

1  
00:00:00,000 --> 00:00:02,759  
good evening ladies and gentlemen and

2  
00:00:01,350 --> 00:00:06,899  
welcome to the Hubble Space Telescope

3  
00:00:02,759 --> 00:00:09,388  
public lecture series as all as I hope

4  
00:00:06,899 --> 00:00:11,009  
to be always every month although as you

5  
00:00:09,388 --> 00:00:13,349  
know this year I've been on a lot of

6  
00:00:11,009 --> 00:00:17,278  
travel I am your host dr. Frank summers

7  
00:00:13,349 --> 00:00:19,890  
of the office of public outreach if you

8  
00:00:17,278 --> 00:00:21,210  
did not get one on your way in over on

9  
00:00:19,890 --> 00:00:23,339  
the table you can get one on your way

10  
00:00:21,210 --> 00:00:26,070  
out we have our beautiful Hubble picture

11  
00:00:23,339 --> 00:00:29,250  
lithographs and tonight is an oldie but

12  
00:00:26,070 --> 00:00:34,140  
a goodie one of one of the favorites

13  
00:00:29,250 --> 00:00:35,519  
from 2009 the butterfly nebula now I

14  
00:00:34,140 --> 00:00:37,649  
will actually tell you the truth this

15  
00:00:35,520 --> 00:00:40,680  
isn't really the butterfly nebula it's

16  
00:00:37,649 --> 00:00:42,210  
the bug nebula but in our press release

17  
00:00:40,679 --> 00:00:44,670  
we said hey it looks a lot like a

18  
00:00:42,210 --> 00:00:46,829  
butterfly the press called it the

19  
00:00:44,670 --> 00:00:49,230  
butterfly nebula and the name is stuck

20  
00:00:46,829 --> 00:00:51,600  
so this is something that got renamed by

21  
00:00:49,229 --> 00:00:53,339  
a press release if you want to know more

22  
00:00:51,600 --> 00:00:54,989  
than just trivia about it if you want to

23  
00:00:53,340 --> 00:00:57,289  
know some science about it turn it over

24  
00:00:54,988 --> 00:01:00,718  
on the back and we have approximately

25  
00:00:57,289 --> 00:01:02,129  
330 words because I write some of these

26  
00:01:00,719 --> 00:01:03,870  
and when I'm giving it as a Frank you

27  
00:01:02,128 --> 00:01:06,509  
have 330 words and that's all you have

28  
00:01:03,869 --> 00:01:10,349  
to write on the back and information

29

00:01:06,510 --> 00:01:13,530  
about it grab one on the way out our

30  
00:01:10,349 --> 00:01:16,109  
talk tonight Greg Snyder studying

31  
00:01:13,530 --> 00:01:19,040  
virtual universes with supercomputer

32  
00:01:16,109 --> 00:01:23,188  
simulations this is gonna be a high-tech

33  
00:01:19,040 --> 00:01:27,299  
extravaganza and he gave me his his

34  
00:01:23,188 --> 00:01:29,879  
keynote file had 700 megabytes of visual

35  
00:01:27,299 --> 00:01:32,040  
goodness in it so I'm expecting some

36  
00:01:29,879 --> 00:01:33,929  
really cool movies because hey if you do

37  
00:01:32,040 --> 00:01:36,329  
simulations you got to do the cool

38  
00:01:33,930 --> 00:01:37,829  
movies got to attract attention but

39  
00:01:36,328 --> 00:01:39,449  
there's also fantastic science because

40  
00:01:37,828 --> 00:01:43,828  
I've seen some of the results from this

41  
00:01:39,450 --> 00:01:46,609  
this this work upcoming now next month

42  
00:01:43,828 --> 00:01:49,019  
we are voting on the first Tuesday right

43  
00:01:46,609 --> 00:01:50,578

everyone shake your head yes at least

44

00:01:49,019 --> 00:01:52,618

those who are at least at our 18 and a

45

00:01:50,578 --> 00:01:54,449

voting age in a retro if you're not

46

00:01:52,618 --> 00:01:56,640

registered go gout and get registered I

47

00:01:54,450 --> 00:01:58,740

don't care which party you vote for or

48

00:01:56,640 --> 00:02:00,560

who a candidate you vote for just get

49

00:01:58,739 --> 00:02:04,468

out and exercise your democratic right

50

00:02:00,560 --> 00:02:06,180

and vote on November 4th then remember

51

00:02:04,468 --> 00:02:08,758

you have your little I voted sticker

52

00:02:06,180 --> 00:02:10,430

well maybe we'll get I went to astronomy

53

00:02:08,758 --> 00:02:12,479

lecture stickers for the next weekend

54

00:02:10,430 --> 00:02:15,090

because we're going to have

55

00:02:12,479 --> 00:02:17,310

Cammi and kelskiy talking a telegram

56

00:02:15,090 --> 00:02:19,500

from the early universe and let me tell

57

00:02:17,310 --> 00:02:21,628

you folks this is one of the world

58  
00:02:19,500 --> 00:02:24,449  
experts on the Cosmic Microwave

59  
00:02:21,628 --> 00:02:26,399  
Background the remnant radiation from

60  
00:02:24,449 --> 00:02:29,639  
the Big Bang comes from half a million

61  
00:02:26,400 --> 00:02:31,980  
years after the Big Bang mark I worked

62  
00:02:29,639 --> 00:02:38,189  
with him Oh

63  
00:02:31,979 --> 00:02:40,649  
much too long ago 1997 1997-98 up at

64  
00:02:38,189 --> 00:02:43,439  
Columbia University I worked with him

65  
00:02:40,650 --> 00:02:45,060  
there he's fantastic he went out to

66  
00:02:43,439 --> 00:02:48,930  
Caltech and fortunately we got him back

67  
00:02:45,060 --> 00:02:51,000  
here to Johns Hopkins expert on this

68  
00:02:48,930 --> 00:02:53,840  
thing if you want to know that all the

69  
00:02:51,000 --> 00:02:59,250  
the the true nitty gritty he's the one

70  
00:02:53,840 --> 00:03:01,259  
December 2nd Joshua peak has volunteered

71  
00:02:59,250 --> 00:03:02,848  
to give that one but he didn't give me a

72  
00:03:01,259 --> 00:03:05,548  
title he just said he's talking about

73  
00:03:02,848 --> 00:03:07,949  
the is M which in astronomy is M is

74  
00:03:05,549 --> 00:03:11,819  
short for interstellar medium the gas

75  
00:03:07,949 --> 00:03:13,919  
the diffuse gas in between the stars he

76  
00:03:11,818 --> 00:03:16,169  
said he gave this talk in Princeton and

77  
00:03:13,919 --> 00:03:18,059  
it was an award-winning talk so I'm

78  
00:03:16,169 --> 00:03:20,098  
expecting it to be wonderful even if

79  
00:03:18,060 --> 00:03:20,750  
though I don't know quite all the

80  
00:03:20,098 --> 00:03:23,729  
details

81  
00:03:20,750 --> 00:03:27,629  
finally in January we will also have

82  
00:03:23,729 --> 00:03:29,848  
another second Tuesday because the

83  
00:03:27,629 --> 00:03:33,239  
auditorium is going to get retrofitted

84  
00:03:29,848 --> 00:03:35,358  
over the holidays well so what I'm told

85  
00:03:33,239 --> 00:03:39,060  
is we're going to have new carpets and

86

00:03:35,359 --> 00:03:41,159  
new chairs I'm looking up in the corner

87  
00:03:39,060 --> 00:03:43,079  
and I noticed some some chairs up there

88  
00:03:41,159 --> 00:03:44,969  
that aren't like the others and I'm

89  
00:03:43,079 --> 00:03:46,500  
wondering if those are prototypes as for

90  
00:03:44,969 --> 00:03:48,509  
what the chairs in this auditorium might

91  
00:03:46,500 --> 00:03:50,759  
look like when you come in in January

92  
00:03:48,509 --> 00:03:52,918  
but when I was trying to schedule this

93  
00:03:50,759 --> 00:03:55,439  
on the calendar the auditorium was

94  
00:03:52,919 --> 00:03:59,129  
blacked out for two weeks and they said

95  
00:03:55,439 --> 00:04:00,659  
push push the PLS back one week so that

96  
00:03:59,128 --> 00:04:03,179  
they can make sure the auditorium is

97  
00:04:00,659 --> 00:04:06,030  
pristine and beautiful for you so

98  
00:04:03,180 --> 00:04:08,819  
January 13th will have a fascinating

99  
00:04:06,030 --> 00:04:12,030  
topic by some amazing astronomer who I

100  
00:04:08,818 --> 00:04:15,149

will hook into and and and twist arms

101

00:04:12,030 --> 00:04:16,949

etc in the next month or two okay all

102

00:04:15,150 --> 00:04:18,750

right if you want to find out who that

103

00:04:16,949 --> 00:04:21,978

person is that I get the art gets the

104

00:04:18,750 --> 00:04:24,889

arm twisting you can go to our website

105

00:04:21,978 --> 00:04:27,348

here's our goal income site or goat

106

00:04:24,889 --> 00:04:29,780

or if you just search for Hubble public

107

00:04:27,348 --> 00:04:31,310

lecture you should find this page it has

108

00:04:29,779 --> 00:04:35,859

a list of the next three upcoming

109

00:04:31,310 --> 00:04:39,288

lectures as well as the archive back to

110

00:04:35,860 --> 00:04:42,439

2005 nine years of wonderful astronomy

111

00:04:39,288 --> 00:04:44,688

talks this link down here is also the

112

00:04:42,439 --> 00:04:47,090

one to go to our web casting our

113

00:04:44,689 --> 00:04:50,330

wonderful web casting team has web cast

114

00:04:47,089 --> 00:04:53,119

almost all of the talks back to dating



115  
00:04:50,329 --> 00:04:56,779  
back to 2005

116  
00:04:53,120 --> 00:04:58,370  
let's see email if you want a once a

117  
00:04:56,779 --> 00:05:00,348  
month or so announcement of what's

118  
00:04:58,370 --> 00:05:02,418  
coming just sign up on finding your

119  
00:05:00,348 --> 00:05:06,589  
email address we have a good record of

120  
00:05:02,418 --> 00:05:09,529  
no spam if you want to contact us send

121  
00:05:06,589 --> 00:05:12,049  
an email to public lecture at STScI edu

122  
00:05:09,529 --> 00:05:14,179  
you can give us a comment ask a question

123  
00:05:12,050 --> 00:05:15,770  
or it's a great way to sign up for the

124  
00:05:14,180 --> 00:05:18,468  
announcements because we'll already have

125  
00:05:15,769 --> 00:05:20,810  
your email address let's see for those

126  
00:05:18,468 --> 00:05:23,329  
who do social media we have facebook we

127  
00:05:20,810 --> 00:05:27,620  
have twitter we have Google+ we have

128  
00:05:23,329 --> 00:05:29,120  
Pinterest we may have other things that

129  
00:05:27,620 --> 00:05:30,408  
I don't know about Instagram or things

130  
00:05:29,120 --> 00:05:33,800  
like that

131  
00:05:30,408 --> 00:05:35,810  
I do Facebook and Google+ and Twitter a

132  
00:05:33,800 --> 00:05:39,288  
little every now and then and people

133  
00:05:35,810 --> 00:05:41,060  
sometimes want to follow me I don't do

134  
00:05:39,288 --> 00:05:46,009  
it that much so you're not gonna get a

135  
00:05:41,060 --> 00:05:47,329  
lot but hey I'm there just to keep up

136  
00:05:46,009 --> 00:05:49,490  
keep it up

137  
00:05:47,329 --> 00:05:51,829  
the observatory tonight is not going to

138  
00:05:49,490 --> 00:05:53,629  
happen unless you like to look through a

139  
00:05:51,829 --> 00:05:56,088  
telescope at raindrops you're not going

140  
00:05:53,629 --> 00:05:58,218  
to see much tonight so unfortunately

141  
00:05:56,088 --> 00:06:00,680  
have to come back Maryland space grant

142  
00:05:58,218 --> 00:06:02,718  
observatory does have open houses with

143

00:06:00,680 --> 00:06:04,939  
their telescope every Friday night if

144  
00:06:02,718 --> 00:06:07,629  
you go to their website MD dot space

145  
00:06:04,939 --> 00:06:10,879  
grant org you can find their observatory

146  
00:06:07,629 --> 00:06:13,789  
listed and they will tell you when their

147  
00:06:10,879 --> 00:06:18,080  
next open observing night is going to be

148  
00:06:13,788 --> 00:06:19,399  
okay all right so now my favorite part

149  
00:06:18,079 --> 00:06:22,538  
time of the evening news from the

150  
00:06:19,399 --> 00:06:26,258  
universe for October 2014

151  
00:06:22,538 --> 00:06:30,740  
our first story tonight hidden by a

152  
00:06:26,259 --> 00:06:34,158  
supernova well this is a story about the

153  
00:06:30,740 --> 00:06:36,588  
galaxy Messier 81 and this is a

154  
00:06:34,158 --> 00:06:37,478  
beautiful picture of this spiral galaxy

155  
00:06:36,588 --> 00:06:38,889  
from Hubble

156  
00:06:37,478 --> 00:06:40,930  
all right you can see it's got a

157  
00:06:38,889 --> 00:06:42,668

relatively large bulge it's got a

158

00:06:40,930 --> 00:06:45,370

somewhat circular feature around here

159

00:06:42,668 --> 00:06:49,778

with the spiral arms tailing off around

160

00:06:45,370 --> 00:06:52,269

it now there was a supernova in Messier

161

00:06:49,778 --> 00:06:55,990

81 Messier 81 it's actually relatively

162

00:06:52,269 --> 00:06:58,299

close by okay it's only tens of millions

163

00:06:55,990 --> 00:07:01,960

of light years away so it's relatively

164

00:06:58,300 --> 00:07:06,038

nearby and we saw a supernova back in

165

00:07:01,959 --> 00:07:09,248

1993 here's the image ground-based image

166

00:07:06,038 --> 00:07:11,978

from the Canada France Hawaii telescope

167

00:07:09,249 --> 00:07:13,900

see fht before the supernova went off

168

00:07:11,978 --> 00:07:19,658

and you see that bright spot there that

169

00:07:13,899 --> 00:07:22,478

is the supernova 1993 J and so you can

170

00:07:19,658 --> 00:07:25,569

see that the supernovae are extremely

171

00:07:22,478 --> 00:07:28,240

bright they can be seen galaxies tens of

172  
00:07:25,569 --> 00:07:30,669  
millions of light years away really cool

173  
00:07:28,240 --> 00:07:36,278  
that makes a supernova study of all

174  
00:07:30,668 --> 00:07:40,418  
across the local universe now 1993 J is

175  
00:07:36,278 --> 00:07:42,399  
a type 2b supernova and I'm not going to

176  
00:07:40,418 --> 00:07:45,758  
explain that in great detail just it's a

177  
00:07:42,399 --> 00:07:49,930  
massive star and the presence or not

178  
00:07:45,759 --> 00:07:52,658  
presence of hydrogen lines etc is is

179  
00:07:49,930 --> 00:07:55,478  
noted in its spectrum so the idea is

180  
00:07:52,658 --> 00:07:57,610  
that you have two massive stars orbiting

181  
00:07:55,478 --> 00:08:01,658  
around each other that they are a binary

182  
00:07:57,610 --> 00:08:04,028  
star one of them evolves to become a

183  
00:08:01,658 --> 00:08:06,418  
giant star which that happens at the end

184  
00:08:04,028 --> 00:08:10,259  
of the lives of a massive star and

185  
00:08:06,418 --> 00:08:13,028  
material it flows off of the giant of

186  
00:08:10,259 --> 00:08:16,120  
the more massive one the one that

187  
00:08:13,028 --> 00:08:18,870  
evolves first on to the other one That

188  
00:08:16,120 --> 00:08:23,379  
star then goes supernova explodes and

189  
00:08:18,870 --> 00:08:24,968  
when and leaving behind a supernova

190  
00:08:23,379 --> 00:08:28,749  
remnant that eventually will fade away

191  
00:08:24,968 --> 00:08:31,899  
but also the material fed onto this

192  
00:08:28,749 --> 00:08:33,729  
other companion star rejuvenates the

193  
00:08:31,899 --> 00:08:36,698  
star it adds more hydrogen to its

194  
00:08:33,729 --> 00:08:38,889  
envelope allows it to get bigger and

195  
00:08:36,698 --> 00:08:43,509  
more and brighter and sort of

196  
00:08:38,889 --> 00:08:44,769  
rejuvenates that star missus I want to

197  
00:08:43,509 --> 00:08:46,409  
say it's like a blue straggler but you

198  
00:08:44,769 --> 00:08:50,310  
guys don't know what a blue striker is

199  
00:08:46,409 --> 00:08:52,829  
it's where by adding new material on

200

00:08:50,309 --> 00:08:56,849  
the star it gives it a new lease on life

201  
00:08:52,830 --> 00:09:00,629  
for a little bit longer so seeing 1993 J

202  
00:08:56,850 --> 00:09:04,259  
as as a supernova explosion and from its

203  
00:09:00,629 --> 00:09:08,549  
spectrum determining that it's a type 2b

204  
00:09:04,259 --> 00:09:14,659  
and this is our idea of what a type 2b

205  
00:09:08,549 --> 00:09:18,809  
should be so the question is is there a

206  
00:09:14,659 --> 00:09:21,419  
rejuvenated bright blue star left in the

207  
00:09:18,809 --> 00:09:23,579  
wake of the supernova how are we gonna

208  
00:09:21,419 --> 00:09:26,129  
tell well the thing I didn't tell you

209  
00:09:23,580 --> 00:09:27,480  
about is that Hubble image is twenty two

210  
00:09:26,129 --> 00:09:30,360  
thousand six hundred and twenty pixels

211  
00:09:27,480 --> 00:09:34,070  
by fifteen thousand two hundred pixels

212  
00:09:30,360 --> 00:09:38,310  
or three hundred and eighty four

213  
00:09:34,070 --> 00:09:41,700  
megapixels that's a lot of galaxies okay

214  
00:09:38,309 --> 00:09:44,369

that's a lot of resolution so much

215

00:09:41,700 --> 00:09:48,450  
resolution that we can go back in there

216

00:09:44,370 --> 00:09:51,778  
and start searching for the leftover

217

00:09:48,450 --> 00:09:54,870  
star now for the past twenty years

218

00:09:51,778 --> 00:09:57,330  
the supernova explosion the remnant the

219

00:09:54,870 --> 00:10:00,740  
the gas blown off in that supernova

220

00:09:57,330 --> 00:10:03,570  
explosion has been too bright but

221

00:10:00,740 --> 00:10:05,970  
recently we were able to look in with

222

00:10:03,570 --> 00:10:08,700  
Hubble and can you pick out the

223

00:10:05,970 --> 00:10:10,529  
supernova you shouldn't be able to

224

00:10:08,700 --> 00:10:14,220  
because that's faded away but you know

225

00:10:10,529 --> 00:10:18,149  
it's somewhere in here alright alright

226

00:10:14,220 --> 00:10:22,649  
and we're I in one of these blue dots in

227

00:10:18,149 --> 00:10:27,199  
here is supposed to be the blue star of

228

00:10:22,649 --> 00:10:32,059  
the companion ok this is the first time



229  
00:10:27,200 --> 00:10:35,970  
that they have been able to identify the

230  
00:10:32,059 --> 00:10:38,579  
companion star left over from a type 2b

231  
00:10:35,970 --> 00:10:40,320  
supernova alright that idea that I that

232  
00:10:38,580 --> 00:10:42,780  
cartoon that I showed you has been our

233  
00:10:40,320 --> 00:10:47,129  
theoretical model of how these type two

234  
00:10:42,779 --> 00:10:49,230  
bees must happen but this is of now we

235  
00:10:47,129 --> 00:10:52,439  
have confirmation in that yes there is a

236  
00:10:49,230 --> 00:10:55,440  
bright big blue star left over in the

237  
00:10:52,440 --> 00:10:57,089  
wake of supernova 1993 J it has just

238  
00:10:55,440 --> 00:11:00,570  
been hidden within a supernova explosion

239  
00:10:57,089 --> 00:11:02,210  
for the past twenty years that's kind of

240  
00:11:00,570 --> 00:11:05,910  
cool

241  
00:11:02,210 --> 00:11:09,210  
next we have signing up to Mars but in

242  
00:11:05,909 --> 00:11:11,399  
the fall not the spring which is a

243  
00:11:09,210 --> 00:11:14,160  
convoluted title because I wanted to get

244  
00:11:11,399 --> 00:11:18,208  
the word siding and spring in there you

245  
00:11:14,159 --> 00:11:20,819  
guys remember yes we have comet siding

246  
00:11:18,208 --> 00:11:24,389  
spring I told you about this a few

247  
00:11:20,820 --> 00:11:26,070  
months ago okay and I haven't mentioned

248  
00:11:24,389 --> 00:11:27,659  
it since because well I'll tell you why

249  
00:11:26,070 --> 00:11:30,629  
I haven't mentioned it since all right

250  
00:11:27,659 --> 00:11:34,860  
so this is a wonderful picture of comet

251  
00:11:30,629 --> 00:11:37,769  
siding spring taken in February 2nd of

252  
00:11:34,860 --> 00:11:40,019  
2014 by a wonderful astronomer I used a

253  
00:11:37,769 --> 00:11:42,149  
lot of his Ison images to Damian peach

254  
00:11:40,019 --> 00:11:44,129  
he's become very famous for his

255  
00:11:42,149 --> 00:11:46,769  
wonderful comet images alright and it's

256  
00:11:44,129 --> 00:11:48,208  
just hey it's another comet right what's

257

00:11:46,769 --> 00:11:51,799  
special about siding spring you guys

258  
00:11:48,208 --> 00:11:54,028  
remember well siding spring is special

259  
00:11:51,799 --> 00:11:56,370  
well alright this is a Hubble image of

260  
00:11:54,028 --> 00:11:57,689  
it I want to show in March of it so

261  
00:11:56,370 --> 00:11:59,909  
Hubble has actually been taking images

262  
00:11:57,690 --> 00:12:02,730  
of it why is hoping taking image of it

263  
00:11:59,909 --> 00:12:06,449  
because siding spring is going to pass

264  
00:12:02,730 --> 00:12:09,120  
very close to Mars now this is really

265  
00:12:06,450 --> 00:12:10,950  
crazy because siding spring is coming in

266  
00:12:09,120 --> 00:12:13,230  
from the Oort cloud it's way way out

267  
00:12:10,950 --> 00:12:16,830  
there it's coming in and if this is the

268  
00:12:13,230 --> 00:12:19,129  
plane of our planet orbits its orbit is

269  
00:12:16,830 --> 00:12:21,750  
like this okay so it's coming in

270  
00:12:19,129 --> 00:12:24,929  
swooping up and it just happens to have

271  
00:12:21,750 --> 00:12:27,839

its its perihelion close to the orbit of

272

00:12:24,929 --> 00:12:30,179

Mars and it's passing through it's at

273

00:12:27,839 --> 00:12:33,240

that point at the same time Mars is

274

00:12:30,179 --> 00:12:36,419

passing by which is really crazy what a

275

00:12:33,240 --> 00:12:39,509

wonderful coincidence okay siding spring

276

00:12:36,419 --> 00:12:44,490

is going to pass by Mars this month okay

277

00:12:39,509 --> 00:12:47,850

all right and here is the closeness of

278

00:12:44,490 --> 00:12:49,950

the passage this is a scale of scale

279

00:12:47,850 --> 00:12:51,690

scale drawing of Mars and here is the

280

00:12:49,950 --> 00:12:53,190

orbit of siding spring there gonna be a

281

00:12:51,690 --> 00:12:54,480

hundred and thirty-five thousand

282

00:12:53,190 --> 00:12:58,230

kilometers across

283

00:12:54,480 --> 00:13:00,089

apart which in terms of astronomical

284

00:12:58,230 --> 00:13:04,649

context that's a near miss

285

00:13:00,089 --> 00:13:06,720

okay I know 135,000 kilometers is a lot

286  
00:13:04,649 --> 00:13:08,339  
to you and me but on the scale of the

287  
00:13:06,720 --> 00:13:12,450  
solar system especially on the scale the

288  
00:13:08,339 --> 00:13:13,900  
Oort cloud that's nothing all right and

289  
00:13:12,450 --> 00:13:17,290  
one way to remember it

290  
00:13:13,899 --> 00:13:20,769  
about 20 Mars diameters okay

291  
00:13:17,289 --> 00:13:23,439  
whereas our moon is 30 earth diameters

292  
00:13:20,769 --> 00:13:25,840  
away so this would effectively pass

293  
00:13:23,440 --> 00:13:28,030  
closer if it were coming past Earth on

294  
00:13:25,840 --> 00:13:30,100  
the same scale it would be closer than

295  
00:13:28,029 --> 00:13:31,480  
the moon right it passed between Earth

296  
00:13:30,100 --> 00:13:33,940  
and the moon's that's how close it's

297  
00:13:31,480 --> 00:13:37,360  
going to come all right but it's 20 Mars

298  
00:13:33,940 --> 00:13:40,000  
diameters I will also note that Mars is

299  
00:13:37,360 --> 00:13:42,009  
pathetic little nothings of moons phobos

300  
00:13:40,000 --> 00:13:43,750  
and deimos which are most likely just

301  
00:13:42,009 --> 00:13:46,179  
captured asteroids and not really

302  
00:13:43,750 --> 00:13:48,039  
respectable moons not that I have

303  
00:13:46,179 --> 00:13:51,339  
opinion on opinions on these things

304  
00:13:48,039 --> 00:13:53,529  
all right orbiting much much closer so

305  
00:13:51,340 --> 00:13:57,629  
it won't be it won't be passing inside

306  
00:13:53,529 --> 00:14:01,000  
of Mars as months so the question is as

307  
00:13:57,629 --> 00:14:03,580  
citing spring is getting closer to the

308  
00:14:01,000 --> 00:14:05,740  
Sun it should be melting more it should

309  
00:14:03,580 --> 00:14:08,320  
be giving off more gas and should be

310  
00:14:05,740 --> 00:14:10,269  
developing a larger coma and the

311  
00:14:08,320 --> 00:14:14,170  
question is whether or not that coma is

312  
00:14:10,269 --> 00:14:16,929  
large enough so that the gas will

313  
00:14:14,169 --> 00:14:19,509  
actually pass over Mars well Mars pass

314

00:14:16,929 --> 00:14:22,179  
through the comet of the coma of the

315  
00:14:19,509 --> 00:14:23,710  
comet okay all that gas come across Mars

316  
00:14:22,179 --> 00:14:28,149  
because then you could see some cool

317  
00:14:23,710 --> 00:14:30,250  
interactions all right well Hubble has

318  
00:14:28,149 --> 00:14:32,860  
been monitoring has been has been

319  
00:14:30,250 --> 00:14:35,470  
looking at it and this is the normal

320  
00:14:32,860 --> 00:14:38,289  
image from Hubble and this is the model

321  
00:14:35,470 --> 00:14:40,480  
subtracted image okay so taking a smooth

322  
00:14:38,289 --> 00:14:42,429  
spherical model out of it to try and see

323  
00:14:40,480 --> 00:14:44,110  
if there are jets coming off because the

324  
00:14:42,429 --> 00:14:46,299  
amount of Jets that it's it's emitting

325  
00:14:44,110 --> 00:14:49,330  
has something to tell us

326  
00:14:46,299 --> 00:14:52,209  
how large the coma might become and

327  
00:14:49,330 --> 00:14:54,700  
Hubble has moderate it since October of

328  
00:14:52,210 --> 00:14:57,370

last year of course people have

329

00:14:54,700 --> 00:15:00,820

continued to monitor it here is one from

330

00:14:57,370 --> 00:15:02,460

September 6th and here's a picture of

331

00:15:00,820 --> 00:15:05,920

siding spring

332

00:15:02,460 --> 00:15:08,019

unfortunately the reports are that it

333

00:15:05,919 --> 00:15:12,000

has dimmed in brightness considerably

334

00:15:08,019 --> 00:15:16,449

over the past few weeks two months okay

335

00:15:12,000 --> 00:15:18,879

so the current view is that the coma

336

00:15:16,450 --> 00:15:21,550

isn't really huge enough that it's going

337

00:15:18,879 --> 00:15:24,340

to cause a like a really amazing

338

00:15:21,549 --> 00:15:26,679

interaction with Mars okay you could

339

00:15:24,340 --> 00:15:27,519

imagine that material from the coma

340

00:15:26,679 --> 00:15:29,529

could hit MA

341

00:15:27,519 --> 00:15:31,750

you get Aurora you can get an amazing

342

00:15:29,529 --> 00:15:35,980

meteor show all right



343  
00:15:31,750 --> 00:15:37,299  
meteor meteor shower but we're not sure

344  
00:15:35,980 --> 00:15:40,389  
we're gonna see much okay

345  
00:15:37,299 --> 00:15:41,589  
so there's very we're optimistic like

346  
00:15:40,389 --> 00:15:44,110  
Ison you remember what happened with

347  
00:15:41,590 --> 00:15:46,360  
Ison last year right all this build-up

348  
00:15:44,110 --> 00:15:48,700  
and then oh it breaks up as it passes

349  
00:15:46,360 --> 00:15:50,289  
the Sun well at least this one were sure

350  
00:15:48,700 --> 00:15:52,330  
we're telling you in advance hey it's

351  
00:15:50,289 --> 00:15:54,219  
dimmed a bit it's not necessarily gonna

352  
00:15:52,330 --> 00:15:56,020  
be a spectacular show but we're gonna

353  
00:15:54,220 --> 00:15:57,700  
still watch anyways because we get

354  
00:15:56,019 --> 00:16:00,250  
science out of it no matter whether it's

355  
00:15:57,700 --> 00:16:03,070  
a great show visual show or not okay

356  
00:16:00,250 --> 00:16:04,480  
Hubble will be watching Hubble has the

357  
00:16:03,070 --> 00:16:06,190  
finest resolution so it'll be looking at

358  
00:16:04,480 --> 00:16:08,789  
the comet other things we'll be

359  
00:16:06,190 --> 00:16:11,500  
monitoring Mars and the most important

360  
00:16:08,789 --> 00:16:14,889  
missions will of course already be at

361  
00:16:11,500 --> 00:16:18,039  
Mars they're in situ okay so we have the

362  
00:16:14,889 --> 00:16:19,689  
Rovers on the surface of Mars but the

363  
00:16:18,039 --> 00:16:21,639  
ones that are really a little more

364  
00:16:19,690 --> 00:16:23,440  
concerned are the ones in orbit around

365  
00:16:21,639 --> 00:16:26,319  
Mars like Mars Reconnaissance Orbiter

366  
00:16:23,440 --> 00:16:29,680  
and the brand-new maven mission that is

367  
00:16:26,320 --> 00:16:32,110  
just arriving at Mars this month okay

368  
00:16:29,679 --> 00:16:34,870  
they need to make sure that if there's

369  
00:16:32,110 --> 00:16:38,379  
going to be a significant meteor storm

370  
00:16:34,870 --> 00:16:40,029  
that they are protected okay so they

371

00:16:38,379 --> 00:16:42,909  
have various plans and they're watching

372  
00:16:40,029 --> 00:16:45,100  
extremely carefully they will also be

373  
00:16:42,909 --> 00:16:46,959  
doing as many observations as possible

374  
00:16:45,100 --> 00:16:52,590  
so I can't tell you what's gonna happen

375  
00:16:46,960 --> 00:16:55,690  
in what is it 12 days 11 12 days but

376  
00:16:52,590 --> 00:16:57,519  
Sciences are gonna look at and what I

377  
00:16:55,690 --> 00:16:59,980  
really hope is that we can get something

378  
00:16:57,519 --> 00:17:02,169  
cool like this with all sorts of meteors

379  
00:16:59,980 --> 00:17:05,588  
crashing in on and Mars is thin

380  
00:17:02,169 --> 00:17:09,609  
atmosphere but stay tuned we'll find out

381  
00:17:05,588 --> 00:17:12,819  
in two weeks time alright finally the

382  
00:17:09,609 --> 00:17:15,759  
last story blood moon in the morning and

383  
00:17:12,819 --> 00:17:19,299  
what is Blood Moon refer to it refers to

384  
00:17:15,759 --> 00:17:21,819  
a total lunar eclipse this is a

385  
00:17:19,299 --> 00:17:25,240

wonderful picture composite picture from

386

00:17:21,819 --> 00:17:28,839

our very own Zolt Levay of a total lunar

387

00:17:25,240 --> 00:17:31,750

eclipse where when the moon is in the

388

00:17:28,839 --> 00:17:34,669

Umbra of Earth's shadow it becomes red

389

00:17:31,750 --> 00:17:37,599

and hence the name Blood Moon

390

00:17:34,670 --> 00:17:40,880

all right this is happening tonight

391

00:17:37,599 --> 00:17:43,459

tomorrow morning there will be a total

392

00:17:40,880 --> 00:17:46,400

lunar eclipse and it will be visible for

393

00:17:43,460 --> 00:17:48,019

a very short time from Baltimore but

394

00:17:46,400 --> 00:17:51,620

there are a few problems with it okay so

395

00:17:48,019 --> 00:17:53,599

here is the timing of it the partial

396

00:17:51,619 --> 00:17:56,779

eclipses starting into the Umbra starts

397

00:17:53,599 --> 00:18:00,649

at 5:15 a.m. it total eclipse begins at

398

00:17:56,779 --> 00:18:02,960

6:25 a.m. the total eclipse ends at 7:24

399

00:18:00,650 --> 00:18:06,620

a.m. and the partial eclipse ends at

400  
00:18:02,960 --> 00:18:08,329  
8:34 a.m. if you look at those times and

401  
00:18:06,619 --> 00:18:11,089  
think about it well there's one major

402  
00:18:08,329 --> 00:18:14,449  
problem with that well first of all

403  
00:18:11,089 --> 00:18:17,179  
sunrise is at 7:09 a.m. and the moon

404  
00:18:14,450 --> 00:18:19,340  
sets at 7:00 11 a.m. so somewhere

405  
00:18:17,180 --> 00:18:21,950  
between here and here the moon's gonna

406  
00:18:19,339 --> 00:18:24,379  
go below the horizon so you're not gonna

407  
00:18:21,950 --> 00:18:26,720  
be able to see it furthermore if the

408  
00:18:24,380 --> 00:18:29,540  
moon is that close to the horizon you

409  
00:18:26,720 --> 00:18:32,630  
really need a very clear western horizon

410  
00:18:29,539 --> 00:18:36,619  
okay the last total lunar eclipse that I

411  
00:18:32,630 --> 00:18:38,810  
saw I was on a cruise ship we are

412  
00:18:36,619 --> 00:18:41,000  
pulling into port in San Diego and off

413  
00:18:38,809 --> 00:18:42,589  
the back of the ship we had a fantastic

414  
00:18:41,000 --> 00:18:44,720  
view because all we had was ocean out

415  
00:18:42,589 --> 00:18:48,079  
there to the west it was it was

416  
00:18:44,720 --> 00:18:50,360  
wonderful I don't know of a good place

417  
00:18:48,079 --> 00:18:52,789  
in Baltimore that has a totally clear

418  
00:18:50,359 --> 00:18:55,099  
western horizon but if you can find one

419  
00:18:52,789 --> 00:18:59,329  
and want to get up early tomorrow I

420  
00:18:55,099 --> 00:19:01,189  
would say that about 6 a.m. 5:45 6 a.m.

421  
00:18:59,329 --> 00:19:03,919  
you'll start to be able to notice the

422  
00:19:01,190 --> 00:19:05,990  
partial eclipse and you'll be able to

423  
00:19:03,920 --> 00:19:08,090  
watch it through till about 6:30 being

424  
00:19:05,990 --> 00:19:10,039  
in a really clear western horizon it's

425  
00:19:08,089 --> 00:19:11,569  
also kind of cool because you're looking

426  
00:19:10,039 --> 00:19:13,759  
out into the West and you're seeing them

427  
00:19:11,569 --> 00:19:15,139  
the eclipse of the Moon and then all

428

00:19:13,759 --> 00:19:16,879  
wrong the East you're seeing the

429  
00:19:15,140 --> 00:19:19,070  
pre-dawn sunrise stuff coming up it's

430  
00:19:16,880 --> 00:19:22,010  
just a sort of a magical feeling alright

431  
00:19:19,069 --> 00:19:25,399  
looking at that so if you can find a

432  
00:19:22,009 --> 00:19:26,930  
really cool empty western horizon please

433  
00:19:25,400 --> 00:19:28,610  
go out and observe it and enjoy

434  
00:19:26,930 --> 00:19:30,590  
yourselves and dress warmly bring hot

435  
00:19:28,609 --> 00:19:32,240  
chocolate that's true for all observing

436  
00:19:30,589 --> 00:19:35,169  
right you got to bring hot chocolate for

437  
00:19:32,240 --> 00:19:35,170  
observing yes

438  
00:19:38,829 --> 00:19:52,049  
okay so we're all gonna invade this

439  
00:19:48,369 --> 00:19:52,049  
building at 5:30 in the morning right

440  
00:19:52,319 --> 00:19:55,869  
the World Trade Center the World Trade

441  
00:19:54,640 --> 00:19:57,310  
Center but will they be able to see the

442  
00:19:55,869 --> 00:20:00,099

West okay

443

00:19:57,309 --> 00:20:02,379

seeing the East with the ocean over the

444

00:20:00,099 --> 00:20:05,519

Atlantic Ocean is easy but remember you

445

00:20:02,380 --> 00:20:08,140

got to be able to look to the west okay

446

00:20:05,519 --> 00:20:09,910

anyways good luck to you all

447

00:20:08,140 --> 00:20:12,670

if you want to get up early to do your

448

00:20:09,910 --> 00:20:15,009

Eclipse of observing okay all right I

449

00:20:12,670 --> 00:20:18,460

have taken enough time it's time to get

450

00:20:15,009 --> 00:20:22,569

to our featured speaker and our speaker

451

00:20:18,460 --> 00:20:26,289

tonight is Greg Snyder Greg started his

452

00:20:22,569 --> 00:20:27,639

undergraduate work at Princeton he

453

00:20:26,289 --> 00:20:31,659

started I guess he finished it there too

454

00:20:27,640 --> 00:20:34,240

yes then went on to Harvard where he

455

00:20:31,660 --> 00:20:36,279

worked in his graduate work with a

456

00:20:34,240 --> 00:20:39,099

friend of mine Lars Hearn Quist one of



457  
00:20:36,279 --> 00:20:42,009  
the preeminent astronomers in computer

458  
00:20:39,099 --> 00:20:43,990  
simulations and then he we are fortunate

459  
00:20:42,009 --> 00:20:46,390  
enough to get him down here

460  
00:20:43,990 --> 00:20:48,609  
he has worked on one of the most

461  
00:20:46,390 --> 00:20:50,710  
exciting projects in computer

462  
00:20:48,609 --> 00:20:51,490  
simulations in astronomy and he'll tell

463  
00:20:50,710 --> 00:20:55,799  
you about that tonight

464  
00:20:51,490 --> 00:20:55,799  
ladies and gentlemen dr. Greg Snyder

465  
00:21:07,690 --> 00:21:15,409  
testing can everyone hear me

466  
00:21:10,398 --> 00:21:17,148  
great so thanks for coming to my talk

467  
00:21:15,409 --> 00:21:18,109  
and it's it's a great pleasure for me to

468  
00:21:17,148 --> 00:21:19,428  
be able to tell you a little bit about

469  
00:21:18,108 --> 00:21:21,499  
the work that I've been involved with

470  
00:21:19,429 --> 00:21:25,460  
the past couple of years and so my talk

471  
00:21:21,499 --> 00:21:30,079  
is titled sorry first time I've used

472  
00:21:25,460 --> 00:21:31,729  
this gadget my studying virtual you know

473  
00:21:30,079 --> 00:21:35,269  
universities with supercomputer

474  
00:21:31,729 --> 00:21:37,879  
simulations and that is sort of a

475  
00:21:35,269 --> 00:21:39,700  
shorthand for trying to understand the

476  
00:21:37,878 --> 00:21:41,628  
formation of galaxies in the universe

477  
00:21:39,700 --> 00:21:43,819  
and so I'm gonna tell you a little bit

478  
00:21:41,628 --> 00:21:45,858  
about something called the illustrious

479  
00:21:43,819 --> 00:21:48,558  
project and so here's our website down

480  
00:21:45,858 --> 00:21:51,439  
at the bottom Electress project org and

481  
00:21:48,558 --> 00:21:54,138  
this collaboration is from these folks

482  
00:21:51,440 --> 00:21:56,298  
listed here and others and the the dry

483  
00:21:54,138 --> 00:21:58,699  
title of a paper that we put out in the

484  
00:21:56,298 --> 00:22:00,710  
spring is called properties of galaxies

485

00:21:58,700 --> 00:22:02,659  
reproduced by a hydrodynamic simulation

486  
00:22:00,710 --> 00:22:03,979  
and so in my talk I'll unpack that a

487  
00:22:02,659 --> 00:22:05,419  
little bit and try and describe to you

488  
00:22:03,979 --> 00:22:08,509  
what what what this means and why this

489  
00:22:05,419 --> 00:22:10,519  
is a challenging thing to do and so the

490  
00:22:08,509 --> 00:22:13,009  
the one word I wanted to highlight here

491  
00:22:10,519 --> 00:22:15,769  
is hydrodynamic simulation so that just

492  
00:22:13,009 --> 00:22:18,528  
means gas physics so it's hydro for

493  
00:22:15,769 --> 00:22:20,719  
water but in the same way it's sort of

494  
00:22:18,528 --> 00:22:22,548  
modeling the fluids that are important

495  
00:22:20,719 --> 00:22:24,710  
in the universe so that's where that

496  
00:22:22,548 --> 00:22:27,469  
word comes from and the main challenge

497  
00:22:24,710 --> 00:22:29,479  
with a simulation like this one is to

498  
00:22:27,469 --> 00:22:30,889  
reproduce galaxies so the topic of this

499  
00:22:29,479 --> 00:22:32,659

talk is going to be about galaxies and

500

00:22:30,888 --> 00:22:33,798

here's just a smattering of simulated

501

00:22:32,659 --> 00:22:35,299

galaxies that came out of the

502

00:22:33,798 --> 00:22:37,278

illustrious project so these are

503

00:22:35,298 --> 00:22:38,868

galaxies as they exist today as they

504

00:22:37,278 --> 00:22:41,058

might be observed with a telescope like

505

00:22:38,868 --> 00:22:42,528

HST or the Hubble Space Telescope and so

506

00:22:41,058 --> 00:22:44,358

what we see in the engineer by the

507

00:22:42,528 --> 00:22:46,669

universe is galaxies fall into roughly

508

00:22:44,358 --> 00:22:48,319

two categories there are disk galaxies

509

00:22:46,669 --> 00:22:49,580

there are these star forming spiral

510

00:22:48,319 --> 00:22:51,048

galaxies like the one Frank showed

511

00:22:49,579 --> 00:22:52,668

earlier and then there are these

512

00:22:51,048 --> 00:22:55,579

elliptical galaxies which are smoother

513

00:22:52,669 --> 00:22:57,169

and redder galaxies and so the idea is

514  
00:22:55,579 --> 00:23:01,728  
to try and simulate this population of

515  
00:22:57,169 --> 00:23:03,349  
galaxies all at once I want to put this

516  
00:23:01,729 --> 00:23:04,969  
we'll spend a few minutes to put this in

517  
00:23:03,348 --> 00:23:05,829  
context a little bit so no galaxies can

518  
00:23:04,969 --> 00:23:07,960  
be kind of an abstract

519  
00:23:05,829 --> 00:23:09,460  
topic so first I want to imagine that

520  
00:23:07,960 --> 00:23:11,259  
you're in the solar system so we all

521  
00:23:09,460 --> 00:23:12,970  
live on planet Earth here third planet

522  
00:23:11,259 --> 00:23:15,278  
from the Sun this is not exactly to

523  
00:23:12,970 --> 00:23:17,140  
scale it's a sort of a toy model of a

524  
00:23:15,278 --> 00:23:19,179  
solar system so imagine that you're a

525  
00:23:17,140 --> 00:23:22,299  
star system or a solar system like this

526  
00:23:19,179 --> 00:23:23,590  
one a galaxy is just a collection of a

527  
00:23:22,298 --> 00:23:26,139  
hundred billion different star systems

528  
00:23:23,589 --> 00:23:28,329  
so you can imagine putting our solar

529  
00:23:26,140 --> 00:23:30,278  
system or any solar system in its proper

530  
00:23:28,329 --> 00:23:31,928  
place in the galaxy like this so if you

531  
00:23:30,278 --> 00:23:33,970  
take the solar system and shrink it down

532  
00:23:31,929 --> 00:23:35,798  
to a size much smaller than even a

533  
00:23:33,970 --> 00:23:37,538  
single pixel of the 38 or more

534  
00:23:35,798 --> 00:23:39,009  
megapixels that may be on this image

535  
00:23:37,538 --> 00:23:40,720  
it's still smaller than that

536  
00:23:39,009 --> 00:23:43,480  
and so our solar system is extremely

537  
00:23:40,720 --> 00:23:45,669  
tiny compared to the system of a galaxy

538  
00:23:43,480 --> 00:23:47,860  
and so galaxy is now this hundred

539  
00:23:45,669 --> 00:23:49,960  
billion star systems that are bound

540  
00:23:47,859 --> 00:23:51,849  
together by their own gravity and so

541  
00:23:49,960 --> 00:23:53,288  
this is say an image of the light from a

542

00:23:51,849 --> 00:23:56,349  
hundred billion stars that are orbiting

543  
00:23:53,288 --> 00:23:59,829  
around this galaxy over the course of

544  
00:23:56,349 --> 00:24:02,288  
hundreds of millions of years so that's

545  
00:23:59,829 --> 00:24:04,928  
a galaxy and galaxies live in a very

546  
00:24:02,288 --> 00:24:06,069  
large observed universe that we've come

547  
00:24:04,929 --> 00:24:08,950  
to understand over the past couple

548  
00:24:06,069 --> 00:24:11,619  
decades and I want to take take this a

549  
00:24:08,950 --> 00:24:13,419  
few steps and show you the solar system

550  
00:24:11,619 --> 00:24:15,308  
disappearing there and this galaxy

551  
00:24:13,419 --> 00:24:17,080  
fitting into its context in the universe

552  
00:24:15,308 --> 00:24:19,509  
and so this is now a cluster of galaxies

553  
00:24:17,079 --> 00:24:22,089  
of different types shown with an HST

554  
00:24:19,509 --> 00:24:23,950  
image here so this is a cluster of

555  
00:24:22,089 --> 00:24:26,408  
galaxies and I wanted to just highlight

556  
00:24:23,950 --> 00:24:27,940

where a galaxy like this one which is

557

00:24:26,409 --> 00:24:29,440

not exactly the Milky Way but it looks

558

00:24:27,940 --> 00:24:32,019

like we think the Milky Way it looks

559

00:24:29,440 --> 00:24:33,340

like would appear in its context in the

560

00:24:32,019 --> 00:24:35,888

universe and so this is a cluster of

561

00:24:33,339 --> 00:24:38,500

galaxies and here is now what a galaxy

562

00:24:35,888 --> 00:24:42,689

might look like inside this this larger

563

00:24:38,500 --> 00:24:46,480

group of galaxies that's not all

564

00:24:42,690 --> 00:24:47,980

galaxies are even are there are hundreds

565

00:24:46,480 --> 00:24:49,630

of billions of known galaxies this is a

566

00:24:47,980 --> 00:24:51,788

survey of galaxies the Sloan Digital Sky

567

00:24:49,630 --> 00:24:52,809

Survey showing you where this cluster of

568

00:24:51,788 --> 00:24:54,970

galaxies that I showed you on the

569

00:24:52,808 --> 00:24:56,980

previous slide might fall with respect

570

00:24:54,970 --> 00:24:59,319

to the so called cosmic web of galaxies



571  
00:24:56,980 --> 00:25:01,360  
and so this is what I heard - as the

572  
00:24:59,319 --> 00:25:03,009  
observed universe and this is what we're

573  
00:25:01,359 --> 00:25:04,990  
trying to understand with our virtual

574  
00:25:03,009 --> 00:25:06,308  
universes in the OO stress project and

575  
00:25:04,990 --> 00:25:11,798  
so this is the con is the kind of thing

576  
00:25:06,308 --> 00:25:14,288  
that we're hoping to simulate and we

577  
00:25:11,798 --> 00:25:17,230  
know frightening ly little about what

578  
00:25:14,288 --> 00:25:18,700  
constitutes galaxies and so the picture

579  
00:25:17,230 --> 00:25:19,480  
that we've been put together over the

580  
00:25:18,700 --> 00:25:22,600  
past couple decade

581  
00:25:19,480 --> 00:25:24,599  
is one where the content of galaxies is

582  
00:25:22,599 --> 00:25:27,369  
broken down into three basic categories

583  
00:25:24,599 --> 00:25:29,259  
there's the dark matter of galaxies and

584  
00:25:27,369 --> 00:25:32,229  
the dark energy of galaxies that take up

585  
00:25:29,259 --> 00:25:34,269  
96% of the known energy density of the

586  
00:25:32,230 --> 00:25:36,430  
universe we don't know what they are but

587  
00:25:34,269 --> 00:25:38,799  
we know what they do so we know exactly

588  
00:25:36,430 --> 00:25:41,140  
how these two things behave in the

589  
00:25:38,799 --> 00:25:43,119  
dynamics of galaxies in particular the

590  
00:25:41,140 --> 00:25:45,340  
gravity of dark matter brings galaxies

591  
00:25:43,119 --> 00:25:47,619  
together and holds them together and the

592  
00:25:45,339 --> 00:25:49,689  
cosmic expansion which is accelerated by

593  
00:25:47,619 --> 00:25:52,539  
dark energy moves galaxies apart in

594  
00:25:49,690 --> 00:25:55,480  
cosmic expansion and these two processes

595  
00:25:52,539 --> 00:25:57,460  
are shockingly simple to model and all

596  
00:25:55,480 --> 00:26:00,069  
of the the hard parts of galaxies

597  
00:25:57,460 --> 00:26:03,130  
happens in this four to five percent of

598  
00:26:00,069 --> 00:26:05,259  
atoms which we which we know about which

599

00:26:03,130 --> 00:26:07,120  
we can model and so the visible galaxies

600  
00:26:05,259 --> 00:26:10,269  
are for the most part along for the ride

601  
00:26:07,119 --> 00:26:11,919  
in this cosmic voyage but the a lot of

602  
00:26:10,269 --> 00:26:13,629  
these visible parts they get the atoms

603  
00:26:11,920 --> 00:26:15,610  
that constitute galaxies and stars is

604  
00:26:13,630 --> 00:26:17,380  
where a lot of the the uncertainty and

605  
00:26:15,609 --> 00:26:23,649  
the challenge comes in modeling modeling

606  
00:26:17,380 --> 00:26:26,380  
our universe and so when we look at the

607  
00:26:23,650 --> 00:26:28,750  
universe we don't see it in its perfect

608  
00:26:26,380 --> 00:26:31,720  
context like I just laid out this is an

609  
00:26:28,750 --> 00:26:33,369  
image taken by Hubble of the Ultra Deep

610  
00:26:31,720 --> 00:26:36,549  
Field so this is an image taken around

611  
00:26:33,369 --> 00:26:38,199  
2004 of a region of the sky that's about

612  
00:26:36,549 --> 00:26:40,180  
one one thousandth the size of a full

613  
00:26:38,200 --> 00:26:41,680

moon and if you stare at that region for

614

00:26:40,180 --> 00:26:43,380  
long enough you'll see all of the

615

00:26:41,680 --> 00:26:45,610  
galaxies along that line of sight

616

00:26:43,380 --> 00:26:47,380  
eventually come into focus and so here's

617

00:26:45,609 --> 00:26:49,149  
a couple hundred galaxies from a region

618

00:26:47,380 --> 00:26:50,860  
of the Hubble ultra-deep field and what

619

00:26:49,150 --> 00:26:53,710  
I want want to point out is that we can

620

00:26:50,859 --> 00:26:56,349  
see all the way back in time to the

621

00:26:53,710 --> 00:26:58,240  
beginning of galaxies in these images so

622

00:26:56,349 --> 00:27:00,309  
not all the way but most of the way back

623

00:26:58,240 --> 00:27:02,259  
95% of the way back in time we can see

624

00:27:00,309 --> 00:27:04,480  
in images like this and the reason is

625

00:27:02,259 --> 00:27:06,099  
that light has a finite speed it doesn't

626

00:27:04,480 --> 00:27:07,809  
come to us instantaneously from the very

627

00:27:06,099 --> 00:27:09,819  
distant galaxies and so when you take a

628  
00:27:07,809 --> 00:27:12,039  
very deep image like this one we can see

629  
00:27:09,819 --> 00:27:14,439  
galaxies as they existed many billions

630  
00:27:12,039 --> 00:27:16,059  
of years ago so these very tiny galaxies

631  
00:27:14,440 --> 00:27:18,070  
it kind of looks like they're far away

632  
00:27:16,059 --> 00:27:20,319  
because they're smaller but that is

633  
00:27:18,069 --> 00:27:22,179  
partially true the very small galaxies

634  
00:27:20,319 --> 00:27:23,619  
in the in the the faint regions of this

635  
00:27:22,180 --> 00:27:25,570  
image are the faint points in this image

636  
00:27:23,619 --> 00:27:26,949  
are very distant galaxies as they

637  
00:27:25,569 --> 00:27:29,649  
existed billions and billions of years

638  
00:27:26,950 --> 00:27:31,720  
ago and so we can kind of work work back

639  
00:27:29,650 --> 00:27:32,980  
in time and see how the population of

640  
00:27:31,720 --> 00:27:33,610  
galaxies evolved from an image like this

641  
00:27:32,980 --> 00:27:37,120  
one

642  
00:27:33,609 --> 00:27:38,529  
and so the the visible galaxies there so

643  
00:27:37,119 --> 00:27:40,029  
what we're looking at here is starlight

644  
00:27:38,529 --> 00:27:42,210  
from a bunch of galaxies in the Hubble

645  
00:27:40,029 --> 00:27:44,740  
ultra-deep field that visible light

646  
00:27:42,210 --> 00:27:47,079  
reflects an enormous diversity of

647  
00:27:44,740 --> 00:27:48,970  
galaxies appearance and so what you see

648  
00:27:47,079 --> 00:27:51,519  
here is that galaxies are not just one

649  
00:27:48,970 --> 00:27:53,500  
shape or size so even if they are just

650  
00:27:51,519 --> 00:27:55,930  
very simply pulled along by dark matter

651  
00:27:53,500 --> 00:27:57,549  
and dark energy they can rivalry

652  
00:27:55,930 --> 00:27:58,810  
different from one galaxy to another and

653  
00:27:57,549 --> 00:28:01,269  
so that's what we see here and so we're

654  
00:27:58,809 --> 00:28:02,859  
trying to build a model of this and how

655  
00:28:01,269 --> 00:28:04,420  
these galaxies came about in their

656

00:28:02,859 --> 00:28:08,349  
amazing diversity that we see in the

657  
00:28:04,420 --> 00:28:09,940  
real universe and the the fundamental

658  
00:28:08,349 --> 00:28:12,339  
challenge that are the thing that we

659  
00:28:09,940 --> 00:28:14,799  
want to understand is say how a distant

660  
00:28:12,339 --> 00:28:17,289  
galaxies or galaxies from early in the

661  
00:28:14,799 --> 00:28:19,329  
universe evolved to be a galaxy like we

662  
00:28:17,289 --> 00:28:21,039  
see today like the Milky Way so if we

663  
00:28:19,329 --> 00:28:22,750  
look at an observation of the sky or

664  
00:28:21,039 --> 00:28:25,059  
really any survey of galaxies in the

665  
00:28:22,750 --> 00:28:27,460  
universe we can identify galaxies like

666  
00:28:25,059 --> 00:28:29,049  
these three that I've circled here but

667  
00:28:27,460 --> 00:28:30,519  
we have no way of knowing how they

668  
00:28:29,049 --> 00:28:32,379  
relate to each other we just get a

669  
00:28:30,519 --> 00:28:34,180  
single snapshot of the galaxies as they

670  
00:28:32,380 --> 00:28:35,920

existed at the time we observe them and

671

00:28:34,180 --> 00:28:37,210

so we don't know whether a galaxy that

672

00:28:35,920 --> 00:28:38,350

looks like this one which most of you

673

00:28:37,210 --> 00:28:40,269

probably can't even see it's a little

674

00:28:38,349 --> 00:28:41,559

yellow smudge here on the picture might

675

00:28:40,269 --> 00:28:43,779

evolve into a galaxies like this one

676

00:28:41,559 --> 00:28:45,519

which is a blue spiral galaxy that's a

677

00:28:43,779 --> 00:28:46,750

little bit closer and how that might

678

00:28:45,519 --> 00:28:48,309

have changed and evolved over time into

679

00:28:46,750 --> 00:28:51,039

a galaxy that looks like an elliptical

680

00:28:48,309 --> 00:28:52,509

or the smooth red galaxy here and so we

681

00:28:51,039 --> 00:28:54,639

don't we don't have the ability to watch

682

00:28:52,509 --> 00:28:55,509

these observe evolve in time and so

683

00:28:54,640 --> 00:29:00,580

that's why we want to turn to

684

00:28:55,509 --> 00:29:02,200

simulations and so we have this this



685  
00:29:00,579 --> 00:29:05,019  
picture we've put together from images

686  
00:29:02,200 --> 00:29:06,519  
like this one of the Hubble Space

687  
00:29:05,019 --> 00:29:08,200  
Telescope observing galaxies in the

688  
00:29:06,519 --> 00:29:10,240  
Ultra Deep Field like this and we can

689  
00:29:08,200 --> 00:29:12,880  
see them build up over time on average

690  
00:29:10,240 --> 00:29:15,250  
but we don't know how one particular

691  
00:29:12,880 --> 00:29:19,420  
kind of galaxy could evolve through this

692  
00:29:15,250 --> 00:29:21,309  
space of possible possibilities and so

693  
00:29:19,420 --> 00:29:23,650  
the analogy that I like to make about

694  
00:29:21,309 --> 00:29:26,079  
galaxies is that it's exactly or almost

695  
00:29:23,650 --> 00:29:28,509  
exactly like archaeology where we have

696  
00:29:26,079 --> 00:29:30,399  
precisely one fossil record of galaxies

697  
00:29:28,509 --> 00:29:32,559  
that as we as observed in one particular

698  
00:29:30,400 --> 00:29:34,150  
time time in the universe but we don't

699  
00:29:32,559 --> 00:29:37,000  
know how they lived we don't know how

700  
00:29:34,150 --> 00:29:39,040  
they evolved to be the way they were so

701  
00:29:37,000 --> 00:29:41,559  
it's almost like the Ultra Deep Field or

702  
00:29:39,039 --> 00:29:42,970  
Hubble Ultra Deep Field is like an

703  
00:29:41,559 --> 00:29:44,589  
archaeological dig site where you're

704  
00:29:42,970 --> 00:29:47,420  
going down layer by layer and you get to

705  
00:29:44,589 --> 00:29:50,359  
see the fossils of living things as they

706  
00:29:47,420 --> 00:29:51,740  
as they become older and older so the

707  
00:29:50,359 --> 00:29:53,689  
lower the farther down you go the

708  
00:29:51,740 --> 00:29:57,589  
farther back in Earth's history you will

709  
00:29:53,690 --> 00:30:00,200  
see you'll see fossils however you can't

710  
00:29:57,589 --> 00:30:02,449  
then watch how those fossils evolved or

711  
00:30:00,200 --> 00:30:03,890  
lived we have to put together a story of

712  
00:30:02,450 --> 00:30:08,539  
how they live devices by studying them

713

00:30:03,890 --> 00:30:10,160  
in this indirect way so I'm going to

714  
00:30:08,539 --> 00:30:12,730  
talk about the Electress project in

715  
00:30:10,160 --> 00:30:14,779  
three main points or three main sections

716  
00:30:12,730 --> 00:30:15,950  
first a little bit more background about

717  
00:30:14,779 --> 00:30:17,629  
galaxies and why I think they're

718  
00:30:15,950 --> 00:30:19,430  
fascinating then I'm going to talk to

719  
00:30:17,630 --> 00:30:21,200  
you about computational astrophysics as

720  
00:30:19,430 --> 00:30:22,370  
applied to this problem and then I'll

721  
00:30:21,200 --> 00:30:24,200  
tell you about the illustrious project

722  
00:30:22,369 --> 00:30:29,119  
and and a few other virtual universe

723  
00:30:24,200 --> 00:30:32,600  
projects so a bit more about galaxies so

724  
00:30:29,119 --> 00:30:35,449  
I love galaxies but I like to say they

725  
00:30:32,599 --> 00:30:38,149  
have issues like all of us do and so

726  
00:30:35,450 --> 00:30:40,819  
galaxies have a lot of things that make

727  
00:30:38,150 --> 00:30:42,740

them complicated so the here is a nice

728

00:30:40,819 --> 00:30:44,869

Hubble Space Telescope image of two

729

00:30:42,740 --> 00:30:46,069

interacting galaxies and I like to use

730

00:30:44,869 --> 00:30:48,919

this to highlight the different

731

00:30:46,069 --> 00:30:51,079

challenges we have in that 5% of guests

732

00:30:48,920 --> 00:30:53,180

or of atoms that we can understand the

733

00:30:51,079 --> 00:30:54,799

galaxies and that is there's these

734

00:30:53,180 --> 00:30:56,720

couple these processes that are really

735

00:30:54,799 --> 00:30:58,549

hard to model so there's star creation

736

00:30:56,720 --> 00:31:00,140

so I'll come back to some of these in

737

00:30:58,549 --> 00:31:03,009

more detail but there's the creation of

738

00:31:00,140 --> 00:31:06,290

stars which happens on very small scales

739

00:31:03,009 --> 00:31:07,819

there's gas and dust cloud so this is

740

00:31:06,289 --> 00:31:10,009

where the hydrodynamic stuff comes into

741

00:31:07,819 --> 00:31:12,559

play there's gas diffused gas that fills

742  
00:31:10,009 --> 00:31:14,720  
the interstellar medium stars can

743  
00:31:12,559 --> 00:31:16,399  
explode as supernovae that's why I

744  
00:31:14,720 --> 00:31:18,589  
talked about in his in his presentation

745  
00:31:16,400 --> 00:31:21,170  
and that those explosions can have an

746  
00:31:18,589 --> 00:31:22,730  
impact on this gas these these gas

747  
00:31:21,170 --> 00:31:25,100  
clouds and so that actually can feed

748  
00:31:22,730 --> 00:31:27,049  
back onto the the process of star

749  
00:31:25,099 --> 00:31:28,849  
creation and so this all of these these

750  
00:31:27,049 --> 00:31:30,769  
three processes are coupled in some in

751  
00:31:28,849 --> 00:31:33,829  
some sense and that you can't model one

752  
00:31:30,769 --> 00:31:36,139  
without model than the others another

753  
00:31:33,829 --> 00:31:37,879  
important challenge is we've come to

754  
00:31:36,140 --> 00:31:39,380  
understand that most galaxies have a

755  
00:31:37,880 --> 00:31:41,570  
supermassive black hole at their center

756  
00:31:39,380 --> 00:31:42,950  
and these supermassive black holes can

757  
00:31:41,569 --> 00:31:44,450  
have dynamically interesting or

758  
00:31:42,950 --> 00:31:47,600  
dynamically important effects on their

759  
00:31:44,450 --> 00:31:49,160  
galaxy so as these this diffuse gas gets

760  
00:31:47,599 --> 00:31:51,589  
funneled into the center of the galaxy

761  
00:31:49,160 --> 00:31:53,300  
the supermassive black hole can heat

762  
00:31:51,589 --> 00:31:55,490  
that gas and expel it out of the galaxy

763  
00:31:53,299 --> 00:31:57,200  
entirely and so all four of these

764  
00:31:55,490 --> 00:31:59,720  
processes need to be needs to be taken

765  
00:31:57,200 --> 00:32:00,860  
into account at least these four

766  
00:31:59,720 --> 00:32:02,870  
processes in order to

767  
00:32:00,859 --> 00:32:05,719  
understand the issues that galaxies have

768  
00:32:02,869 --> 00:32:07,189  
and then the the final thing I want to

769  
00:32:05,720 --> 00:32:08,600  
point out is that mergers and collisions

770

00:32:07,190 --> 00:32:11,298  
among galaxies are thought to be very

771  
00:32:08,599 --> 00:32:12,619  
common and so this is showing the two

772  
00:32:11,298 --> 00:32:14,900  
galaxies that have interacting

773  
00:32:12,619 --> 00:32:16,699  
gravitationally and this process can

774  
00:32:14,900 --> 00:32:18,650  
actually trigger certain effects among

775  
00:32:16,700 --> 00:32:21,110  
these other four that are that are that

776  
00:32:18,650 --> 00:32:23,150  
are important and so it'll it'll shift

777  
00:32:21,109 --> 00:32:24,979  
around the gas and dust and push around

778  
00:32:23,150 --> 00:32:26,900  
the stars and trigger star creation and

779  
00:32:24,980 --> 00:32:31,660  
things and so all five of these are

780  
00:32:26,900 --> 00:32:31,660  
important aspects of galaxy formation

781  
00:32:33,130 --> 00:32:38,510  
arguably the most important and perhaps

782  
00:32:35,630 --> 00:32:40,790  
the most interesting is what I call the

783  
00:32:38,509 --> 00:32:43,339  
Galactic life cycle and so this is just

784  
00:32:40,789 --> 00:32:44,869

a sort of artist's rendition of what the

785

00:32:43,339 --> 00:32:46,459

Galactic life cycle is and I touched on

786

00:32:44,869 --> 00:32:49,369

this a little bit in the previous slide

787

00:32:46,460 --> 00:32:52,730

but that is that the everything is tied

788

00:32:49,369 --> 00:32:55,000

together so stars form out of gas clouds

789

00:32:52,730 --> 00:32:57,200

in the interstellar medium of galaxies

790

00:32:55,000 --> 00:32:58,940

so that leads to star formation in the

791

00:32:57,200 --> 00:33:01,009

very centres or very dense regions

792

00:32:58,940 --> 00:33:02,600

inside these gas clouds these stars

793

00:33:01,009 --> 00:33:04,220

these regions of star formation then

794

00:33:02,599 --> 00:33:06,589

become the solar systems like like the

795

00:33:04,220 --> 00:33:08,900

one we live in but stars have this habit

796

00:33:06,589 --> 00:33:11,139

of not being the same for their entire

797

00:33:08,900 --> 00:33:13,850

lives and so they can either explode or

798

00:33:11,140 --> 00:33:15,440

shed their outer parts into the back



799

00:33:13,849 --> 00:33:17,869  
into the interstellar medium so I call

800

00:33:15,440 --> 00:33:19,519  
this star recycling a supernovae so the

801

00:33:17,869 --> 00:33:21,798  
Stars can then put back the matter that

802

00:33:19,519 --> 00:33:23,599  
they that they accreted from gravity in

803

00:33:21,798 --> 00:33:25,819  
this process back into the interstellar

804

00:33:23,599 --> 00:33:27,859  
medium and form new gas clouds in the

805

00:33:25,819 --> 00:33:30,019  
future and so the Galactic lifecycle is

806

00:33:27,859 --> 00:33:31,819  
really the the interrelationship between

807

00:33:30,019 --> 00:33:34,160  
all of these different things and so if

808

00:33:31,819 --> 00:33:35,869  
we look at a Hubble image of galaxies we

809

00:33:34,160 --> 00:33:38,630  
are basically looking at the light from

810

00:33:35,869 --> 00:33:42,849  
their stars but we miss or we might miss

811

00:33:38,630 --> 00:33:45,950  
a lot of these other important processes

812

00:33:42,849 --> 00:33:48,469  
like whole activity here's a galaxy

813  
00:33:45,950 --> 00:33:51,890  
showing some interesting black hole

814  
00:33:48,470 --> 00:33:54,319  
activity here this is a galaxy with very

815  
00:33:51,890 --> 00:33:56,059  
large Jets so this is a radio

816  
00:33:54,319 --> 00:33:58,250  
observation overlaid on top of an HST

817  
00:33:56,058 --> 00:34:00,589  
image showing gas that's being ejected

818  
00:33:58,250 --> 00:34:02,960  
by a very massive black hole in the

819  
00:34:00,589 --> 00:34:04,220  
center of this galaxy and so if gas it

820  
00:34:02,960 --> 00:34:07,308  
can get to the center of this galaxy

821  
00:34:04,220 --> 00:34:08,840  
it'll be accreted or on to this the

822  
00:34:07,308 --> 00:34:11,239  
central region near the black hole and

823  
00:34:08,840 --> 00:34:13,340  
this causes the gas to be heated to

824  
00:34:11,239 --> 00:34:14,959  
extreme temperatures and that heating

825  
00:34:13,340 --> 00:34:17,450  
can do one of two things

826  
00:34:14,960 --> 00:34:21,108  
either fall onto the black hole and be

827

00:34:17,449 --> 00:34:23,598  
and be absorbed and create mass or it

828  
00:34:21,108 --> 00:34:25,309  
can be ejected so the the actual gas

829  
00:34:23,599 --> 00:34:26,869  
dynamics of this this process is

830  
00:34:25,309 --> 00:34:28,608  
extremely complicated but what can

831  
00:34:26,869 --> 00:34:30,108  
happen is the gas goes in and then gets

832  
00:34:28,608 --> 00:34:34,250  
flung out at extremely high velocities

833  
00:34:30,108 --> 00:34:35,960  
and extremely high rates and so the gas

834  
00:34:34,250 --> 00:34:37,550  
can come out of galaxies and then just

835  
00:34:35,960 --> 00:34:42,440  
not be available to form stars for some

836  
00:34:37,550 --> 00:34:45,950  
period of time and as I mentioned before

837  
00:34:42,440 --> 00:34:48,588  
galaxies can interact so this is Hubble

838  
00:34:45,949 --> 00:34:49,730  
images of different merging galaxies at

839  
00:34:48,588 --> 00:34:51,648  
different stages of the merging process

840  
00:34:49,730 --> 00:34:53,628  
just to show some beautiful examples of

841  
00:34:51,648 --> 00:34:55,489

galaxy mergers and to show that this

842

00:34:53,628 --> 00:34:57,710

really does happen in the real universe

843

00:34:55,489 --> 00:34:58,848

and so here are two galaxies that may be

844

00:34:57,710 --> 00:35:01,400

like the Milky Way approaching each

845

00:34:58,849 --> 00:35:03,710

other they get closer and they sort of

846

00:35:01,400 --> 00:35:06,588

tear each other apart as they come to

847

00:35:03,710 --> 00:35:09,949

final coalescence and this can rearrange

848

00:35:06,588 --> 00:35:12,289

the gas in such a way that that it forms

849

00:35:09,949 --> 00:35:14,118

stars in new places so it can form this

850

00:35:12,289 --> 00:35:16,070

very red bulge in the center a very

851

00:35:14,119 --> 00:35:17,539

large bulge or massive bulge and it can

852

00:35:16,070 --> 00:35:19,099

drive gas to the center to the black

853

00:35:17,539 --> 00:35:25,159

hole and cause more of this gas

854

00:35:19,099 --> 00:35:26,690

expulsion in the process so those are

855

00:35:25,159 --> 00:35:28,848

the issues that galaxies have and now

856  
00:35:26,690 --> 00:35:30,559  
this is that is the primary motivation

857  
00:35:28,849 --> 00:35:32,900  
for why we turn to computers to do this

858  
00:35:30,559 --> 00:35:35,690  
for us so if we tried to model all of

859  
00:35:32,900 --> 00:35:37,670  
this by hands we would be out of luck we

860  
00:35:35,690 --> 00:35:39,349  
just cannot possibly ever do it so we

861  
00:35:37,670 --> 00:35:43,539  
use computers to do the dirty work for

862  
00:35:39,349 --> 00:35:48,380  
us and the way we set this up is is

863  
00:35:43,539 --> 00:35:50,838  
fairly fairly nice and fairly simple the

864  
00:35:48,380 --> 00:35:52,099  
idea is just to start with the initial

865  
00:35:50,838 --> 00:35:54,799  
conditions as we know them in the

866  
00:35:52,099 --> 00:35:56,900  
universe and so on the left here is a

867  
00:35:54,800 --> 00:35:59,060  
map of the sky made by the Planck

868  
00:35:56,900 --> 00:36:01,099  
satellite and so I'm not going to talk

869  
00:35:59,059 --> 00:36:02,449  
too much detail about this but if you

870  
00:36:01,099 --> 00:36:04,490  
want to hear more come to Mark

871  
00:36:02,449 --> 00:36:06,259  
kamionkowski stalk next month he'll talk

872  
00:36:04,489 --> 00:36:08,299  
I think about this issue in great detail

873  
00:36:06,260 --> 00:36:09,680  
but we take the results of that which is

874  
00:36:08,300 --> 00:36:12,140  
essentially a map of the matter

875  
00:36:09,679 --> 00:36:14,358  
fluctuations as they were right after

876  
00:36:12,139 --> 00:36:16,429  
the Big Bang we take a map like that and

877  
00:36:14,358 --> 00:36:18,108  
then seed that as at the beginning of

878  
00:36:16,429 --> 00:36:20,118  
our simulation so we start with a met

879  
00:36:18,108 --> 00:36:21,259  
with matter fluctuations and then in

880  
00:36:20,119 --> 00:36:23,930  
this example that I'm about to show you

881  
00:36:21,260 --> 00:36:26,300  
let gravity evolve under its own under

882  
00:36:23,929 --> 00:36:27,469  
its own power we look the equations

883  
00:36:26,300 --> 00:36:29,000  
evolve as they should see fit

884

00:36:27,469 --> 00:36:30,500  
and so we take some

885  
00:36:29,000 --> 00:36:33,619  
initial initialization of the universe

886  
00:36:30,500 --> 00:36:36,349  
as as measured from the Planck satellite

887  
00:36:33,619 --> 00:36:38,389  
and then just let the matter collapse on

888  
00:36:36,349 --> 00:36:41,299  
itself and form galaxies and so this is

889  
00:36:38,389 --> 00:36:42,920  
a dark matter only simulation rotating

890  
00:36:41,300 --> 00:36:44,660  
around a volume of galaxies where each

891  
00:36:42,920 --> 00:36:46,730  
of these each of these points that

892  
00:36:44,659 --> 00:36:50,000  
appear at the center will be a galaxy

893  
00:36:46,730 --> 00:36:51,349  
like the Milky Way and so from the very

894  
00:36:50,000 --> 00:36:53,690  
beginning of the universe the universe

895  
00:36:51,349 --> 00:36:55,639  
is very smooth but these tiny

896  
00:36:53,690 --> 00:36:57,409  
fluctuations in the matter density then

897  
00:36:55,639 --> 00:36:59,599  
grow under the influence of gravity to

898  
00:36:57,409 --> 00:37:06,289

form the backbone or the cosmic web of

899

00:36:59,599 --> 00:37:08,179

galaxies that we see today so that's a

900

00:37:06,289 --> 00:37:11,869

fairly straightforward experiment so we

901

00:37:08,179 --> 00:37:13,549

can this is not sort of done by hands

902

00:37:11,869 --> 00:37:16,190

the way we used to have to do this so we

903

00:37:13,550 --> 00:37:18,530

used to have to to create galaxies in

904

00:37:16,190 --> 00:37:20,900

the computer by hand and then smash them

905

00:37:18,530 --> 00:37:22,760

together in some some arbitrary way but

906

00:37:20,900 --> 00:37:26,329

this is now a sort of it's almost a

907

00:37:22,760 --> 00:37:28,430

prediction of the universe model that we

908

00:37:26,329 --> 00:37:30,079

have and so it's we can then very easily

909

00:37:28,429 --> 00:37:37,159

test the effects of these different

910

00:37:30,079 --> 00:37:39,170

issues on galaxies of course I just

911

00:37:37,159 --> 00:37:40,969

spent a really long time telling you

912

00:37:39,170 --> 00:37:42,980

about the issues and galaxies and so



913  
00:37:40,969 --> 00:37:44,449  
that was ignoring all of those things so

914  
00:37:42,980 --> 00:37:47,300  
ignoring the gas physics of ignoring

915  
00:37:44,449 --> 00:37:49,039  
star formation and the the the problem

916  
00:37:47,300 --> 00:37:51,950  
computationally boils down to this fact

917  
00:37:49,039 --> 00:37:54,289  
is that stars are extremely small

918  
00:37:51,949 --> 00:37:56,509  
compared to galaxies and so stars form

919  
00:37:54,289 --> 00:38:00,949  
in very very tiny regions of space tiny

920  
00:37:56,510 --> 00:38:02,800  
parts of galaxies and that that simple

921  
00:38:00,949 --> 00:38:04,969  
fact main means that in order to

922  
00:38:02,800 --> 00:38:06,800  
correctly form stars in a simulation

923  
00:38:04,969 --> 00:38:08,569  
like this one you have to also model

924  
00:38:06,800 --> 00:38:10,730  
very tiny regions of galaxies and not

925  
00:38:08,570 --> 00:38:13,280  
just their their large structure and so

926  
00:38:10,730 --> 00:38:15,889  
here's a an HST image of a dark cloud

927  
00:38:13,280 --> 00:38:18,769  
and a newly formed star which is

928  
00:38:15,889 --> 00:38:20,779  
probably acting on it via by its energy

929  
00:38:18,769 --> 00:38:22,460  
so the Stars feedback energy into the

930  
00:38:20,780 --> 00:38:25,010  
into the I mean it's pushing on this

931  
00:38:22,460 --> 00:38:27,079  
cloud here and the dynamics of that that

932  
00:38:25,010 --> 00:38:28,400  
resulting interaction has to be modeled

933  
00:38:27,079 --> 00:38:30,049  
if you want to actually get the

934  
00:38:28,400 --> 00:38:32,360  
prediction for the locations of the

935  
00:38:30,050 --> 00:38:34,610  
stars in galaxies and so this life cycle

936  
00:38:32,360 --> 00:38:37,490  
has to be taken into account at each

937  
00:38:34,610 --> 00:38:38,690  
point in the galaxy and galaxies are at

938  
00:38:37,489 --> 00:38:42,049  
least a hundred thousand times bigger

939  
00:38:38,690 --> 00:38:45,079  
than that region so okay

940  
00:38:42,050 --> 00:38:46,460  
so say we have as much computer time as

941

00:38:45,079 --> 00:38:49,610  
we wanted as many computers as we could

942  
00:38:46,460 --> 00:38:51,170  
possibly have access to what would we

943  
00:38:49,610 --> 00:38:52,820  
need in order to do this problem right

944  
00:38:51,170 --> 00:38:54,530  
in order to model the formation of

945  
00:38:52,820 --> 00:38:56,630  
virtually every star in a galaxy

946  
00:38:54,530 --> 00:38:59,450  
throughout its history during the during

947  
00:38:56,630 --> 00:39:01,570  
in the past 14 billion years so this is

948  
00:38:59,449 --> 00:39:03,889  
the in ideal world what you would want

949  
00:39:01,570 --> 00:39:07,250  
you'd want something like ten thousand

950  
00:39:03,889 --> 00:39:09,079  
galaxies and that's just kind of just a

951  
00:39:07,250 --> 00:39:10,639  
nice round number to give you the

952  
00:39:09,079 --> 00:39:12,019  
diversity of galaxies that we see in the

953  
00:39:10,639 --> 00:39:13,219  
Hubble ultra-deep field it's roughly the

954  
00:39:12,019 --> 00:39:15,559  
number of galaxies in the Hubble

955  
00:39:13,219 --> 00:39:17,179

ultra-deep field and then if you want to

956

00:39:15,559 --> 00:39:19,039

divide each of those galaxies up into

957

00:39:17,179 --> 00:39:20,659

regions of star formation that are

958

00:39:19,039 --> 00:39:22,340

realistic in a sense that I just talked

959

00:39:20,659 --> 00:39:24,679

about you need about a million elements

960

00:39:22,340 --> 00:39:26,210

per galaxy size so if you imagine the

961

00:39:24,679 --> 00:39:28,460

galaxy is a cube which is a very

962

00:39:26,210 --> 00:39:29,780

simplistic approximation to a galaxy you

963

00:39:28,460 --> 00:39:34,039

need about a million elements of

964

00:39:29,780 --> 00:39:36,650

star-forming gas per side and so to fill

965

00:39:34,039 --> 00:39:38,539

a galaxy's volume entirely you need a

966

00:39:36,650 --> 00:39:40,369

million cubed of these elements per

967

00:39:38,539 --> 00:39:44,329

galaxy so that's starting to get to a

968

00:39:40,369 --> 00:39:46,549

big number and so that's about four for

969

00:39:44,329 --> 00:39:50,239

all 10,000 galaxies you need one

970  
00:39:46,550 --> 00:39:52,420  
followed by 22 zeroes of elements of gas

971  
00:39:50,239 --> 00:39:55,219  
dynamics to solve in your computer

972  
00:39:52,420 --> 00:39:56,809  
that's to do it at a single time to

973  
00:39:55,219 --> 00:39:58,969  
follow the evolution and formation of

974  
00:39:56,809 --> 00:40:00,529  
those stars in those galaxies you need

975  
00:39:58,969 --> 00:40:02,809  
to do this at each of about a hundred

976  
00:40:00,530 --> 00:40:04,820  
thousand times and so that now we're

977  
00:40:02,809 --> 00:40:07,099  
starting to get into thirdly large

978  
00:40:04,820 --> 00:40:08,690  
numbers and that even though that even

979  
00:40:07,099 --> 00:40:10,489  
though each of these calculations of the

980  
00:40:08,690 --> 00:40:13,099  
effect of star formation in each in each

981  
00:40:10,489 --> 00:40:15,379  
cell takes a fraction of a second you

982  
00:40:13,099 --> 00:40:17,360  
still need something like one and 23

983  
00:40:15,380 --> 00:40:19,579  
zeros of computer hours in order to

984  
00:40:17,360 --> 00:40:22,099  
compute the evolution of galaxies from

985  
00:40:19,579 --> 00:40:24,440  
the beginning of the universe and just

986  
00:40:22,099 --> 00:40:27,920  
to put that that number in context 10 to

987  
00:40:24,440 --> 00:40:29,780  
the 23 computer hours on my laptop here

988  
00:40:27,920 --> 00:40:32,059  
that would take about 10 billion times

989  
00:40:29,780 --> 00:40:35,660  
the current age of the universe to run a

990  
00:40:32,059 --> 00:40:38,360  
simulation like this so 14 billion years

991  
00:40:35,659 --> 00:40:41,719  
times 10 billion to run it on my laptop

992  
00:40:38,360 --> 00:40:44,780  
here on the world's best supercomputers

993  
00:40:41,719 --> 00:40:47,480  
it's about 1 billion times the current

994  
00:40:44,780 --> 00:40:49,670  
age of the universe sorry I got that

995  
00:40:47,480 --> 00:40:52,099  
wrong it's about it's about once times

996  
00:40:49,670 --> 00:40:53,269  
the current age it's about 10,000 times

997  
00:40:52,099 --> 00:40:54,860  
the current age of the universe sorry

998

00:40:53,269 --> 00:40:55,730  
about that so about 10,000 times the

999  
00:40:54,860 --> 00:40:57,800  
current age of the universe

1000  
00:40:55,730 --> 00:41:00,130  
on the world's biggest supercomputers

1001  
00:40:57,800 --> 00:41:02,869  
that exists in say in a single room and

1002  
00:41:00,130 --> 00:41:04,309  
it's roughly a billion years still on

1003  
00:41:02,869 --> 00:41:06,108  
every computer that's connected to the

1004  
00:41:04,309 --> 00:41:08,750  
Internet today so there's something like

1005  
00:41:06,108 --> 00:41:09,980  
100 billion or 20 billion devices

1006  
00:41:08,750 --> 00:41:11,420  
connected to the Internet if we could

1007  
00:41:09,980 --> 00:41:13,519  
run our simulation on that it would only

1008  
00:41:11,420 --> 00:41:15,530  
take a billion years to run this ideal

1009  
00:41:13,519 --> 00:41:16,909  
simulation but still longer than I'm

1010  
00:41:15,530 --> 00:41:22,550  
willing to wait for for our

1011  
00:41:16,909 --> 00:41:38,960  
understanding of galaxies and so how do

1012  
00:41:22,550 --> 00:41:42,289

we get around this in our lifetimes and

1013

00:41:38,960 --> 00:41:43,789

the answer is we cheat so we we make we

1014

00:41:42,289 --> 00:41:46,909

make simplifications and approximations

1015

00:41:43,789 --> 00:41:48,829

to our equations that allow us to get

1016

00:41:46,909 --> 00:41:50,719

the gist of galaxies without actually

1017

00:41:48,829 --> 00:41:52,250

modeling all the stars and so the

1018

00:41:50,719 --> 00:41:54,799

solution is to make approximations so

1019

00:41:52,250 --> 00:41:56,539

the first major approximation is to

1020

00:41:54,800 --> 00:41:58,550

focus effort only on the most important

1021

00:41:56,539 --> 00:42:01,009

regions and galaxies so we're not going

1022

00:41:58,550 --> 00:42:03,710

to focus our effort on the the regions

1023

00:42:01,010 --> 00:42:05,240

that are maybe very low density or have

1024

00:42:03,710 --> 00:42:06,409

very few stars in them we're not gonna

1025

00:42:05,239 --> 00:42:08,299

we're not gonna spend as much time on

1026

00:42:06,409 --> 00:42:10,849

those and just approximate the solutions



1027  
00:42:08,300 --> 00:42:13,010  
in those cases and the second one that

1028  
00:42:10,849 --> 00:42:14,960  
is arguably the most important is to

1029  
00:42:13,010 --> 00:42:15,830  
create toy models of star formation so

1030  
00:42:14,960 --> 00:42:17,960  
that we don't have to model the

1031  
00:42:15,829 --> 00:42:21,139  
formation of every star but we model the

1032  
00:42:17,960 --> 00:42:23,150  
formation of stars on galaxy scales so

1033  
00:42:21,139 --> 00:42:25,279  
we can then so we have these scaling

1034  
00:42:23,150 --> 00:42:27,320  
relations that allow us to connect the

1035  
00:42:25,280 --> 00:42:28,970  
formation of stars with the amount of

1036  
00:42:27,320 --> 00:42:31,460  
gas that exists in a particular region

1037  
00:42:28,969 --> 00:42:33,799  
in space and so we can then chop off our

1038  
00:42:31,460 --> 00:42:36,079  
scales in our in our problem and only

1039  
00:42:33,800 --> 00:42:39,140  
and only model scales above a certain

1040  
00:42:36,079 --> 00:42:41,000  
size and so here's our galaxy with

1041  
00:42:39,139 --> 00:42:43,909  
issues on the left and on the right is

1042  
00:42:41,000 --> 00:42:46,699  
how you might divide this space it in

1043  
00:42:43,909 --> 00:42:48,699  
order to make this first point so focus

1044  
00:42:46,699 --> 00:42:51,409  
only on the most important regions and

1045  
00:42:48,699 --> 00:42:58,189  
so I'm going to zoom in and overlay that

1046  
00:42:51,409 --> 00:43:00,349  
on top here and so in our in our

1047  
00:42:58,190 --> 00:43:04,220  
calculations what we like to do is to

1048  
00:43:00,349 --> 00:43:05,989  
spend less time on a particular volume

1049  
00:43:04,219 --> 00:43:08,089  
element over here on the left or these

1050  
00:43:05,989 --> 00:43:09,419  
these wide ones over here and spend a

1051  
00:43:08,090 --> 00:43:11,369  
lot of effort in the center of gal

1052  
00:43:09,420 --> 00:43:13,019  
where the real action is happening where

1053  
00:43:11,369 --> 00:43:15,000  
there might be more star formation there

1054  
00:43:13,019 --> 00:43:16,199  
are more supernovae there the black hole

1055

00:43:15,000 --> 00:43:17,548  
is in the center so that's a really

1056  
00:43:16,199 --> 00:43:19,348  
important thing to model correctly and

1057  
00:43:17,548 --> 00:43:20,880  
so then we spend a little bit less time

1058  
00:43:19,349 --> 00:43:22,650  
or a little bit less effort on the outer

1059  
00:43:20,880 --> 00:43:24,838  
regions and so we'll just let these

1060  
00:43:22,650 --> 00:43:26,400  
outer regions evolve according to say a

1061  
00:43:24,838 --> 00:43:28,858  
very simplistic form of star formation

1062  
00:43:26,400 --> 00:43:32,068  
and gravity itself so we just let these

1063  
00:43:28,858 --> 00:43:36,380  
things evolve and then actually do some

1064  
00:43:32,068 --> 00:43:36,380  
hard computations and inner regions only

1065  
00:43:36,798 --> 00:43:44,579  
this pattern is a certain tessellation

1066  
00:43:40,889 --> 00:43:45,929  
of the space so it's not ideally matched

1067  
00:43:44,579 --> 00:43:47,490  
to this galaxy it's just a sort of a

1068  
00:43:45,929 --> 00:43:50,338  
circular thing that I put down to

1069  
00:43:47,489 --> 00:43:52,259

visualize it but the idea is then is to

1070

00:43:50,338 --> 00:43:55,588

break up break it up into things of the

1071

00:43:52,260 --> 00:43:56,790

same mass so a single cell in the center

1072

00:43:55,588 --> 00:43:59,219

of this galaxy will have the same mass

1073

00:43:56,789 --> 00:44:00,568

as one of these cells out here and so

1074

00:43:59,219 --> 00:44:05,959

that makes it a little bit more

1075

00:44:00,568 --> 00:44:08,670

computationally tractable to perform and

1076

00:44:05,960 --> 00:44:10,260

then the models of star formation is we

1077

00:44:08,670 --> 00:44:13,019

take one of these these regions that

1078

00:44:10,260 --> 00:44:14,790

we've defined and write down very simple

1079

00:44:13,019 --> 00:44:16,380

equations for the Galactic life cycle so

1080

00:44:14,789 --> 00:44:18,539

instead of modeling one of those

1081

00:44:16,380 --> 00:44:20,970

individual dark gas clouds that I showed

1082

00:44:18,539 --> 00:44:23,460

you before we smear that out over the

1083

00:44:20,969 --> 00:44:27,779

entire region so this is maybe a tenth

1084  
00:44:23,460 --> 00:44:29,579  
of a galaxy on a side here kiloparsec or

1085  
00:44:27,780 --> 00:44:32,730  
so in size for those for those who know

1086  
00:44:29,579 --> 00:44:34,140  
that scale and that then we take the

1087  
00:44:32,730 --> 00:44:36,449  
amount of gas that happens to fall in

1088  
00:44:34,139 --> 00:44:37,858  
that region and then just multiply by a

1089  
00:44:36,449 --> 00:44:39,899  
sum factor and that tells us how many

1090  
00:44:37,858 --> 00:44:41,789  
stars we get in the end and then we have

1091  
00:44:39,900 --> 00:44:43,440  
some other equation that tells us how

1092  
00:44:41,789 --> 00:44:45,329  
the supernovae affect the regions

1093  
00:44:43,440 --> 00:44:48,389  
surrounding that that particular cell

1094  
00:44:45,329 --> 00:44:50,880  
and so it's not you know we have no idea

1095  
00:44:48,389 --> 00:44:53,098  
about the light coming from the stars as

1096  
00:44:50,880 --> 00:44:55,108  
you can see the galaxy here you can see

1097  
00:44:53,099 --> 00:44:57,210  
that the distribution of stars within a

1098  
00:44:55,108 --> 00:44:58,920  
cell we ignore all that in our

1099  
00:44:57,210 --> 00:45:01,139  
calculations we only have information

1100  
00:44:58,920 --> 00:45:02,608  
about this say the cell averaged star

1101  
00:45:01,139 --> 00:45:04,650  
formation rate so we can only see sort

1102  
00:45:02,608 --> 00:45:06,869  
of like a faint blue fuzz in each of

1103  
00:45:04,650 --> 00:45:09,510  
these these regions so that's the

1104  
00:45:06,869 --> 00:45:11,130  
approximation we make in order to handle

1105  
00:45:09,510 --> 00:45:13,230  
the ability of star formation on scales

1106  
00:45:11,130 --> 00:45:14,940  
like this one and so we won't get a

1107  
00:45:13,230 --> 00:45:18,420  
galaxy that looks like this one what's

1108  
00:45:14,940 --> 00:45:19,980  
pixelated on mega mega pixels but we can

1109  
00:45:18,420 --> 00:45:21,990  
get a couple tens of thousands of pixels

1110  
00:45:19,980 --> 00:45:25,139  
of galaxies that

1111  
00:45:21,989 --> 00:45:27,389  
look realistic and in practice this

1112

00:45:25,139 --> 00:45:28,829  
process of creating models toy models

1113  
00:45:27,389 --> 00:45:31,409  
for star formation and black holes is

1114  
00:45:28,829 --> 00:45:33,869  
done just by trial and error so we have

1115  
00:45:31,409 --> 00:45:35,699  
no better way of going in and modeling

1116  
00:45:33,869 --> 00:45:37,590  
this process other than to say come up

1117  
00:45:35,699 --> 00:45:39,269  
with some educated guesses see how the

1118  
00:45:37,590 --> 00:45:43,050  
galaxies look in the end and then repeat

1119  
00:45:39,269 --> 00:45:44,519  
so this is a kind of a unsatisfying way

1120  
00:45:43,050 --> 00:45:47,250  
to do it but it's currently the best way

1121  
00:45:44,519 --> 00:45:52,949  
that we have of getting a galaxy and

1122  
00:45:47,250 --> 00:45:54,510  
simulation so our approximations are

1123  
00:45:52,949 --> 00:45:56,399  
wonderful and they help us get this

1124  
00:45:54,510 --> 00:45:58,260  
problem to be tractable but we still

1125  
00:45:56,400 --> 00:46:00,240  
need to appeal to supercomputers in

1126  
00:45:58,260 --> 00:46:02,730

order to solve the resulting problem and

1127

00:46:00,239 --> 00:46:04,769

so this is the IBM Blue Gene computer

1128

00:46:02,730 --> 00:46:06,059

with a person there for scale to give

1129

00:46:04,769 --> 00:46:07,739

you an idea of how big these computers

1130

00:46:06,059 --> 00:46:10,500

are so do we appeal to supercomputers

1131

00:46:07,739 --> 00:46:12,209

then to solve the remaining calculations

1132

00:46:10,500 --> 00:46:14,550

and so even though we've made these

1133

00:46:12,210 --> 00:46:16,470

really really great assumptions that

1134

00:46:14,550 --> 00:46:19,320

help us to solve the equations in a

1135

00:46:16,469 --> 00:46:21,089

finite number of universe times which is

1136

00:46:19,320 --> 00:46:22,680

great we still need something like ten

1137

00:46:21,090 --> 00:46:26,160

thousand or a hundred thousand computers

1138

00:46:22,679 --> 00:46:27,779

to do the work for us and a

1139

00:46:26,159 --> 00:46:29,489

supercomputer is really nothing more

1140

00:46:27,780 --> 00:46:32,070

than a whole bunch of regular computers



1141  
00:46:29,489 --> 00:46:33,469  
strung together in a fancy way so this

1142  
00:46:32,070 --> 00:46:36,600  
is the computer that I showed before

1143  
00:46:33,469 --> 00:46:38,849  
each of these racks as we might call

1144  
00:46:36,599 --> 00:46:42,690  
them would look like this perhaps and so

1145  
00:46:38,849 --> 00:46:44,969  
each of these slices in the rack is one

1146  
00:46:42,690 --> 00:46:48,599  
computer so we use it as we would a

1147  
00:46:44,969 --> 00:46:49,589  
normal computer and then so I just have

1148  
00:46:48,599 --> 00:46:51,358  
this down here on the bottom this is a

1149  
00:46:49,590 --> 00:46:53,850  
gateway computer I had one of these in

1150  
00:46:51,358 --> 00:46:55,230  
like the late 1990s or something so

1151  
00:46:53,849 --> 00:46:57,630  
that's essentially what we're putting in

1152  
00:46:55,230 --> 00:47:00,389  
here just new and updated version and

1153  
00:46:57,630 --> 00:47:02,670  
compactified version into into the racks

1154  
00:47:00,389 --> 00:47:04,949  
of supercomputers and so it's really not

1155  
00:47:02,670 --> 00:47:06,329  
it's all of the same functionality maybe

1156  
00:47:04,949 --> 00:47:08,309  
a little bit less functionality than

1157  
00:47:06,329 --> 00:47:09,989  
then a computer like this one but the

1158  
00:47:08,309 --> 00:47:11,429  
same kind of processor would go into

1159  
00:47:09,989 --> 00:47:14,069  
this this super computer and then

1160  
00:47:11,429 --> 00:47:16,769  
coupled together to form our super

1161  
00:47:14,070 --> 00:47:20,280  
computers and on the left here I have

1162  
00:47:16,769 --> 00:47:22,079  
just a kind of a toy model of how the

1163  
00:47:20,280 --> 00:47:23,190  
computers communicate with each other so

1164  
00:47:22,079 --> 00:47:27,210  
I wanted to put this in here just to

1165  
00:47:23,190 --> 00:47:29,909  
show that really these are computers are

1166  
00:47:27,210 --> 00:47:32,639  
all acting as one so if you imagine that

1167  
00:47:29,909 --> 00:47:35,909  
each of these sort of clusters of

1168  
00:47:32,639 --> 00:47:38,549  
computers say 12 computers or so is laid

1169

00:47:35,909 --> 00:47:41,129  
a a cluster B cluster C cluster and so

1170  
00:47:38,550 --> 00:47:43,590  
on up the rack those are connected by

1171  
00:47:41,130 --> 00:47:45,420  
really high bandwidth fiber in between

1172  
00:47:43,590 --> 00:47:46,829  
them and so this is the the a cluster of

1173  
00:47:45,420 --> 00:47:49,170  
computers here the B cluster the C

1174  
00:47:46,829 --> 00:47:51,299  
cluster and so on and so the entire

1175  
00:47:49,170 --> 00:47:53,190  
supercomputer which might be tens of

1176  
00:47:51,300 --> 00:47:54,750  
thousands of these these these systems

1177  
00:47:53,190 --> 00:47:57,300  
are connected with extremely high

1178  
00:47:54,750 --> 00:47:59,760  
bandwidth links so that in order to get

1179  
00:47:57,300 --> 00:48:01,590  
the galaxies on one side to communicate

1180  
00:47:59,760 --> 00:48:02,850  
with the galaxies on the other side that

1181  
00:48:01,590 --> 00:48:06,720  
can transmit the information extremely

1182  
00:48:02,849 --> 00:48:08,519  
quickly so it rates that that are much

1183  
00:48:06,719 --> 00:48:10,589

faster than you can do over the internet

1184

00:48:08,519 --> 00:48:12,389

for example so factors of a hundred or a

1185

00:48:10,590 --> 00:48:14,630

thousand times faster than than internet

1186

00:48:12,389 --> 00:48:14,629

speeds

1187

00:48:15,860 --> 00:48:22,590

and so in practice to actually compute a

1188

00:48:19,739 --> 00:48:25,199

virtual universe like like like we want

1189

00:48:22,590 --> 00:48:28,610

to do I just want to show you how that

1190

00:48:25,199 --> 00:48:30,389

breaks down in practice the this is a

1191

00:48:28,610 --> 00:48:32,910

visualization of the illustrious

1192

00:48:30,389 --> 00:48:34,409

simulation and to give you an idea of

1193

00:48:32,909 --> 00:48:36,809

where our galaxies fall that we're

1194

00:48:34,409 --> 00:48:39,599

trying to model here's one down here

1195

00:48:36,809 --> 00:48:40,949

this is not in galaxy light we're

1196

00:48:39,599 --> 00:48:42,779

looking at but this is what it where it

1197

00:48:40,949 --> 00:48:44,730

might fit in terms of sizes so you can

1198  
00:48:42,780 --> 00:48:46,350  
see that we might have hundreds of

1199  
00:48:44,730 --> 00:48:49,050  
thousands of galaxies in this particular

1200  
00:48:46,349 --> 00:48:51,089  
image the blue purplish light that you

1201  
00:48:49,050 --> 00:48:53,760  
see in this image is dark matter so it's

1202  
00:48:51,090 --> 00:48:56,519  
the cosmic web the matter structure of

1203  
00:48:53,760 --> 00:48:58,320  
the universe here and the red or

1204  
00:48:56,519 --> 00:49:00,030  
yellowish tints of the image is

1205  
00:48:58,320 --> 00:49:02,280  
something to do with gas dynamics so

1206  
00:49:00,030 --> 00:49:05,370  
this is the gas velocity field and so

1207  
00:49:02,280 --> 00:49:06,780  
this is a way of visual getting a visual

1208  
00:49:05,369 --> 00:49:08,969  
impression of all of these these

1209  
00:49:06,780 --> 00:49:10,950  
processes acting on galaxies and so you

1210  
00:49:08,969 --> 00:49:12,959  
have the the cosmic web of dark matter

1211  
00:49:10,949 --> 00:49:15,359  
forming galaxies at the intersections

1212  
00:49:12,960 --> 00:49:17,579  
and then you have this gas being pushed

1213  
00:49:15,360 --> 00:49:19,349  
around by black holes in supernovae so

1214  
00:49:17,579 --> 00:49:21,090  
you can see that on the scale of a

1215  
00:49:19,349 --> 00:49:23,099  
galaxy which is this tiny thing here a

1216  
00:49:21,090 --> 00:49:25,530  
few laser pointer with the cross or less

1217  
00:49:23,099 --> 00:49:28,199  
probably less that there's this really

1218  
00:49:25,530 --> 00:49:30,540  
large spherical region of gas that's

1219  
00:49:28,199 --> 00:49:33,779  
been pushed out of another galaxy and so

1220  
00:49:30,539 --> 00:49:35,730  
this size region here is several or tens

1221  
00:49:33,780 --> 00:49:38,820  
of times bigger than that galaxy itself

1222  
00:49:35,730 --> 00:49:40,889  
so in order to actually compute what

1223  
00:49:38,820 --> 00:49:42,600  
happens to this galaxy over time we have

1224  
00:49:40,889 --> 00:49:44,699  
to know what happens at all these other

1225  
00:49:42,599 --> 00:49:46,230  
regions of space so we can't just break

1226

00:49:44,699 --> 00:49:47,969  
these apart and never communicate with

1227  
00:49:46,230 --> 00:49:49,530  
each other again we have to actually

1228  
00:49:47,969 --> 00:49:51,719  
have the ability to go back and

1229  
00:49:49,530 --> 00:49:53,310  
say oh there's gas being pushed onto

1230  
00:49:51,719 --> 00:49:54,899  
this region of space by these other

1231  
00:49:53,309 --> 00:49:56,940  
galaxies and that's why we need this

1232  
00:49:54,900 --> 00:50:00,450  
these sort of high bandwidth links among

1233  
00:49:56,940 --> 00:50:01,769  
the supercomputer nodes and this is now

1234  
00:50:00,449 --> 00:50:04,379  
the same grid that I showed you before

1235  
00:50:01,769 --> 00:50:06,719  
but now divide it up as you might assign

1236  
00:50:04,380 --> 00:50:09,119  
it to different computers so if you have

1237  
00:50:06,719 --> 00:50:11,339  
a supercomputer like IBM Blue Gene or

1238  
00:50:09,119 --> 00:50:14,250  
others you might break up the volume

1239  
00:50:11,340 --> 00:50:16,110  
like this and then assign to the a

1240  
00:50:14,250 --> 00:50:17,730

cluster of computers this one the B

1241

00:50:16,110 --> 00:50:21,059

cluster this one and the C cluster this

1242

00:50:17,730 --> 00:50:23,250

one so assign them all the galaxies and

1243

00:50:21,059 --> 00:50:25,529

and and actually the matter processes

1244

00:50:23,250 --> 00:50:27,690

that that happen in that region let that

1245

00:50:25,530 --> 00:50:30,090

computer work on it for a while same

1246

00:50:27,690 --> 00:50:32,970

with BCD and so on for a couple thousand

1247

00:50:30,090 --> 00:50:35,610

computers and then after each each

1248

00:50:32,969 --> 00:50:37,769

iteration of the equations you ask ok

1249

00:50:35,610 --> 00:50:39,990

does a need to communicate with B and C

1250

00:50:37,769 --> 00:50:43,230

and so on and then transfer the data

1251

00:50:39,989 --> 00:50:44,789

across those those high bandwidth links

1252

00:50:43,230 --> 00:50:47,070

that I showed before in order to get

1253

00:50:44,789 --> 00:50:52,199

that information that they need at all

1254

00:50:47,070 --> 00:50:55,650

the different regions so that's kind of



1255  
00:50:52,199 --> 00:50:57,629  
a heuristic view of what we do to model

1256  
00:50:55,650 --> 00:50:59,280  
a virtual universe I'm gonna spend the

1257  
00:50:57,630 --> 00:51:00,809  
rest of the talk just introducing the

1258  
00:50:59,280 --> 00:51:04,519  
illustrious project and what we were

1259  
00:51:00,809 --> 00:51:07,679  
able to accomplish using these methods

1260  
00:51:04,519 --> 00:51:09,389  
so the the goal as I've talked about a

1261  
00:51:07,679 --> 00:51:12,149  
few times is to simulate the formation

1262  
00:51:09,389 --> 00:51:15,569  
of galaxies specifically the the sort of

1263  
00:51:12,150 --> 00:51:17,639  
main idea of this was to form things

1264  
00:51:15,570 --> 00:51:19,440  
form about ten thousand galaxies that

1265  
00:51:17,639 --> 00:51:21,210  
have roughly the same mass as the Milky

1266  
00:51:19,440 --> 00:51:22,769  
Way galaxy so we live in the Milky Way

1267  
00:51:21,210 --> 00:51:24,329  
we wanted to form something like ten

1268  
00:51:22,769 --> 00:51:28,530  
thousand times that that particular

1269  
00:51:24,329 --> 00:51:29,940  
galaxy size or mass this is one of the

1270  
00:51:28,530 --> 00:51:31,950  
supercomputers that it was run on this

1271  
00:51:29,940 --> 00:51:34,409  
is the super MOOC computer in Garching

1272  
00:51:31,949 --> 00:51:37,529  
Germany it was run on another very

1273  
00:51:34,409 --> 00:51:39,690  
similar one in France for uptime and so

1274  
00:51:37,530 --> 00:51:43,500  
here the hallways of racks upon racks of

1275  
00:51:39,690 --> 00:51:45,000  
supercomputers here and here's the kind

1276  
00:51:43,500 --> 00:51:46,769  
of vital statistics of the illustris

1277  
00:51:45,000 --> 00:51:48,360  
project and I couldn't think of a much

1278  
00:51:46,769 --> 00:51:49,289  
better way to present this I'll just

1279  
00:51:48,360 --> 00:51:52,620  
I'll just give you the numbers

1280  
00:51:49,289 --> 00:51:55,559  
I took roughly 20 million computer hours

1281  
00:51:52,619 --> 00:51:57,719  
of total computation to compute the

1282  
00:51:55,559 --> 00:51:59,610  
10000 Milky Way's and their formation so

1283

00:51:57,719 --> 00:52:03,239  
it take my laptop about 20 million hours

1284  
00:51:59,610 --> 00:52:05,010  
to compute this that ended up

1285  
00:52:03,239 --> 00:52:06,059  
taking about six months on 8,000

1286  
00:52:05,010 --> 00:52:07,680  
computers that are connected together

1287  
00:52:06,059 --> 00:52:10,829  
and it was completed about a year ago in

1288  
00:52:07,679 --> 00:52:12,899  
November 2013 they're about 20 billion

1289  
00:52:10,829 --> 00:52:15,269  
elements that it ended up being so 20

1290  
00:52:12,900 --> 00:52:17,730  
billion bits of galaxies that were that

1291  
00:52:15,269 --> 00:52:19,860  
were remodeled and that volume

1292  
00:52:17,730 --> 00:52:21,389  
corresponds to about a million times the

1293  
00:52:19,860 --> 00:52:23,130  
space between the Milky Way and the

1294  
00:52:21,389 --> 00:52:26,940  
Andromeda galaxy which is our nearest

1295  
00:52:23,130 --> 00:52:28,740  
massive galaxy neighbour and the output

1296  
00:52:26,940 --> 00:52:31,170  
of the simulation was stored 150 times

1297  
00:52:28,739 --> 00:52:33,750

so at different cosmic times we have the

1298

00:52:31,170 --> 00:52:36,180

history of those galaxies stored 150

1299

00:52:33,750 --> 00:52:37,980

times and that amounts to something like

1300

00:52:36,179 --> 00:52:39,899

200 trillion bytes of data that are

1301

00:52:37,980 --> 00:52:42,119

stored on disk and I was a little bit

1302

00:52:39,900 --> 00:52:43,829

surprised that that's only 5000 iPhones

1303

00:52:42,119 --> 00:52:46,350

so if you if you deleted all your music

1304

00:52:43,829 --> 00:52:47,670

um your iPhones and put together 5000 of

1305

00:52:46,349 --> 00:52:50,130

them you could store the orchestra

1306

00:52:47,670 --> 00:52:51,210

stimulation on all of them I don't know

1307

00:52:50,130 --> 00:52:53,250

how useful that would be probably not

1308

00:52:51,210 --> 00:52:58,050

very useful but just to give you an idea

1309

00:52:53,250 --> 00:53:00,179

of how much data there is so without

1310

00:52:58,050 --> 00:53:02,310

much further ado I just want to show you

1311

00:53:00,179 --> 00:53:04,500

some visualizations of the orchestra

1312  
00:53:02,309 --> 00:53:05,579  
simulation so these were not being by me

1313  
00:53:04,500 --> 00:53:08,190  
but were made by others on the

1314  
00:53:05,579 --> 00:53:10,799  
collaboration and so this is now the

1315  
00:53:08,190 --> 00:53:13,380  
large scale of the olestra simulation so

1316  
00:53:10,800 --> 00:53:15,930  
each of these blue right blue nodes here

1317  
00:53:13,380 --> 00:53:16,920  
is where you might form a galaxy similar

1318  
00:53:15,929 --> 00:53:19,139  
to the simulation that I showed before

1319  
00:53:16,920 --> 00:53:21,119  
and this is not going to evolve in time

1320  
00:53:19,139 --> 00:53:22,559  
I'm just going to zoom in and then zoom

1321  
00:53:21,119 --> 00:53:24,090  
back out to give you an idea of the

1322  
00:53:22,559 --> 00:53:26,219  
different scales that are involved and

1323  
00:53:24,090 --> 00:53:27,600  
so you know our Milky Way galaxy might

1324  
00:53:26,219 --> 00:53:30,239  
reside here and we're going to zoom into

1325  
00:53:27,599 --> 00:53:32,368  
one example of a galaxy so this is

1326  
00:53:30,239 --> 00:53:33,449  
showing just the matter density and then

1327  
00:53:32,369 --> 00:53:34,829  
it's going to change the different

1328  
00:53:33,449 --> 00:53:37,409  
quantities here's and then it's going to

1329  
00:53:34,829 --> 00:53:38,670  
show gas temperature so this is the the

1330  
00:53:37,409 --> 00:53:40,319  
temperature of the gas that might be

1331  
00:53:38,670 --> 00:53:42,180  
heated by supernovae or black hole for

1332  
00:53:40,320 --> 00:53:45,059  
me black hole accretion and and energy

1333  
00:53:42,179 --> 00:53:48,719  
feedback and so each of these points is

1334  
00:53:45,059 --> 00:53:51,659  
a galaxy this is gas middle isset II so

1335  
00:53:48,719 --> 00:53:53,009  
this is the sort of heavier elements

1336  
00:53:51,659 --> 00:53:56,009  
than hydrogen and helium that form in

1337  
00:53:53,010 --> 00:53:57,480  
stars and then eventually we go back to

1338  
00:53:56,010 --> 00:54:00,240  
stellar light and so now we're zooming

1339  
00:53:57,480 --> 00:54:01,920  
in finally to a galaxy scale something

1340

00:54:00,239 --> 00:54:04,439  
like that might look like the Milky Way

1341  
00:54:01,920 --> 00:54:06,780  
galaxy it's a little bit more coarsely

1342  
00:54:04,440 --> 00:54:08,579  
resolved then the nice HST images but

1343  
00:54:06,780 --> 00:54:10,560  
you can get an idea that this is a nice

1344  
00:54:08,579 --> 00:54:13,319  
disc galaxy that might evolve in the

1345  
00:54:10,559 --> 00:54:15,269  
same way as as the spiral galaxies that

1346  
00:54:13,320 --> 00:54:16,539  
we see in the local universe and we're

1347  
00:54:15,269 --> 00:54:18,219  
going to zoom back out to this

1348  
00:54:16,539 --> 00:54:20,619  
large scale again going through gas

1349  
00:54:18,219 --> 00:54:22,838  
density now showing all the companions

1350  
00:54:20,619 --> 00:54:24,939  
of the galaxy so the these companions

1351  
00:54:22,838 --> 00:54:26,889  
can interact as they evolve in time and

1352  
00:54:24,938 --> 00:54:33,639  
and have to have those issues that we

1353  
00:54:26,889 --> 00:54:35,588  
talked about with galaxy mergers and

1354  
00:54:33,639 --> 00:54:37,958

then now getting to the the sort of full

1355

00:54:35,588 --> 00:54:42,099

scale of a lustrous at the very end

1356

00:54:37,958 --> 00:54:50,318

again in gas velocity and then finally

1357

00:54:42,099 --> 00:54:52,959

in dark matter again and so we have all

1358

00:54:50,318 --> 00:54:54,548

this information on scales ranging from

1359

00:54:52,958 --> 00:54:56,588

the whole universe of the whole virtual

1360

00:54:54,548 --> 00:54:58,150

universe in this case down to the

1361

00:54:56,588 --> 00:55:00,788

individual galaxies like the Milky Way

1362

00:54:58,150 --> 00:55:03,818

that we can watch evolve in time and so

1363

00:55:00,789 --> 00:55:05,890

speaking of evolving in time here is now

1364

00:55:03,818 --> 00:55:08,708

a movie put together by the team by Mark

1365

00:55:05,889 --> 00:55:10,418

Vogel's burger in particular of that

1366

00:55:08,708 --> 00:55:12,578

evolving in time and so there's a couple

1367

00:55:10,418 --> 00:55:14,228

things happening in this movie one we're

1368

00:55:12,579 --> 00:55:16,028

rotating around the virtual universe



1369  
00:55:14,228 --> 00:55:17,108  
which is a little bit unphysical but it

1370  
00:55:16,028 --> 00:55:19,059  
just helps you to visualize what's

1371  
00:55:17,108 --> 00:55:20,409  
happening and the galaxies are revolving

1372  
00:55:19,059 --> 00:55:21,609  
in time so the time since the Big Bang

1373  
00:55:20,409 --> 00:55:23,828  
which you might not be able to read to

1374  
00:55:21,608 --> 00:55:26,528  
the bottom left but you can see the

1375  
00:55:23,829 --> 00:55:28,919  
galaxies evolve and at first all the

1376  
00:55:26,528 --> 00:55:30,759  
galaxies were in just dark matter

1377  
00:55:28,918 --> 00:55:32,759  
visualization and now we're adding on

1378  
00:55:30,759 --> 00:55:35,528  
top of that some rendering of the gas

1379  
00:55:32,759 --> 00:55:42,188  
and so you get to see pretty cool colors

1380  
00:55:35,528 --> 00:55:45,068  
and explosions I like the explosions and

1381  
00:55:42,188 --> 00:55:47,158  
so each of these blue knots are galaxies

1382  
00:55:45,068 --> 00:55:49,088  
like we saw in the previous zoom in

1383  
00:55:47,159 --> 00:55:51,548  
there's other things happening now that

1384  
00:55:49,088 --> 00:55:54,009  
we can see what's happening in time and

1385  
00:55:51,548 --> 00:55:55,900  
that's these these galaxies issues that

1386  
00:55:54,009 --> 00:55:57,909  
talked about so you can see the galaxies

1387  
00:55:55,900 --> 00:55:59,079  
flickering a little bit I'm not sure how

1388  
00:55:57,909 --> 00:56:00,939  
many of you will be able to see that but

1389  
00:55:59,079 --> 00:56:03,179  
there's a small level of flickering

1390  
00:56:00,938 --> 00:56:07,118  
among the blue regions in the galaxies

1391  
00:56:03,179 --> 00:56:09,039  
those are feedback events so these are

1392  
00:56:07,119 --> 00:56:11,108  
they did these energetic events like

1393  
00:56:09,039 --> 00:56:13,599  
stars exploding or black holes are

1394  
00:56:11,108 --> 00:56:15,248  
creating gas so these are pushing energy

1395  
00:56:13,599 --> 00:56:16,869  
back into the I am and so that's heating

1396  
00:56:15,248 --> 00:56:18,608  
the gas and expelling it at high

1397

00:56:16,869 --> 00:56:20,559  
velocities and that's what's causing

1398  
00:56:18,608 --> 00:56:23,828  
those that flickering or the explosions

1399  
00:56:20,559 --> 00:56:26,019  
that you see and so those explosions are

1400  
00:56:23,829 --> 00:56:27,909  
on huge scales here so I didn't put a

1401  
00:56:26,018 --> 00:56:29,989  
scale on this but you can see it's you

1402  
00:56:27,909 --> 00:56:31,610  
know these those explosions were plowing

1403  
00:56:29,989 --> 00:56:33,799  
through multiple galaxies as they

1404  
00:56:31,610 --> 00:56:38,000  
evolved in and through the IgM the

1405  
00:56:33,800 --> 00:56:40,630  
intergalactic medium so I want to show

1406  
00:56:38,000 --> 00:56:44,000  
that again actually just to just to get

1407  
00:56:40,630 --> 00:56:52,849  
get it in get the explosions again I

1408  
00:56:44,000 --> 00:57:03,280  
really like the explosions not yet do

1409  
00:56:52,849 --> 00:57:05,239  
you know it yes so I think the

1410  
00:57:03,280 --> 00:57:06,860  
flickering I think our supernova

1411  
00:57:05,239 --> 00:57:09,199

explosions happening in the galaxies and

1412

00:57:06,860 --> 00:57:11,539

the explosions I think our energetic

1413

00:57:09,199 --> 00:57:13,039

black hole events so there the black

1414

00:57:11,539 --> 00:57:15,170

hole is accreting and then expelling the

1415

00:57:13,039 --> 00:57:22,579

gas out entirely out of the galaxies in

1416

00:57:15,170 --> 00:57:24,650

those those red explosions and so this

1417

00:57:22,579 --> 00:57:26,900

is largely just visualizing the gas so

1418

00:57:24,650 --> 00:57:29,119

the the gas dynamics of galaxies which

1419

00:57:26,900 --> 00:57:31,010

we don't actually get to see when we

1420

00:57:29,119 --> 00:57:32,630

look at a galaxy with Hubble so all of

1421

00:57:31,010 --> 00:57:34,880

the very beautiful Hubble images of

1422

00:57:32,630 --> 00:57:37,250

galaxies that we've seen show primarily

1423

00:57:34,880 --> 00:57:39,260

the stars but we don't get to see all

1424

00:57:37,250 --> 00:57:41,059

this action happening in the galaxies

1425

00:57:39,260 --> 00:57:42,050

with an image like like we get simply

1426  
00:57:41,059 --> 00:57:44,989  
out of Hubble in the Hubble Ultra Deep

1427  
00:57:42,050 --> 00:57:46,580  
Field or surveys like it and so we

1428  
00:57:44,989 --> 00:57:49,069  
really like to have these simulations to

1429  
00:57:46,579 --> 00:57:51,289  
get at that that at that aspect of the

1430  
00:57:49,070 --> 00:57:52,880  
science so we don't actually get to see

1431  
00:57:51,289 --> 00:58:02,559  
this happen very often in the real

1432  
00:57:52,880 --> 00:58:02,559  
universe that's right yeah so that helps

1433  
00:58:04,179 --> 00:58:09,079  
of course yeah so we can then we can

1434  
00:58:07,280 --> 00:58:10,700  
then see how things evolve in the

1435  
00:58:09,079 --> 00:58:16,009  
simulation see if it matches what we see

1436  
00:58:10,699 --> 00:58:17,989  
in the real universe and so that's great

1437  
00:58:16,010 --> 00:58:20,270  
so now we have all the pieces we need in

1438  
00:58:17,989 --> 00:58:21,979  
order to put together our story of the

1439  
00:58:20,269 --> 00:58:24,079  
evolution of certain galaxies in the

1440  
00:58:21,980 --> 00:58:26,269  
simulation and so now we can take our

1441  
00:58:24,079 --> 00:58:28,039  
simulation and identify galaxies at

1442  
00:58:26,269 --> 00:58:29,690  
different times and then see how they

1443  
00:58:28,039 --> 00:58:31,340  
evolve into the galaxies that we see

1444  
00:58:29,690 --> 00:58:33,079  
today and we can watch them happen one

1445  
00:58:31,340 --> 00:58:34,400  
by one and track them and see what

1446  
00:58:33,079 --> 00:58:37,630  
happens and sort of tell each galaxies

1447  
00:58:34,400 --> 00:58:37,630  
story by itself

1448  
00:58:38,590 --> 00:58:42,610  
and so in the end I showed you a couple

1449  
00:58:41,260 --> 00:58:44,350  
of neat visualizations of the olestra

1450  
00:58:42,610 --> 00:58:45,849  
simulation what you get are galaxies

1451  
00:58:44,349 --> 00:58:47,650  
like we know and love in the local

1452  
00:58:45,849 --> 00:58:49,360  
universe and so these are simulated

1453  
00:58:47,650 --> 00:58:52,599  
galaxies from the illustrious simulation

1454

00:58:49,360 --> 00:58:54,789  
just fewer than 20 of them shown on a

1455  
00:58:52,599 --> 00:58:56,889  
slide these were selected visually just

1456  
00:58:54,789 --> 00:58:58,360  
to show you the the sampling of disk

1457  
00:58:56,889 --> 00:58:59,859  
galaxies and elliptical galaxies that we

1458  
00:58:58,360 --> 00:59:02,200  
get in the end and this was the ultimate

1459  
00:58:59,860 --> 00:59:04,599  
goal of the austria's project to get

1460  
00:59:02,199 --> 00:59:06,460  
this sort of separation in the galaxies

1461  
00:59:04,599 --> 00:59:07,569  
types and just to sample the different

1462  
00:59:06,460 --> 00:59:09,309  
types of galaxies that we see in the

1463  
00:59:07,570 --> 00:59:12,340  
universe and I think we've accomplished

1464  
00:59:09,309 --> 00:59:14,110  
that we've gotten to that point but with

1465  
00:59:12,340 --> 00:59:17,079  
the simulation of this scope in this

1466  
00:59:14,110 --> 00:59:20,019  
size we have I think access to a lot

1467  
00:59:17,079 --> 00:59:21,460  
more power in the future so let me just

1468  
00:59:20,019 --> 00:59:25,179

talk a little bit about where I see this

1469

00:59:21,460 --> 00:59:27,610

going and the specific example I want to

1470

00:59:25,179 --> 00:59:30,099

show is a model of the Hubble Ultra Deep

1471

00:59:27,610 --> 00:59:31,800

Field so on the left is the actual

1472

00:59:30,099 --> 00:59:33,369

Hubble Ultra Deep Field from the

1473

00:59:31,800 --> 00:59:35,289

observations made by the Hubble Space

1474

00:59:33,369 --> 00:59:37,329

Telescope and on the right you're

1475

00:59:35,289 --> 00:59:38,949

looking at the olestra simulation in the

1476

00:59:37,329 --> 00:59:40,529

exactly the same units as you would

1477

00:59:38,949 --> 00:59:43,599

observe them in Hubble ultra-deep field

1478

00:59:40,530 --> 00:59:46,180

so I've taken that simulated volume and

1479

00:59:43,599 --> 00:59:47,920

then observed it with a Hubble Space

1480

00:59:46,179 --> 00:59:49,839

Telescope in the computers basically so

1481

00:59:47,920 --> 00:59:52,930

it's an imaginary Hubble Space Telescope

1482

00:59:49,840 --> 00:59:55,090

drawn a line of sight through the Box in



1483  
00:59:52,929 --> 00:59:57,069  
the olestra simulation and then at each

1484  
00:59:55,090 --> 00:59:58,360  
galaxy point decided how it should look

1485  
00:59:57,070 --> 01:00:00,070  
according to the Hubble Space

1486  
00:59:58,360 --> 01:00:01,809  
Telescope's filters and cameras and

1487  
01:00:00,070 --> 01:00:03,850  
things like that and then just rendered

1488  
01:00:01,809 --> 01:00:06,309  
that in the same size same region of sky

1489  
01:00:03,849 --> 01:00:07,839  
as the Ultra Deep Field so here is

1490  
01:00:06,309 --> 01:00:10,329  
10,000 galaxies observed in the universe

1491  
01:00:07,840 --> 01:00:12,640  
now we have 10,000 galaxies

1492  
01:00:10,329 --> 01:00:14,619  
mact observed in a mock universe from

1493  
01:00:12,639 --> 01:00:16,420  
the austria simulation and the

1494  
01:00:14,619 --> 01:00:18,609  
illustrious simulation is one of several

1495  
01:00:16,420 --> 01:00:20,530  
collaborations that have finally reached

1496  
01:00:18,610 --> 01:00:22,780  
the point of being able to do this kind

1497  
01:00:20,530 --> 01:00:24,610  
of this kind of rendering it is never

1498  
01:00:22,780 --> 01:00:26,830  
before been possible to populate a

1499  
01:00:24,610 --> 01:00:28,420  
Hubble Ultra Deep Field with galaxies

1500  
01:00:26,829 --> 01:00:30,279  
that are simulated from the beginning of

1501  
01:00:28,420 --> 01:00:32,889  
the universe and so this is the really a

1502  
01:00:30,280 --> 01:00:34,980  
first in theoretical astrophysics we've

1503  
01:00:32,889 --> 01:00:36,759  
been we've been pushed along by

1504  
01:00:34,980 --> 01:00:38,650  
observational advances like the Hubble

1505  
01:00:36,760 --> 01:00:41,860  
Ultra Deep Field for 30 years now and

1506  
01:00:38,650 --> 01:00:43,450  
we've only just caught up to the sort of

1507  
01:00:41,860 --> 01:00:46,210  
Hubble Space Telescope like surveys of

1508  
01:00:43,449 --> 01:00:48,849  
galaxies in our simulations of galaxies

1509  
01:00:46,210 --> 01:00:51,010  
and so that's sort of representing this

1510  
01:00:48,849 --> 01:00:51,940  
this this slide is representing of that

1511

01:00:51,010 --> 01:00:54,610  
that fact

1512  
01:00:51,940 --> 01:00:57,490  
that we've come a long way and we

1513  
01:00:54,610 --> 01:01:01,630  
finally can have a mock universe to call

1514  
01:00:57,489 --> 01:01:03,789  
our own so I'm gonna zoom in here on the

1515  
01:01:01,630 --> 01:01:04,869  
real sky so this is the similar to the

1516  
01:01:03,789 --> 01:01:06,670  
one that I showed earlier in the talk of

1517  
01:01:04,869 --> 01:01:08,409  
the Hubble Ultra Deep Field showing the

1518  
01:01:06,670 --> 01:01:11,079  
diversity of galaxies as observed

1519  
01:01:08,409 --> 01:01:13,149  
directly with Hubble and I'm going to

1520  
01:01:11,079 --> 01:01:14,769  
slide over slowly to the simulated side

1521  
01:01:13,150 --> 01:01:18,849  
and you can see where the transition

1522  
01:01:14,769 --> 01:01:22,179  
happens here and these are now entirely

1523  
01:01:18,849 --> 01:01:23,889  
a simulated universe so we can see a

1524  
01:01:22,179 --> 01:01:27,579  
nice diversity of galaxies of different

1525  
01:01:23,889 --> 01:01:29,469

colors and shapes and and yeah so this

1526

01:01:27,579 --> 01:01:31,869

is sort of a mock observation of the

1527

01:01:29,469 --> 01:01:33,369

illustrious simulation itself here and

1528

01:01:31,869 --> 01:01:35,739

so you can see an elliptical galaxy up

1529

01:01:33,369 --> 01:01:40,719

at the top blue star forming spiral

1530

01:01:35,739 --> 01:01:43,329

galaxies all around and so on now it's

1531

01:01:40,719 --> 01:01:44,709

not perfect so I I don't want to claim

1532

01:01:43,329 --> 01:01:46,389

that it's perfect and I think we have a

1533

01:01:44,710 --> 01:01:48,130

long way to go to actually get it to

1534

01:01:46,389 --> 01:01:49,210

look more like the Ultra Deep Field so

1535

01:01:48,130 --> 01:01:51,280

I'm gonna jump back and forth now

1536

01:01:49,210 --> 01:01:53,740

quickly here's the Hubble Ultra Deep

1537

01:01:51,280 --> 01:01:56,530

Field again and here's the simulated sky

1538

01:01:53,739 --> 01:01:58,059

of the same size in the same units so

1539

01:01:56,530 --> 01:02:01,780

you're looking at the same rendering are

1540  
01:01:58,059 --> 01:02:03,159  
the same colors are the same but

1541  
01:02:01,780 --> 01:02:05,320  
galaxies are a little bit bigger in the

1542  
01:02:03,159 --> 01:02:07,359  
simulation so the galaxies are much

1543  
01:02:05,320 --> 01:02:09,550  
larger they a factor of two or so than

1544  
01:02:07,360 --> 01:02:11,410  
they then they are observed and the

1545  
01:02:09,550 --> 01:02:13,390  
colors are a little wonky so the colors

1546  
01:02:11,409 --> 01:02:16,469  
are not perfectly matched to the real

1547  
01:02:13,389 --> 01:02:19,119  
sky and we think we think we have now

1548  
01:02:16,469 --> 01:02:21,519  
the ability to take this information and

1549  
01:02:19,119 --> 01:02:24,299  
then improve our models of virtual

1550  
01:02:21,519 --> 01:02:24,300  
universe formation

1551  
01:02:33,980 --> 01:02:38,300  
so what this allows now that we can

1552  
01:02:36,710 --> 01:02:40,190  
populate things like the Hubble

1553  
01:02:38,300 --> 01:02:43,280  
ultra-deep field and other surveys of

1554  
01:02:40,190 --> 01:02:45,679  
galaxies with fake galaxies this allows

1555  
01:02:43,280 --> 01:02:47,480  
us to make a statistically robust

1556  
01:02:45,679 --> 01:02:49,819  
comparison against observations across

1557  
01:02:47,480 --> 01:02:51,650  
all of cosmic time so this is a quote

1558  
01:02:49,820 --> 01:02:53,269  
that I really like that was in the CNN

1559  
01:02:51,650 --> 01:02:54,829  
article about the illustrious project by

1560  
01:02:53,269 --> 01:02:57,429  
one of the team members Dylan Nelson

1561  
01:02:54,829 --> 01:02:59,810  
who's a graduate student at Harvard and

1562  
01:02:57,429 --> 01:03:02,569  
so this is kind of a long way of saying

1563  
01:02:59,809 --> 01:03:04,039  
we get a lot of galaxies so we get a

1564  
01:03:02,570 --> 01:03:05,809  
number of galaxies that we can then

1565  
01:03:04,039 --> 01:03:08,929  
statistically compared with the real

1566  
01:03:05,809 --> 01:03:10,279  
universe and then iterate again and so

1567  
01:03:08,929 --> 01:03:11,649  
the next model universe will take the

1568

01:03:10,280 --> 01:03:13,910  
lessons we've learned from that

1569  
01:03:11,650 --> 01:03:15,500  
statistical sample which we we have for

1570  
01:03:13,909 --> 01:03:18,529  
the first time and then iterate and

1571  
01:03:15,500 --> 01:03:20,750  
create better ones but I want to end on

1572  
01:03:18,530 --> 01:03:24,019  
the on the note that quantity is not

1573  
01:03:20,750 --> 01:03:25,849  
everything in this and so the the

1574  
01:03:24,019 --> 01:03:27,440  
quality of the galaxies you get out is

1575  
01:03:25,849 --> 01:03:29,990  
also something that people are modeling

1576  
01:03:27,440 --> 01:03:31,369  
and trying trying to get at and in

1577  
01:03:29,989 --> 01:03:33,289  
particular there are other groups

1578  
01:03:31,369 --> 01:03:35,088  
simulating galaxies that made different

1579  
01:03:33,289 --> 01:03:37,039  
choices about how to handle the issues

1580  
01:03:35,088 --> 01:03:38,630  
of galaxies so I described one one

1581  
01:03:37,039 --> 01:03:41,059  
example the olestra simulation there are

1582  
01:03:38,630 --> 01:03:43,280

other groups and including our own group

1583

01:03:41,059 --> 01:03:45,500

which are taking different choices for

1584

01:03:43,280 --> 01:03:47,810

how you model star formation and what

1585

01:03:45,500 --> 01:03:51,260

that lets you do is say trade away the

1586

01:03:47,809 --> 01:03:52,880

statistics for higher fidelity images of

1587

01:03:51,260 --> 01:03:54,589

galaxies so you can get a better handle

1588

01:03:52,880 --> 01:03:57,019

on the formation of stars within

1589

01:03:54,588 --> 01:03:59,480

galaxies rather than the formation of a

1590

01:03:57,019 --> 01:04:01,568

population of galaxies and so I just

1591

01:03:59,480 --> 01:04:04,969

want to show a couple examples of that

1592

01:04:01,568 --> 01:04:06,440

here so this is a simulated galaxy on

1593

01:04:04,969 --> 01:04:08,598

the left as it would be observed with

1594

01:04:06,440 --> 01:04:12,108

HST if you could observe for a long

1595

01:04:08,599 --> 01:04:13,880

period of time we would see this but the

1596

01:04:12,108 --> 01:04:16,670

simulations now are getting to the point



1597  
01:04:13,880 --> 01:04:18,950  
where we can go beyond what HST is even

1598  
01:04:16,670 --> 01:04:20,869  
capable of so the fidelity of the

1599  
01:04:18,949 --> 01:04:22,939  
simulations this one is not the

1600  
01:04:20,869 --> 01:04:24,640  
illustrious simulation goes well beyond

1601  
01:04:22,940 --> 01:04:26,990  
what you can do with a just T so HST

1602  
01:04:24,639 --> 01:04:29,358  
which is a two point four meter mirror

1603  
01:04:26,989 --> 01:04:30,799  
can only resolve so much and so the

1604  
01:04:29,358 --> 01:04:32,420  
resolving power of a telescope is

1605  
01:04:30,800 --> 01:04:34,460  
directly proportional to the size of its

1606  
01:04:32,420 --> 01:04:36,380  
primary mirror here at two point four

1607  
01:04:34,460 --> 01:04:37,909  
meters a galaxy that's three billion

1608  
01:04:36,380 --> 01:04:40,338  
years old or three billion years after

1609  
01:04:37,909 --> 01:04:42,440  
the Big Bang will be largely a smudge

1610  
01:04:40,338 --> 01:04:44,059  
and so that all of the interesting stuff

1611  
01:04:42,440 --> 01:04:45,530  
that I talked about the issues that are

1612  
01:04:44,059 --> 01:04:47,750  
involved in galaxies the formation of

1613  
01:04:45,530 --> 01:04:51,019  
stars are smeared out along these

1614  
01:04:47,750 --> 01:04:52,909  
big these big regions and the simulation

1615  
01:04:51,019 --> 01:04:55,039  
the galaxy formation can now go well

1616  
01:04:52,909 --> 01:04:56,899  
beyond that so here's a rendering of a

1617  
01:04:55,039 --> 01:04:59,150  
16 meter telescope so imagine if you

1618  
01:04:56,900 --> 01:05:01,369  
could take Hubble and make it 16 meters

1619  
01:04:59,150 --> 01:05:02,930  
and put a big camera in it and you get a

1620  
01:05:01,369 --> 01:05:04,519  
gallon you get an image like this one so

1621  
01:05:02,929 --> 01:05:06,019  
this is a very distant galaxy one of

1622  
01:05:04,519 --> 01:05:08,030  
those little smudges on the ultra-deep

1623  
01:05:06,019 --> 01:05:09,920  
field that I showed a telescope like

1624  
01:05:08,030 --> 01:05:12,110  
this one could resolve all of them into

1625

01:05:09,920 --> 01:05:13,579  
its constituent parts and we could see

1626  
01:05:12,110 --> 01:05:17,599  
all of the the interesting bits of

1627  
01:05:13,579 --> 01:05:21,110  
galaxies here in the in the observation

1628  
01:05:17,599 --> 01:05:23,089  
and so this simulation is is you know

1629  
01:05:21,110 --> 01:05:24,829  
one galaxy we don't really know how to

1630  
01:05:23,090 --> 01:05:26,870  
say same thing about the statistics of

1631  
01:05:24,829 --> 01:05:29,239  
galaxies but we can start to understand

1632  
01:05:26,869 --> 01:05:31,819  
where our place in the universe really

1633  
01:05:29,239 --> 01:05:33,829  
is here so I showed you before where our

1634  
01:05:31,820 --> 01:05:36,860  
solar system would fit in in a real

1635  
01:05:33,829 --> 01:05:38,779  
image of a galaxy with the simulations

1636  
01:05:36,860 --> 01:05:42,500  
that are coming online now and the

1637  
01:05:38,780 --> 01:05:43,640  
possible future missions beyond HST we

1638  
01:05:42,500 --> 01:05:45,469  
might be able to start to see the

1639  
01:05:43,639 --> 01:05:47,960

regions of space where our solar system

1640

01:05:45,469 --> 01:05:50,449

formed in model universes in virtual

1641

01:05:47,960 --> 01:05:52,130

universes like this one we're still not

1642

01:05:50,449 --> 01:05:54,919

there yet but I think in the coming

1643

01:05:52,130 --> 01:05:57,650

decades we'll be able to get there and

1644

01:05:54,920 --> 01:06:00,139

so this this is an image of some of the

1645

01:05:57,650 --> 01:06:02,119

missions that nASA has launched and is

1646

01:06:00,139 --> 01:06:04,670

launching and may launch in the future

1647

01:06:02,119 --> 01:06:07,699

so here's HST which is launched in 1990

1648

01:06:04,670 --> 01:06:09,680

and I think we've just caught up with HS

1649

01:06:07,699 --> 01:06:11,989

T's ability to observe the universe with

1650

01:06:09,679 --> 01:06:14,119

our virtual universes so we've finally

1651

01:06:11,989 --> 01:06:17,389

gotten back to the 1990 era galaxies

1652

01:06:14,119 --> 01:06:18,409

that we can observe with HST JWST will

1653

01:06:17,389 --> 01:06:20,599

be launched the James Webb Space

1654  
01:06:18,409 --> 01:06:21,829  
Telescope is currently being built down

1655  
01:06:20,599 --> 01:06:26,420  
and Goddard Space Flight Center in

1656  
01:06:21,829 --> 01:06:28,610  
Maryland with a plan 2018 launch so this

1657  
01:06:26,420 --> 01:06:30,889  
will then set the bar even further for

1658  
01:06:28,610 --> 01:06:32,390  
our models of galaxy formation and the

1659  
01:06:30,889 --> 01:06:34,009  
one that I showed you the cognition

1660  
01:06:32,389 --> 01:06:35,389  
concept that I showed you is one that's

1661  
01:06:34,010 --> 01:06:37,430  
currently being discussed by some

1662  
01:06:35,389 --> 01:06:38,869  
scientists here at Space Telescope it's

1663  
01:06:37,429 --> 01:06:40,909  
called the advanced technology mission

1664  
01:06:38,869 --> 01:06:43,159  
concept which could have a 16 meter

1665  
01:06:40,909 --> 01:06:44,899  
diameter mirror and would give you those

1666  
01:06:43,159 --> 01:06:47,659  
perfect images of galaxies that I showed

1667  
01:06:44,900 --> 01:06:50,119  
on the previous slide it could also

1668  
01:06:47,659 --> 01:06:52,219  
observe an earth around another star

1669  
01:06:50,119 --> 01:06:53,719  
directly so it has a couple it has a

1670  
01:06:52,219 --> 01:06:55,459  
couple different things going for it so

1671  
01:06:53,719 --> 01:06:56,359  
in addition to resolving galaxies it

1672  
01:06:55,460 --> 01:06:59,940  
could take a picture of an earth

1673  
01:06:56,360 --> 01:07:03,298  
orbiting a star in in our galaxy

1674  
01:06:59,940 --> 01:07:07,260  
and so it then is to summarize that

1675  
01:07:03,298 --> 01:07:08,460  
here's an HST image of a galaxy 3

1676  
01:07:07,260 --> 01:07:10,829  
billion years after the Big Bang a very

1677  
01:07:08,460 --> 01:07:12,659  
distant galaxy and here's how it would

1678  
01:07:10,829 --> 01:07:14,970  
look according to a 16 meter telescope

1679  
01:07:12,659 --> 01:07:16,588  
and so we can actually begin to resolve

1680  
01:07:14,969 --> 01:07:19,199  
the bits of galaxies that HST is

1681  
01:07:16,588 --> 01:07:22,558  
revealing to us into the regions of

1682

01:07:19,199 --> 01:07:26,219  
space where stars like ours formed in in

1683  
01:07:22,559 --> 01:07:28,769  
the past and so then I'll just end with

1684  
01:07:26,219 --> 01:07:31,578  
a movie of that particular simulation

1685  
01:07:28,769 --> 01:07:35,460  
evolving in time showing HST on left

1686  
01:07:31,579 --> 01:07:36,839  
JWST on the right and then to sort of

1687  
01:07:35,460 --> 01:07:37,559  
toy models for telescopes that could

1688  
01:07:36,838 --> 01:07:40,108  
exist in the future

1689  
01:07:37,559 --> 01:07:41,940  
and maybe a little bit hard to see in

1690  
01:07:40,108 --> 01:07:43,588  
the back so feel free to come up

1691  
01:07:41,940 --> 01:07:44,849  
afterwards and take a look at this or

1692  
01:07:43,588 --> 01:07:47,338  
look at these these screens which might

1693  
01:07:44,849 --> 01:07:48,619  
be a little bit crisper that the 16

1694  
01:07:47,338 --> 01:07:50,730  
metre telescope an 8 metre telescope

1695  
01:07:48,619 --> 01:07:52,410  
really resolved the fine bits of

1696  
01:07:50,730 --> 01:07:54,510

galaxies that you don't get to see in

1697

01:07:52,409 --> 01:07:56,068

HST so the fine-structure internal

1698

01:07:54,510 --> 01:07:59,400

structures of galaxies where are the

1699

01:07:56,068 --> 01:08:02,480

stars like ours formed is is revealed in

1700

01:07:59,400 --> 01:08:02,480

the telescope like this one

1701

01:08:07,599 --> 01:08:13,170

and so uh that's the end of my talking

1702

01:08:09,489 --> 01:08:13,170

all in there take any questions you have

1703

01:08:35,908 --> 01:08:50,500

and I can't even think what it cost to

1704

01:08:45,460 --> 01:08:52,838

use that German super six months so I

1705

01:08:50,500 --> 01:08:55,810

computed this once I calculated how much

1706

01:08:52,838 --> 01:08:58,389

the cost of it was and luckily to the

1707

01:08:55,810 --> 01:09:01,079

scientists like myself and dr. summers

1708

01:08:58,389 --> 01:09:03,969

and my collaborators it's virtually free

1709

01:09:01,078 --> 01:09:05,679

so the the supercomputer centers

1710

01:09:03,969 --> 01:09:09,750

actually have a really strong need for



1711  
01:09:05,679 --> 01:09:09,750  
problems that can run on their computers

1712  
01:09:10,439 --> 01:09:14,348  
from scientists who want to do these big

1713  
01:09:12,849 --> 01:09:16,509  
projects and they provide a little bit

1714  
01:09:14,349 --> 01:09:18,279  
of support and and hand-holding to get

1715  
01:09:16,509 --> 01:09:19,719  
us up and running on them and so they're

1716  
01:09:18,279 --> 01:09:21,790  
actually it's the supercomputer centers

1717  
01:09:19,719 --> 01:09:23,289  
who are investing all the money and the

1718  
01:09:21,789 --> 01:09:26,039  
government's are investing the money and

1719  
01:09:23,289 --> 01:09:27,939  
it's not coming out of NASA's pocket

1720  
01:09:26,039 --> 01:09:30,969  
recognizing that you know these super

1721  
01:09:27,939 --> 01:09:32,888  
centers exist not to do astronomy

1722  
01:09:30,969 --> 01:09:34,630  
actually but they they exist to solve

1723  
01:09:32,889 --> 01:09:37,779  
problems in computer science and how to

1724  
01:09:34,630 --> 01:09:41,139  
do even better computing and so they

1725  
01:09:37,779 --> 01:09:42,759  
love astronomers because we can as we

1726  
01:09:41,139 --> 01:09:44,828  
say if you as you build a bigger

1727  
01:09:42,759 --> 01:10:05,260  
supercomputer we can fill it with more

1728  
01:09:44,828 --> 01:10:06,488  
astrophysics so I was a rough

1729  
01:10:05,260 --> 01:10:09,070  
approximation of the number of the

1730  
01:10:06,488 --> 01:10:11,439  
computer hours but there's also you know

1731  
01:10:09,069 --> 01:10:12,929  
I made it sound like it was all easy at

1732  
01:10:11,439 --> 01:10:14,399  
random six months but there were problem

1733  
01:10:12,930 --> 01:10:17,340  
the computers crashed every once in a

1734  
01:10:14,399 --> 01:10:19,170  
while and we have to use a couple couple

1735  
01:10:17,340 --> 01:10:21,210  
of million CPU hours and then start over

1736  
01:10:19,170 --> 01:10:24,869  
we do but to answer your original

1737  
01:10:21,210 --> 01:10:26,730  
question so the primary cost to use a

1738  
01:10:24,869 --> 01:10:31,079  
computer once it's built is in

1739

01:10:26,729 --> 01:10:33,479  
electricity the vast majority of the

1740  
01:10:31,079 --> 01:10:36,029  
light for this project was spent on

1741  
01:10:33,479 --> 01:10:37,439  
electricity in Europe so generating

1742  
01:10:36,029 --> 01:10:39,029  
electricity in Europe for the computer

1743  
01:10:37,439 --> 01:10:48,769  
was something like five to ten million

1744  
01:10:39,029 --> 01:10:52,250  
dollars I look this up for this talk

1745  
01:10:48,770 --> 01:10:55,800  
maybe a hundred yes some similar scale

1746  
01:10:52,250 --> 01:10:58,979  
no more than that I mean I know it

1747  
01:10:55,800 --> 01:11:01,619  
sounds huge to the general public but a

1748  
01:10:58,979 --> 01:11:04,439  
cluster of a thousand CPUs is nothing

1749  
01:11:01,619 --> 01:11:07,019  
these days sorry it when you're talking

1750  
01:11:04,439 --> 01:11:09,269  
high-end supercomputing they can put

1751  
01:11:07,020 --> 01:11:11,760  
lots of cores on on one die and then

1752  
01:11:09,270 --> 01:11:13,920  
lots of chips in one slot and lots of

1753  
01:11:11,760 --> 01:11:15,960

slots in one chassis and lots of chassis

1754

01:11:13,920 --> 01:11:18,359

in one rack and lots of racks in the

1755

01:11:15,960 --> 01:11:21,270

room and you know just think of what

1756

01:11:18,359 --> 01:11:23,039

Google has and other Internet companies

1757

01:11:21,270 --> 01:11:27,600

in terms of their racks they're gonna

1758

01:11:23,039 --> 01:11:30,329

dwarf these things question back so is

1759

01:11:27,600 --> 01:11:34,400

your standard for evaluating your models

1760

01:11:30,329 --> 01:11:41,189

essentially the spatial distribution of

1761

01:11:34,399 --> 01:11:48,199

stars of mass and light and gas you're

1762

01:11:41,189 --> 01:11:51,149

judging lives that's what we hope to do

1763

01:11:48,199 --> 01:11:53,460

what we have done in the past is focus

1764

01:11:51,149 --> 01:11:56,909

on more global quantities about galaxies

1765

01:11:53,460 --> 01:11:58,890

so if the galaxies have so many issues

1766

01:11:56,909 --> 01:12:00,960

that we have not even been able to get

1767

01:11:58,890 --> 01:12:03,210

the star formation rate of galaxies

1768  
01:12:00,960 --> 01:12:04,710  
simulated correctly so we're only now

1769  
01:12:03,210 --> 01:12:06,239  
just at the point where we can start to

1770  
01:12:04,710 --> 01:12:08,520  
talk about where the star formation is

1771  
01:12:06,239 --> 01:12:10,109  
happening within galaxies or is spatial

1772  
01:12:08,520 --> 01:12:10,650  
reservation resolving that star

1773  
01:12:10,109 --> 01:12:13,229  
formation

1774  
01:12:10,649 --> 01:12:15,329  
so our metric for creating the initial

1775  
01:12:13,229 --> 01:12:17,279  
simulation had nothing to do with the

1776  
01:12:15,329 --> 01:12:19,039  
shapes of galaxies and everything to do

1777  
01:12:17,279 --> 01:12:22,289  
with the amount of stars in the galaxy

1778  
01:12:19,039 --> 01:12:23,640  
basically and so we where once we got to

1779  
01:12:22,289 --> 01:12:25,369  
that point we said okay let's run a

1780  
01:12:23,640 --> 01:12:26,990  
simulation and see what we get

1781  
01:12:25,369 --> 01:12:29,029  
but now that we have all of this data

1782  
01:12:26,989 --> 01:12:30,739  
from this simulation and maybe a half a

1783  
01:12:29,029 --> 01:12:33,649  
dozen other simulation projects with

1784  
01:12:30,739 --> 01:12:35,359  
similar amounts of data what my research

1785  
01:12:33,649 --> 01:12:37,369  
is now actually is to take that

1786  
01:12:35,359 --> 01:12:39,529  
information and ask what is the new

1787  
01:12:37,369 --> 01:12:40,909  
metric can we now write a metric that

1788  
01:12:39,529 --> 01:12:42,229  
takes the shapes of galaxies into

1789  
01:12:40,909 --> 01:12:44,059  
account and the spatial distribution of

1790  
01:12:42,229 --> 01:12:46,519  
light in the individual galaxies into

1791  
01:12:44,060 --> 01:12:48,950  
account but we don't do that yet it's

1792  
01:12:46,520 --> 01:12:51,560  
still still in the works you talked

1793  
01:12:48,949 --> 01:12:53,630  
about the comment and frequency of the

1794  
01:12:51,560 --> 01:12:57,980  
interaction between galaxies so in this

1795  
01:12:53,630 --> 01:13:00,140  
simulation are you able to determine how

1796

01:12:57,979 --> 01:13:03,079  
that may have changed over time with the

1797  
01:13:00,140 --> 01:13:04,960  
expansion of the universe sure yeah so

1798  
01:13:03,079 --> 01:13:07,069  
there are members of the collaboration

1799  
01:13:04,960 --> 01:13:08,329  
literally calculating the number of

1800  
01:13:07,069 --> 01:13:10,189  
interaction interactions between

1801  
01:13:08,329 --> 01:13:13,489  
galaxies and mergers of galaxies and

1802  
01:13:10,189 --> 01:13:15,079  
today it's the rate is very low so in

1803  
01:13:13,489 --> 01:13:16,789  
the current universe as the universe

1804  
01:13:15,079 --> 01:13:19,460  
expanded things grew farther and farther

1805  
01:13:16,789 --> 01:13:21,829  
apart galaxies are less likely to merge

1806  
01:13:19,460 --> 01:13:23,210  
now than they were in the past but yes

1807  
01:13:21,829 --> 01:13:25,909  
in the past the histories of these

1808  
01:13:23,210 --> 01:13:28,670  
galaxies are filled with mergers in the

1809  
01:13:25,909 --> 01:13:30,470  
distant past and many of them happened

1810  
01:13:28,670 --> 01:13:32,420

when the galaxies were infants basically

1811

01:13:30,470 --> 01:13:34,460

so the galaxies were really tiny when

1812

01:13:32,420 --> 01:13:36,440

the murders were happening so you may

1813

01:13:34,460 --> 01:13:38,960

not be able to see those grand mergers

1814

01:13:36,439 --> 01:13:40,339

in the in a distant universe but they're

1815

01:13:38,960 --> 01:13:43,039

going to be really tiny things that are

1816

01:13:40,340 --> 01:13:47,930

very faint and hard to detect so it's

1817

01:13:43,039 --> 01:13:50,600

the interactions are our image are they

1818

01:13:47,930 --> 01:13:52,579

appear they're hard to see and in the

1819

01:13:50,600 --> 01:13:53,750

real universe and so we're not we can

1820

01:13:52,579 --> 01:13:56,059

simulate them but we won't be able to

1821

01:13:53,750 --> 01:14:09,350

test it until things like JWST come

1822

01:13:56,060 --> 01:14:14,030

online gravity is basically as it was in

1823

01:14:09,350 --> 01:14:16,370

1700 as it was understood recognize it's

1824

01:14:14,029 --> 01:14:18,739

approximations and you can do scale



1825  
01:14:16,369 --> 01:14:20,510  
order calculations to see whether

1826  
01:14:18,739 --> 01:14:22,069  
relativistic effects are necessary

1827  
01:14:20,510 --> 01:14:23,780  
compared to other effects that we're

1828  
01:14:22,069 --> 01:14:26,299  
using for approximations and they are

1829  
01:14:23,779 --> 01:14:28,789  
second a third order and

1830  
01:14:26,300 --> 01:14:30,409  
in the computer simulation so you take

1831  
01:14:28,789 --> 01:14:33,500  
your first and second order effects and

1832  
01:14:30,409 --> 01:14:36,139  
you'll go further down the chain as time

1833  
01:14:33,500 --> 01:14:37,970  
becomes available but they aren't

1834  
01:14:36,140 --> 01:14:39,710  
necessary that does those Corrections

1835  
01:14:37,970 --> 01:14:41,480  
are necessary do those Corrections are

1836  
01:14:39,710 --> 01:14:43,399  
certainly important for modeling the

1837  
01:14:41,479 --> 01:14:45,079  
black holes at Centers of galaxies which

1838  
01:14:43,399 --> 01:14:47,239  
we don't do so we've made a toy model

1839  
01:14:45,079 --> 01:14:48,949  
for that so we basically cover up all of

1840  
01:14:47,239 --> 01:14:50,539  
that general relativity stuff in a toy

1841  
01:14:48,949 --> 01:14:56,090  
model and so we don't we don't directly

1842  
01:14:50,539 --> 01:14:58,579  
simulate it yeah what's the like

1843  
01:14:56,090 --> 01:15:00,680  
long-term goal of perfecting these

1844  
01:14:58,579 --> 01:15:03,680  
virtual universes and the context that

1845  
01:15:00,680 --> 01:15:05,240  
it has in like the larger Astrophysical

1846  
01:15:03,680 --> 01:15:07,460  
community so like are you hoping to

1847  
01:15:05,239 --> 01:15:11,679  
actually discover things via simulation

1848  
01:15:07,460 --> 01:15:11,680  
that we haven't been able to observe

1849  
01:15:11,890 --> 01:15:18,170  
partly yes so I think a lot of it has to

1850  
01:15:16,250 --> 01:15:20,510  
do with being able to understand the

1851  
01:15:18,170 --> 01:15:22,100  
data we already have so we have this

1852  
01:15:20,510 --> 01:15:23,239  
enormous diversity of galaxies and

1853

01:15:22,100 --> 01:15:25,430  
things like the Hubble Ultra Deep Field

1854  
01:15:23,239 --> 01:15:27,500  
and other HST surveys but we don't

1855  
01:15:25,430 --> 01:15:29,360  
understand it we don't know what any

1856  
01:15:27,500 --> 01:15:31,550  
particular shaped galaxy means at a

1857  
01:15:29,359 --> 01:15:33,289  
particular time in the universe so we

1858  
01:15:31,550 --> 01:15:35,900  
have to make these these models of

1859  
01:15:33,289 --> 01:15:37,579  
things in order to to basically read

1860  
01:15:35,899 --> 01:15:40,009  
between the lines of what is happening

1861  
01:15:37,579 --> 01:15:41,989  
in the galaxies and so we're gonna maybe

1862  
01:15:40,010 --> 01:15:43,489  
not discover a new phenomenon but we

1863  
01:15:41,989 --> 01:15:45,649  
will discover a phenomenon and say hey

1864  
01:15:43,489 --> 01:15:47,210  
we can test that now with our telescopes

1865  
01:15:45,649 --> 01:15:49,789  
so we're gonna have these phenomenon

1866  
01:15:47,210 --> 01:15:51,319  
that you know we had no idea we're

1867  
01:15:49,789 --> 01:15:53,300

interesting so we can see them and we

1868

01:15:51,319 --> 01:15:54,979

can see them in our surveys but we can't

1869

01:15:53,300 --> 01:15:56,810

assign anything meaningful to them until

1870

01:15:54,979 --> 01:15:58,399

we have a simulation like this one and

1871

01:15:56,810 --> 01:16:01,190

so that's the basic idea we can look and

1872

01:15:58,399 --> 01:16:03,319

then say with with some better

1873

01:16:01,189 --> 01:16:04,309

confidence what we'll expect to see in a

1874

01:16:03,319 --> 01:16:05,989

different survey

1875

01:16:04,310 --> 01:16:07,820

so basically being able to go back and

1876

01:16:05,989 --> 01:16:09,500

say okay now we want to look for

1877

01:16:07,819 --> 01:16:11,569

something else look at a different

1878

01:16:09,500 --> 01:16:13,520

wavelength of light that's so on and so

1879

01:16:11,569 --> 01:16:15,109

forth and in that respect so not

1880

01:16:13,520 --> 01:16:18,170

necessarily discovering something

1881

01:16:15,109 --> 01:16:20,239

brand-new but alright but let me just

1882  
01:16:18,170 --> 01:16:23,230  
give some old geezer perspective because

1883  
01:16:20,239 --> 01:16:25,760  
when I was doing my PhD simulation do it

1884  
01:16:23,229 --> 01:16:28,519  
simulations etc a lot of what we were

1885  
01:16:25,760 --> 01:16:31,010  
trying to do was help pin down what the

1886  
01:16:28,520 --> 01:16:32,780  
basic structure of the universe was was

1887  
01:16:31,010 --> 01:16:35,060  
it cold dark matter was it warm dark

1888  
01:16:32,779 --> 01:16:37,039  
matter was it you know was this crazy

1889  
01:16:35,060 --> 01:16:39,409  
thing idea of a cosmological

1890  
01:16:37,039 --> 01:16:41,300  
even to be taken seriously and the

1891  
01:16:39,408 --> 01:16:43,429  
simulations could show you there's

1892  
01:16:41,300 --> 01:16:45,860  
distributions of galaxies in these

1893  
01:16:43,429 --> 01:16:48,350  
various cosmological models and that led

1894  
01:16:45,859 --> 01:16:52,009  
us towards a you know a flat universe

1895  
01:16:48,350 --> 01:16:53,780  
that eventually you know over the past

1896  
01:16:52,010 --> 01:16:57,020  
two decades we've come up with a

1897  
01:16:53,779 --> 01:16:58,939  
concordance cosmological model so he had

1898  
01:16:57,020 --> 01:17:01,870  
that this illustrious simulation has the

1899  
01:16:58,939 --> 01:17:03,948  
benefit of really having a well-defined

1900  
01:17:01,869 --> 01:17:06,289  
relatively well defined cosmological

1901  
01:17:03,948 --> 01:17:08,119  
model in which to do the computations

1902  
01:17:06,289 --> 01:17:10,789  
and so they can get down to the

1903  
01:17:08,119 --> 01:17:13,789  
nitty-gritty of what galaxies what types

1904  
01:17:10,789 --> 01:17:16,039  
of galaxies form what are the details of

1905  
01:17:13,789 --> 01:17:18,679  
them how quickly do they form I mean you

1906  
01:17:16,039 --> 01:17:20,210  
know when we can't see the development

1907  
01:17:18,679 --> 01:17:22,369  
of galaxies over the first three to five

1908  
01:17:20,210 --> 01:17:24,770  
billion years you can give predictions

1909  
01:17:22,369 --> 01:17:27,859  
as to what you should see and whether or

1910

01:17:24,770 --> 01:17:50,840  
not telescopes should should be able to

1911  
01:17:27,859 --> 01:17:52,639  
see some of these ideas so that's a good

1912  
01:17:50,840 --> 01:17:54,890  
question they're currently pipe dreams

1913  
01:17:52,640 --> 01:17:57,230  
yeah so they're they're currently being

1914  
01:17:54,890 --> 01:17:59,989  
discussed among the astronomy astronomy

1915  
01:17:57,229 --> 01:18:15,559  
community as things we might want to

1916  
01:17:59,988 --> 01:18:17,899  
think about after HST and JWST it's not

1917  
01:18:15,560 --> 01:18:19,670  
too far off there's another issue that

1918  
01:18:17,899 --> 01:18:21,289  
I've glossed over here and that is that

1919  
01:18:19,670 --> 01:18:23,210  
the James Webb Space Telescope is tuned

1920  
01:18:21,289 --> 01:18:25,519  
for different wavelengths of light then

1921  
01:18:23,210 --> 01:18:28,060  
is the Hubble Space Telescope and so the

1922  
01:18:25,520 --> 01:18:30,500  
the large mirror on James Webb will not

1923  
01:18:28,060 --> 01:18:32,780  
entirely go to resolving the bits of

1924  
01:18:30,500 --> 01:18:34,760

galaxies as well as these future

1925

01:18:32,779 --> 01:18:36,769

concepts might so these two mission

1926

01:18:34,760 --> 01:18:39,050

concepts are tuned to blue light lucky

1927

01:18:36,770 --> 01:18:40,699

just he is and so in blue light you can

1928

01:18:39,050 --> 01:18:42,409

really resolve the features of galaxies

1929

01:18:40,698 --> 01:18:44,299

more clearly than than an infrared light

1930

01:18:42,408 --> 01:18:45,589

where the light gets smeared out even a

1931

01:18:44,300 --> 01:18:46,989

time even with big telescopes the light

1932

01:18:45,590 --> 01:18:49,369

gets smeared out to a point where

1933

01:18:46,989 --> 01:18:52,069

quite similar to HST resolution actually

1934

01:18:49,369 --> 01:18:55,309

in the end but the fact that JT OST is a

1935

01:18:52,069 --> 01:18:58,399

multi mirror telescope in space 18

1936

01:18:55,310 --> 01:19:01,010

segmented mirrors is the precedents for

1937

01:18:58,399 --> 01:19:04,189

having very large multi mirror

1938

01:19:01,010 --> 01:19:05,500

telescopes in space and as jazz we what



1939  
01:19:04,189 --> 01:19:08,509  
we learned from Joao Steve will

1940  
01:19:05,500 --> 01:19:12,130  
definitely help us get towards these 16

1941  
01:19:08,510 --> 01:19:12,130  
metre multi mirror telescopes as well

1942  
01:19:28,510 --> 01:19:33,110  
yeah it's pretty big it does fit in the

1943  
01:19:31,729 --> 01:19:34,579  
sort of next-generation heavy launch

1944  
01:19:33,109 --> 01:19:37,489  
vehicles that NASA is considering

1945  
01:19:34,579 --> 01:19:39,050  
building now so that it's not totally

1946  
01:19:37,489 --> 01:19:41,179  
outside of the realm of possibility but

1947  
01:19:39,050 --> 01:19:42,289  
it's hard it is gonna be hard to do

1948  
01:19:41,180 --> 01:19:44,180  
something like that and and then I think

1949  
01:19:42,289 --> 01:19:46,850  
I didn't end up answering the timeline

1950  
01:19:44,180 --> 01:19:52,430  
question it would be something like the

1951  
01:19:46,850 --> 01:19:54,770  
2030s at the earliest and so we when

1952  
01:19:52,430 --> 01:19:55,280  
when James Webb was dreamed up we

1953  
01:19:54,770 --> 01:19:59,600  
thought it would be

1954  
01:19:55,279 --> 01:20:02,929  
what 2,095 for so many years it was 2012

1955  
01:19:59,600 --> 01:20:06,380  
and then it was 2014 and now it's 2018 I

1956  
01:20:02,930 --> 01:20:08,750  
just you know so it's it's yeah it's

1957  
01:20:06,380 --> 01:20:10,989  
where James Webb was 20 years ago

1958  
01:20:08,750 --> 01:20:15,020  
basically so it could be 20 or 30 years

1959  
01:20:10,989 --> 01:20:23,300  
if if we are able to obtain funding or

1960  
01:20:15,020 --> 01:20:26,720  
something like that taxpayers so you and

1961  
01:20:23,300 --> 01:20:27,829  
I largely so it's the us largely the

1962  
01:20:26,720 --> 01:20:30,110  
National Aeronautics and Space

1963  
01:20:27,829 --> 01:20:33,170  
Administration NASA the European

1964  
01:20:30,109 --> 01:20:34,639  
counterpart who collect you know tax

1965  
01:20:33,170 --> 01:20:38,140  
money through the government and then

1966  
01:20:34,640 --> 01:20:38,140  
pay for it through publishers

1967

01:20:43,310 --> 01:20:47,960  
know there's a space program there is

1968  
01:20:45,289 --> 01:20:49,369  
not a manned space program currently in

1969  
01:20:47,960 --> 01:20:51,579  
the u.s. so they're not we're not

1970  
01:20:49,369 --> 01:20:56,659  
sending our own astronauts with our own

1971  
01:20:51,579 --> 01:20:58,399  
spacecraft but there are these yes we

1972  
01:20:56,659 --> 01:21:00,139  
have these these are all robots now so

1973  
01:20:58,399 --> 01:21:02,719  
we have a robotic space program

1974  
01:21:00,140 --> 01:21:04,310  
essentially and for the purposes of

1975  
01:21:02,720 --> 01:21:07,130  
astronomy a lot of us can be done

1976  
01:21:04,310 --> 01:21:11,060  
robotically right and just for

1977  
01:21:07,130 --> 01:21:13,640  
perspective about 1/2 of a penny out of

1978  
01:21:11,060 --> 01:21:16,880  
the per dollar of the US budget goes to

1979  
01:21:13,640 --> 01:21:20,060  
NASA it's not a lot there's a question

1980  
01:21:16,880 --> 01:21:22,520  
way up in the corner those launch dates

1981  
01:21:20,060 --> 01:21:26,090

are predicated mainly as we were

1982

01:21:22,520 --> 01:21:29,930  
discussing when we go about is it is it

1983

01:21:26,090 --> 01:21:33,619  
technology or is it the is it the

1984

01:21:29,930 --> 01:21:34,909  
funding considerations both as far as

1985

01:21:33,619 --> 01:21:36,559  
when you're setting these possible

1986

01:21:34,909 --> 01:21:40,159  
launch dates when we talk about yeah

1987

01:21:36,560 --> 01:21:43,070  
2018 apparently it sounds like it's more

1988

01:21:40,159 --> 01:21:44,809  
of a funding matter I would say it's all

1989

01:21:43,069 --> 01:21:47,809  
of the above

1990

01:21:44,810 --> 01:21:49,610  
so if we were given an infinite number

1991

01:21:47,810 --> 01:21:52,010  
of dollars right now it would still take

1992

01:21:49,609 --> 01:21:54,349  
some time I think to create something

1993

01:21:52,010 --> 01:21:56,480  
like this in part because all the people

1994

01:21:54,350 --> 01:21:58,400  
who have expertise in telescope design

1995

01:21:56,479 --> 01:22:00,500  
in space are currently working on James

1996  
01:21:58,399 --> 01:22:02,479  
Webb Space Telescope it's actually

1997  
01:22:00,500 --> 01:22:03,859  
people that you need to you need people

1998  
01:22:02,479 --> 01:22:05,629  
to work through the technological

1999  
01:22:03,859 --> 01:22:08,119  
challenges and sit down and actually

2000  
01:22:05,630 --> 01:22:10,250  
build engineer something like this and

2001  
01:22:08,119 --> 01:22:11,689  
so I think you know it's it's a

2002  
01:22:10,250 --> 01:22:13,189  
combination of these things we need the

2003  
01:22:11,689 --> 01:22:15,889  
money first of all to have to pay the

2004  
01:22:13,189 --> 01:22:18,109  
people to do the work but the technology

2005  
01:22:15,890 --> 01:22:20,119  
seems once it's written down and once

2006  
01:22:18,109 --> 01:22:22,609  
it's it's been thought up as a

2007  
01:22:20,119 --> 01:22:25,039  
possibility it's it's largely just

2008  
01:22:22,609 --> 01:22:26,329  
working through the details which I'm

2009  
01:22:25,039 --> 01:22:29,630  
glossing over a lot of stuff obviously

2010  
01:22:26,329 --> 01:22:32,180  
but I think many of the the major

2011  
01:22:29,630 --> 01:22:33,859  
challenges they are being overcome with

2012  
01:22:32,180 --> 01:22:35,990  
the James Webb Space Telescope so this

2013  
01:22:33,859 --> 01:22:38,000  
this advanced technology mission concept

2014  
01:22:35,989 --> 01:22:40,189  
doesn't have any major sort of

2015  
01:22:38,000 --> 01:22:41,989  
technological barriers in fact it has

2016  
01:22:40,189 --> 01:22:43,969  
fewer technological barriers than James

2017  
01:22:41,989 --> 01:22:45,920  
Webb did when it was brought up because

2018  
01:22:43,970 --> 01:22:47,449  
it's not gonna work in the infrared and

2019  
01:22:45,920 --> 01:22:50,239  
so that helps that helps a lot in terms

2020  
01:22:47,449 --> 01:22:52,609  
of the technology development and just

2021  
01:22:50,239 --> 01:22:55,039  
put in perspective what became Hubble

2022  
01:22:52,609 --> 01:22:59,210  
was first discussed by the National

2023  
01:22:55,039 --> 01:23:02,510  
Academy of Sciences in 1962 or 63 okay

2024

01:22:59,210 --> 01:23:05,180  
so a having a pie in the sky idea can

2025  
01:23:02,510 --> 01:23:07,159  
take decades to come to come to an

2026  
01:23:05,180 --> 01:23:11,659  
actual telescope all right any last

2027  
01:23:07,159 --> 01:23:13,670  
questions all right let's see you

2028  
01:23:11,659 --> 01:23:14,090  
wouldn't let's say it's October next

2029  
01:23:13,670 --> 01:23:16,850  
month

2030  
01:23:14,090 --> 01:23:19,340  
November Mark kamionkowski second

2031  
01:23:16,850 --> 01:23:23,560  
Tuesday of the month and everybody let's

2032  
01:23:19,340 --> 01:23:23,560  
give a great big hand for tonight