture of comet

251
00:11:37,760 --> 00:11:34,860
siding spring taken in February 2nd of

252
00:11:40,010 --> 00:11:37,770
2014 by a wonderful astronomer I used a

253
00:11:42,139 --> 00:11:40,020
lot of his Ison images to Damian peach

254
00:11:44,120 --> 00:11:42,149
he's become very famous for his

255
00:11:46,760 --> 00:11:44,130
wonderful comet images alright and it's

256
00:11:48,199 --> 00:11:46,770
just hey it's another comet right what's

257
00:11:51,790 --> 00:11:48,209
special about siding spring you guys

258
00:11:54,019 --> 00:11:51,800
remember well siding spring is special

259
00:11:56,360 --> 00:11:54,029
well alright this is a Hubble image of

260
00:11:57,680 --> 00:11:56,370
it I want to show in March of it so

261
00:11:59,900 --> 00:11:57,690
Hubble has actually been taking images

262
00:12:02,720 --> 00:11:59,910
of it why is hoping taking image of it

263
00:12:06,440 --> 00:12:02,730

because siding spring is going to pass

264
00:12:09,110 --> 00:12:06,450
very close to Mars now this is really

265
00:12:10,940 --> 00:12:09,120
crazy because siding spring is coming in

266
00:12:13,220 --> 00:12:10,950
from the Oort cloud it's way way out

267
00:12:16,820 --> 00:12:13,230
there it's coming in and if this is the

268
00:12:19,120 --> 00:12:16,830
plane of our planet orbits its orbit is

269
00:12:21,740 --> 00:12:19,130
like this okay so it's coming in

270
00:12:24,920 --> 00:12:21,750
swooping up and it just happens to have

271
00:12:27,829 --> 00:12:24,930
its its perihelion close to the orbit of

272
00:12:30,170 --> 00:12:27,839
Mars and it's passing through it's at

273
00:12:33,230 --> 00:12:30,180
that point at the same time Mars is

274
00:12:36,410 --> 00:12:33,240
passing by which is really crazy what a

275
00:12:39,500 --> 00:12:36,420
wonderful coincidence okay siding spring

276
00:12:44,480 --> 00:12:39,510
is going to pass by Mars this month okay

277
00:12:47,840 --> 00:12:44,490
all right and here is the closeness of

278
00:12:49,940 --> 00:12:47,850
the passage this is a scale of scale

279
00:12:51,680 --> 00:12:49,950
scale drawing of Mars and here is the

280
00:12:53,180 --> 00:12:51,690
orbit of siding spring there gonna be a

281
00:12:54,470 --> 00:12:53,190
hundred and thirty-five thousand

282
00:12:58,220 --> 00:12:54,480
kilometers across

283
00:13:00,079 --> 00:12:58,230
apart which in terms of astronomical

284
00:13:04,639 --> 00:13:00,089
context that's a near miss

285
00:13:06,710 --> 00:13:04,649
okay I know 135,000 kilometers is a lot

286
00:13:08,329 --> 00:13:06,720
to you and me but on the scale of the

287
00:13:12,440 --> 00:13:08,339
solar system especially on the scale the

288
00:13:13,890 --> 00:13:12,450

Oort cloud that's nothing all right and

289
00:13:17,280 --> 00:13:13,900
one way to remember it

290
00:13:20,760 --> 00:13:17,290
about 20 Mars diameters okay

291
00:13:23,430 --> 00:13:20,770
whereas our moon is 30 earth diameters

292
00:13:25,830 --> 00:13:23,440
away so this would effectively pass

293
00:13:28,020 --> 00:13:25,840
closer if it were coming past Earth on

294
00:13:30,090 --> 00:13:28,030
the same scale it would be closer than

295
00:13:31,470 --> 00:13:30,100
the moon right it passed between Earth

296
00:13:33,930 --> 00:13:31,480
and the moon's that's how close it's

297
00:13:37,350 --> 00:13:33,940
going to come all right but it's 20 Mars

298
00:13:39,990 --> 00:13:37,360
diameters I will also note that Mars is

299
00:13:42,000 --> 00:13:40,000
pathetic little nothings of moons phobos

300
00:13:43,740 --> 00:13:42,010
and deimos which are most likely just

301
00:13:46,170 --> 00:13:43,750
captured asteroids and not really

302
00:13:48,030 --> 00:13:46,180
respectable moons not that I have

303
00:13:51,330 --> 00:13:48,040
opinion on opinions on these things

304
00:13:53,520 --> 00:13:51,340
all right orbiting much much closer so

305
00:13:57,620 --> 00:13:53,530
it won't be it won't be passing inside

306
00:14:00,990 --> 00:13:57,630
of Mars as months so the question is as

307
00:14:03,570 --> 00:14:01,000
citing spring is getting closer to the

308
00:14:05,730 --> 00:14:03,580
Sun it should be melting more it should

309
00:14:08,310 --> 00:14:05,740
be giving off more gas and should be

310
00:14:10,260 --> 00:14:08,320
developing a larger coma and the

311
00:14:14,160 --> 00:14:10,270
question is whether or not that coma is

312
00:14:16,920 --> 00:14:14,170
large enough so that the gas will

313
00:14:19,500 --> 00:14:16,930

actually pass over Mars well Mars pass

314
00:14:22,170 --> 00:14:19,510
through the comet of the coma of the

315
00:14:23,700 --> 00:14:22,180
comet okay all that gas come across Mars

316
00:14:28,140 --> 00:14:23,710
because then you could see some cool

317
00:14:30,240 --> 00:14:28,150
interactions all right well Hubble has

318
00:14:32,850 --> 00:14:30,250
been monitoring has been has been

319
00:14:35,460 --> 00:14:32,860
looking at it and this is the normal

320
00:14:38,280 --> 00:14:35,470
image from Hubble and this is the model

321
00:14:40,470 --> 00:14:38,290
subtracted image okay so taking a smooth

322
00:14:42,420 --> 00:14:40,480
spherical model out of it to try and see

323
00:14:44,100 --> 00:14:42,430
if there are jets coming off because the

324
00:14:46,290 --> 00:14:44,110
amount of Jets that it's it's emitting

325
00:14:49,320 --> 00:14:46,300
has something to tell us

326
00:14:52,200 --> 00:14:49,330
how large the coma might become and

327
00:14:54,690 --> 00:14:52,210
Hubble has moderate it since October of

328
00:14:57,360 --> 00:14:54,700
last year of course people have

329
00:15:00,810 --> 00:14:57,370
continued to monitor it here is one from

330
00:15:02,450 --> 00:15:00,820
September 6th and here's a picture of

331
00:15:05,910 --> 00:15:02,460
siding spring

332
00:15:08,010 --> 00:15:05,920
unfortunately the reports are that it

333
00:15:11,990 --> 00:15:08,020
has dimmed in brightness considerably

334
00:15:16,440 --> 00:15:12,000
over the past few weeks two months okay

335
00:15:18,870 --> 00:15:16,450
so the current view is that the coma

336
00:15:21,540 --> 00:15:18,880
isn't really huge enough that it's going

337
00:15:24,330 --> 00:15:21,550
to cause a like a really amazing

338
00:15:26,670 --> 00:15:24,340

interaction with Mars okay you could

339
00:15:27,510 --> 00:15:26,680
imagine that material from the coma

340
00:15:29,520 --> 00:15:27,520
could hit MA

341
00:15:31,740 --> 00:15:29,530
you get Aurora you can get an amazing

342
00:15:35,970 --> 00:15:31,750
meteor show all right

343
00:15:37,290 --> 00:15:35,980
meteor meteor shower but we're not sure

344
00:15:40,380 --> 00:15:37,300
we're gonna see much okay

345
00:15:41,580 --> 00:15:40,390
so there's very we're optimistic like

346
00:15:44,100 --> 00:15:41,590
Ison you remember what happened with

347
00:15:46,350 --> 00:15:44,110
Ison last year right all this build-up

348
00:15:48,690 --> 00:15:46,360
and then oh it breaks up as it passes

349
00:15:50,280 --> 00:15:48,700
the Sun well at least this one were sure

350
00:15:52,320 --> 00:15:50,290
we're telling you in advance hey it's

351
00:15:54,210 --> 00:15:52,330
dimmed a bit it's not necessarily gonna

352
00:15:56,010 --> 00:15:54,220
be a spectacular show but we're gonna

353
00:15:57,690 --> 00:15:56,020
still watch anyways because we get

354
00:16:00,240 --> 00:15:57,700
science out of it no matter whether it's

355
00:16:03,060 --> 00:16:00,250
a great show visual show or not okay

356
00:16:04,470 --> 00:16:03,070
Hubble will be watching Hubble has the

357
00:16:06,180 --> 00:16:04,480
finest resolution so it'll be looking at

358
00:16:08,780 --> 00:16:06,190
the comet other things we'll be

359
00:16:11,490 --> 00:16:08,790
monitoring Mars and the most important

360
00:16:14,880 --> 00:16:11,500
missions will of course already be at

361
00:16:18,030 --> 00:16:14,890
Mars they're in situ okay so we have the

362
00:16:19,680 --> 00:16:18,040
Rovers on the surface of Mars but the

363
00:16:21,630 --> 00:16:19,690

ones that are really a little more

364
00:16:23,430 --> 00:16:21,640
concerned are the ones in orbit around

365
00:16:26,310 --> 00:16:23,440
Mars like Mars Reconnaissance Orbiter

366
00:16:29,670 --> 00:16:26,320
and the brand-new maven mission that is

367
00:16:32,100 --> 00:16:29,680
just arriving at Mars this month okay

368
00:16:34,860 --> 00:16:32,110
they need to make sure that if there's

369
00:16:38,370 --> 00:16:34,870
going to be a significant meteor storm

370
00:16:40,020 --> 00:16:38,380
that they are protected okay so they

371
00:16:42,900 --> 00:16:40,030
have various plans and they're watching

372
00:16:45,090 --> 00:16:42,910
extremely carefully they will also be

373
00:16:46,950 --> 00:16:45,100
doing as many observations as possible

374
00:16:52,580 --> 00:16:46,960
so I can't tell you what's gonna happen

375
00:16:55,680 --> 00:16:52,590
in what is it 12 days 11 12 days but

376
00:16:57,510 --> 00:16:55,690
Sciences are gonna look at and what I

377
00:16:59,970 --> 00:16:57,520
really hope is that we can get something

378
00:17:02,160 --> 00:16:59,980
cool like this with all sorts of meteors

379
00:17:05,579 --> 00:17:02,170
crashing in on and Mars is thin

380
00:17:09,600 --> 00:17:05,589
atmosphere but stay tuned we'll find out

381
00:17:12,810 --> 00:17:09,610
in two weeks time alright finally the

382
00:17:15,750 --> 00:17:12,820
last story blood moon in the morning and

383
00:17:19,290 --> 00:17:15,760
what is Blood Moon refer to it refers to

384
00:17:21,810 --> 00:17:19,300
a total lunar eclipse this is a

385
00:17:25,230 --> 00:17:21,820
wonderful picture composite picture from

386
00:17:28,830 --> 00:17:25,240
our very own Zolt Levay of a total lunar

387
00:17:31,740 --> 00:17:28,840
eclipse where when the moon is in the

388
00:17:34,660 --> 00:17:31,750

Umbra of Earth's shadow it becomes red

389
00:17:37,590 --> 00:17:34,670
and hence the name Blood Moon

390
00:17:40,870 --> 00:17:37,600
all right this is happening tonight

391
00:17:43,450 --> 00:17:40,880
tomorrow morning there will be a total

392
00:17:46,390 --> 00:17:43,460
lunar eclipse and it will be visible for

393
00:17:48,010 --> 00:17:46,400
a very short time from Baltimore but

394
00:17:51,610 --> 00:17:48,020
there are a few problems with it okay so

395
00:17:53,590 --> 00:17:51,620
here is the timing of it the partial

396
00:17:56,770 --> 00:17:53,600
eclipses starting into the Umbra starts

397
00:18:00,640 --> 00:17:56,780
at 5:15 a.m. it total eclipse begins at

398
00:18:02,950 --> 00:18:00,650
6:25 a.m. the total eclipse ends at 7:24

399
00:18:06,610 --> 00:18:02,960
a.m. and the partial eclipse ends at

400
00:18:08,320 --> 00:18:06,620
8:34 a.m. if you look at those times and

401
00:18:11,080 --> 00:18:08,330
think about it well there's one major

402
00:18:14,440 --> 00:18:11,090
problem with that well first of all

403
00:18:17,170 --> 00:18:14,450
sunrise is at 7:09 a.m. and the moon

404
00:18:19,330 --> 00:18:17,180
sets at 7:00 11 a.m. so somewhere

405
00:18:21,940 --> 00:18:19,340
between here and here the moon's gonna

406
00:18:24,370 --> 00:18:21,950
go below the horizon so you're not gonna

407
00:18:26,710 --> 00:18:24,380
be able to see it furthermore if the

408
00:18:29,530 --> 00:18:26,720
moon is that close to the horizon you

409
00:18:32,620 --> 00:18:29,540
really need a very clear western horizon

410
00:18:36,610 --> 00:18:32,630
okay the last total lunar eclipse that I

411
00:18:38,800 --> 00:18:36,620
saw I was on a cruise ship we are

412
00:18:40,990 --> 00:18:38,810
pulling into port in San Diego and off

413
00:18:42,580 --> 00:18:41,000

the back of the ship we had a fantastic

414
00:18:44,710 --> 00:18:42,590
view because all we had was ocean out

415
00:18:48,070 --> 00:18:44,720
there to the west it was it was

416
00:18:50,350 --> 00:18:48,080
wonderful I don't know of a good place

417
00:18:52,780 --> 00:18:50,360
in Baltimore that has a totally clear

418
00:18:55,090 --> 00:18:52,790
western horizon but if you can find one

419
00:18:59,320 --> 00:18:55,100
and want to get up early tomorrow I

420
00:19:01,180 --> 00:18:59,330
would say that about 6 a.m. 5:45 6 a.m.

421
00:19:03,910 --> 00:19:01,190
you'll start to be able to notice the

422
00:19:05,980 --> 00:19:03,920
partial eclipse and you'll be able to

423
00:19:08,080 --> 00:19:05,990
watch it through till about 6:30 being

424
00:19:10,030 --> 00:19:08,090
in a really clear western horizon it's

425
00:19:11,560 --> 00:19:10,040
also kind of cool because you're looking

426
00:19:13,750 --> 00:19:11,570
out into the West and you're seeing them

427
00:19:15,130 --> 00:19:13,760
the eclipse of the Moon and then all

428
00:19:16,870 --> 00:19:15,140
wrong the East you're seeing the

429
00:19:19,060 --> 00:19:16,880
pre-dawn sunrise stuff coming up it's

430
00:19:22,000 --> 00:19:19,070
just a sort of a magical feeling alright

431
00:19:25,390 --> 00:19:22,010
looking at that so if you can find a

432
00:19:26,920 --> 00:19:25,400
really cool empty western horizon please

433
00:19:28,600 --> 00:19:26,930
go out and observe it and enjoy

434
00:19:30,580 --> 00:19:28,610
yourselves and dress warmly bring hot

435
00:19:32,230 --> 00:19:30,590
chocolate that's true for all observing

436
00:19:38,820 --> 00:19:32,240
right you got to bring hot chocolate for

437
00:19:52,310 --> 00:19:48,360
okay so we're all gonna invade this

438
00:19:55,860 --> 00:19:54,630

the World Trade Center the World Trade

439
00:19:57,300 --> 00:19:55,870
Center but will they be able to see the

440
00:20:00,090 --> 00:19:57,310
West okay

441
00:20:02,370 --> 00:20:00,100
seeing the East with the ocean over the

442
00:20:05,510 --> 00:20:02,380
Atlantic Ocean is easy but remember you

443
00:20:08,130 --> 00:20:05,520
got to be able to look to the west okay

444
00:20:09,900 --> 00:20:08,140
anyways good luck to you all

445
00:20:12,660 --> 00:20:09,910
if you want to get up early to do your

446
00:20:15,000 --> 00:20:12,670
Eclipse of observing okay all right I

447
00:20:18,450 --> 00:20:15,010
have taken enough time it's time to get

448
00:20:22,560 --> 00:20:18,460
to our featured speaker and our speaker

449
00:20:26,280 --> 00:20:22,570
tonight is Greg Snyder Greg started his

450
00:20:27,630 --> 00:20:26,290
undergraduate work at Princeton he

451
00:20:31,650 --> 00:20:27,640
started I guess he finished it there too

452
00:20:34,230 --> 00:20:31,660
yes then went on to Harvard where he

453
00:20:36,270 --> 00:20:34,240
worked in his graduate work with a

454
00:20:39,090 --> 00:20:36,280
friend of mine Lars Hearn Quist one of

455
00:20:42,000 --> 00:20:39,100
the preeminent astronomers in computer

456
00:20:43,980 --> 00:20:42,010
simulations and then he we are fortunate

457
00:20:46,380 --> 00:20:43,990
enough to get him down here

458
00:20:48,600 --> 00:20:46,390
he has worked on one of the most

459
00:20:50,700 --> 00:20:48,610
exciting projects in computer

460
00:20:51,480 --> 00:20:50,710
simulations in astronomy and he'll tell

461
00:21:07,680 --> 00:20:51,490
you about that tonight

462
00:21:15,399 --> 00:21:10,389
testing can everyone hear me

463
00:21:17,139 --> 00:21:15,409

great so thanks for coming to my talk

464
00:21:18,099 --> 00:21:17,149
and it's it's a great pleasure for me to

465
00:21:19,419 --> 00:21:18,109
be able to tell you a little bit about

466
00:21:21,489 --> 00:21:19,429
the work that I've been involved with

467
00:21:25,450 --> 00:21:21,499
the past couple of years and so my talk

468
00:21:30,070 --> 00:21:25,460
is titled sorry first time I've used

469
00:21:31,719 --> 00:21:30,080
this gadget my studying virtual you know

470
00:21:35,259 --> 00:21:31,729
universities with supercomputer

471
00:21:37,869 --> 00:21:35,269
simulations and that is sort of a

472
00:21:39,690 --> 00:21:37,879
shorthand for trying to understand the

473
00:21:41,619 --> 00:21:39,700
formation of galaxies in the universe

474
00:21:43,810 --> 00:21:41,629
and so I'm gonna tell you a little bit

475
00:21:45,849 --> 00:21:43,820
about something called the illustrious

476
00:21:48,549 --> 00:21:45,859
project and so here's our website down

477
00:21:51,430 --> 00:21:48,559
at the bottom Electress project org and

478
00:21:54,129 --> 00:21:51,440
this collaboration is from these folks

479
00:21:56,289 --> 00:21:54,139
listed here and others and the the dry

480
00:21:58,690 --> 00:21:56,299
title of a paper that we put out in the

481
00:22:00,700 --> 00:21:58,700
spring is called properties of galaxies

482
00:22:02,649 --> 00:22:00,710
reproduced by a hydrodynamic simulation

483
00:22:03,969 --> 00:22:02,659
and so in my talk I'll unpack that a

484
00:22:05,409 --> 00:22:03,979
little bit and try and describe to you

485
00:22:08,499 --> 00:22:05,419
what what what this means and why this

486
00:22:10,509 --> 00:22:08,509
is a challenging thing to do and so the

487
00:22:12,999 --> 00:22:10,519
the one word I wanted to highlight here

488
00:22:15,759 --> 00:22:13,009

is hydrodynamic simulation so that just

489
00:22:18,519 --> 00:22:15,769
means gas physics so it's hydro for

490
00:22:20,709 --> 00:22:18,529
water but in the same way it's sort of

491
00:22:22,539 --> 00:22:20,719
modeling the fluids that are important

492
00:22:24,700 --> 00:22:22,549
in the universe so that's where that

493
00:22:27,459 --> 00:22:24,710
word comes from and the main challenge

494
00:22:29,469 --> 00:22:27,469
with a simulation like this one is to

495
00:22:30,879 --> 00:22:29,479
reproduce galaxies so the topic of this

496
00:22:32,649 --> 00:22:30,889
talk is going to be about galaxies and

497
00:22:33,789 --> 00:22:32,659
here's just a smattering of simulated

498
00:22:35,289 --> 00:22:33,799
galaxies that came out of the

499
00:22:37,269 --> 00:22:35,299
illustrious project so these are

500
00:22:38,859 --> 00:22:37,279
galaxies as they exist today as they

501
00:22:41,049 --> 00:22:38,869
might be observed with a telescope like

502
00:22:42,519 --> 00:22:41,059
HST or the Hubble Space Telescope and so

503
00:22:44,349 --> 00:22:42,529
what we see in the engineer by the

504
00:22:46,659 --> 00:22:44,359
universe is galaxies fall into roughly

505
00:22:48,310 --> 00:22:46,669
two categories there are disk galaxies

506
00:22:49,570 --> 00:22:48,320
there are these star forming spiral

507
00:22:51,039 --> 00:22:49,580
galaxies like the one Frank showed

508
00:22:52,659 --> 00:22:51,049
earlier and then there are these

509
00:22:55,570 --> 00:22:52,669
elliptical galaxies which are smoother

510
00:22:57,159 --> 00:22:55,580
and redder galaxies and so the idea is

511
00:23:01,719 --> 00:22:57,169
to try and simulate this population of

512
00:23:03,339 --> 00:23:01,729
galaxies all at once I want to put this

513
00:23:04,959 --> 00:23:03,349

we'll spend a few minutes to put this in

514
00:23:05,820 --> 00:23:04,969
context a little bit so no galaxies can

515
00:23:07,950 --> 00:23:05,830
be kind of an abstract

516
00:23:09,450 --> 00:23:07,960
topic so first I want to imagine that

517
00:23:11,250 --> 00:23:09,460
you're in the solar system so we all

518
00:23:12,960 --> 00:23:11,260
live on planet Earth here third planet

519
00:23:15,269 --> 00:23:12,970
from the Sun this is not exactly to

520
00:23:17,130 --> 00:23:15,279
scale it's a sort of a toy model of a

521
00:23:19,169 --> 00:23:17,140
solar system so imagine that you're a

522
00:23:22,289 --> 00:23:19,179
star system or a solar system like this

523
00:23:23,580 --> 00:23:22,299
one a galaxy is just a collection of a

524
00:23:26,130 --> 00:23:23,590
hundred billion different star systems

525
00:23:28,320 --> 00:23:26,140
so you can imagine putting our solar

526
00:23:30,269 --> 00:23:28,330
system or any solar system in its proper

527
00:23:31,919 --> 00:23:30,279
place in the galaxy like this so if you

528
00:23:33,960 --> 00:23:31,929
take the solar system and shrink it down

529
00:23:35,789 --> 00:23:33,970
to a size much smaller than even a

530
00:23:37,529 --> 00:23:35,799
single pixel of the 38 or more

531
00:23:39,000 --> 00:23:37,539
megapixels that may be on this image

532
00:23:40,710 --> 00:23:39,010
it's still smaller than that

533
00:23:43,470 --> 00:23:40,720
and so our solar system is extremely

534
00:23:45,659 --> 00:23:43,480
tiny compared to the system of a galaxy

535
00:23:47,850 --> 00:23:45,669
and so galaxy is now this hundred

536
00:23:49,950 --> 00:23:47,860
billion star systems that are bound

537
00:23:51,840 --> 00:23:49,960
together by their own gravity and so

538
00:23:53,279 --> 00:23:51,850

this is say an image of the light from a

539
00:23:56,340 --> 00:23:53,289
hundred billion stars that are orbiting

540
00:23:59,820 --> 00:23:56,350
around this galaxy over the course of

541
00:24:02,279 --> 00:23:59,830
hundreds of millions of years so that's

542
00:24:04,919 --> 00:24:02,289
a galaxy and galaxies live in a very

543
00:24:06,060 --> 00:24:04,929
large observed universe that we've come

544
00:24:08,940 --> 00:24:06,070
to understand over the past couple

545
00:24:11,610 --> 00:24:08,950
decades and I want to take take this a

546
00:24:13,409 --> 00:24:11,620
few steps and show you the solar system

547
00:24:15,299 --> 00:24:13,419
disappearing there and this galaxy

548
00:24:17,070 --> 00:24:15,309
fitting into its context in the universe

549
00:24:19,500 --> 00:24:17,080
and so this is now a cluster of galaxies

550
00:24:22,080 --> 00:24:19,510
of different types shown with an HST

551
00:24:23,940 --> 00:24:22,090
image here so this is a cluster of

552
00:24:26,399 --> 00:24:23,950
galaxies and I wanted to just highlight

553
00:24:27,930 --> 00:24:26,409
where a galaxy like this one which is

554
00:24:29,430 --> 00:24:27,940
not exactly the Milky Way but it looks

555
00:24:32,009 --> 00:24:29,440
like we think the Milky Way it looks

556
00:24:33,330 --> 00:24:32,019
like would appear in its context in the

557
00:24:35,879 --> 00:24:33,340
universe and so this is a cluster of

558
00:24:38,490 --> 00:24:35,889
galaxies and here is now what a galaxy

559
00:24:42,680 --> 00:24:38,500
might look like inside this this larger

560
00:24:46,470 --> 00:24:42,690
group of galaxies that's not all

561
00:24:47,970 --> 00:24:46,480
galaxies are even are there are hundreds

562
00:24:49,620 --> 00:24:47,980
of billions of known galaxies this is a

563
00:24:51,779 --> 00:24:49,630

survey of galaxies the Sloan Digital Sky

564
00:24:52,799 --> 00:24:51,789
Survey showing you where this cluster of

565
00:24:54,960 --> 00:24:52,809
galaxies that I showed you on the

566
00:24:56,970 --> 00:24:54,970
previous slide might fall with respect

567
00:24:59,310 --> 00:24:56,980
to the so called cosmic web of galaxies

568
00:25:01,350 --> 00:24:59,320
and so this is what I heard - as the

569
00:25:03,000 --> 00:25:01,360
observed universe and this is what we're

570
00:25:04,980 --> 00:25:03,010
trying to understand with our virtual

571
00:25:06,299 --> 00:25:04,990
universes in the OO stress project and

572
00:25:11,789 --> 00:25:06,309
so this is the con is the kind of thing

573
00:25:14,279 --> 00:25:11,799
that we're hoping to simulate and we

574
00:25:17,220 --> 00:25:14,289
know frightening ly little about what

575
00:25:18,690 --> 00:25:17,230
constitutes galaxies and so the picture

576
00:25:19,470 --> 00:25:18,700
that we've been put together over the

577
00:25:22,590 --> 00:25:19,480
past couple decade

578
00:25:24,590 --> 00:25:22,600
is one where the content of galaxies is

579
00:25:27,360 --> 00:25:24,600
broken down into three basic categories

580
00:25:29,250 --> 00:25:27,370
there's the dark matter of galaxies and

581
00:25:32,220 --> 00:25:29,260
the dark energy of galaxies that take up

582
00:25:34,260 --> 00:25:32,230
96% of the known energy density of the

583
00:25:36,420 --> 00:25:34,270
universe we don't know what they are but

584
00:25:38,790 --> 00:25:36,430
we know what they do so we know exactly

585
00:25:41,130 --> 00:25:38,800
how these two things behave in the

586
00:25:43,110 --> 00:25:41,140
dynamics of galaxies in particular the

587
00:25:45,330 --> 00:25:43,120
gravity of dark matter brings galaxies

588
00:25:47,610 --> 00:25:45,340

together and holds them together and the

589
00:25:49,680 --> 00:25:47,620
cosmic expansion which is accelerated by

590
00:25:52,530 --> 00:25:49,690
dark energy moves galaxies apart in

591
00:25:55,470 --> 00:25:52,540
cosmic expansion and these two processes

592
00:25:57,450 --> 00:25:55,480
are shockingly simple to model and all

593
00:26:00,060 --> 00:25:57,460
of the the hard parts of galaxies

594
00:26:03,120 --> 00:26:00,070
happens in this four to five percent of

595
00:26:05,250 --> 00:26:03,130
atoms which we which we know about which

596
00:26:07,110 --> 00:26:05,260
we can model and so the visible galaxies

597
00:26:10,260 --> 00:26:07,120
are for the most part along for the ride

598
00:26:11,910 --> 00:26:10,270
in this cosmic voyage but the a lot of

599
00:26:13,620 --> 00:26:11,920
these visible parts they get the atoms

600
00:26:15,600 --> 00:26:13,630
that constitute galaxies and stars is

601
00:26:17,370 --> 00:26:15,610
where a lot of the the uncertainty and

602
00:26:23,640 --> 00:26:17,380
the challenge comes in modeling modeling

603
00:26:26,370 --> 00:26:23,650
our universe and so when we look at the

604
00:26:28,740 --> 00:26:26,380
universe we don't see it in its perfect

605
00:26:31,710 --> 00:26:28,750
context like I just laid out this is an

606
00:26:33,360 --> 00:26:31,720
image taken by Hubble of the Ultra Deep

607
00:26:36,540 --> 00:26:33,370
Field so this is an image taken around

608
00:26:38,190 --> 00:26:36,550
2004 of a region of the sky that's about

609
00:26:40,170 --> 00:26:38,200
one one thousandth the size of a full

610
00:26:41,670 --> 00:26:40,180
moon and if you stare at that region for

611
00:26:43,370 --> 00:26:41,680
long enough you'll see all of the

612
00:26:45,600 --> 00:26:43,380
galaxies along that line of sight

613
00:26:47,370 --> 00:26:45,610

eventually come into focus and so here's

614
00:26:49,140 --> 00:26:47,380
a couple hundred galaxies from a region

615
00:26:50,850 --> 00:26:49,150
of the Hubble ultra-deep field and what

616
00:26:53,700 --> 00:26:50,860
I want want to point out is that we can

617
00:26:56,340 --> 00:26:53,710
see all the way back in time to the

618
00:26:58,230 --> 00:26:56,350
beginning of galaxies in these images so

619
00:27:00,300 --> 00:26:58,240
not all the way but most of the way back

620
00:27:02,250 --> 00:27:00,310
95% of the way back in time we can see

621
00:27:04,470 --> 00:27:02,260
in images like this and the reason is

622
00:27:06,090 --> 00:27:04,480
that light has a finite speed it doesn't

623
00:27:07,800 --> 00:27:06,100
come to us instantaneously from the very

624
00:27:09,810 --> 00:27:07,810
distant galaxies and so when you take a

625
00:27:12,030 --> 00:27:09,820
very deep image like this one we can see

626
00:27:14,430 --> 00:27:12,040
galaxies as they existed many billions

627
00:27:16,050 --> 00:27:14,440
of years ago so these very tiny galaxies

628
00:27:18,060 --> 00:27:16,060
it kind of looks like they're far away

629
00:27:20,310 --> 00:27:18,070
because they're smaller but that is

630
00:27:22,170 --> 00:27:20,320
partially true the very small galaxies

631
00:27:23,610 --> 00:27:22,180
in the in the the faint regions of this

632
00:27:25,560 --> 00:27:23,620
image are the faint points in this image

633
00:27:26,940 --> 00:27:25,570
are very distant galaxies as they

634
00:27:29,640 --> 00:27:26,950
existed billions and billions of years

635
00:27:31,710 --> 00:27:29,650
ago and so we can kind of work work back

636
00:27:32,970 --> 00:27:31,720
in time and see how the population of

637
00:27:33,600 --> 00:27:32,980
galaxies evolved from an image like this

638
00:27:37,110 --> 00:27:33,610

one

639
00:27:38,520 --> 00:27:37,120
and so the the visible galaxies there so

640
00:27:40,020 --> 00:27:38,530
what we're looking at here is starlight

641
00:27:42,200 --> 00:27:40,030
from a bunch of galaxies in the Hubble

642
00:27:44,730 --> 00:27:42,210
ultra-deep field that visible light

643
00:27:47,070 --> 00:27:44,740
reflects an enormous diversity of

644
00:27:48,960 --> 00:27:47,080
galaxies appearance and so what you see

645
00:27:51,510 --> 00:27:48,970
here is that galaxies are not just one

646
00:27:53,490 --> 00:27:51,520
shape or size so even if they are just

647
00:27:55,920 --> 00:27:53,500
very simply pulled along by dark matter

648
00:27:57,540 --> 00:27:55,930
and dark energy they can rivairy

649
00:27:58,800 --> 00:27:57,550
different from one galaxy to another and

650
00:28:01,260 --> 00:27:58,810
so that's what we see here and so we're

651
00:28:02,850 --> 00:28:01,270
trying to build a model of this and how

652
00:28:04,410 --> 00:28:02,860
these galaxies came about in their

653
00:28:08,340 --> 00:28:04,420
amazing diversity that we see in the

654
00:28:09,930 --> 00:28:08,350
real universe and the the fundamental

655
00:28:12,330 --> 00:28:09,940
challenge that are the thing that we

656
00:28:14,790 --> 00:28:12,340
want to understand is say how a distant

657
00:28:17,280 --> 00:28:14,800
galaxies or galaxies from early in the

658
00:28:19,320 --> 00:28:17,290
universe evolved to be a galaxy like we

659
00:28:21,030 --> 00:28:19,330
see today like the Milky Way so if we

660
00:28:22,740 --> 00:28:21,040
look at an observation of the sky or

661
00:28:25,050 --> 00:28:22,750
really any survey of galaxies in the

662
00:28:27,450 --> 00:28:25,060
universe we can identify galaxies like

663
00:28:29,040 --> 00:28:27,460

these three that I've circled here but

664
00:28:30,510 --> 00:28:29,050
we have no way of knowing how they

665
00:28:32,370 --> 00:28:30,520
relate to each other we just get a

666
00:28:34,170 --> 00:28:32,380
single snapshot of the galaxies as they

667
00:28:35,910 --> 00:28:34,180
existed at the time we observe them and

668
00:28:37,200 --> 00:28:35,920
so we don't know whether a galaxy that

669
00:28:38,340 --> 00:28:37,210
looks like this one which most of you

670
00:28:40,260 --> 00:28:38,350
probably can't even see it's a little

671
00:28:41,550 --> 00:28:40,270
yellow smudge here on the picture might

672
00:28:43,770 --> 00:28:41,560
evolve into a galaxies like this one

673
00:28:45,510 --> 00:28:43,780
which is a blue spiral galaxy that's a

674
00:28:46,740 --> 00:28:45,520
little bit closer and how that might

675
00:28:48,300 --> 00:28:46,750
have changed and evolved over time into

676
00:28:51,030 --> 00:28:48,310
a galaxy that looks like an elliptical

677
00:28:52,500 --> 00:28:51,040
or the smooth red galaxy here and so we

678
00:28:54,630 --> 00:28:52,510
don't we don't have the ability to watch

679
00:28:55,500 --> 00:28:54,640
these observe evolve in time and so

680
00:29:00,570 --> 00:28:55,510
that's why we want to turn to

681
00:29:02,190 --> 00:29:00,580
simulations and so we have this this

682
00:29:05,010 --> 00:29:02,200
picture we've put together from images

683
00:29:06,510 --> 00:29:05,020
like this one of the Hubble Space

684
00:29:08,190 --> 00:29:06,520
Telescope observing galaxies in the

685
00:29:10,230 --> 00:29:08,200
Ultra Deep Field like this and we can

686
00:29:12,870 --> 00:29:10,240
see them build up over time on average

687
00:29:15,240 --> 00:29:12,880
but we don't know how one particular

688
00:29:19,410 --> 00:29:15,250

kind of galaxy could evolve through this

689
00:29:21,300 --> 00:29:19,420
space of possible possibilities and so

690
00:29:23,640 --> 00:29:21,310
the analogy that I like to make about

691
00:29:26,070 --> 00:29:23,650
galaxies is that it's exactly or almost

692
00:29:28,500 --> 00:29:26,080
exactly like archaeology where we have

693
00:29:30,390 --> 00:29:28,510
precisely one fossil record of galaxies

694
00:29:32,550 --> 00:29:30,400
that as we as observed in one particular

695
00:29:34,140 --> 00:29:32,560
time time in the universe but we don't

696
00:29:36,990 --> 00:29:34,150
know how they lived we don't know how

697
00:29:39,030 --> 00:29:37,000
they evolved to be the way they were so

698
00:29:41,550 --> 00:29:39,040
it's almost like the Ultra Deep Field or

699
00:29:42,960 --> 00:29:41,560
Hubble Ultra Deep Field is like an

700
00:29:44,580 --> 00:29:42,970
archaeological dig site where you're

701
00:29:47,410 --> 00:29:44,590
going down layer by layer and you get to

702
00:29:50,350 --> 00:29:47,420
see the fossils of living things as they

703
00:29:51,730 --> 00:29:50,360
as they become older and older so the

704
00:29:53,680 --> 00:29:51,740
lower the farther down you go the

705
00:29:57,580 --> 00:29:53,690
farther back in Earth's history you will

706
00:30:00,190 --> 00:29:57,590
see you'll see fossils however you can't

707
00:30:02,440 --> 00:30:00,200
then watch how those fossils evolved or

708
00:30:03,880 --> 00:30:02,450
lived we have to put together a story of

709
00:30:08,530 --> 00:30:03,890
how they live devices by studying them

710
00:30:10,150 --> 00:30:08,540
in this indirect way so I'm going to

711
00:30:12,720 --> 00:30:10,160
talk about the Electress project in

712
00:30:14,770 --> 00:30:12,730
three main points or three main sections

713
00:30:15,940 --> 00:30:14,780

first a little bit more background about

714
00:30:17,620 --> 00:30:15,950
galaxies and why I think they're

715
00:30:19,420 --> 00:30:17,630
fascinating then I'm going to talk to

716
00:30:21,190 --> 00:30:19,430
you about computational astrophysics as

717
00:30:22,360 --> 00:30:21,200
applied to this problem and then I'll

718
00:30:24,190 --> 00:30:22,370
tell you about the illustrious project

719
00:30:29,110 --> 00:30:24,200
and and a few other virtual universe

720
00:30:32,590 --> 00:30:29,120
projects so a bit more about galaxies so

721
00:30:35,440 --> 00:30:32,600
I love galaxies but I like to say they

722
00:30:38,140 --> 00:30:35,450
have issues like all of us do and so

723
00:30:40,810 --> 00:30:38,150
galaxies have a lot of things that make

724
00:30:42,730 --> 00:30:40,820
them complicated so the here is a nice

725
00:30:44,860 --> 00:30:42,740
Hubble Space Telescope image of two

726
00:30:46,060 --> 00:30:44,870
interacting galaxies and I like to use

727
00:30:48,910 --> 00:30:46,070
this to highlight the different

728
00:30:51,070 --> 00:30:48,920
challenges we have in that 5% of guests

729
00:30:53,170 --> 00:30:51,080
or of atoms that we can understand the

730
00:30:54,790 --> 00:30:53,180
galaxies and that is there's these

731
00:30:56,710 --> 00:30:54,800
couple these processes that are really

732
00:30:58,540 --> 00:30:56,720
hard to model so there's star creation

733
00:31:00,130 --> 00:30:58,550
so I'll come back to some of these in

734
00:31:03,000 --> 00:31:00,140
more detail but there's the creation of

735
00:31:06,280 --> 00:31:03,010
stars which happens on very small scales

736
00:31:07,810 --> 00:31:06,290
there's gas and dust cloud so this is

737
00:31:10,000 --> 00:31:07,820
where the hydrodynamic stuff comes into

738
00:31:12,550 --> 00:31:10,010

play there's gas diffused gas that fills

739
00:31:14,710 --> 00:31:12,560
the interstellar medium stars can

740
00:31:16,390 --> 00:31:14,720
explode as supernovae that's why I

741
00:31:18,580 --> 00:31:16,400
talked about in his in his presentation

742
00:31:21,160 --> 00:31:18,590
and that those explosions can have an

743
00:31:22,720 --> 00:31:21,170
impact on this gas these these gas

744
00:31:25,090 --> 00:31:22,730
clouds and so that actually can feed

745
00:31:27,040 --> 00:31:25,100
back onto the the process of star

746
00:31:28,840 --> 00:31:27,050
creation and so this all of these these

747
00:31:30,760 --> 00:31:28,850
three processes are coupled in some in

748
00:31:33,820 --> 00:31:30,770
some sense and that you can't model one

749
00:31:36,130 --> 00:31:33,830
without model than the others another

750
00:31:37,870 --> 00:31:36,140
important challenge is we've come to

751
00:31:39,370 --> 00:31:37,880
understand that most galaxies have a

752
00:31:41,560 --> 00:31:39,380
supermassive black hole at their center

753
00:31:42,940 --> 00:31:41,570
and these supermassive black holes can

754
00:31:44,440 --> 00:31:42,950
have dynamically interesting or

755
00:31:47,590 --> 00:31:44,450
dynamically important effects on their

756
00:31:49,150 --> 00:31:47,600
galaxy so as these this diffuse gas gets

757
00:31:51,580 --> 00:31:49,160
funneled into the center of the galaxy

758
00:31:53,290 --> 00:31:51,590
the supermassive black hole can heat

759
00:31:55,480 --> 00:31:53,300
that gas and expel it out of the galaxy

760
00:31:57,190 --> 00:31:55,490
entirely and so all four of these

761
00:31:59,710 --> 00:31:57,200
processes need to be needs to be taken

762
00:32:00,850 --> 00:31:59,720
into account at least these four

763
00:32:02,860 --> 00:32:00,860

processes in order to

764
00:32:05,710 --> 00:32:02,870
understand the issues that galaxies have

765
00:32:07,180 --> 00:32:05,720
and then the the final thing I want to

766
00:32:08,590 --> 00:32:07,190
point out is that mergers and collisions

767
00:32:11,289 --> 00:32:08,600
among galaxies are thought to be very

768
00:32:12,610 --> 00:32:11,299
common and so this is showing the two

769
00:32:14,890 --> 00:32:12,620
galaxies that have interacting

770
00:32:16,690 --> 00:32:14,900
gravitationally and this process can

771
00:32:18,640 --> 00:32:16,700
actually trigger certain effects among

772
00:32:21,100 --> 00:32:18,650
these other four that are that are that

773
00:32:23,140 --> 00:32:21,110
are important and so it'll it'll shift

774
00:32:24,970 --> 00:32:23,150
around the gas and dust and push around

775
00:32:26,890 --> 00:32:24,980
the stars and trigger star creation and

776
00:32:33,120 --> 00:32:26,900
things and so all five of these are

777
00:32:38,500 --> 00:32:35,620
arguably the most important and perhaps

778
00:32:40,780 --> 00:32:38,510
the most interesting is what I call the

779
00:32:43,330 --> 00:32:40,790
Galactic life cycle and so this is just

780
00:32:44,860 --> 00:32:43,340
a sort of artist's rendition of what the

781
00:32:46,450 --> 00:32:44,870
Galactic life cycle is and I touched on

782
00:32:49,360 --> 00:32:46,460
this a little bit in the previous slide

783
00:32:52,720 --> 00:32:49,370
but that is that the everything is tied

784
00:32:54,990 --> 00:32:52,730
together so stars form out of gas clouds

785
00:32:57,190 --> 00:32:55,000
in the interstellar medium of galaxies

786
00:32:58,930 --> 00:32:57,200
so that leads to star formation in the

787
00:33:01,000 --> 00:32:58,940
very centres or very dense regions

788
00:33:02,590 --> 00:33:01,010

inside these gas clouds these stars

789
00:33:04,210 --> 00:33:02,600
these regions of star formation then

790
00:33:06,580 --> 00:33:04,220
become the solar systems like like the

791
00:33:08,890 --> 00:33:06,590
one we live in but stars have this habit

792
00:33:11,130 --> 00:33:08,900
of not being the same for their entire

793
00:33:13,840 --> 00:33:11,140
lives and so they can either explode or

794
00:33:15,430 --> 00:33:13,850
shed their outer parts into the back

795
00:33:17,860 --> 00:33:15,440
into the interstellar medium so I call

796
00:33:19,510 --> 00:33:17,870
this star recycling a supernovae so the

797
00:33:21,789 --> 00:33:19,520
Stars can then put back the matter that

798
00:33:23,590 --> 00:33:21,799
they that they accreted from gravity in

799
00:33:25,810 --> 00:33:23,600
this process back into the interstellar

800
00:33:27,850 --> 00:33:25,820
medium and form new gas clouds in the

801
00:33:30,010 --> 00:33:27,860
future and so the Galactic lifecycle is

802
00:33:31,810 --> 00:33:30,020
really the the interrelationship between

803
00:33:34,150 --> 00:33:31,820
all of these different things and so if

804
00:33:35,860 --> 00:33:34,160
we look at a Hubble image of galaxies we

805
00:33:38,620 --> 00:33:35,870
are basically looking at the light from

806
00:33:42,840 --> 00:33:38,630
their stars but we miss or we might miss

807
00:33:45,940 --> 00:33:42,850
a lot of these other important processes

808
00:33:48,460 --> 00:33:45,950
like whole activity here's a galaxy

809
00:33:51,880 --> 00:33:48,470
showing some interesting black hole

810
00:33:54,310 --> 00:33:51,890
activity here this is a galaxy with very

811
00:33:56,049 --> 00:33:54,320
large Jets so this is a radio

812
00:33:58,240 --> 00:33:56,059
observation overlaid on top of an HST

813
00:34:00,580 --> 00:33:58,250

image showing gas that's being ejected

814
00:34:02,950 --> 00:34:00,590
by a very massive black hole in the

815
00:34:04,210 --> 00:34:02,960
center of this galaxy and so if gas it

816
00:34:07,299 --> 00:34:04,220
can get to the center of this galaxy

817
00:34:08,830 --> 00:34:07,309
it'll be accreted or on to this the

818
00:34:11,230 --> 00:34:08,840
central region near the black hole and

819
00:34:13,330 --> 00:34:11,240
this causes the gas to be heated to

820
00:34:14,950 --> 00:34:13,340
extreme temperatures and that heating

821
00:34:17,440 --> 00:34:14,960
can do one of two things

822
00:34:21,099 --> 00:34:17,450
either fall onto the black hole and be

823
00:34:23,589 --> 00:34:21,109
and be absorbed and create mass or it

824
00:34:25,300 --> 00:34:23,599
can be ejected so the the actual gas

825
00:34:26,859 --> 00:34:25,310
dynamics of this this process is

826
00:34:28,599 --> 00:34:26,869
extremely complicated but what can

827
00:34:30,099 --> 00:34:28,609
happen is the gas goes in and then gets

828
00:34:34,240 --> 00:34:30,109
flung out at extremely high velocities

829
00:34:35,950 --> 00:34:34,250
and extremely high rates and so the gas

830
00:34:37,540 --> 00:34:35,960
can come out of galaxies and then just

831
00:34:42,430 --> 00:34:37,550
not be available to form stars for some

832
00:34:45,940 --> 00:34:42,440
period of time and as I mentioned before

833
00:34:48,579 --> 00:34:45,950
galaxies can interact so this is Hubble

834
00:34:49,720 --> 00:34:48,589
images of different merging galaxies at

835
00:34:51,639 --> 00:34:49,730
different stages of the merging process

836
00:34:53,619 --> 00:34:51,649
just to show some beautiful examples of

837
00:34:55,480 --> 00:34:53,629
galaxy mergers and to show that this

838
00:34:57,700 --> 00:34:55,490

really does happen in the real universe

839
00:34:58,839 --> 00:34:57,710
and so here are two galaxies that may be

840
00:35:01,390 --> 00:34:58,849
like the Milky Way approaching each

841
00:35:03,700 --> 00:35:01,400
other they get closer and they sort of

842
00:35:06,579 --> 00:35:03,710
tear each other apart as they come to

843
00:35:09,940 --> 00:35:06,589
final coalescence and this can rearrange

844
00:35:12,280 --> 00:35:09,950
the gas in such a way that that it forms

845
00:35:14,109 --> 00:35:12,290
stars in new places so it can form this

846
00:35:16,060 --> 00:35:14,119
very red bulge in the center a very

847
00:35:17,530 --> 00:35:16,070
large bulge or massive bulge and it can

848
00:35:19,089 --> 00:35:17,540
drive gas to the center to the black

849
00:35:25,150 --> 00:35:19,099
hole and cause more of this gas

850
00:35:26,680 --> 00:35:25,160
expulsion in the process so those are

851
00:35:28,839 --> 00:35:26,690
the issues that galaxies have and now

852
00:35:30,550 --> 00:35:28,849
this is that is the primary motivation

853
00:35:32,890 --> 00:35:30,560
for why we turn to computers to do this

854
00:35:35,680 --> 00:35:32,900
for us so if we tried to model all of

855
00:35:37,660 --> 00:35:35,690
this by hands we would be out of luck we

856
00:35:39,339 --> 00:35:37,670
just cannot possibly ever do it so we

857
00:35:43,530 --> 00:35:39,349
use computers to do the dirty work for

858
00:35:48,370 --> 00:35:43,540
us and the way we set this up is is

859
00:35:50,829 --> 00:35:48,380
fairly fairly nice and fairly simple the

860
00:35:52,089 --> 00:35:50,839
idea is just to start with the initial

861
00:35:54,790 --> 00:35:52,099
conditions as we know them in the

862
00:35:56,890 --> 00:35:54,800
universe and so on the left here is a

863
00:35:59,050 --> 00:35:56,900

map of the sky made by the Planck

864
00:36:01,089 --> 00:35:59,060
satellite and so I'm not going to talk

865
00:36:02,440 --> 00:36:01,099
too much detail about this but if you

866
00:36:04,480 --> 00:36:02,450
want to hear more come to Mark

867
00:36:06,250 --> 00:36:04,490
kamionkowski stalk next month he'll talk

868
00:36:08,290 --> 00:36:06,260
I think about this issue in great detail

869
00:36:09,670 --> 00:36:08,300
but we take the results of that which is

870
00:36:12,130 --> 00:36:09,680
essentially a map of the matter

871
00:36:14,349 --> 00:36:12,140
fluctuations as they were right after

872
00:36:16,420 --> 00:36:14,359
the Big Bang we take a map like that and

873
00:36:18,099 --> 00:36:16,430
then seed that as at the beginning of

874
00:36:20,109 --> 00:36:18,109
our simulation so we start with a met

875
00:36:21,250 --> 00:36:20,119
with matter fluctuations and then in

876
00:36:23,920 --> 00:36:21,260
this example that I'm about to show you

877
00:36:26,290 --> 00:36:23,930
let gravity evolve under its own under

878
00:36:27,460 --> 00:36:26,300
its own power we look the equations

879
00:36:28,990 --> 00:36:27,470
evolve as they should see fit

880
00:36:30,490 --> 00:36:29,000
and so we take some

881
00:36:33,610 --> 00:36:30,500
initial initialization of the universe

882
00:36:36,340 --> 00:36:33,620
as as measured from the Planck satellite

883
00:36:38,380 --> 00:36:36,350
and then just let the matter collapse on

884
00:36:41,290 --> 00:36:38,390
itself and form galaxies and so this is

885
00:36:42,910 --> 00:36:41,300
a dark matter only simulation rotating

886
00:36:44,650 --> 00:36:42,920
around a volume of galaxies where each

887
00:36:46,720 --> 00:36:44,660
of these each of these points that

888
00:36:49,990 --> 00:36:46,730

appear at the center will be a galaxy

889
00:36:51,340 --> 00:36:50,000
like the Milky Way and so from the very

890
00:36:53,680 --> 00:36:51,350
beginning of the universe the universe

891
00:36:55,630 --> 00:36:53,690
is very smooth but these tiny

892
00:36:57,400 --> 00:36:55,640
fluctuations in the matter density then

893
00:36:59,590 --> 00:36:57,410
grow under the influence of gravity to

894
00:37:06,280 --> 00:36:59,600
form the backbone or the cosmic web of

895
00:37:08,170 --> 00:37:06,290
galaxies that we see today so that's a

896
00:37:11,860 --> 00:37:08,180
fairly straightforward experiment so we

897
00:37:13,540 --> 00:37:11,870
can this is not sort of done by hands

898
00:37:16,180 --> 00:37:13,550
the way we used to have to do this so we

899
00:37:18,520 --> 00:37:16,190
used to have to to create galaxies in

900
00:37:20,890 --> 00:37:18,530
the computer by hand and then smash them

901
00:37:22,750 --> 00:37:20,900
together in some some arbitrary way but

902
00:37:26,320 --> 00:37:22,760
this is now a sort of it's almost a

903
00:37:28,420 --> 00:37:26,330
prediction of the universe model that we

904
00:37:30,070 --> 00:37:28,430
have and so it's we can then very easily

905
00:37:37,150 --> 00:37:30,080
test the effects of these different

906
00:37:39,160 --> 00:37:37,160
issues on galaxies of course I just

907
00:37:40,960 --> 00:37:39,170
spent a really long time telling you

908
00:37:42,970 --> 00:37:40,970
about the issues and galaxies and so

909
00:37:44,440 --> 00:37:42,980
that was ignoring all of those things so

910
00:37:47,290 --> 00:37:44,450
ignoring the gas physics of ignoring

911
00:37:49,030 --> 00:37:47,300
star formation and the the the problem

912
00:37:51,940 --> 00:37:49,040
computationally boils down to this fact

913
00:37:54,280 --> 00:37:51,950

is that stars are extremely small

914
00:37:56,500 --> 00:37:54,290
compared to galaxies and so stars form

915
00:38:00,940 --> 00:37:56,510
in very very tiny regions of space tiny

916
00:38:02,790 --> 00:38:00,950
parts of galaxies and that that simple

917
00:38:04,960 --> 00:38:02,800
fact main means that in order to

918
00:38:06,790 --> 00:38:04,970
correctly form stars in a simulation

919
00:38:08,560 --> 00:38:06,800
like this one you have to also model

920
00:38:10,720 --> 00:38:08,570
very tiny regions of galaxies and not

921
00:38:13,270 --> 00:38:10,730
just their their large structure and so

922
00:38:15,880 --> 00:38:13,280
here's a an HST image of a dark cloud

923
00:38:18,760 --> 00:38:15,890
and a newly formed star which is

924
00:38:20,770 --> 00:38:18,770
probably acting on it via by its energy

925
00:38:22,450 --> 00:38:20,780
so the Stars feedback energy into the

926
00:38:25,000 --> 00:38:22,460
into the I mean it's pushing on this

927
00:38:27,070 --> 00:38:25,010
cloud here and the dynamics of that that

928
00:38:28,390 --> 00:38:27,080
resulting interaction has to be modeled

929
00:38:30,040 --> 00:38:28,400
if you want to actually get the

930
00:38:32,350 --> 00:38:30,050
prediction for the locations of the

931
00:38:34,600 --> 00:38:32,360
stars in galaxies and so this life cycle

932
00:38:37,480 --> 00:38:34,610
has to be taken into account at each

933
00:38:38,680 --> 00:38:37,490
point in the galaxy and galaxies are at

934
00:38:42,040 --> 00:38:38,690
least a hundred thousand times bigger

935
00:38:45,070 --> 00:38:42,050
than that region so okay

936
00:38:46,450 --> 00:38:45,080
so say we have as much computer time as

937
00:38:49,600 --> 00:38:46,460
we wanted as many computers as we could

938
00:38:51,160 --> 00:38:49,610

possibly have access to what would we

939
00:38:52,810 --> 00:38:51,170
need in order to do this problem right

940
00:38:54,520 --> 00:38:52,820
in order to model the formation of

941
00:38:56,620 --> 00:38:54,530
virtually every star in a galaxy

942
00:38:59,440 --> 00:38:56,630
throughout its history during the during

943
00:39:01,560 --> 00:38:59,450
in the past 14 billion years so this is

944
00:39:03,880 --> 00:39:01,570
the in ideal world what you would want

945
00:39:07,240 --> 00:39:03,890
you'd want something like ten thousand

946
00:39:09,070 --> 00:39:07,250
galaxies and that's just kind of just a

947
00:39:10,630 --> 00:39:09,080
nice round number to give you the

948
00:39:12,010 --> 00:39:10,640
diversity of galaxies that we see in the

949
00:39:13,210 --> 00:39:12,020
Hubble ultra-deep field it's roughly the

950
00:39:15,550 --> 00:39:13,220
number of galaxies in the Hubble

951
00:39:17,170 --> 00:39:15,560
ultra-deep field and then if you want to

952
00:39:19,030 --> 00:39:17,180
divide each of those galaxies up into

953
00:39:20,650 --> 00:39:19,040
regions of star formation that are

954
00:39:22,330 --> 00:39:20,660
realistic in a sense that I just talked

955
00:39:24,670 --> 00:39:22,340
about you need about a million elements

956
00:39:26,200 --> 00:39:24,680
per galaxy size so if you imagine the

957
00:39:28,450 --> 00:39:26,210
galaxy is a cube which is a very

958
00:39:29,770 --> 00:39:28,460
simplistic approximation to a galaxy you

959
00:39:34,030 --> 00:39:29,780
need about a million elements of

960
00:39:36,640 --> 00:39:34,040
star-forming gas per side and so to fill

961
00:39:38,530 --> 00:39:36,650
a galaxy's volume entirely you need a

962
00:39:40,360 --> 00:39:38,540
million cubed of these elements per

963
00:39:44,320 --> 00:39:40,370

galaxy so that's starting to get to a

964
00:39:46,540 --> 00:39:44,330
big number and so that's about four for

965
00:39:50,230 --> 00:39:46,550
all 10,000 galaxies you need one

966
00:39:52,410 --> 00:39:50,240
followed by 22 zeroes of elements of gas

967
00:39:55,210 --> 00:39:52,420
dynamics to solve in your computer

968
00:39:56,800 --> 00:39:55,220
that's to do it at a single time to

969
00:39:58,960 --> 00:39:56,810
follow the evolution and formation of

970
00:40:00,520 --> 00:39:58,970
those stars in those galaxies you need

971
00:40:02,800 --> 00:40:00,530
to do this at each of about a hundred

972
00:40:04,810 --> 00:40:02,810
thousand times and so that now we're

973
00:40:07,090 --> 00:40:04,820
starting to get into thirdly large

974
00:40:08,680 --> 00:40:07,100
numbers and that even though that even

975
00:40:10,480 --> 00:40:08,690
though each of these calculations of the

976
00:40:13,090 --> 00:40:10,490
effect of star formation in each in each

977
00:40:15,370 --> 00:40:13,100
cell takes a fraction of a second you

978
00:40:17,350 --> 00:40:15,380
still need something like one and 23

979
00:40:19,570 --> 00:40:17,360
zeros of computer hours in order to

980
00:40:22,090 --> 00:40:19,580
compute the evolution of galaxies from

981
00:40:24,430 --> 00:40:22,100
the beginning of the universe and just

982
00:40:27,910 --> 00:40:24,440
to put that that number in context 10 to

983
00:40:29,770 --> 00:40:27,920
the 23 computer hours on my laptop here

984
00:40:32,050 --> 00:40:29,780
that would take about 10 billion times

985
00:40:35,650 --> 00:40:32,060
the current age of the universe to run a

986
00:40:38,350 --> 00:40:35,660
simulation like this so 14 billion years

987
00:40:41,710 --> 00:40:38,360
times 10 billion to run it on my laptop

988
00:40:44,770 --> 00:40:41,720

here on the world's best supercomputers

989
00:40:47,470 --> 00:40:44,780
it's about 1 billion times the current

990
00:40:49,660 --> 00:40:47,480
age of the universe sorry I got that

991
00:40:52,090 --> 00:40:49,670
wrong it's about it's about once times

992
00:40:53,260 --> 00:40:52,100
the current age it's about 10,000 times

993
00:40:54,850 --> 00:40:53,270
the current age of the universe sorry

994
00:40:55,720 --> 00:40:54,860
about that so about 10,000 times the

995
00:40:57,790 --> 00:40:55,730
current age of the universe

996
00:41:00,120 --> 00:40:57,800
on the world's biggest supercomputers

997
00:41:02,859 --> 00:41:00,130
that exists in say in a single room and

998
00:41:04,300 --> 00:41:02,869
it's roughly a billion years still on

999
00:41:06,099 --> 00:41:04,310
every computer that's connected to the

1000
00:41:08,740 --> 00:41:06,109
Internet today so there's something like

1001
00:41:09,970 --> 00:41:08,750
100 billion or 20 billion devices

1002
00:41:11,410 --> 00:41:09,980
connected to the Internet if we could

1003
00:41:13,510 --> 00:41:11,420
run our simulation on that it would only

1004
00:41:15,520 --> 00:41:13,520
take a billion years to run this ideal

1005
00:41:16,900 --> 00:41:15,530
simulation but still longer than I'm

1006
00:41:22,540 --> 00:41:16,910
willing to wait for for our

1007
00:41:38,950 --> 00:41:22,550
understanding of galaxies and so how do

1008
00:41:42,280 --> 00:41:38,960
we get around this in our lifetimes and

1009
00:41:43,780 --> 00:41:42,290
the answer is we cheat so we we make we

1010
00:41:46,900 --> 00:41:43,790
make simplifications and approximations

1011
00:41:48,820 --> 00:41:46,910
to our equations that allow us to get

1012
00:41:50,710 --> 00:41:48,830
the gist of galaxies without actually

1013
00:41:52,240 --> 00:41:50,720

modeling all the stars and so the

1014
00:41:54,790 --> 00:41:52,250
solution is to make approximations so

1015
00:41:56,530 --> 00:41:54,800
the first major approximation is to

1016
00:41:58,540 --> 00:41:56,540
focus effort only on the most important

1017
00:42:01,000 --> 00:41:58,550
regions and galaxies so we're not going

1018
00:42:03,700 --> 00:42:01,010
to focus our effort on the the regions

1019
00:42:05,230 --> 00:42:03,710
that are maybe very low density or have

1020
00:42:06,400 --> 00:42:05,240
very few stars in them we're not gonna

1021
00:42:08,290 --> 00:42:06,410
we're not gonna spend as much time on

1022
00:42:10,840 --> 00:42:08,300
those and just approximate the solutions

1023
00:42:13,000 --> 00:42:10,850
in those cases and the second one that

1024
00:42:14,950 --> 00:42:13,010
is arguably the most important is to

1025
00:42:15,820 --> 00:42:14,960
create toy models of star formation so

1026
00:42:17,950 --> 00:42:15,830
that we don't have to model the

1027
00:42:21,130 --> 00:42:17,960
formation of every star but we model the

1028
00:42:23,140 --> 00:42:21,140
formation of stars on galaxy scales so

1029
00:42:25,270 --> 00:42:23,150
we can then so we have these scaling

1030
00:42:27,310 --> 00:42:25,280
relations that allow us to connect the

1031
00:42:28,960 --> 00:42:27,320
formation of stars with the amount of

1032
00:42:31,450 --> 00:42:28,970
gas that exists in a particular region

1033
00:42:33,790 --> 00:42:31,460
in space and so we can then chop off our

1034
00:42:36,070 --> 00:42:33,800
scales in our in our problem and only

1035
00:42:39,130 --> 00:42:36,080
and only model scales above a certain

1036
00:42:40,990 --> 00:42:39,140
size and so here's our galaxy with

1037
00:42:43,900 --> 00:42:41,000
issues on the left and on the right is

1038
00:42:46,690 --> 00:42:43,910

how you might divide this space it in

1039
00:42:48,690 --> 00:42:46,700
order to make this first point so focus

1040
00:42:51,400 --> 00:42:48,700
only on the most important regions and

1041
00:42:58,180 --> 00:42:51,410
so I'm going to zoom in and overlay that

1042
00:43:00,340 --> 00:42:58,190
on top here and so in our in our

1043
00:43:04,210 --> 00:43:00,350
calculations what we like to do is to

1044
00:43:05,980 --> 00:43:04,220
spend less time on a particular volume

1045
00:43:08,080 --> 00:43:05,990
element over here on the left or these

1046
00:43:09,410 --> 00:43:08,090
these wide ones over here and spend a

1047
00:43:11,359 --> 00:43:09,420
lot of effort in the center of gal

1048
00:43:13,010 --> 00:43:11,369
where the real action is happening where

1049
00:43:14,990 --> 00:43:13,020
there might be more star formation there

1050
00:43:16,190 --> 00:43:15,000
are more supernovae there the black hole

1051
00:43:17,539 --> 00:43:16,200
is in the center so that's a really

1052
00:43:19,339 --> 00:43:17,549
important thing to model correctly and

1053
00:43:20,870 --> 00:43:19,349
so then we spend a little bit less time

1054
00:43:22,640 --> 00:43:20,880
or a little bit less effort on the outer

1055
00:43:24,829 --> 00:43:22,650
regions and so we'll just let these

1056
00:43:26,390 --> 00:43:24,839
outer regions evolve according to say a

1057
00:43:28,849 --> 00:43:26,400
very simplistic form of star formation

1058
00:43:32,059 --> 00:43:28,859
and gravity itself so we just let these

1059
00:43:36,789 --> 00:43:32,069
things evolve and then actually do some

1060
00:43:44,569 --> 00:43:40,880
this pattern is a certain tessellation

1061
00:43:45,920 --> 00:43:44,579
of the space so it's not ideally matched

1062
00:43:47,480 --> 00:43:45,930
to this galaxy it's just a sort of a

1063
00:43:50,329 --> 00:43:47,490

circular thing that I put down to

1064
00:43:52,250 --> 00:43:50,339
visualize it but the idea is then is to

1065
00:43:55,579 --> 00:43:52,260
break up break it up into things of the

1066
00:43:56,780 --> 00:43:55,589
same mass so a single cell in the center

1067
00:43:59,210 --> 00:43:56,790
of this galaxy will have the same mass

1068
00:44:00,559 --> 00:43:59,220
as one of these cells out here and so

1069
00:44:05,950 --> 00:44:00,569
that makes it a little bit more

1070
00:44:08,660 --> 00:44:05,960
computationally tractable to perform and

1071
00:44:10,250 --> 00:44:08,670
then the models of star formation is we

1072
00:44:13,010 --> 00:44:10,260
take one of these these regions that

1073
00:44:14,780 --> 00:44:13,020
we've defined and write down very simple

1074
00:44:16,370 --> 00:44:14,790
equations for the Galactic life cycle so

1075
00:44:18,530 --> 00:44:16,380
instead of modeling one of those

1076
00:44:20,960 --> 00:44:18,540
individual dark gas clouds that I showed

1077
00:44:23,450 --> 00:44:20,970
you before we smear that out over the

1078
00:44:27,770 --> 00:44:23,460
entire region so this is maybe a tenth

1079
00:44:29,569 --> 00:44:27,780
of a galaxy on a side here kiloparsec or

1080
00:44:32,720 --> 00:44:29,579
so in size for those for those who know

1081
00:44:34,130 --> 00:44:32,730
that scale and that then we take the

1082
00:44:36,440 --> 00:44:34,140
amount of gas that happens to fall in

1083
00:44:37,849 --> 00:44:36,450
that region and then just multiply by a

1084
00:44:39,890 --> 00:44:37,859
sum factor and that tells us how many

1085
00:44:41,780 --> 00:44:39,900
stars we get in the end and then we have

1086
00:44:43,430 --> 00:44:41,790
some other equation that tells us how

1087
00:44:45,319 --> 00:44:43,440
the supernovae affect the regions

1088
00:44:48,380 --> 00:44:45,329

surrounding that that particular cell

1089
00:44:50,870 --> 00:44:48,390
and so it's not you know we have no idea

1090
00:44:53,089 --> 00:44:50,880
about the light coming from the stars as

1091
00:44:55,099 --> 00:44:53,099
you can see the galaxy here you can see

1092
00:44:57,200 --> 00:44:55,109
that the distribution of stars within a

1093
00:44:58,910 --> 00:44:57,210
cell we ignore all that in our

1094
00:45:01,130 --> 00:44:58,920
calculations we only have information

1095
00:45:02,599 --> 00:45:01,140
about this say the cell averaged star

1096
00:45:04,640 --> 00:45:02,609
formation rate so we can only see sort

1097
00:45:06,859 --> 00:45:04,650
of like a faint blue fuzz in each of

1098
00:45:09,500 --> 00:45:06,869
these these regions so that's the

1099
00:45:11,120 --> 00:45:09,510
approximation we make in order to handle

1100
00:45:13,220 --> 00:45:11,130
the ability of star formation on scales

1101
00:45:14,930 --> 00:45:13,230
like this one and so we won't get a

1102
00:45:18,410 --> 00:45:14,940
galaxy that looks like this one what's

1103
00:45:19,970 --> 00:45:18,420
pixelated on mega mega pixels but we can

1104
00:45:21,980 --> 00:45:19,980
get a couple tens of thousands of pixels

1105
00:45:25,130 --> 00:45:21,990
of galaxies that

1106
00:45:27,380 --> 00:45:25,140
look realistic and in practice this

1107
00:45:28,820 --> 00:45:27,390
process of creating models toy models

1108
00:45:31,400 --> 00:45:28,830
for star formation and black holes is

1109
00:45:33,859 --> 00:45:31,410
done just by trial and error so we have

1110
00:45:35,690 --> 00:45:33,869
no better way of going in and modeling

1111
00:45:37,580 --> 00:45:35,700
this process other than to say come up

1112
00:45:39,260 --> 00:45:37,590
with some educated guesses see how the

1113
00:45:43,040 --> 00:45:39,270

galaxies look in the end and then repeat

1114
00:45:44,510 --> 00:45:43,050
so this is a kind of a unsatisfying way

1115
00:45:47,240 --> 00:45:44,520
to do it but it's currently the best way

1116
00:45:52,940 --> 00:45:47,250
that we have of getting a galaxy and

1117
00:45:54,500 --> 00:45:52,950
simulation so our approximations are

1118
00:45:56,390 --> 00:45:54,510
wonderful and they help us get this

1119
00:45:58,250 --> 00:45:56,400
problem to be tractable but we still

1120
00:46:00,230 --> 00:45:58,260
need to appeal to supercomputers in

1121
00:46:02,720 --> 00:46:00,240
order to solve the resulting problem and

1122
00:46:04,760 --> 00:46:02,730
so this is the IBM Blue Gene computer

1123
00:46:06,050 --> 00:46:04,770
with a person there for scale to give

1124
00:46:07,730 --> 00:46:06,060
you an idea of how big these computers

1125
00:46:10,490 --> 00:46:07,740
are so do we appeal to supercomputers

1126
00:46:12,200 --> 00:46:10,500
then to solve the remaining calculations

1127
00:46:14,540 --> 00:46:12,210
and so even though we've made these

1128
00:46:16,460 --> 00:46:14,550
really really great assumptions that

1129
00:46:19,310 --> 00:46:16,470
help us to solve the equations in a

1130
00:46:21,080 --> 00:46:19,320
finite number of universe times which is

1131
00:46:22,670 --> 00:46:21,090
great we still need something like ten

1132
00:46:26,150 --> 00:46:22,680
thousand or a hundred thousand computers

1133
00:46:27,770 --> 00:46:26,160
to do the work for us and a

1134
00:46:29,480 --> 00:46:27,780
supercomputer is really nothing more

1135
00:46:32,060 --> 00:46:29,490
than a whole bunch of regular computers

1136
00:46:33,460 --> 00:46:32,070
strung together in a fancy way so this

1137
00:46:36,590 --> 00:46:33,470
is the computer that I showed before

1138
00:46:38,840 --> 00:46:36,600

each of these racks as we might call

1139
00:46:42,680 --> 00:46:38,850
them would look like this perhaps and so

1140
00:46:44,960 --> 00:46:42,690
each of these slices in the rack is one

1141
00:46:48,590 --> 00:46:44,970
computer so we use it as we would a

1142
00:46:49,580 --> 00:46:48,600
normal computer and then so I just have

1143
00:46:51,349 --> 00:46:49,590
this down here on the bottom this is a

1144
00:46:53,840 --> 00:46:51,359
gateway computer I had one of these in

1145
00:46:55,220 --> 00:46:53,850
like the late 1990s or something so

1146
00:46:57,620 --> 00:46:55,230
that's essentially what we're putting in

1147
00:47:00,380 --> 00:46:57,630
here just new and updated version and

1148
00:47:02,660 --> 00:47:00,390
compactified version into into the racks

1149
00:47:04,940 --> 00:47:02,670
of supercomputers and so it's really not

1150
00:47:06,320 --> 00:47:04,950
it's all of the same functionality maybe

1151
00:47:08,300 --> 00:47:06,330
a little bit less functionality than

1152
00:47:09,980 --> 00:47:08,310
then a computer like this one but the

1153
00:47:11,420 --> 00:47:09,990
same kind of processor would go into

1154
00:47:14,060 --> 00:47:11,430
this this super computer and then

1155
00:47:16,760 --> 00:47:14,070
coupled together to form our super

1156
00:47:20,270 --> 00:47:16,770
computers and on the left here I have

1157
00:47:22,070 --> 00:47:20,280
just a kind of a toy model of how the

1158
00:47:23,180 --> 00:47:22,080
computers communicate with each other so

1159
00:47:27,200 --> 00:47:23,190
I wanted to put this in here just to

1160
00:47:29,900 --> 00:47:27,210
show that really these are computers are

1161
00:47:32,630 --> 00:47:29,910
all acting as one so if you imagine that

1162
00:47:35,900 --> 00:47:32,640
each of these sort of clusters of

1163
00:47:38,540 --> 00:47:35,910

computers say 12 computers or so is laid

1164
00:47:41,120 --> 00:47:38,550
a a cluster B cluster C cluster and so

1165
00:47:43,580 --> 00:47:41,130
on up the rack those are connected by

1166
00:47:45,410 --> 00:47:43,590
really high bandwidth fiber in between

1167
00:47:46,820 --> 00:47:45,420
them and so this is the the a cluster of

1168
00:47:49,160 --> 00:47:46,830
computers here the B cluster the C

1169
00:47:51,290 --> 00:47:49,170
cluster and so on and so the entire

1170
00:47:53,180 --> 00:47:51,300
supercomputer which might be tens of

1171
00:47:54,740 --> 00:47:53,190
thousands of these these these systems

1172
00:47:57,290 --> 00:47:54,750
are connected with extremely high

1173
00:47:59,750 --> 00:47:57,300
bandwidth links so that in order to get

1174
00:48:01,580 --> 00:47:59,760
the galaxies on one side to communicate

1175
00:48:02,840 --> 00:48:01,590
with the galaxies on the other side that

1176
00:48:06,710 --> 00:48:02,850
can transmit the information extremely

1177
00:48:08,510 --> 00:48:06,720
quickly so it rates that that are much

1178
00:48:10,580 --> 00:48:08,520
faster than you can do over the internet

1179
00:48:12,380 --> 00:48:10,590
for example so factors of a hundred or a

1180
00:48:15,850 --> 00:48:12,390
thousand times faster than than internet

1181
00:48:22,580 --> 00:48:19,730
and so in practice to actually compute a

1182
00:48:25,190 --> 00:48:22,590
virtual universe like like like we want

1183
00:48:28,600 --> 00:48:25,200
to do I just want to show you how that

1184
00:48:30,380 --> 00:48:28,610
breaks down in practice the this is a

1185
00:48:32,900 --> 00:48:30,390
visualization of the illustrious

1186
00:48:34,400 --> 00:48:32,910
simulation and to give you an idea of

1187
00:48:36,800 --> 00:48:34,410
where our galaxies fall that we're

1188
00:48:39,590 --> 00:48:36,810

trying to model here's one down here

1189
00:48:40,940 --> 00:48:39,600
this is not in galaxy light we're

1190
00:48:42,770 --> 00:48:40,950
looking at but this is what it where it

1191
00:48:44,720 --> 00:48:42,780
might fit in terms of sizes so you can

1192
00:48:46,340 --> 00:48:44,730
see that we might have hundreds of

1193
00:48:49,040 --> 00:48:46,350
thousands of galaxies in this particular

1194
00:48:51,080 --> 00:48:49,050
image the blue purplish light that you

1195
00:48:53,750 --> 00:48:51,090
see in this image is dark matter so it's

1196
00:48:56,510 --> 00:48:53,760
the cosmic web the matter structure of

1197
00:48:58,310 --> 00:48:56,520
the universe here and the red or

1198
00:49:00,020 --> 00:48:58,320
yellowish tints of the image is

1199
00:49:02,270 --> 00:49:00,030
something to do with gas dynamics so

1200
00:49:05,360 --> 00:49:02,280
this is the gas velocity field and so

1201
00:49:06,770 --> 00:49:05,370
this is a way of visual getting a visual

1202
00:49:08,960 --> 00:49:06,780
impression of all of these these

1203
00:49:10,940 --> 00:49:08,970
processes acting on galaxies and so you

1204
00:49:12,950 --> 00:49:10,950
have the the cosmic web of dark matter

1205
00:49:15,350 --> 00:49:12,960
forming galaxies at the intersections

1206
00:49:17,570 --> 00:49:15,360
and then you have this gas being pushed

1207
00:49:19,340 --> 00:49:17,580
around by black holes in supernovae so

1208
00:49:21,080 --> 00:49:19,350
you can see that on the scale of a

1209
00:49:23,090 --> 00:49:21,090
galaxy which is this tiny thing here a

1210
00:49:25,520 --> 00:49:23,100
few laser pointer with the cross or less

1211
00:49:28,190 --> 00:49:25,530
probably less that there's this really

1212
00:49:30,530 --> 00:49:28,200
large spherical region of gas that's

1213
00:49:33,770 --> 00:49:30,540

been pushed out of another galaxy and so

1214
00:49:35,720 --> 00:49:33,780
this size region here is several or tens

1215
00:49:38,810 --> 00:49:35,730
of times bigger than that galaxy itself

1216
00:49:40,880 --> 00:49:38,820
so in order to actually compute what

1217
00:49:42,590 --> 00:49:40,890
happens to this galaxy over time we have

1218
00:49:44,690 --> 00:49:42,600
to know what happens at all these other

1219
00:49:46,220 --> 00:49:44,700
regions of space so we can't just break

1220
00:49:47,960 --> 00:49:46,230
these apart and never communicate with

1221
00:49:49,520 --> 00:49:47,970
each other again we have to actually

1222
00:49:51,710 --> 00:49:49,530
have the ability to go back and

1223
00:49:53,300 --> 00:49:51,720
say oh there's gas being pushed onto

1224
00:49:54,890 --> 00:49:53,310
this region of space by these other

1225
00:49:56,930 --> 00:49:54,900
galaxies and that's why we need this

1226
00:50:00,440 --> 00:49:56,940
these sort of high bandwidth links among

1227
00:50:01,760 --> 00:50:00,450
the supercomputer nodes and this is now

1228
00:50:04,370 --> 00:50:01,770
the same grid that I showed you before

1229
00:50:06,710 --> 00:50:04,380
but now divide it up as you might assign

1230
00:50:09,110 --> 00:50:06,720
it to different computers so if you have

1231
00:50:11,330 --> 00:50:09,120
a supercomputer like IBM Blue Gene or

1232
00:50:14,240 --> 00:50:11,340
others you might break up the volume

1233
00:50:16,100 --> 00:50:14,250
like this and then assign to the a

1234
00:50:17,720 --> 00:50:16,110
cluster of computers this one the B

1235
00:50:21,050 --> 00:50:17,730
cluster this one and the C cluster this

1236
00:50:23,240 --> 00:50:21,060
one so assign them all the galaxies and

1237
00:50:25,520 --> 00:50:23,250
and and actually the matter processes

1238
00:50:27,680 --> 00:50:25,530

that that happen in that region let that

1239
00:50:30,080 --> 00:50:27,690
computer work on it for a while same

1240
00:50:32,960 --> 00:50:30,090
with BCD and so on for a couple thousand

1241
00:50:35,600 --> 00:50:32,970
computers and then after each each

1242
00:50:37,760 --> 00:50:35,610
iteration of the equations you ask ok

1243
00:50:39,980 --> 00:50:37,770
does a need to communicate with B and C

1244
00:50:43,220 --> 00:50:39,990
and so on and then transfer the data

1245
00:50:44,780 --> 00:50:43,230
across those those high bandwidth links

1246
00:50:47,060 --> 00:50:44,790
that I showed before in order to get

1247
00:50:52,190 --> 00:50:47,070
that information that they need at all

1248
00:50:55,640 --> 00:50:52,200
the different regions so that's kind of

1249
00:50:57,620 --> 00:50:55,650
a heuristic view of what we do to model

1250
00:50:59,270 --> 00:50:57,630
a virtual universe I'm gonna spend the

1251
00:51:00,800 --> 00:50:59,280
rest of the talk just introducing the

1252
00:51:04,510 --> 00:51:00,810
illustrious project and what we were

1253
00:51:07,670 --> 00:51:04,520
able to accomplish using these methods

1254
00:51:09,380 --> 00:51:07,680
so the the goal as I've talked about a

1255
00:51:12,140 --> 00:51:09,390
few times is to simulate the formation

1256
00:51:15,560 --> 00:51:12,150
of galaxies specifically the the sort of

1257
00:51:17,630 --> 00:51:15,570
main idea of this was to form things

1258
00:51:19,430 --> 00:51:17,640
form about ten thousand galaxies that

1259
00:51:21,200 --> 00:51:19,440
have roughly the same mass as the Milky

1260
00:51:22,760 --> 00:51:21,210
Way galaxy so we live in the Milky Way

1261
00:51:24,320 --> 00:51:22,770
we wanted to form something like ten

1262
00:51:28,520 --> 00:51:24,330
thousand times that that particular

1263
00:51:29,930 --> 00:51:28,530

galaxy size or mass this is one of the

1264
00:51:31,940 --> 00:51:29,940
supercomputers that it was run on this

1265
00:51:34,400 --> 00:51:31,950
is the super MOOC computer in Garching

1266
00:51:37,520 --> 00:51:34,410
Germany it was run on another very

1267
00:51:39,680 --> 00:51:37,530
similar one in France for uptime and so

1268
00:51:43,490 --> 00:51:39,690
here the hallways of racks upon racks of

1269
00:51:44,990 --> 00:51:43,500
supercomputers here and here's the kind

1270
00:51:46,760 --> 00:51:45,000
of vital statistics of the illustris

1271
00:51:48,350 --> 00:51:46,770
project and I couldn't think of a much

1272
00:51:49,280 --> 00:51:48,360
better way to present this I'll just

1273
00:51:52,610 --> 00:51:49,290
I'll just give you the numbers

1274
00:51:55,550 --> 00:51:52,620
I took roughly 20 million computer hours

1275
00:51:57,710 --> 00:51:55,560
of total computation to compute the

1276
00:51:59,600 --> 00:51:57,720
10000 Milky Way's and their formation so

1277
00:52:03,230 --> 00:51:59,610
it take my laptop about 20 million hours

1278
00:52:05,000 --> 00:52:03,240
to compute this that ended up

1279
00:52:06,050 --> 00:52:05,010
taking about six months on 8,000

1280
00:52:07,670 --> 00:52:06,060
computers that are connected together

1281
00:52:10,820 --> 00:52:07,680
and it was completed about a year ago in

1282
00:52:12,890 --> 00:52:10,830
November 2013 they're about 20 billion

1283
00:52:15,260 --> 00:52:12,900
elements that it ended up being so 20

1284
00:52:17,720 --> 00:52:15,270
billion bits of galaxies that were that

1285
00:52:19,850 --> 00:52:17,730
were remodeled and that volume

1286
00:52:21,380 --> 00:52:19,860
corresponds to about a million times the

1287
00:52:23,120 --> 00:52:21,390
space between the Milky Way and the

1288
00:52:26,930 --> 00:52:23,130

Andromeda galaxy which is our nearest

1289
00:52:28,730 --> 00:52:26,940
massive galaxy neighbour and the output

1290
00:52:31,160 --> 00:52:28,740
of the simulation was stored 150 times

1291
00:52:33,740 --> 00:52:31,170
so at different cosmic times we have the

1292
00:52:36,170 --> 00:52:33,750
history of those galaxies stored 150

1293
00:52:37,970 --> 00:52:36,180
times and that amounts to something like

1294
00:52:39,890 --> 00:52:37,980
200 trillion bytes of data that are

1295
00:52:42,109 --> 00:52:39,900
stored on disk and I was a little bit

1296
00:52:43,820 --> 00:52:42,119
surprised that that's only 5000 iPhones

1297
00:52:46,340 --> 00:52:43,830
so if you if you deleted all your music

1298
00:52:47,660 --> 00:52:46,350
um your iPhones and put together 5000 of

1299
00:52:50,120 --> 00:52:47,670
them you could store the olestra

1300
00:52:51,200 --> 00:52:50,130
stimulation on all of them I don't know

1301
00:52:53,240 --> 00:52:51,210
how useful that would be probably not

1302
00:52:58,040 --> 00:52:53,250
very useful but just to give you an idea

1303
00:53:00,170 --> 00:52:58,050
of how much data there is so without

1304
00:53:02,300 --> 00:53:00,180
much further ado I just want to show you

1305
00:53:04,490 --> 00:53:02,310
some visualizations of the olestra

1306
00:53:05,570 --> 00:53:04,500
simulation so these were not being by me

1307
00:53:08,180 --> 00:53:05,580
but were made by others on the

1308
00:53:10,790 --> 00:53:08,190
collaboration and so this is now the

1309
00:53:13,370 --> 00:53:10,800
large scale of the olestra simulation so

1310
00:53:15,920 --> 00:53:13,380
each of these blue right blue nodes here

1311
00:53:16,910 --> 00:53:15,930
is where you might form a galaxy similar

1312
00:53:19,130 --> 00:53:16,920
to the simulation that I showed before

1313
00:53:21,109 --> 00:53:19,140

and this is not going to evolve in time

1314
00:53:22,550 --> 00:53:21,119
I'm just going to zoom in and then zoom

1315
00:53:24,080 --> 00:53:22,560
back out to give you an idea of the

1316
00:53:26,210 --> 00:53:24,090
different scales that are involved and

1317
00:53:27,590 --> 00:53:26,220
so you know our Milky Way galaxy might

1318
00:53:30,230 --> 00:53:27,600
reside here and we're going to zoom into

1319
00:53:32,359 --> 00:53:30,240
one example of a galaxy so this is

1320
00:53:33,440 --> 00:53:32,369
showing just the matter density and then

1321
00:53:34,820 --> 00:53:33,450
it's going to change the different

1322
00:53:37,400 --> 00:53:34,830
quantities here's and then it's going to

1323
00:53:38,660 --> 00:53:37,410
show gas temperature so this is the the

1324
00:53:40,310 --> 00:53:38,670
temperature of the gas that might be

1325
00:53:42,170 --> 00:53:40,320
heated by supernovae or black hole for

1326
00:53:45,050 --> 00:53:42,180
me black hole accretion and and energy

1327
00:53:48,710 --> 00:53:45,060
feedback and so each of these points is

1328
00:53:51,650 --> 00:53:48,720
a galaxy this is gas middle isset II so

1329
00:53:53,000 --> 00:53:51,660
this is the sort of heavier elements

1330
00:53:56,000 --> 00:53:53,010
than hydrogen and helium that form in

1331
00:53:57,470 --> 00:53:56,010
stars and then eventually we go back to

1332
00:54:00,230 --> 00:53:57,480
stellar light and so now we're zooming

1333
00:54:01,910 --> 00:54:00,240
in finally to a galaxy scale something

1334
00:54:04,430 --> 00:54:01,920
like that might look like the Milky Way

1335
00:54:06,770 --> 00:54:04,440
galaxy it's a little bit more coarsely

1336
00:54:08,570 --> 00:54:06,780
resolved then the nice HST images but

1337
00:54:10,550 --> 00:54:08,580
you can get an idea that this is a nice

1338
00:54:13,310 --> 00:54:10,560

disc galaxy that might evolve in the

1339
00:54:15,260 --> 00:54:13,320
same way as as the spiral galaxies that

1340
00:54:16,529 --> 00:54:15,270
we see in the local universe and we're

1341
00:54:18,209 --> 00:54:16,539
going to zoom back out to this

1342
00:54:20,609 --> 00:54:18,219
large scale again going through gas

1343
00:54:22,829 --> 00:54:20,619
density now showing all the companions

1344
00:54:24,929 --> 00:54:22,839
of the galaxy so the these companions

1345
00:54:26,880 --> 00:54:24,939
can interact as they evolve in time and

1346
00:54:33,630 --> 00:54:26,890
and have to have those issues that we

1347
00:54:35,579 --> 00:54:33,640
talked about with galaxy mergers and

1348
00:54:37,949 --> 00:54:35,589
then now getting to the the sort of full

1349
00:54:42,089 --> 00:54:37,959
scale of a lustrous at the very end

1350
00:54:50,309 --> 00:54:42,099
again in gas velocity and then finally

1351
00:54:52,949 --> 00:54:50,319
in dark matter again and so we have all

1352
00:54:54,539 --> 00:54:52,959
this information on scales ranging from

1353
00:54:56,579 --> 00:54:54,549
the whole universe of the whole virtual

1354
00:54:58,140 --> 00:54:56,589
universe in this case down to the

1355
00:55:00,779 --> 00:54:58,150
individual galaxies like the Milky Way

1356
00:55:03,809 --> 00:55:00,789
that we can watch evolve in time and so

1357
00:55:05,880 --> 00:55:03,819
speaking of evolving in time here is now

1358
00:55:08,699 --> 00:55:05,890
a movie put together by the team by Mark

1359
00:55:10,409 --> 00:55:08,709
Vogel's burger in particular of that

1360
00:55:12,569 --> 00:55:10,419
evolving in time and so there's a couple

1361
00:55:14,219 --> 00:55:12,579
things happening in this movie one we're

1362
00:55:16,019 --> 00:55:14,229
rotating around the virtual universe

1363
00:55:17,099 --> 00:55:16,029

which is a little bit unphysical but it

1364
00:55:19,049 --> 00:55:17,109
just helps you to visualize what's

1365
00:55:20,400 --> 00:55:19,059
happening and the galaxies are revolving

1366
00:55:21,599 --> 00:55:20,410
in time so the time since the Big Bang

1367
00:55:23,819 --> 00:55:21,609
which you might not be able to read to

1368
00:55:26,519 --> 00:55:23,829
the bottom left but you can see the

1369
00:55:28,909 --> 00:55:26,529
galaxies evolve and at first all the

1370
00:55:30,749 --> 00:55:28,919
galaxies were in just dark matter

1371
00:55:32,749 --> 00:55:30,759
visualization and now we're adding on

1372
00:55:35,519 --> 00:55:32,759
top of that some rendering of the gas

1373
00:55:42,179 --> 00:55:35,529
and so you get to see pretty cool colors

1374
00:55:45,059 --> 00:55:42,189
and explosions I like the explosions and

1375
00:55:47,149 --> 00:55:45,069
so each of these blue knots are galaxies

1376
00:55:49,079 --> 00:55:47,159
like we saw in the previous zoom in

1377
00:55:51,539 --> 00:55:49,089
there's other things happening now that

1378
00:55:53,999 --> 00:55:51,549
we can see what's happening in time and

1379
00:55:55,890 --> 00:55:54,009
that's these these galaxies issues that

1380
00:55:57,899 --> 00:55:55,900
talked about so you can see the galaxies

1381
00:55:59,069 --> 00:55:57,909
flickering a little bit I'm not sure how

1382
00:56:00,929 --> 00:55:59,079
many of you will be able to see that but

1383
00:56:03,169 --> 00:56:00,939
there's a small level of flickering

1384
00:56:07,109 --> 00:56:03,179
among the blue regions in the galaxies

1385
00:56:09,029 --> 00:56:07,119
those are feedback events so these are

1386
00:56:11,099 --> 00:56:09,039
they did these energetic events like

1387
00:56:13,589 --> 00:56:11,109
stars exploding or black holes are

1388
00:56:15,239 --> 00:56:13,599

creating gas so these are pushing energy

1389
00:56:16,859 --> 00:56:15,249
back into the I am and so that's heating

1390
00:56:18,599 --> 00:56:16,869
the gas and expelling it at high

1391
00:56:20,549 --> 00:56:18,609
velocities and that's what's causing

1392
00:56:23,819 --> 00:56:20,559
those that flickering or the explosions

1393
00:56:26,009 --> 00:56:23,829
that you see and so those explosions are

1394
00:56:27,899 --> 00:56:26,019
on huge scales here so I didn't put a

1395
00:56:29,980 --> 00:56:27,909
scale on this but you can see it's you

1396
00:56:31,600 --> 00:56:29,990
know these those explosions were plowing

1397
00:56:33,790 --> 00:56:31,610
through multiple galaxies as they

1398
00:56:37,990 --> 00:56:33,800
evolved in and through the IgM the

1399
00:56:40,620 --> 00:56:38,000
intergalactic medium so I want to show

1400
00:56:43,990 --> 00:56:40,630
that again actually just to just to get

1401
00:56:52,840 --> 00:56:44,000
get it in get the explosions again I

1402
00:57:03,270 --> 00:56:52,850
really like the explosions not yet do

1403
00:57:05,230 --> 00:57:03,280
you know it yes so I think the

1404
00:57:06,850 --> 00:57:05,240
flickering I think our supernova

1405
00:57:09,190 --> 00:57:06,860
explosions happening in the galaxies and

1406
00:57:11,530 --> 00:57:09,200
the explosions I think our energetic

1407
00:57:13,030 --> 00:57:11,540
black hole events so there the black

1408
00:57:15,160 --> 00:57:13,040
hole is accreting and then expelling the

1409
00:57:22,570 --> 00:57:15,170
gas out entirely out of the galaxies in

1410
00:57:24,640 --> 00:57:22,580
those those red explosions and so this

1411
00:57:26,890 --> 00:57:24,650
is largely just visualizing the gas so

1412
00:57:29,109 --> 00:57:26,900
the the gas dynamics of galaxies which

1413
00:57:31,000 --> 00:57:29,119

we don't actually get to see when we

1414
00:57:32,620 --> 00:57:31,010
look at a galaxy with Hubble so all of

1415
00:57:34,870 --> 00:57:32,630
the very beautiful Hubble images of

1416
00:57:37,240 --> 00:57:34,880
galaxies that we've seen show primarily

1417
00:57:39,250 --> 00:57:37,250
the stars but we don't get to see all

1418
00:57:41,050 --> 00:57:39,260
this action happening in the galaxies

1419
00:57:42,040 --> 00:57:41,060
with an image like like we get simply

1420
00:57:44,980 --> 00:57:42,050
out of Hubble in the Hubble Ultra Deep

1421
00:57:46,570 --> 00:57:44,990
Field or surveys like it and so we

1422
00:57:49,060 --> 00:57:46,580
really like to have these simulations to

1423
00:57:51,280 --> 00:57:49,070
get at that that at that aspect of the

1424
00:57:52,870 --> 00:57:51,290
science so we don't actually get to see

1425
00:58:04,170 --> 00:57:52,880
this happen very often in the real

1426
00:58:09,070 --> 00:58:07,270
of course yeah so we can then we can

1427
00:58:10,690 --> 00:58:09,080
then see how things evolve in the

1428
00:58:16,000 --> 00:58:10,700
simulation see if it matches what we see

1429
00:58:17,980 --> 00:58:16,010
in the real universe and so that's great

1430
00:58:20,260 --> 00:58:17,990
so now we have all the pieces we need in

1431
00:58:21,970 --> 00:58:20,270
order to put together our story of the

1432
00:58:24,070 --> 00:58:21,980
evolution of certain galaxies in the

1433
00:58:26,260 --> 00:58:24,080
simulation and so now we can take our

1434
00:58:28,030 --> 00:58:26,270
simulation and identify galaxies at

1435
00:58:29,680 --> 00:58:28,040
different times and then see how they

1436
00:58:31,330 --> 00:58:29,690
evolve into the galaxies that we see

1437
00:58:33,070 --> 00:58:31,340
today and we can watch them happen one

1438
00:58:34,390 --> 00:58:33,080

by one and track them and see what

1439
00:58:38,580 --> 00:58:34,400
happens and sort of tell each galaxies

1440
00:58:42,600 --> 00:58:41,250
and so in the end I showed you a couple

1441
00:58:44,340 --> 00:58:42,610
of neat visualizations of the olestra

1442
00:58:45,840 --> 00:58:44,350
simulation what you get are galaxies

1443
00:58:47,640 --> 00:58:45,850
like we know and love in the local

1444
00:58:49,350 --> 00:58:47,650
universe and so these are simulated

1445
00:58:52,590 --> 00:58:49,360
galaxies from the illustrious simulation

1446
00:58:54,780 --> 00:58:52,600
just fewer than 20 of them shown on a

1447
00:58:56,880 --> 00:58:54,790
slide these were selected visually just

1448
00:58:58,350 --> 00:58:56,890
to show you the the sampling of disk

1449
00:58:59,850 --> 00:58:58,360
galaxies and elliptical galaxies that we

1450
00:59:02,190 --> 00:58:59,860
get in the end and this was the ultimate

1451
00:59:04,590 --> 00:59:02,200
goal of the austria's project to get

1452
00:59:06,450 --> 00:59:04,600
this sort of separation in the galaxies

1453
00:59:07,560 --> 00:59:06,460
types and just to sample the different

1454
00:59:09,300 --> 00:59:07,570
types of galaxies that we see in the

1455
00:59:12,330 --> 00:59:09,310
universe and I think we've accomplished

1456
00:59:14,100 --> 00:59:12,340
that we've gotten to that point but with

1457
00:59:17,070 --> 00:59:14,110
the simulation of this scope in this

1458
00:59:20,010 --> 00:59:17,080
size we have I think access to a lot

1459
00:59:21,450 --> 00:59:20,020
more power in the future so let me just

1460
00:59:25,170 --> 00:59:21,460
talk a little bit about where I see this

1461
00:59:27,600 --> 00:59:25,180
going and the specific example I want to

1462
00:59:30,090 --> 00:59:27,610
show is a model of the Hubble Ultra Deep

1463
00:59:31,790 --> 00:59:30,100

Field so on the left is the actual

1464
00:59:33,360 --> 00:59:31,800
Hubble Ultra Deep Field from the

1465
00:59:35,280 --> 00:59:33,370
observations made by the Hubble Space

1466
00:59:37,320 --> 00:59:35,290
Telescope and on the right you're

1467
00:59:38,940 --> 00:59:37,330
looking at the olestra simulation in the

1468
00:59:40,520 --> 00:59:38,950
exactly the same units as you would

1469
00:59:43,590 --> 00:59:40,530
observe them in Hubble ultra-deep field

1470
00:59:46,170 --> 00:59:43,600
so I've taken that simulated volume and

1471
00:59:47,910 --> 00:59:46,180
then observed it with a Hubble Space

1472
00:59:49,830 --> 00:59:47,920
Telescope in the computers basically so

1473
00:59:52,920 --> 00:59:49,840
it's an imaginary Hubble Space Telescope

1474
00:59:55,080 --> 00:59:52,930
drawn a line of sight through the Box in

1475
00:59:57,060 --> 00:59:55,090
the olestra simulation and then at each

1476
00:59:58,350 --> 00:59:57,070
galaxy point decided how it should look

1477
01:00:00,060 --> 00:59:58,360
according to the Hubble Space

1478
01:00:01,800 --> 01:00:00,070
Telescope's filters and cameras and

1479
01:00:03,840 --> 01:00:01,810
things like that and then just rendered

1480
01:00:06,300 --> 01:00:03,850
that in the same size same region of sky

1481
01:00:07,830 --> 01:00:06,310
as the Ultra Deep Field so here is

1482
01:00:10,320 --> 01:00:07,840
10,000 galaxies observed in the universe

1483
01:00:12,630 --> 01:00:10,330
now we have 10,000 galaxies

1484
01:00:14,610 --> 01:00:12,640
macht observed in a mock universe from

1485
01:00:16,410 --> 01:00:14,620
the austria simulation and the

1486
01:00:18,600 --> 01:00:16,420
illustrious simulation is one of several

1487
01:00:20,520 --> 01:00:18,610
collaborations that have finally reached

1488
01:00:22,770 --> 01:00:20,530

the point of being able to do this kind

1489
01:00:24,600 --> 01:00:22,780
of this kind of rendering it is never

1490
01:00:26,820 --> 01:00:24,610
before been possible to populate a

1491
01:00:28,410 --> 01:00:26,830
Hubble Ultra Deep Field with galaxies

1492
01:00:30,270 --> 01:00:28,420
that are simulated from the beginning of

1493
01:00:32,880 --> 01:00:30,280
the universe and so this is the really a

1494
01:00:34,970 --> 01:00:32,890
first in theoretical astrophysics we've

1495
01:00:36,750 --> 01:00:34,980
been we've been pushed along by

1496
01:00:38,640 --> 01:00:36,760
observational advances like the Hubble

1497
01:00:41,850 --> 01:00:38,650
Ultra Deep Field for 30 years now and

1498
01:00:43,440 --> 01:00:41,860
we've only just caught up to the sort of

1499
01:00:46,200 --> 01:00:43,450
Hubble Space Telescope like surveys of

1500
01:00:48,840 --> 01:00:46,210
galaxies in our simulations of galaxies

1501
01:00:51,000 --> 01:00:48,850
and so that's sort of representing this

1502
01:00:51,930 --> 01:00:51,010
this this slide is representing of that

1503
01:00:54,600 --> 01:00:51,940
that fact

1504
01:00:57,480 --> 01:00:54,610
that we've come a long way and we

1505
01:01:01,620 --> 01:00:57,490
finally can have a mock universe to call

1506
01:01:03,780 --> 01:01:01,630
our own so I'm gonna zoom in here on the

1507
01:01:04,860 --> 01:01:03,790
real sky so this is the similar to the

1508
01:01:06,660 --> 01:01:04,870
one that I showed earlier in the talk of

1509
01:01:08,400 --> 01:01:06,670
the Hubble Ultra Deep Field showing the

1510
01:01:11,070 --> 01:01:08,410
diversity of galaxies as observed

1511
01:01:13,140 --> 01:01:11,080
directly with Hubble and I'm going to

1512
01:01:14,760 --> 01:01:13,150
slide over slowly to the simulated side

1513
01:01:18,840 --> 01:01:14,770

and you can see where the transition

1514
01:01:22,170 --> 01:01:18,850
happens here and these are now entirely

1515
01:01:23,880 --> 01:01:22,180
a simulated universe so we can see a

1516
01:01:27,570 --> 01:01:23,890
nice diversity of galaxies of different

1517
01:01:29,460 --> 01:01:27,580
colors and shapes and and yeah so this

1518
01:01:31,860 --> 01:01:29,470
is sort of a mock observation of the

1519
01:01:33,360 --> 01:01:31,870
illustrious simulation itself here and

1520
01:01:35,730 --> 01:01:33,370
so you can see an elliptical galaxy up

1521
01:01:40,710 --> 01:01:35,740
at the top blue star forming spiral

1522
01:01:43,320 --> 01:01:40,720
galaxies all around and so on now it's

1523
01:01:44,700 --> 01:01:43,330
not perfect so I I don't want to claim

1524
01:01:46,380 --> 01:01:44,710
that it's perfect and I think we have a

1525
01:01:48,120 --> 01:01:46,390
long way to go to actually get it to

1526
01:01:49,200 --> 01:01:48,130
look more like the Ultra Deep Field so

1527
01:01:51,270 --> 01:01:49,210
I'm gonna jump back and forth now

1528
01:01:53,730 --> 01:01:51,280
quickly here's the Hubble Ultra Deep

1529
01:01:56,520 --> 01:01:53,740
Field again and here's the simulated sky

1530
01:01:58,050 --> 01:01:56,530
of the same size in the same units so

1531
01:02:01,770 --> 01:01:58,060
you're looking at the same rendering are

1532
01:02:03,150 --> 01:02:01,780
the same colors are the same but

1533
01:02:05,310 --> 01:02:03,160
galaxies are a little bit bigger in the

1534
01:02:07,350 --> 01:02:05,320
simulation so the galaxies are much

1535
01:02:09,540 --> 01:02:07,360
larger they a factor of two or so than

1536
01:02:11,400 --> 01:02:09,550
they then they are observed and the

1537
01:02:13,380 --> 01:02:11,410
colors are a little wonky so the colors

1538
01:02:16,460 --> 01:02:13,390

are not perfectly matched to the real

1539
01:02:19,110 --> 01:02:16,470
sky and we think we think we have now

1540
01:02:21,510 --> 01:02:19,120
the ability to take this information and

1541
01:02:33,970 --> 01:02:21,520
then improve our models of virtual

1542
01:02:38,290 --> 01:02:36,700
so what this allows now that we can

1543
01:02:40,180 --> 01:02:38,300
populate things like the Hubble

1544
01:02:43,270 --> 01:02:40,190
ultra-deep field and other surveys of

1545
01:02:45,670 --> 01:02:43,280
galaxies with fake galaxies this allows

1546
01:02:47,470 --> 01:02:45,680
us to make a statistically robust

1547
01:02:49,810 --> 01:02:47,480
comparison against observations across

1548
01:02:51,640 --> 01:02:49,820
all of cosmic time so this is a quote

1549
01:02:53,260 --> 01:02:51,650
that I really like that was in the CNN

1550
01:02:54,819 --> 01:02:53,270
article about the illustrious project by

1551
01:02:57,420 --> 01:02:54,829
one of the team members Dylan Nelson

1552
01:02:59,800 --> 01:02:57,430
who's a graduate student at Harvard and

1553
01:03:02,560 --> 01:02:59,810
so this is kind of a long way of saying

1554
01:03:04,030 --> 01:03:02,570
we get a lot of galaxies so we get a

1555
01:03:05,800 --> 01:03:04,040
number of galaxies that we can then

1556
01:03:08,920 --> 01:03:05,810
statistically compared with the real

1557
01:03:10,270 --> 01:03:08,930
universe and then iterate again and so

1558
01:03:11,640 --> 01:03:10,280
the next model universe will take the

1559
01:03:13,900 --> 01:03:11,650
lessons we've learned from that

1560
01:03:15,490 --> 01:03:13,910
statistical sample which we we have for

1561
01:03:18,520 --> 01:03:15,500
the first time and then iterate and

1562
01:03:20,740 --> 01:03:18,530
create better ones but I want to end on

1563
01:03:24,010 --> 01:03:20,750

the on the note that quantity is not

1564
01:03:25,839 --> 01:03:24,020
everything in this and so the the

1565
01:03:27,430 --> 01:03:25,849
quality of the galaxies you get out is

1566
01:03:29,980 --> 01:03:27,440
also something that people are modeling

1567
01:03:31,359 --> 01:03:29,990
and trying trying to get at and in

1568
01:03:33,280 --> 01:03:31,369
particular there are other groups

1569
01:03:35,079 --> 01:03:33,290
simulating galaxies that made different

1570
01:03:37,030 --> 01:03:35,089
choices about how to handle the issues

1571
01:03:38,620 --> 01:03:37,040
of galaxies so I described one one

1572
01:03:41,050 --> 01:03:38,630
example the olestra simulation there are

1573
01:03:43,270 --> 01:03:41,060
other groups and including our own group

1574
01:03:45,490 --> 01:03:43,280
which are taking different choices for

1575
01:03:47,800 --> 01:03:45,500
how you model star formation and what

1576
01:03:51,250 --> 01:03:47,810
that lets you do is say trade away the

1577
01:03:52,870 --> 01:03:51,260
statistics for higher fidelity images of

1578
01:03:54,579 --> 01:03:52,880
galaxies so you can get a better handle

1579
01:03:57,010 --> 01:03:54,589
on the formation of stars within

1580
01:03:59,470 --> 01:03:57,020
galaxies rather than the formation of a

1581
01:04:01,559 --> 01:03:59,480
population of galaxies and so I just

1582
01:04:04,960 --> 01:04:01,569
want to show a couple examples of that

1583
01:04:06,430 --> 01:04:04,970
here so this is a simulated galaxy on

1584
01:04:08,589 --> 01:04:06,440
the left as it would be observed with

1585
01:04:12,099 --> 01:04:08,599
HST if you could observe for a long

1586
01:04:13,870 --> 01:04:12,109
period of time we would see this but the

1587
01:04:16,660 --> 01:04:13,880
simulations now are getting to the point

1588
01:04:18,940 --> 01:04:16,670

where we can go beyond what HST is even

1589
01:04:20,859 --> 01:04:18,950
capable of so the fidelity of the

1590
01:04:22,930 --> 01:04:20,869
simulations this one is not the

1591
01:04:24,630 --> 01:04:22,940
illustrious simulation goes well beyond

1592
01:04:26,980 --> 01:04:24,640
what you can do with a just T so HST

1593
01:04:29,349 --> 01:04:26,990
which is a two point four meter mirror

1594
01:04:30,790 --> 01:04:29,359
can only resolve so much and so the

1595
01:04:32,410 --> 01:04:30,800
resolving power of a telescope is

1596
01:04:34,450 --> 01:04:32,420
directly proportional to the size of its

1597
01:04:36,370 --> 01:04:34,460
primary mirror here at two point four

1598
01:04:37,900 --> 01:04:36,380
meters a galaxy that's three billion

1599
01:04:40,329 --> 01:04:37,910
years old or three billion years after

1600
01:04:42,430 --> 01:04:40,339
the Big Bang will be largely a smudge

1601
01:04:44,050 --> 01:04:42,440
and so that all of the interesting stuff

1602
01:04:45,520 --> 01:04:44,060
that I talked about the issues that are

1603
01:04:47,740 --> 01:04:45,530
involved in galaxies the formation of

1604
01:04:51,010 --> 01:04:47,750
stars are smeared out along these

1605
01:04:52,900 --> 01:04:51,020
big these big regions and the simulation

1606
01:04:55,030 --> 01:04:52,910
the galaxy formation can now go well

1607
01:04:56,890 --> 01:04:55,040
beyond that so here's a rendering of a

1608
01:04:59,140 --> 01:04:56,900
16 meter telescope so imagine if you

1609
01:05:01,360 --> 01:04:59,150
could take Hubble and make it 16 meters

1610
01:05:02,920 --> 01:05:01,370
and put a big camera in it and you get a

1611
01:05:04,510 --> 01:05:02,930
gallon you get an image like this one so

1612
01:05:06,010 --> 01:05:04,520
this is a very distant galaxy one of

1613
01:05:08,020 --> 01:05:06,020

those little smudges on the ultra-deep

1614
01:05:09,910 --> 01:05:08,030
field that I showed a telescope like

1615
01:05:12,100 --> 01:05:09,920
this one could resolve all of them into

1616
01:05:13,570 --> 01:05:12,110
its constituent parts and we could see

1617
01:05:17,590 --> 01:05:13,580
all of the the interesting bits of

1618
01:05:21,100 --> 01:05:17,600
galaxies here in the in the observation

1619
01:05:23,080 --> 01:05:21,110
and so this simulation is is you know

1620
01:05:24,820 --> 01:05:23,090
one galaxy we don't really know how to

1621
01:05:26,860 --> 01:05:24,830
say same thing about the statistics of

1622
01:05:29,230 --> 01:05:26,870
galaxies but we can start to understand

1623
01:05:31,810 --> 01:05:29,240
where our place in the universe really

1624
01:05:33,820 --> 01:05:31,820
is here so I showed you before where our

1625
01:05:36,850 --> 01:05:33,830
solar system would fit in in a real

1626
01:05:38,770 --> 01:05:36,860
image of a galaxy with the simulations

1627
01:05:42,490 --> 01:05:38,780
that are coming online now and the

1628
01:05:43,630 --> 01:05:42,500
possible future missions beyond HST we

1629
01:05:45,460 --> 01:05:43,640
might be able to start to see the

1630
01:05:47,950 --> 01:05:45,470
regions of space where our solar system

1631
01:05:50,440 --> 01:05:47,960
formed in model universes in virtual

1632
01:05:52,120 --> 01:05:50,450
universes like this one we're still not

1633
01:05:54,910 --> 01:05:52,130
there yet but I think in the coming

1634
01:05:57,640 --> 01:05:54,920
decades we'll be able to get there and

1635
01:06:00,130 --> 01:05:57,650
so this this is an image of some of the

1636
01:06:02,110 --> 01:06:00,140
missions that nASA has launched and is

1637
01:06:04,660 --> 01:06:02,120
launching and may launch in the future

1638
01:06:07,690 --> 01:06:04,670

so here's HST which is launched in 1990

1639
01:06:09,670 --> 01:06:07,700
and I think we've just caught up with HS

1640
01:06:11,980 --> 01:06:09,680
T's ability to observe the universe with

1641
01:06:14,110 --> 01:06:11,990
our virtual universes so we've finally

1642
01:06:17,380 --> 01:06:14,120
gotten back to the 1990 era galaxies

1643
01:06:18,400 --> 01:06:17,390
that we can observe with HST JWST will

1644
01:06:20,590 --> 01:06:18,410
be launched the James Webb Space

1645
01:06:21,820 --> 01:06:20,600
Telescope is currently being built down

1646
01:06:26,410 --> 01:06:21,830
and Goddard Space Flight Center in

1647
01:06:28,600 --> 01:06:26,420
Maryland with a plan 2018 launch so this

1648
01:06:30,880 --> 01:06:28,610
will then set the bar even further for

1649
01:06:32,380 --> 01:06:30,890
our models of galaxy formation and the

1650
01:06:34,000 --> 01:06:32,390
one that I showed you the cognition

1651
01:06:35,380 --> 01:06:34,010
concept that I showed you is one that's

1652
01:06:37,420 --> 01:06:35,390
currently being discussed by some

1653
01:06:38,860 --> 01:06:37,430
scientists here at Space Telescope it's

1654
01:06:40,900 --> 01:06:38,870
called the advanced technology mission

1655
01:06:43,150 --> 01:06:40,910
concept which could have a 16 meter

1656
01:06:44,890 --> 01:06:43,160
diameter mirror and would give you those

1657
01:06:47,650 --> 01:06:44,900
perfect images of galaxies that I showed

1658
01:06:50,110 --> 01:06:47,660
on the previous slide it could also

1659
01:06:52,210 --> 01:06:50,120
observe an earth around another star

1660
01:06:53,710 --> 01:06:52,220
directly so it has a couple it has a

1661
01:06:55,450 --> 01:06:53,720
couple different things going for it so

1662
01:06:56,350 --> 01:06:55,460
in addition to resolving galaxies it

1663
01:06:59,930 --> 01:06:56,360

could take a picture of an earth

1664
01:07:03,289 --> 01:06:59,940
orbiting a star in in our galaxy

1665
01:07:07,250 --> 01:07:03,299
and so it then is to summarize that

1666
01:07:08,450 --> 01:07:07,260
here's an HST image of a galaxy 3

1667
01:07:10,819 --> 01:07:08,460
billion years after the Big Bang a very

1668
01:07:12,650 --> 01:07:10,829
distant galaxy and here's how it would

1669
01:07:14,960 --> 01:07:12,660
look according to a 16 meter telescope

1670
01:07:16,579 --> 01:07:14,970
and so we can actually begin to resolve

1671
01:07:19,190 --> 01:07:16,589
the bits of galaxies that HST is

1672
01:07:22,549 --> 01:07:19,200
revealing to us into the regions of

1673
01:07:26,210 --> 01:07:22,559
space where stars like ours formed in in

1674
01:07:28,760 --> 01:07:26,220
the past and so then I'll just end with

1675
01:07:31,569 --> 01:07:28,770
a movie of that particular simulation

1676
01:07:35,450 --> 01:07:31,579
evolving in time showing HST on left

1677
01:07:36,829 --> 01:07:35,460
JWST on the right and then to sort of

1678
01:07:37,549 --> 01:07:36,839
toy models for telescopes that could

1679
01:07:40,099 --> 01:07:37,559
exist in the future

1680
01:07:41,930 --> 01:07:40,109
and maybe a little bit hard to see in

1681
01:07:43,579 --> 01:07:41,940
the back so feel free to come up

1682
01:07:44,839 --> 01:07:43,589
afterwards and take a look at this or

1683
01:07:47,329 --> 01:07:44,849
look at these these screens which might

1684
01:07:48,609 --> 01:07:47,339
be a little bit crisper that the 16

1685
01:07:50,720 --> 01:07:48,619
metre telescope an 8 metre telescope

1686
01:07:52,400 --> 01:07:50,730
really resolved the fine bits of

1687
01:07:54,500 --> 01:07:52,410
galaxies that you don't get to see in

1688
01:07:56,059 --> 01:07:54,510

HST so the fine-structure internal

1689
01:07:59,390 --> 01:07:56,069
structures of galaxies where are the

1690
01:08:07,589 --> 01:07:59,400
stars like ours formed is is revealed in

1691
01:08:35,899 --> 01:08:09,479
and so uh that's the end of my talking

1692
01:08:50,490 --> 01:08:45,450
and I can't even think what it cost to

1693
01:08:52,829 --> 01:08:50,500
use that German super six months so I

1694
01:08:55,800 --> 01:08:52,839
computed this once I calculated how much

1695
01:08:58,379 --> 01:08:55,810
the cost of it was and luckily to the

1696
01:09:01,069 --> 01:08:58,389
scientists like myself and dr. summers

1697
01:09:03,959 --> 01:09:01,079
and my collaborators it's virtually free

1698
01:09:05,669 --> 01:09:03,969
so the the supercomputer centers

1699
01:09:10,430 --> 01:09:05,679
actually have a really strong need for

1700
01:09:14,339 --> 01:09:12,839
from scientists who want to do these big

1701
01:09:16,499 --> 01:09:14,349
projects and they provide a little bit

1702
01:09:18,269 --> 01:09:16,509
of support and and hand-holding to get

1703
01:09:19,709 --> 01:09:18,279
us up and running on them and so they're

1704
01:09:21,780 --> 01:09:19,719
actually it's the supercomputer centers

1705
01:09:23,280 --> 01:09:21,790
who are investing all the money and the

1706
01:09:26,030 --> 01:09:23,290
government's are investing the money and

1707
01:09:27,930 --> 01:09:26,040
it's not coming out of NASA's pocket

1708
01:09:30,959 --> 01:09:27,940
recognizing that you know these super

1709
01:09:32,879 --> 01:09:30,969
centers exist not to do astronomy

1710
01:09:34,620 --> 01:09:32,889
actually but they they exist to solve

1711
01:09:37,769 --> 01:09:34,630
problems in computer science and how to

1712
01:09:41,129 --> 01:09:37,779
do even better computing and so they

1713
01:09:42,749 --> 01:09:41,139

love astronomers because we can as we

1714
01:09:44,819 --> 01:09:42,759
say if you as you build a bigger

1715
01:10:05,250 --> 01:09:44,829
supercomputer we can fill it with more

1716
01:10:06,479 --> 01:10:05,260
astrophysics so I was a rough

1717
01:10:09,060 --> 01:10:06,489
approximation of the number of the

1718
01:10:11,430 --> 01:10:09,070
computer hours but there's also you know

1719
01:10:12,920 --> 01:10:11,440
I made it sound like it was all easy at

1720
01:10:14,390 --> 01:10:12,930
random six months but there were problem

1721
01:10:17,330 --> 01:10:14,400
the computers crashed every once in a

1722
01:10:19,160 --> 01:10:17,340
while and we have to use a couple couple

1723
01:10:21,200 --> 01:10:19,170
of million CPU hours and then start over

1724
01:10:24,860 --> 01:10:21,210
we do but to answer your original

1725
01:10:26,720 --> 01:10:24,870
question so the primary cost to use a

1726
01:10:31,070 --> 01:10:26,730
computer once it's built is in

1727
01:10:33,470 --> 01:10:31,080
electricity the vast majority of the

1728
01:10:36,020 --> 01:10:33,480
light for this project was spent on

1729
01:10:37,430 --> 01:10:36,030
electricity in Europe so generating

1730
01:10:39,020 --> 01:10:37,440
electricity in Europe for the computer

1731
01:10:48,760 --> 01:10:39,030
was something like five to ten million

1732
01:10:52,240 --> 01:10:48,770
dollars I look this up for this talk

1733
01:10:55,790 --> 01:10:52,250
maybe a hundred yes some similar scale

1734
01:10:58,970 --> 01:10:55,800
no more than that I mean I know it

1735
01:11:01,610 --> 01:10:58,980
sounds huge to the general public but a

1736
01:11:04,430 --> 01:11:01,620
cluster of a thousand CPUs is nothing

1737
01:11:07,010 --> 01:11:04,440
these days sorry it when you're talking

1738
01:11:09,260 --> 01:11:07,020

high-end supercomputing they can put

1739
01:11:11,750 --> 01:11:09,270
lots of cores on on one die and then

1740
01:11:13,910 --> 01:11:11,760
lots of chips in one slot and lots of

1741
01:11:15,950 --> 01:11:13,920
slots in one chassis and lots of chassis

1742
01:11:18,350 --> 01:11:15,960
in one rack and lots of racks in the

1743
01:11:21,260 --> 01:11:18,360
room and you know just think of what

1744
01:11:23,030 --> 01:11:21,270
Google has and other Internet companies

1745
01:11:27,590 --> 01:11:23,040
in terms of their racks they're gonna

1746
01:11:30,320 --> 01:11:27,600
dwarf these things question back so is

1747
01:11:34,390 --> 01:11:30,330
your standard for evaluating your models

1748
01:11:41,180 --> 01:11:34,400
essentially the spatial distribution of

1749
01:11:48,190 --> 01:11:41,190
stars of mass and light and gas you're

1750
01:11:51,140 --> 01:11:48,200
judging lives that's what we hope to do

1751
01:11:53,450 --> 01:11:51,150
what we have done in the past is focus

1752
01:11:56,900 --> 01:11:53,460
on more global quantities about galaxies

1753
01:11:58,880 --> 01:11:56,910
so if the galaxies have so many issues

1754
01:12:00,950 --> 01:11:58,890
that we have not even been able to get

1755
01:12:03,200 --> 01:12:00,960
the star formation rate of galaxies

1756
01:12:04,700 --> 01:12:03,210
simulated correctly so we're only now

1757
01:12:06,230 --> 01:12:04,710
just at the point where we can start to

1758
01:12:08,510 --> 01:12:06,240
talk about where the star formation is

1759
01:12:10,100 --> 01:12:08,520
happening within galaxies or is spatial

1760
01:12:10,640 --> 01:12:10,110
reservation resolving that star

1761
01:12:13,220 --> 01:12:10,650
formation

1762
01:12:15,320 --> 01:12:13,230
so our metric for creating the initial

1763
01:12:17,270 --> 01:12:15,330

simulation had nothing to do with the

1764
01:12:19,030 --> 01:12:17,280
shapes of galaxies and everything to do

1765
01:12:22,280 --> 01:12:19,040
with the amount of stars in the galaxy

1766
01:12:23,630 --> 01:12:22,290
basically and so we where once we got to

1767
01:12:25,360 --> 01:12:23,640
that point we said okay let's run a

1768
01:12:26,980 --> 01:12:25,370
simulation and see what we get

1769
01:12:29,020 --> 01:12:26,990
but now that we have all of this data

1770
01:12:30,730 --> 01:12:29,030
from this simulation and maybe a half a

1771
01:12:33,640 --> 01:12:30,740
dozen other simulation projects with

1772
01:12:35,350 --> 01:12:33,650
similar amounts of data what my research

1773
01:12:37,360 --> 01:12:35,360
is now actually is to take that

1774
01:12:39,520 --> 01:12:37,370
information and ask what is the new

1775
01:12:40,900 --> 01:12:39,530
metric can we now write a metric that

1776
01:12:42,220 --> 01:12:40,910
takes the shapes of galaxies into

1777
01:12:44,050 --> 01:12:42,230
account and the spatial distribution of

1778
01:12:46,510 --> 01:12:44,060
light in the individual galaxies into

1779
01:12:48,940 --> 01:12:46,520
account but we don't do that yet it's

1780
01:12:51,550 --> 01:12:48,950
still still in the works you talked

1781
01:12:53,620 --> 01:12:51,560
about the comment and frequency of the

1782
01:12:57,970 --> 01:12:53,630
interaction between galaxies so in this

1783
01:13:00,130 --> 01:12:57,980
simulation are you able to determine how

1784
01:13:03,070 --> 01:13:00,140
that may have changed over time with the

1785
01:13:04,950 --> 01:13:03,080
expansion of the universe sure yeah so

1786
01:13:07,060 --> 01:13:04,960
there are members of the collaboration

1787
01:13:08,320 --> 01:13:07,070
literally calculating the number of

1788
01:13:10,180 --> 01:13:08,330

interaction interactions between

1789
01:13:13,480 --> 01:13:10,190
galaxies and mergers of galaxies and

1790
01:13:15,070 --> 01:13:13,490
today it's the rate is very low so in

1791
01:13:16,780 --> 01:13:15,080
the current universe as the universe

1792
01:13:19,450 --> 01:13:16,790
expanded things grew farther and farther

1793
01:13:21,820 --> 01:13:19,460
apart galaxies are less likely to merge

1794
01:13:23,200 --> 01:13:21,830
now than they were in the past but yes

1795
01:13:25,900 --> 01:13:23,210
in the past the histories of these

1796
01:13:28,660 --> 01:13:25,910
galaxies are filled with mergers in the

1797
01:13:30,460 --> 01:13:28,670
distant past and many of them happened

1798
01:13:32,410 --> 01:13:30,470
when the galaxies were infants basically

1799
01:13:34,450 --> 01:13:32,420
so the galaxies were really tiny when

1800
01:13:36,430 --> 01:13:34,460
the murders were happening so you may

1801
01:13:38,950 --> 01:13:36,440
not be able to see those grand mergers

1802
01:13:40,330 --> 01:13:38,960
in the in a distant universe but they're

1803
01:13:43,030 --> 01:13:40,340
going to be really tiny things that are

1804
01:13:47,920 --> 01:13:43,040
very faint and hard to detect so it's

1805
01:13:50,590 --> 01:13:47,930
the interactions are our image are they

1806
01:13:52,570 --> 01:13:50,600
appear they're hard to see and in the

1807
01:13:53,740 --> 01:13:52,580
real universe and so we're not we can

1808
01:13:56,050 --> 01:13:53,750
simulate them but we won't be able to

1809
01:14:09,340 --> 01:13:56,060
test it until things like JWST come

1810
01:14:14,020 --> 01:14:09,350
online gravity is basically as it was in

1811
01:14:16,360 --> 01:14:14,030
1700 as it was understood recognize it's

1812
01:14:18,730 --> 01:14:16,370
approximations and you can do scale

1813
01:14:20,500 --> 01:14:18,740

order calculations to see whether

1814
01:14:22,060 --> 01:14:20,510
relativistic effects are necessary

1815
01:14:23,770 --> 01:14:22,070
compared to other effects that we're

1816
01:14:26,290 --> 01:14:23,780
using for approximations and they are

1817
01:14:28,780 --> 01:14:26,300
second a third order and

1818
01:14:30,400 --> 01:14:28,790
in the computer simulation so you take

1819
01:14:33,490 --> 01:14:30,410
your first and second order effects and

1820
01:14:36,130 --> 01:14:33,500
you'll go further down the chain as time

1821
01:14:37,960 --> 01:14:36,140
becomes available but they aren't

1822
01:14:39,700 --> 01:14:37,970
necessary that does those Corrections

1823
01:14:41,470 --> 01:14:39,710
are necessary do those Corrections are

1824
01:14:43,390 --> 01:14:41,480
certainly important for modeling the

1825
01:14:45,070 --> 01:14:43,400
black holes at Centers of galaxies which

1826
01:14:47,230 --> 01:14:45,080
we don't do so we've made a toy model

1827
01:14:48,940 --> 01:14:47,240
for that so we basically cover up all of

1828
01:14:50,530 --> 01:14:48,950
that general relativity stuff in a toy

1829
01:14:56,080 --> 01:14:50,540
model and so we don't we don't directly

1830
01:14:58,570 --> 01:14:56,090
simulate it yeah what's the like

1831
01:15:00,670 --> 01:14:58,580
long-term goal of perfecting these

1832
01:15:03,670 --> 01:15:00,680
virtual universes and the context that

1833
01:15:05,230 --> 01:15:03,680
it has in like the larger Astrophysical

1834
01:15:07,450 --> 01:15:05,240
community so like are you hoping to

1835
01:15:11,880 --> 01:15:07,460
actually discover things via simulation

1836
01:15:18,160 --> 01:15:16,240
partly yes so I think a lot of it has to

1837
01:15:20,500 --> 01:15:18,170
do with being able to understand the

1838
01:15:22,090 --> 01:15:20,510

data we already have so we have this

1839
01:15:23,230 --> 01:15:22,100
enormous diversity of galaxies and

1840
01:15:25,420 --> 01:15:23,240
things like the Hubble Ultra Deep Field

1841
01:15:27,490 --> 01:15:25,430
and other HST surveys but we don't

1842
01:15:29,350 --> 01:15:27,500
understand it we don't know what any

1843
01:15:31,540 --> 01:15:29,360
particular shaped galaxy means at a

1844
01:15:33,280 --> 01:15:31,550
particular time in the universe so we

1845
01:15:35,890 --> 01:15:33,290
have to make these these models of

1846
01:15:37,570 --> 01:15:35,900
things in order to to basically read

1847
01:15:40,000 --> 01:15:37,580
between the lines of what is happening

1848
01:15:41,980 --> 01:15:40,010
in the galaxies and so we're gonna maybe

1849
01:15:43,480 --> 01:15:41,990
not discover a new phenomenon but we

1850
01:15:45,640 --> 01:15:43,490
will discover a phenomenon and say hey

1851
01:15:47,200 --> 01:15:45,650
we can test that now with our telescopes

1852
01:15:49,780 --> 01:15:47,210
so we're gonna have these phenomenon

1853
01:15:51,310 --> 01:15:49,790
that you know we had no idea we're

1854
01:15:53,290 --> 01:15:51,320
interesting so we can see them and we

1855
01:15:54,970 --> 01:15:53,300
can see them in our surveys but we can't

1856
01:15:56,800 --> 01:15:54,980
assign anything meaningful to them until

1857
01:15:58,390 --> 01:15:56,810
we have a simulation like this one and

1858
01:16:01,180 --> 01:15:58,400
so that's the basic idea we can look and

1859
01:16:03,310 --> 01:16:01,190
then say with with some better

1860
01:16:04,300 --> 01:16:03,320
confidence what we'll expect to see in a

1861
01:16:05,980 --> 01:16:04,310
different survey

1862
01:16:07,810 --> 01:16:05,990
so basically being able to go back and

1863
01:16:09,490 --> 01:16:07,820

say okay now we want to look for

1864
01:16:11,560 --> 01:16:09,500
something else look at a different

1865
01:16:13,510 --> 01:16:11,570
wavelength of light that's so on and so

1866
01:16:15,100 --> 01:16:13,520
forth and in that respect so not

1867
01:16:18,160 --> 01:16:15,110
necessarily discovering something

1868
01:16:20,230 --> 01:16:18,170
brand-new but alright but let me just

1869
01:16:23,220 --> 01:16:20,240
give some old geezer perspective because

1870
01:16:25,750 --> 01:16:23,230
when I was doing my PhD simulation do it

1871
01:16:28,510 --> 01:16:25,760
simulations etc a lot of what we were

1872
01:16:31,000 --> 01:16:28,520
trying to do was help pin down what the

1873
01:16:32,770 --> 01:16:31,010
basic structure of the universe was was

1874
01:16:35,050 --> 01:16:32,780
it cold dark matter was it warm dark

1875
01:16:37,030 --> 01:16:35,060
matter was it you know was this crazy

1876
01:16:39,399 --> 01:16:37,040
thing idea of a cosmological

1877
01:16:41,290 --> 01:16:39,409
even to be taken seriously and the

1878
01:16:43,419 --> 01:16:41,300
simulations could show you there's

1879
01:16:45,850 --> 01:16:43,429
distributions of galaxies in these

1880
01:16:48,340 --> 01:16:45,860
various cosmological models and that led

1881
01:16:52,000 --> 01:16:48,350
us towards a you know a flat universe

1882
01:16:53,770 --> 01:16:52,010
that eventually you know over the past

1883
01:16:57,010 --> 01:16:53,780
two decades we've come up with a

1884
01:16:58,930 --> 01:16:57,020
concordance cosmological model so he had

1885
01:17:01,860 --> 01:16:58,940
that this illustrious simulation has the

1886
01:17:03,939 --> 01:17:01,870
benefit of really having a well-defined

1887
01:17:06,280 --> 01:17:03,949
relatively well defined cosmological

1888
01:17:08,110 --> 01:17:06,290

model in which to do the computations

1889
01:17:10,780 --> 01:17:08,120
and so they can get down to the

1890
01:17:13,780 --> 01:17:10,790
nitty-gritty of what galaxies what types

1891
01:17:16,030 --> 01:17:13,790
of galaxies form what are the details of

1892
01:17:18,669 --> 01:17:16,040
them how quickly do they form I mean you

1893
01:17:20,200 --> 01:17:18,679
know when we can't see the development

1894
01:17:22,360 --> 01:17:20,210
of galaxies over the first three to five

1895
01:17:24,760 --> 01:17:22,370
billion years you can give predictions

1896
01:17:27,850 --> 01:17:24,770
as to what you should see and whether or

1897
01:17:50,830 --> 01:17:27,860
not telescopes should should be able to

1898
01:17:52,630 --> 01:17:50,840
see some of these ideas so that's a good

1899
01:17:54,880 --> 01:17:52,640
question they're currently pipe dreams

1900
01:17:57,220 --> 01:17:54,890
yeah so they're they're currently being

1901
01:17:59,979 --> 01:17:57,230
discussed among the astronomy astronomy

1902
01:18:15,550 --> 01:17:59,989
community as things we might want to

1903
01:18:17,890 --> 01:18:15,560
think about after HST and JWST it's not

1904
01:18:19,660 --> 01:18:17,900
too far off there's another issue that

1905
01:18:21,280 --> 01:18:19,670
I've glossed over here and that is that

1906
01:18:23,200 --> 01:18:21,290
the James Webb Space Telescope is tuned

1907
01:18:25,510 --> 01:18:23,210
for different wavelengths of light then

1908
01:18:28,050 --> 01:18:25,520
is the Hubble Space Telescope and so the

1909
01:18:30,490 --> 01:18:28,060
the large mirror on James Webb will not

1910
01:18:32,770 --> 01:18:30,500
entirely go to resolving the bits of

1911
01:18:34,750 --> 01:18:32,780
galaxies as well as these future

1912
01:18:36,760 --> 01:18:34,760
concepts might so these two mission

1913
01:18:39,040 --> 01:18:36,770

concepts are tuned to blue light lucky

1914
01:18:40,689 --> 01:18:39,050
just he is and so in blue light you can

1915
01:18:42,399 --> 01:18:40,699
really resolve the features of galaxies

1916
01:18:44,290 --> 01:18:42,409
more clearly than than an infrared light

1917
01:18:45,580 --> 01:18:44,300
where the light gets smeared out even a

1918
01:18:46,980 --> 01:18:45,590
time even with big telescopes the light

1919
01:18:49,360 --> 01:18:46,990
gets smeared out to a point where

1920
01:18:52,060 --> 01:18:49,370
quite similar to HST resolution actually

1921
01:18:55,300 --> 01:18:52,070
in the end but the fact that JT OST is a

1922
01:18:58,390 --> 01:18:55,310
multi mirror telescope in space 18

1923
01:19:01,000 --> 01:18:58,400
segmented mirrors is the precedents for

1924
01:19:04,180 --> 01:19:01,010
having very large multi mirror

1925
01:19:05,490 --> 01:19:04,190
telescopes in space and as jazz we what

1926
01:19:08,500 --> 01:19:05,500
we learned from Joao Steve will

1927
01:19:28,500 --> 01:19:08,510
definitely help us get towards these 16

1928
01:19:33,100 --> 01:19:31,720
yeah it's pretty big it does fit in the

1929
01:19:34,570 --> 01:19:33,110
sort of next-generation heavy launch

1930
01:19:37,480 --> 01:19:34,580
vehicles that NASA is considering

1931
01:19:39,040 --> 01:19:37,490
building now so that it's not totally

1932
01:19:41,170 --> 01:19:39,050
outside of the realm of possibility but

1933
01:19:42,280 --> 01:19:41,180
it's hard it is gonna be hard to do

1934
01:19:44,170 --> 01:19:42,290
something like that and and then I think

1935
01:19:46,840 --> 01:19:44,180
I didn't end up answering the timeline

1936
01:19:52,420 --> 01:19:46,850
question it would be something like the

1937
01:19:54,760 --> 01:19:52,430
2030s at the earliest and so we when

1938
01:19:55,270 --> 01:19:54,770

when James Webb was dreamed up we

1939
01:19:59,590 --> 01:19:55,280
thought it would be

1940
01:20:02,920 --> 01:19:59,600
what 2,095 for so many years it was 2012

1941
01:20:06,370 --> 01:20:02,930
and then it was 2014 and now it's 2018 I

1942
01:20:08,740 --> 01:20:06,380
just you know so it's it's yeah it's

1943
01:20:10,980 --> 01:20:08,750
where James Webb was 20 years ago

1944
01:20:15,010 --> 01:20:10,990
basically so it could be 20 or 30 years

1945
01:20:23,290 --> 01:20:15,020
if if we are able to obtain funding or

1946
01:20:26,710 --> 01:20:23,300
something like that taxpayers so you and

1947
01:20:27,820 --> 01:20:26,720
I largely so it's the us largely the

1948
01:20:30,100 --> 01:20:27,830
National Aeronautics and Space

1949
01:20:33,160 --> 01:20:30,110
Administration NASA the European

1950
01:20:34,630 --> 01:20:33,170
counterpart who collect you know tax

1951
01:20:43,300 --> 01:20:34,640
money through the government and then

1952
01:20:47,950 --> 01:20:45,280
know there's a space program there is

1953
01:20:49,360 --> 01:20:47,960
not a manned space program currently in

1954
01:20:51,570 --> 01:20:49,370
the u.s. so they're not we're not

1955
01:20:56,650 --> 01:20:51,580
sending our own astronauts with our own

1956
01:20:58,390 --> 01:20:56,660
spacecraft but there are these yes we

1957
01:21:00,130 --> 01:20:58,400
have these these are all robots now so

1958
01:21:02,710 --> 01:21:00,140
we have a robotic space program

1959
01:21:04,300 --> 01:21:02,720
essentially and for the purposes of

1960
01:21:07,120 --> 01:21:04,310
astronomy a lot of us can be done

1961
01:21:11,050 --> 01:21:07,130
robotically right and just for

1962
01:21:13,630 --> 01:21:11,060
perspective about 1/2 of a penny out of

1963
01:21:16,870 --> 01:21:13,640

the per dollar of the US budget goes to

1964
01:21:20,050 --> 01:21:16,880
NASA it's not a lot there's a question

1965
01:21:22,510 --> 01:21:20,060
way up in the corner those launch dates

1966
01:21:26,080 --> 01:21:22,520
are predicated mainly as we were

1967
01:21:29,920 --> 01:21:26,090
discussing when we go about is it is it

1968
01:21:33,610 --> 01:21:29,930
technology or is it the is it the

1969
01:21:34,900 --> 01:21:33,620
funding considerations both as far as

1970
01:21:36,550 --> 01:21:34,910
when you're setting these possible

1971
01:21:40,150 --> 01:21:36,560
launch dates when we talk about yeah

1972
01:21:43,060 --> 01:21:40,160
2018 apparently it sounds like it's more

1973
01:21:44,800 --> 01:21:43,070
of a funding matter I would say it's all

1974
01:21:47,800 --> 01:21:44,810
of the above

1975
01:21:49,600 --> 01:21:47,810
so if we were given an infinite number

1976
01:21:52,000 --> 01:21:49,610
of dollars right now it would still take

1977
01:21:54,340 --> 01:21:52,010
some time I think to create something

1978
01:21:56,470 --> 01:21:54,350
like this in part because all the people

1979
01:21:58,390 --> 01:21:56,480
who have expertise in telescope design

1980
01:22:00,490 --> 01:21:58,400
in space are currently working on James

1981
01:22:02,470 --> 01:22:00,500
Webb Space Telescope it's actually

1982
01:22:03,850 --> 01:22:02,480
people that you need to you need people

1983
01:22:05,620 --> 01:22:03,860
to work through the technological

1984
01:22:08,110 --> 01:22:05,630
challenges and sit down and actually

1985
01:22:10,240 --> 01:22:08,120
build engineer something like this and

1986
01:22:11,680 --> 01:22:10,250
so I think you know it's it's a

1987
01:22:13,180 --> 01:22:11,690
combination of these things we need the

1988
01:22:15,880 --> 01:22:13,190

money first of all to have to pay the

1989
01:22:18,100 --> 01:22:15,890
people to do the work but the technology

1990
01:22:20,110 --> 01:22:18,110
seems once it's written down and once

1991
01:22:22,600 --> 01:22:20,120
it's it's been thought up as a

1992
01:22:25,030 --> 01:22:22,610
possibility it's it's largely just

1993
01:22:26,320 --> 01:22:25,040
working through the details which I'm

1994
01:22:29,620 --> 01:22:26,330
glossing over a lot of stuff obviously

1995
01:22:32,170 --> 01:22:29,630
but I think many of the the major

1996
01:22:33,850 --> 01:22:32,180
challenges they are being overcome with

1997
01:22:35,980 --> 01:22:33,860
the James Webb Space Telescope so this

1998
01:22:37,990 --> 01:22:35,990
this advanced technology mission concept

1999
01:22:40,180 --> 01:22:38,000
doesn't have any major sort of

2000
01:22:41,980 --> 01:22:40,190
technological barriers in fact it has

2001
01:22:43,960 --> 01:22:41,990
fewer technological barriers than James

2002
01:22:45,910 --> 01:22:43,970
Webb did when it was brought up because

2003
01:22:47,440 --> 01:22:45,920
it's not gonna work in the infrared and

2004
01:22:50,230 --> 01:22:47,450
so that helps that helps a lot in terms

2005
01:22:52,600 --> 01:22:50,240
of the technology development and just

2006
01:22:55,030 --> 01:22:52,610
put in perspective what became Hubble

2007
01:22:59,200 --> 01:22:55,040
was first discussed by the National

2008
01:23:02,500 --> 01:22:59,210
Academy of Sciences in 1962 or 63 okay

2009
01:23:05,170 --> 01:23:02,510
so a having a pie in the sky idea can

2010
01:23:07,150 --> 01:23:05,180
take decades to come to come to an

2011
01:23:11,650 --> 01:23:07,160
actual telescope all right any last

2012
01:23:13,660 --> 01:23:11,660
questions all right let's see you

2013
01:23:14,080 --> 01:23:13,670

wouldn't let's say it's October next

2014
01:23:16,840 --> 01:23:14,090
month

2015
01:23:19,330 --> 01:23:16,850
November Mark kamionkowski second