
NASA
Priya Natarajan
Professor, Yale University

1
00:00:09,990 --> 00:00:08,710
hi i'm trent perato public affairs

2
00:00:12,070 --> 00:00:10,000
officer for nasa's science mission

3
00:00:13,270 --> 00:00:12,080
directorate in washington dc i'd like to

4
00:00:14,470 --> 00:00:13,280
welcome you all to today's news

5
00:00:15,829 --> 00:00:14,480
conference to discuss the latest

6
00:00:17,990 --> 00:00:15,839
findings of the chandra x-ray

7
00:00:19,349 --> 00:00:18,000
observatory first let me begin by

8
00:00:21,429 --> 00:00:19,359
introducing our five distinguished

9
00:00:23,990 --> 00:00:21,439
panelists for today's presentation

10
00:00:25,910 --> 00:00:24,000
to my left wilt sanders

11
00:00:27,189 --> 00:00:25,920
chandra program scientist at nasa

12
00:00:30,310 --> 00:00:27,199
headquarters

13
00:00:32,870 --> 00:00:30,320

next ezekiel tracer astrophysicist at

14
00:00:35,750 --> 00:00:32,880
the university of hawaii at manoa

15
00:00:37,430 --> 00:00:35,760
next kevin shivinsky astrophysicist at

16
00:00:40,470 --> 00:00:37,440
yale university

17
00:00:41,830 --> 00:00:40,480
next priya nadarajan professor at yale

18
00:00:44,470 --> 00:00:41,840
university

19
00:00:46,950 --> 00:00:44,480
and mitchell beagleman professor the

20
00:00:48,069 --> 00:00:46,960
university of colorado boulder

21
00:00:49,510 --> 00:00:48,079
each speaker will give a short

22
00:00:50,790 --> 00:00:49,520
presentation and then we'll move to

23
00:00:52,549 --> 00:00:50,800
question and answer with the audience

24
00:00:54,069 --> 00:00:52,559
and for those joining by phone

25
00:00:55,350 --> 00:00:54,079
for those of you joining us online you

26
00:00:56,869 --> 00:00:55,360
can find out more information about

27
00:01:02,150 --> 00:00:56,879
today's briefing including related

28
00:01:06,789 --> 00:01:04,950
chandra a reminder that dr treister and

29
00:01:08,230 --> 00:01:06,799
dr shivinsky will participate in a nasa

30
00:01:10,469 --> 00:01:08,240
web chat on these findings in black

31
00:01:12,310 --> 00:01:10,479
holes generally at 3 pm today and you

32
00:01:15,030 --> 00:01:12,320
can find the link to that chat room on

33
00:01:17,030 --> 00:01:15,040
the nasa.gov homepage and with that i'll

34
00:01:18,310 --> 00:01:17,040
hand it over to wilt sanders

35
00:01:20,390 --> 00:01:18,320
thanks trent

36
00:01:23,270 --> 00:01:20,400
the chandra x-ray observatory is the

37
00:01:25,910 --> 00:01:23,280
world's most powerful x-ray telescope it

38
00:01:26,950 --> 00:01:25,920

has eight times the angular resolution

39
00:01:29,590 --> 00:01:26,960
and

40
00:01:30,630 --> 00:01:29,600
can detect sources more than 20 times

41
00:01:33,830 --> 00:01:30,640
fainter

42
00:01:36,069 --> 00:01:33,840
than any previous x-ray telescope

43
00:01:38,550 --> 00:01:36,079
the chandra x-ray observatory is part of

44
00:01:40,789 --> 00:01:38,560
nasa's fleet of great observatories

45
00:01:43,350 --> 00:01:40,799
which also includes the hubble space

46
00:01:46,069 --> 00:01:43,360
telescope the spitzer space telescope

47
00:01:47,510 --> 00:01:46,079
and the now deorbited compton gamma-ray

48
00:01:51,350 --> 00:01:47,520
observatory

49
00:01:53,749 --> 00:01:51,360
chandra's superb imaging and sensitivity

50
00:01:56,550 --> 00:01:53,759
allows scientists from around the world

51
00:01:58,550 --> 00:01:56,560
to obtain x-ray images of exotic

52
00:02:00,310 --> 00:01:58,560
high-energy phenomena and environments

53
00:02:01,590 --> 00:02:00,320
to help us understand

54
00:02:04,630 --> 00:02:01,600
the origin

55
00:02:07,030 --> 00:02:04,640
evolution and structure of the universe

56
00:02:08,469 --> 00:02:07,040
over a decade ago a group of

57
00:02:10,790 --> 00:02:08,479
distinguished scientists

58
00:02:13,589 --> 00:02:10,800
sat on this stage this group included

59
00:02:15,510 --> 00:02:13,599
nobel prize winner ricardo gioconi

60
00:02:17,910 --> 00:02:15,520
and to announce the results from the

61
00:02:20,150 --> 00:02:17,920
first chandra deep field

62
00:02:23,110 --> 00:02:20,160
deep fields at the time these were the

63
00:02:24,869 --> 00:02:23,120

deepest x-ray images ever obtained and

64
00:02:27,750 --> 00:02:24,879
they amazed us with new and exciting

65
00:02:29,589 --> 00:02:27,760
discoveries about the early universe

66
00:02:31,910 --> 00:02:29,599
now we're here again to talk about the

67
00:02:34,470 --> 00:02:31,920
next generation of the chandra deep

68
00:02:36,869 --> 00:02:34,480
fields the image discussed today results

69
00:02:38,869 --> 00:02:36,879
from more than four million seconds of

70
00:02:41,110 --> 00:02:38,879
chandra observing time which is more

71
00:02:42,949 --> 00:02:41,120
than four times as much as the original

72
00:02:44,869 --> 00:02:42,959
deep fields contained

73
00:02:47,190 --> 00:02:44,879
so it's appropriate that this panel also

74
00:02:48,830 --> 00:02:47,200
includes the next generation of

75
00:02:51,509 --> 00:02:48,840
scientists who will lead x-ray

76
00:02:53,190 --> 00:02:51,519
astrophysics in the coming years

77
00:02:56,070 --> 00:02:53,200
all of them are already distinguished

78
00:02:58,229 --> 00:02:56,080
scientists and two are einstein fellows

79
00:03:00,869 --> 00:02:58,239
which is a nasa program to help support

80
00:03:03,670 --> 00:03:00,879
some of the best scientists in their

81
00:03:05,830 --> 00:03:03,680
early career stages without any further

82
00:03:08,309 --> 00:03:05,840
delay then let me give the floor to

83
00:03:10,149 --> 00:03:08,319
ezekiel traister to discuss today's

84
00:03:11,190 --> 00:03:10,159
remarkable new findings

85
00:03:14,070 --> 00:03:11,200
thank you

86
00:03:16,550 --> 00:03:14,080
we found evidence for the existence of a

87
00:03:19,030 --> 00:03:16,560
very large number of massive black holes

88
00:03:21,430 --> 00:03:19,040

in the early universe when it was less

89
00:03:22,630 --> 00:03:21,440
than a billion light years

90
00:03:24,869 --> 00:03:22,640
years old

91
00:03:27,270 --> 00:03:24,879
we performed this study in the general

92
00:03:29,030 --> 00:03:27,280
difficult south and as we can see in the

93
00:03:31,830 --> 00:03:29,040
following animation

94
00:03:34,070 --> 00:03:31,840
this is a very small part of the sky we

95
00:03:36,630 --> 00:03:34,080
now see a big part including the orion

96
00:03:38,630 --> 00:03:36,640
nebula for the ryan constellation for

97
00:03:40,949 --> 00:03:38,640
reference and now we are zooming in in a

98
00:03:43,190 --> 00:03:40,959
region about a third of the size of the

99
00:03:45,190 --> 00:03:43,200
full moon that concentrates the deepest

100
00:03:47,509 --> 00:03:45,200
optical and near-infrared observations

101
00:03:49,830 --> 00:03:47,519
performed by the hubble space telescope

102
00:03:51,830 --> 00:03:49,840
and more importantly for our work the

103
00:03:53,750 --> 00:03:51,840
deepest chandra observations of the

104
00:03:56,470 --> 00:03:53,760
x-ray sky

105
00:04:00,390 --> 00:03:56,480
this field was observed for 45 days by

106
00:04:02,470 --> 00:04:00,400
chandra and about 200 galaxies at

107
00:04:04,949 --> 00:04:02,480
in the first billion years after the big

108
00:04:07,110 --> 00:04:04,959
bang were detected zooming in into a

109
00:04:09,509 --> 00:04:07,120
smaller region we now see a few of these

110
00:04:11,990 --> 00:04:09,519
galaxies and it's important to note that

111
00:04:14,470 --> 00:04:12,000
none of these galaxies were detected in

112
00:04:16,710 --> 00:04:14,480
x-rays however when we use a technique

113
00:04:18,550 --> 00:04:16,720

called x-ray stacking which is basically

114
00:04:21,189 --> 00:04:18,560
summing the x-ray emission from

115
00:04:23,830 --> 00:04:21,199
multi-sources even if it was undetected

116
00:04:26,230 --> 00:04:23,840
we get a very significant signal like

117
00:04:28,230 --> 00:04:26,240
the one we see now in the in the next

118
00:04:30,230 --> 00:04:28,240
image

119
00:04:32,230 --> 00:04:30,240
this detection of x-rays from these

120
00:04:34,310 --> 00:04:32,240
galaxies is very important because it

121
00:04:36,870 --> 00:04:34,320
tells us that there

122
00:04:40,150 --> 00:04:36,880
are supermassive black holes growing in

123
00:04:43,110 --> 00:04:40,160
them as we can see in the next image in

124
00:04:45,749 --> 00:04:43,120
fact we concluded that about an at least

125
00:04:47,909 --> 00:04:45,759
30 percent of the of these galaxies in

126
00:04:49,990 --> 00:04:47,919
the early universe constant growing

127
00:04:52,390 --> 00:04:50,000
supermassive black holes

128
00:04:54,870 --> 00:04:52,400
as we can see in the next image

129
00:04:57,590 --> 00:04:54,880
this black hole is completely surrounded

130
00:05:00,550 --> 00:04:57,600
by large amounts of gas and dust

131
00:05:02,550 --> 00:05:00,560
and only the very high energy x-rays

132
00:05:05,430 --> 00:05:02,560
managed to break through and go through

133
00:05:07,029 --> 00:05:05,440
these trees of curing material it's in

134
00:05:08,629 --> 00:05:07,039
the same way that when you go to a

135
00:05:10,790 --> 00:05:08,639
doctor's office

136
00:05:12,790 --> 00:05:10,800
you perform x-rays that go through this

137
00:05:14,950 --> 00:05:12,800
through your skin then

138
00:05:17,430 --> 00:05:14,960

and you can study you perform medical

139
00:05:19,749 --> 00:05:17,440
studies this also explains why it took

140
00:05:22,629 --> 00:05:19,759
so long to detect these signatures in

141
00:05:24,950 --> 00:05:22,639
fact it took seven years to detect right

142
00:05:26,469 --> 00:05:24,960
now the first signatures of growing

143
00:05:28,790 --> 00:05:26,479
supermassive blood caused into these

144
00:05:30,310 --> 00:05:28,800
galaxies and it took a combination of

145
00:05:33,670 --> 00:05:30,320
the or two of the nasa great

146
00:05:35,749 --> 00:05:33,680
observatories like javelin and chandra

147
00:05:37,510 --> 00:05:35,759
now we knew about existence of other

148
00:05:40,469 --> 00:05:37,520
supermassive black holes in the early

149
00:05:42,150 --> 00:05:40,479
universe the so-called quasars but those

150
00:05:44,710 --> 00:05:42,160
represent the last stage of the

151
00:05:46,870 --> 00:05:44,720
evolution they already did most of the

152
00:05:48,629 --> 00:05:46,880
growth the sources that we found out

153
00:05:51,110 --> 00:05:48,639
that these black holes are the

154
00:05:53,430 --> 00:05:51,120
progenitors of the large supermassive

155
00:05:56,230 --> 00:05:53,440
black holes that that we see today in

156
00:05:58,469 --> 00:05:56,240
the in the nearest galaxies

157
00:06:00,870 --> 00:05:58,479
we were of course very excited to find

158
00:06:02,790 --> 00:06:00,880
this we were not expecting to find this

159
00:06:05,749 --> 00:06:02,800
x-ray signal from from the early

160
00:06:07,510 --> 00:06:05,759
universe and we were even more surprised

161
00:06:09,749 --> 00:06:07,520
to find that they're all heavily

162
00:06:12,309 --> 00:06:09,759
obscured and now i'll leave you with my

163
00:06:13,909 --> 00:06:12,319

colleague dr chavinsky who's going to

164
00:06:16,550 --> 00:06:13,919
say more about the

165
00:06:17,990 --> 00:06:16,560
implications of these results

166
00:06:21,590 --> 00:06:18,000
thank you very much

167
00:06:24,950 --> 00:06:21,600
so as a ezekiel triester um showed us

168
00:06:27,029 --> 00:06:24,960
what we've seen are baby black holes in

169
00:06:28,150 --> 00:06:27,039
very young galaxies at the dawn of the

170
00:06:30,469 --> 00:06:28,160
universe

171
00:06:32,830 --> 00:06:30,479
as we'll see in the next figure

172
00:06:36,150 --> 00:06:32,840
these black holes are feeding

173
00:06:38,469 --> 00:06:36,160
on material gas at the centers of these

174
00:06:40,469 --> 00:06:38,479
galaxies and they'll continue to grow

175
00:06:43,029 --> 00:06:40,479
through the adolescence to adulthood

176
00:06:45,590 --> 00:06:43,039
they may also merge with black holes

177
00:06:47,350 --> 00:06:45,600
from other galaxies as their hosts merge

178
00:06:48,629 --> 00:06:47,360
and they may end up

179
00:06:51,589 --> 00:06:48,639
accumulating

180
00:06:53,270 --> 00:06:51,599
a hundred or even a thousand times the

181
00:06:55,270 --> 00:06:53,280
mass that they have in the early

182
00:06:58,070 --> 00:06:55,280
universe until they end up at the

183
00:07:00,550 --> 00:06:58,080
centers of nearby galaxies

184
00:07:03,270 --> 00:07:00,560
now as we'll see in the next image

185
00:07:05,749 --> 00:07:03,280
this is the center of our own milky way

186
00:07:06,790 --> 00:07:05,759
uh galaxies in the nearby universe

187
00:07:09,189 --> 00:07:06,800
contain

188
00:07:10,950 --> 00:07:09,199

very massive black holes at their center

189
00:07:13,670 --> 00:07:10,960
in the case of our own milky way the

190
00:07:16,309 --> 00:07:13,680
black hole weighs about four million

191
00:07:18,150 --> 00:07:16,319
times as much as our sun but there are

192
00:07:19,830 --> 00:07:18,160
even larger monsters lurking at the

193
00:07:22,469 --> 00:07:19,840
centers of giant elliptical galaxies

194
00:07:25,670 --> 00:07:22,479
such as m87 which may be as much as a

195
00:07:26,950 --> 00:07:25,680
billion times the mass of the sun

196
00:07:28,790 --> 00:07:26,960
now one of the

197
00:07:30,870 --> 00:07:28,800
remarkable discoveries in astrophysics

198
00:07:33,830 --> 00:07:30,880
is that not only do galaxies contain

199
00:07:36,790 --> 00:07:33,840
black holes at the center but galaxies

200
00:07:38,710 --> 00:07:36,800
and black holes seem to grow together

201
00:07:40,870 --> 00:07:38,720
big galaxies have big black holes at the

202
00:07:43,110 --> 00:07:40,880
center small galaxies of small black

203
00:07:45,110 --> 00:07:43,120
holes at their center

204
00:07:47,909 --> 00:07:45,120
we believe that they

205
00:07:50,550 --> 00:07:47,919
have this a fundamental symbiotic

206
00:07:53,270 --> 00:07:50,560
relationship between the two the growth

207
00:07:55,670 --> 00:07:53,280
of one regulates the growth of the other

208
00:07:58,629 --> 00:07:55,680
in a kind of feedback loop

209
00:08:00,230 --> 00:07:58,639
what our observations of galaxies in the

210
00:08:02,230 --> 00:08:00,240
very early universe as the next

211
00:08:03,909 --> 00:08:02,240
animation will show

212
00:08:07,510 --> 00:08:03,919
tells us is

213
00:08:09,189 --> 00:08:07,520

that these very early young galaxies at

214
00:08:12,469 --> 00:08:09,199
the dawn of the universe and their

215
00:08:14,550 --> 00:08:12,479
growing baby black holes already

216
00:08:16,309 --> 00:08:14,560
had some sort of deep fundamental

217
00:08:18,469 --> 00:08:16,319
connection between them they were

218
00:08:20,469 --> 00:08:18,479
already growing together and so this

219
00:08:23,029 --> 00:08:20,479
chicken and egg problem of what was

220
00:08:25,110 --> 00:08:23,039
there first the galaxy or the black hole

221
00:08:27,510 --> 00:08:25,120
has been pushed all the way to the edge

222
00:08:29,430 --> 00:08:27,520
of the universe

223
00:08:31,990 --> 00:08:29,440
previous studies of black holes in the

224
00:08:34,949 --> 00:08:32,000
early universe were limited to quasars

225
00:08:37,589 --> 00:08:34,959
quasars contained black holes already as

226
00:08:40,230 --> 00:08:37,599
massive as a billion solar masses so

227
00:08:42,949 --> 00:08:40,240
already fully grown up so what these

228
00:08:45,030 --> 00:08:42,959
baby black holes tell us is that we can

229
00:08:47,269 --> 00:08:45,040
now move much much closer to the moment

230
00:08:49,110 --> 00:08:47,279
of birth and really understand where

231
00:08:51,829 --> 00:08:49,120
both galaxies and their supermassive

232
00:08:52,870 --> 00:08:51,839
black holes really come from

233
00:08:54,710 --> 00:08:52,880
now

234
00:08:56,710 --> 00:08:54,720
this discovery was enabled by two of

235
00:08:58,630 --> 00:08:56,720
nasa's great observatories

236
00:09:00,949 --> 00:08:58,640
chandra and hubble they make an

237
00:09:03,269 --> 00:09:00,959
excellent team and

238
00:09:05,110 --> 00:09:03,279

we've only just scratched the surface of

239
00:09:06,949 --> 00:09:05,120
the first billion years of the universe

240
00:09:09,269 --> 00:09:06,959
with their help and there are great

241
00:09:10,710 --> 00:09:09,279
prospects for further discoveries uh in

242
00:09:13,269 --> 00:09:10,720
the coming years with the help of these

243
00:09:14,870 --> 00:09:13,279
two great space observatories

244
00:09:16,790 --> 00:09:14,880
now hand over to my colleague professor

245
00:09:19,509 --> 00:09:16,800
natarajan to discuss some of the

246
00:09:20,630 --> 00:09:19,519
theoretical implications of this result

247
00:09:22,790 --> 00:09:20,640
thank you

248
00:09:25,269 --> 00:09:22,800
these results have very important and

249
00:09:27,910 --> 00:09:25,279
significant theoretical implications for

250
00:09:29,590 --> 00:09:27,920
some of the key challenging problems in

251
00:09:31,350 --> 00:09:29,600
cosmology today

252
00:09:33,430 --> 00:09:31,360
one of which pertains to our

253
00:09:36,230 --> 00:09:33,440
understanding of how the first ever

254
00:09:38,550 --> 00:09:36,240
black holes formed in the universe so it

255
00:09:41,030 --> 00:09:38,560
is pretty clear that you first make

256
00:09:43,590 --> 00:09:41,040
small seed black holes in the early

257
00:09:45,670 --> 00:09:43,600
universe and over cosmic time by

258
00:09:46,630 --> 00:09:45,680
swallowing gas in their vicinity they

259
00:09:49,269 --> 00:09:46,640
grow

260
00:09:51,829 --> 00:09:49,279
however how precisely you form seed

261
00:09:53,509 --> 00:09:51,839
black holes is an open-ended question

262
00:09:56,070 --> 00:09:53,519
and there are two schools of thought

263
00:09:58,470 --> 00:09:56,080

theoretically speaking on the matter so

264
00:10:01,430 --> 00:09:58,480
the first model suggests that seed black

265
00:10:03,030 --> 00:10:01,440
holes essentially form as the end states

266
00:10:05,269 --> 00:10:03,040
of the first stars that form in the

267
00:10:06,389 --> 00:10:05,279
universe so seeds that form in this

268
00:10:07,509 --> 00:10:06,399
fashion

269
00:10:09,350 --> 00:10:07,519
roughly

270
00:10:10,870 --> 00:10:09,360
range in mass from a few hundred times

271
00:10:12,710 --> 00:10:10,880
the mass of the sun to perhaps a

272
00:10:15,509 --> 00:10:12,720
thousand times the mass of the sun they

273
00:10:17,670 --> 00:10:15,519
are relatively light the other way to

274
00:10:21,269 --> 00:10:17,680
make seed black holes involves the

275
00:10:23,350 --> 00:10:21,279
direct collapse of gas discs which makes

276
00:10:25,110 --> 00:10:23,360
very very massive seeds and these seeds

277
00:10:27,030 --> 00:10:25,120
can range in mass from about ten

278
00:10:28,790 --> 00:10:27,040
thousand times the mass of the sun to

279
00:10:30,550 --> 00:10:28,800
about a million times the mass of the

280
00:10:32,710 --> 00:10:30,560
sun

281
00:10:34,550 --> 00:10:32,720
starting off with these very massive

282
00:10:36,630 --> 00:10:34,560
seed black holes comes in rather handy

283
00:10:37,670 --> 00:10:36,640
to solve some other observational

284
00:10:40,550 --> 00:10:37,680
puzzles

285
00:10:43,030 --> 00:10:40,560
so we proposed a model a few years ago

286
00:10:46,630 --> 00:10:43,040
that did argue for very early formation

287
00:10:48,790 --> 00:10:46,640
of extremely massive seed black holes

288
00:10:52,790 --> 00:10:48,800

the other interesting feature of those

289
00:10:55,110 --> 00:10:52,800
models was an intimate link was

290
00:10:57,590 --> 00:10:55,120
construed between the formation of the

291
00:11:00,550 --> 00:10:57,600
black hole and the assembly of the stars

292
00:11:02,630 --> 00:11:00,560
in that galaxy initially from when the

293
00:11:05,509 --> 00:11:02,640
seed originally forms

294
00:11:07,269 --> 00:11:05,519
what is very exciting is that these

295
00:11:09,269 --> 00:11:07,279
observational data

296
00:11:11,110 --> 00:11:09,279
seem to suggest that that is indeed the

297
00:11:12,230 --> 00:11:11,120
case that very very early in the

298
00:11:14,069 --> 00:11:12,240
universe

299
00:11:16,150 --> 00:11:14,079
less than a billion years after the big

300
00:11:17,750 --> 00:11:16,160
bang this early population of black

301
00:11:19,590 --> 00:11:17,760
holes there appears to be an intimate

302
00:11:21,509 --> 00:11:19,600
connection between the properties of

303
00:11:23,670 --> 00:11:21,519
these growing black holes and the

304
00:11:25,670 --> 00:11:23,680
galaxies in which they sit

305
00:11:27,509 --> 00:11:25,680
of course a lot more data is needed

306
00:11:29,030 --> 00:11:27,519
before we can adjudicate between these

307
00:11:31,190 --> 00:11:29,040
two models

308
00:11:33,590 --> 00:11:31,200
however what is very exciting is that

309
00:11:36,150 --> 00:11:33,600
now there is observational data for

310
00:11:37,670 --> 00:11:36,160
theoretical modelers to constrain

311
00:11:39,509 --> 00:11:37,680
scenarios

312
00:11:42,470 --> 00:11:39,519
so squasars

313
00:11:43,829 --> 00:11:42,480

that are scant have provided information

314
00:11:45,670 --> 00:11:43,839
about the

315
00:11:47,829 --> 00:11:45,680
life cycle of black holes in just about

316
00:11:50,230 --> 00:11:47,839
the first billion years or so and

317
00:11:52,389 --> 00:11:50,240
quasars are rare therefore finding this

318
00:11:53,350 --> 00:11:52,399
entire population of obscured black

319
00:11:55,509 --> 00:11:53,360
holes

320
00:11:57,190 --> 00:11:55,519
opens up a whole new window into our

321
00:11:58,790 --> 00:11:57,200
understanding of how the first black

322
00:12:01,110 --> 00:11:58,800
holes ever formed

323
00:12:03,670 --> 00:12:01,120
so this isn't a baby step forward in

324
00:12:05,509 --> 00:12:03,680
fact it's a really large leap towards

325
00:12:07,030 --> 00:12:05,519
our understanding of how baby black

326
00:12:10,230 --> 00:12:07,040
holes formed

327
00:12:12,230 --> 00:12:10,240
the second science question upon which

328
00:12:14,150 --> 00:12:12,240
this has huge bearing is our

329
00:12:15,590 --> 00:12:14,160
understanding of the very very early

330
00:12:17,509 --> 00:12:15,600
universe

331
00:12:20,310 --> 00:12:17,519
in particular the phenomenon of

332
00:12:21,990 --> 00:12:20,320
reionization of the universe right after

333
00:12:24,710 --> 00:12:22,000
the big bang the universe basically

334
00:12:26,310 --> 00:12:24,720
consisted of hot plasma and as the

335
00:12:28,470 --> 00:12:26,320
universe expanded

336
00:12:30,310 --> 00:12:28,480
and looking at this graphic

337
00:12:32,150 --> 00:12:30,320
you can see a very nice artist's

338
00:12:34,069 --> 00:12:32,160

impression of how this process might

339
00:12:36,790 --> 00:12:34,079
happen

340
00:12:38,710 --> 00:12:36,800
you need its sources the first sources

341
00:12:40,389 --> 00:12:38,720
stars or recruiting black holes to

342
00:12:41,670 --> 00:12:40,399
actually turn on in the universe and

343
00:12:44,790 --> 00:12:41,680
radiation

344
00:12:47,190 --> 00:12:44,800
from those sources was needed to open up

345
00:12:49,590 --> 00:12:47,200
and clear out this cosmic fog

346
00:12:51,990 --> 00:12:49,600
so prior to that we expect the universe

347
00:12:54,230 --> 00:12:52,000
to be in the stage called the dark ages

348
00:12:56,949 --> 00:12:54,240
of course the question has been which

349
00:12:59,590 --> 00:12:56,959
sources what kinds of objects actually

350
00:13:02,470 --> 00:12:59,600
produce the light that can ionize

351
00:13:04,150 --> 00:13:02,480
hydrogen and re-ionize the universe so

352
00:13:07,030 --> 00:13:04,160
from the fact that this entire

353
00:13:09,829 --> 00:13:07,040
population looks extremely obscured it's

354
00:13:12,230 --> 00:13:09,839
very very clear that these first black

355
00:13:13,110 --> 00:13:12,240
holes are quite unlikely to produce the

356
00:13:16,069 --> 00:13:13,120
light

357
00:13:18,470 --> 00:13:16,079
that removed this dense fog however what

358
00:13:20,949 --> 00:13:18,480
is very interesting is our finding also

359
00:13:24,710 --> 00:13:20,959
suggests that the stars and the black

360
00:13:27,190 --> 00:13:24,720
hole grow in tandem therefore somehow

361
00:13:30,069 --> 00:13:27,200
light escapes from the stars that form

362
00:13:32,470 --> 00:13:30,079
in these baby galaxies however no light

363
00:13:37,030 --> 00:13:32,480

escapes from these very obscured

364
00:13:42,150 --> 00:13:39,829
thank you priya now that we've heard

365
00:13:44,949 --> 00:13:42,160
from the team that's responsible for

366
00:13:46,870 --> 00:13:44,959
these results i'd like to turn to an

367
00:13:50,230 --> 00:13:46,880
outside expert to offer some additional

368
00:13:51,750 --> 00:13:50,240
analysis and commentary and context

369
00:13:53,910 --> 00:13:51,760
mitch thank you

370
00:13:56,790 --> 00:13:53,920
well this result is really several

371
00:13:59,189 --> 00:13:56,800
breakthroughs rolled into one

372
00:14:00,629 --> 00:13:59,199
it's the first time that we've caught

373
00:14:02,389 --> 00:14:00,639
black holes

374
00:14:04,069 --> 00:14:02,399
in the act of vigorously growing in the

375
00:14:06,150 --> 00:14:04,079
early universe now

376
00:14:07,910 --> 00:14:06,160
we know that they were we've known for

377
00:14:09,670 --> 00:14:07,920
some time that there were black holes

378
00:14:10,790 --> 00:14:09,680
around quite early in the universe

379
00:14:12,790 --> 00:14:10,800
because we see

380
00:14:15,590 --> 00:14:12,800
quasars which are absolutely gigantic

381
00:14:18,310 --> 00:14:15,600
black holes that somehow manage to grow

382
00:14:19,990 --> 00:14:18,320
to a billion times the mass of the sun

383
00:14:22,069 --> 00:14:20,000
less than a billion years after the big

384
00:14:24,310 --> 00:14:22,079
bang but these are extremely rare

385
00:14:26,870 --> 00:14:24,320
objects and we never saw

386
00:14:29,590 --> 00:14:26,880
until now the smaller black holes that

387
00:14:30,949 --> 00:14:29,600
must have existed before these quasars

388
00:14:32,470 --> 00:14:30,959

could have formed now and now we're

389
00:14:35,350 --> 00:14:32,480
seeing the first direct evidence for

390
00:14:37,189 --> 00:14:35,360
these smaller black holes

391
00:14:39,269 --> 00:14:37,199
not all of these black holes are going

392
00:14:41,750 --> 00:14:39,279
to become quasars

393
00:14:43,189 --> 00:14:41,760
most of them are going to become

394
00:14:44,550 --> 00:14:43,199
the

395
00:14:46,069 --> 00:14:44,560
ordinary

396
00:14:48,710 --> 00:14:46,079
massive black holes that are in the

397
00:14:50,710 --> 00:14:48,720
centers of every galaxy including

398
00:14:53,110 --> 00:14:50,720
our own milky way galaxy as you saw for

399
00:14:55,110 --> 00:14:53,120
a few minutes ago

400
00:14:58,389 --> 00:14:55,120
and so we're really seeing a process

401
00:15:01,189 --> 00:14:58,399
that is not kind of a an extreme process

402
00:15:02,870 --> 00:15:01,199
that occurs only very so uh very

403
00:15:05,750 --> 00:15:02,880
occasionally in the universe but we're

404
00:15:07,910 --> 00:15:05,760
seeing a natural part of the development

405
00:15:09,670 --> 00:15:07,920
of galaxies and all the structure we see

406
00:15:11,430 --> 00:15:09,680
around us today

407
00:15:13,350 --> 00:15:11,440
and so the first breakthrough is that

408
00:15:16,069 --> 00:15:13,360
this is the first time we really are

409
00:15:18,710 --> 00:15:16,079
pinpointing when these black holes were

410
00:15:20,710 --> 00:15:18,720
really forming and growing

411
00:15:22,629 --> 00:15:20,720
the second breakthrough is that we're

412
00:15:24,870 --> 00:15:22,639
getting the first clues as to how these

413
00:15:26,389 --> 00:15:24,880

black holes grew

414
00:15:27,750 --> 00:15:26,399
when people thought about the growth of

415
00:15:29,990 --> 00:15:27,760
these black holes

416
00:15:32,150 --> 00:15:30,000
they suspected that they had to grow

417
00:15:33,269 --> 00:15:32,160
fairly late in the game of galaxy

418
00:15:35,350 --> 00:15:33,279
formation

419
00:15:37,110 --> 00:15:35,360
because when black holes grow

420
00:15:39,030 --> 00:15:37,120
they liberate a tremendous amount of

421
00:15:41,670 --> 00:15:39,040
energy as matter falls into them as they

422
00:15:43,910 --> 00:15:41,680
swallow matter they just produce a huge

423
00:15:45,430 --> 00:15:43,920
amount of energy which is believed to

424
00:15:47,030 --> 00:15:45,440
have an explosive effect on the

425
00:15:48,870 --> 00:15:47,040
environments now

426
00:15:50,790 --> 00:15:48,880
dr shivinsky talked a few minutes ago

427
00:15:53,110 --> 00:15:50,800
about this feedback loop which we think

428
00:15:55,189 --> 00:15:53,120
regulates the growth of galaxies

429
00:15:56,710 --> 00:15:55,199
and black holes together

430
00:15:58,949 --> 00:15:56,720
but we know

431
00:16:01,269 --> 00:15:58,959
roughly when this feedback must have

432
00:16:04,069 --> 00:16:01,279
occurred and if black holes grew

433
00:16:05,189 --> 00:16:04,079
explosively too early in the universe

434
00:16:07,590 --> 00:16:05,199
that wouldn't agree with our

435
00:16:10,310 --> 00:16:07,600
observations but with these new results

436
00:16:12,710 --> 00:16:10,320
show is that black holes were protected

437
00:16:13,670 --> 00:16:12,720
they were enshrouded in a cocoon of dust

438
00:16:15,430 --> 00:16:13,680

which

439
00:16:18,629 --> 00:16:15,440
dampened the effect that they had on

440
00:16:21,350 --> 00:16:18,639
their surroundings and so um

441
00:16:23,829 --> 00:16:21,360
so this this feedback probably did occur

442
00:16:26,150 --> 00:16:23,839
but it occurred in a much more gradual

443
00:16:28,310 --> 00:16:26,160
fashion and so we now see that these

444
00:16:30,710 --> 00:16:28,320
black holes could have grown uh quite

445
00:16:33,670 --> 00:16:30,720
early without having a dramatic and

446
00:16:35,269 --> 00:16:33,680
unobserved effect on the universe

447
00:16:37,350 --> 00:16:35,279
the third

448
00:16:39,030 --> 00:16:37,360
breakthrough i see in these results is

449
00:16:41,030 --> 00:16:39,040
it tells us something

450
00:16:42,790 --> 00:16:41,040
about the value of these great

451
00:16:45,189 --> 00:16:42,800
observatories

452
00:16:47,509 --> 00:16:45,199
nobody expected and nobody designed the

453
00:16:50,069 --> 00:16:47,519
chandra observatory to discover black

454
00:16:52,389 --> 00:16:50,079
holes it took the research that was done

455
00:16:54,470 --> 00:16:52,399
over the last decade with chandra

456
00:16:56,870 --> 00:16:54,480
for people to begin to realize that you

457
00:16:58,949 --> 00:16:56,880
could by observing very deeply in the

458
00:17:01,030 --> 00:16:58,959
universe that you could piece together

459
00:17:03,829 --> 00:17:01,040
some of the very early history of black

460
00:17:05,029 --> 00:17:03,839
hole growth and so it shows the value of

461
00:17:05,750 --> 00:17:05,039
having a

462
00:17:08,470 --> 00:17:05,760
uh

463
00:17:11,189 --> 00:17:08,480

a satellite up there that um

464
00:17:14,390 --> 00:17:11,199
exists for a long time and is able to

465
00:17:16,230 --> 00:17:14,400
evolve and uh is able to be uh to have

466
00:17:18,470 --> 00:17:16,240
its mission adjusted so that people can

467
00:17:21,350 --> 00:17:18,480
do creative new things um as the

468
00:17:23,590 --> 00:17:21,360
opportunity arises and so uh in

469
00:17:25,429 --> 00:17:23,600
particular having uh chandra there at

470
00:17:27,189 --> 00:17:25,439
the same time as hubble we see there's

471
00:17:28,150 --> 00:17:27,199
been a tremendous symbiosis between

472
00:17:32,789 --> 00:17:28,160
these two

473
00:17:34,470 --> 00:17:32,799
really allowed a discovery that was

474
00:17:37,190 --> 00:17:34,480
completely unforeseen until very

475
00:17:39,909 --> 00:17:37,200
recently so going forward i see that

476
00:17:41,909 --> 00:17:39,919
these observatories continuing to

477
00:17:43,830 --> 00:17:41,919
operate will take deeper and deeper

478
00:17:45,909 --> 00:17:43,840
images and probably over the next few

479
00:17:48,070 --> 00:17:45,919
years we'll we'll see

480
00:17:50,230 --> 00:17:48,080
our picture of the early evolution of

481
00:17:53,110 --> 00:17:50,240
black holes and their relationship to

482
00:17:54,950 --> 00:17:53,120
galaxy formation um fill in and we'll

483
00:17:56,950 --> 00:17:54,960
get a greater understanding of these

484
00:17:58,630 --> 00:17:56,960
processes

485
00:17:59,830 --> 00:17:58,640
great thank you very much mitch we'll

486
00:18:01,510 --> 00:17:59,840
move on to the question and answer

487
00:18:02,630 --> 00:18:01,520
session now uh just a reminder for those

488
00:18:04,070 --> 00:18:02,640

of you in the audience we have a couple

489
00:18:06,549 --> 00:18:04,080
of microphones so just wait until it

490
00:18:09,110 --> 00:18:06,559
gets to you um for for everyone here and

491
00:18:10,549 --> 00:18:09,120
and by phone just please uh remember to

492
00:18:11,750 --> 00:18:10,559
introduce yourself in your affiliation

493
00:18:13,110 --> 00:18:11,760
before asking a question and please try

494
00:18:15,990 --> 00:18:13,120
to direct a question to a specific

495
00:18:19,270 --> 00:18:18,150
and if you can signal the operator if

496
00:18:21,590 --> 00:18:19,280
you're on the phone that you have a

497
00:18:22,950 --> 00:18:21,600
question by pushing the star one keys

498
00:18:27,510 --> 00:18:22,960
so let me start and see through any

499
00:18:30,870 --> 00:18:29,430
okay well let me let me take uh podium

500
00:18:32,789 --> 00:18:30,880
privilege here because i i did have a

501
00:18:34,390 --> 00:18:32,799
question uh for the panelists and you

502
00:18:37,029 --> 00:18:34,400
know mitch spoke a little bit about

503
00:18:38,710 --> 00:18:37,039
upcoming research or what you see the

504
00:18:40,070 --> 00:18:38,720
the potential for being as follow on

505
00:18:41,669 --> 00:18:40,080
research in the next few years but i'd

506
00:18:43,590 --> 00:18:41,679
ask the panelists what's you're most

507
00:18:45,190 --> 00:18:43,600
interested and excited about about this

508
00:18:50,230 --> 00:18:45,200
finding and where you see people taking

509
00:18:56,950 --> 00:18:51,029
so

510
00:18:59,590 --> 00:18:56,960
find this amount if you extrapolate from

511
00:19:01,510 --> 00:18:59,600
what we knew and people did this they

512
00:19:03,750 --> 00:19:01,520
they tried to estimate how much growth

513
00:19:06,950 --> 00:19:03,760

there was at the earlier box based on

514
00:19:08,710 --> 00:19:06,960
what we knew closer to us and turns out

515
00:19:10,710 --> 00:19:08,720
the answer was about a hundred times

516
00:19:13,270 --> 00:19:10,720
shorter than that what we actually

517
00:19:15,270 --> 00:19:13,280
measure so we we found about 100 times

518
00:19:17,430 --> 00:19:15,280
more black hole growth in the uni

519
00:19:20,390 --> 00:19:17,440
universe than what you get for if you

520
00:19:22,310 --> 00:19:20,400
extrapolate from from closer to us from

521
00:19:24,470 --> 00:19:22,320
what we knew before so that was very

522
00:19:26,789 --> 00:19:24,480
exciting also i don't think people

523
00:19:29,909 --> 00:19:26,799
expect most of these sources to be

524
00:19:31,830 --> 00:19:29,919
heavily obscured so so that was very

525
00:19:34,710 --> 00:19:31,840
exciting as well and i think in the

526
00:19:37,669 --> 00:19:34,720
future and and this was as i think dr

527
00:19:39,510 --> 00:19:37,679
natarajan say this is a big step not a

528
00:19:42,789 --> 00:19:39,520
baby step in getting closer to

529
00:19:44,789 --> 00:19:42,799
understand where the black holes uh form

530
00:19:46,789 --> 00:19:44,799
and when they were created and when they

531
00:19:48,390 --> 00:19:46,799
started so i think that was very

532
00:19:53,029 --> 00:19:48,400
exciting

533
00:19:54,070 --> 00:19:53,039
next step to take of course is to tackle

534
00:19:55,270 --> 00:19:54,080
this question that professional

535
00:19:57,350 --> 00:19:55,280
natarajan

536
00:19:59,510 --> 00:19:57,360
uh discussed which is where did the

537
00:20:01,990 --> 00:19:59,520
first seed black holes come from

538
00:20:04,549 --> 00:20:02,000

and it may be possible by

539
00:20:05,590 --> 00:20:04,559
combining both hubble and chandra and

540
00:20:08,549 --> 00:20:05,600
taking

541
00:20:10,390 --> 00:20:08,559
even larger images of the very early

542
00:20:13,750 --> 00:20:10,400
universe we may be able to start up

543
00:20:15,669 --> 00:20:13,760
picking up differences in the properties

544
00:20:17,270 --> 00:20:15,679
and the numbers of black holes in the

545
00:20:18,950 --> 00:20:17,280
very early universe that might deliver

546
00:20:21,110 --> 00:20:18,960
some clues as to

547
00:20:22,789 --> 00:20:21,120
which mechanism the death of the first

548
00:20:25,270 --> 00:20:22,799
stars or the collapse of these

549
00:20:27,270 --> 00:20:25,280
pregalactic discs

550
00:20:30,230 --> 00:20:27,280
really formed the original seeds to

551
00:20:32,230 --> 00:20:30,240
these baby black holes that we're seeing

552
00:20:33,990 --> 00:20:32,240
so i think personally it's very very

553
00:20:35,909 --> 00:20:34,000
exciting to finally have some

554
00:20:37,029 --> 00:20:35,919
observational data points for us

555
00:20:39,669 --> 00:20:37,039
theorists who have been playing with

556
00:20:41,830 --> 00:20:39,679
these models for very long time

557
00:20:43,750 --> 00:20:41,840
i think what is very exciting is till

558
00:20:45,669 --> 00:20:43,760
now the only data point we had to

559
00:20:47,990 --> 00:20:45,679
calibrate our models and to hone our

560
00:20:50,149 --> 00:20:48,000
understanding were from data points from

561
00:20:51,669 --> 00:20:50,159
these very rare quasars

562
00:20:53,590 --> 00:20:51,679
roughly from when the universe was about

563
00:20:56,470 --> 00:20:53,600

two giga years old so pushing that

564
00:20:59,110 --> 00:20:56,480
frontier and getting more data so that

565
00:21:01,350 --> 00:20:59,120
we can push back the wall to see how

566
00:21:03,430 --> 00:21:01,360
much earlier these objects are already

567
00:21:05,510 --> 00:21:03,440
in place or are assembling is going to

568
00:21:07,909 --> 00:21:05,520
be very very important to really

569
00:21:11,190 --> 00:21:07,919
understand how the first black holes

570
00:21:14,230 --> 00:21:12,310
you know just a follow-up question on

571
00:21:16,549 --> 00:21:14,240
that if you were to

572
00:21:18,549 --> 00:21:16,559
estimate future research how far back do

573
00:21:20,390 --> 00:21:18,559
you think we can get based on on what's

574
00:21:24,070 --> 00:21:20,400
there now if you're looking back at the

575
00:21:26,950 --> 00:21:25,909
with with with observations with chandra

576
00:21:28,789 --> 00:21:26,960
and hubble as you said working in

577
00:21:30,950 --> 00:21:28,799
conjunction together how close can we

578
00:21:33,190 --> 00:21:30,960
get to the almost birth dates of some of

579
00:21:34,950 --> 00:21:33,200
these baby black holes

580
00:21:38,070 --> 00:21:34,960
well i think the

581
00:21:40,390 --> 00:21:38,080
models uh for making the seed black

582
00:21:41,430 --> 00:21:40,400
holes in particular the massive seeding

583
00:21:43,190 --> 00:21:41,440
models

584
00:21:45,590 --> 00:21:43,200
really start quite early on in the

585
00:21:47,190 --> 00:21:45,600
universe but we're pretty close to that

586
00:21:50,310 --> 00:21:47,200
wall so i would say that we could

587
00:21:52,549 --> 00:21:50,320
plausibly push another couple hundred

588
00:21:55,190 --> 00:21:52,559

million years or so would you say

589
00:21:57,669 --> 00:21:55,200
ezekiel and kevin would you agree i was

590
00:21:59,830 --> 00:21:57,679
going to supplement your your your

591
00:22:02,470 --> 00:21:59,840
answer from the observational point of

592
00:22:06,549 --> 00:22:02,480
view i think is feasible it's very

593
00:22:08,549 --> 00:22:06,559
ambitious but if we spend a few years uh

594
00:22:09,350 --> 00:22:08,559
not continuous of course

595
00:22:11,750 --> 00:22:09,360
um

596
00:22:13,830 --> 00:22:11,760
observing uh with

597
00:22:15,669 --> 00:22:13,840
and chandra we should be able to push it

598
00:22:17,270 --> 00:22:15,679
a few million years and that's when

599
00:22:19,110 --> 00:22:17,280
things get really interested because

600
00:22:21,110 --> 00:22:19,120
that's when the models really start to

601
00:22:23,110 --> 00:22:21,120
separate and we are we are able to

602
00:22:25,669 --> 00:22:23,120
constrain these models and understand

603
00:22:27,110 --> 00:22:25,679
how the first black hole form

604
00:22:29,110 --> 00:22:27,120
yeah so i think

605
00:22:31,590 --> 00:22:29,120
just exactly how how much further back

606
00:22:33,669 --> 00:22:31,600
we can go with hubble and chandra kind

607
00:22:36,149 --> 00:22:33,679
of depends on

608
00:22:38,789 --> 00:22:36,159
what uh what mechanism was it was at

609
00:22:40,390 --> 00:22:38,799
work what these seed populations were

610
00:22:43,110 --> 00:22:40,400
because these these baby black holes

611
00:22:45,270 --> 00:22:43,120
they grow very rapidly and uh but they

612
00:22:47,190 --> 00:22:45,280
have to reach a certain size before they

613
00:22:50,870 --> 00:22:47,200

become bright enough to be so we can

614
00:22:54,630 --> 00:22:51,990
i know there are a lot of people joining

615
00:22:56,149 --> 00:22:54,640
us online and watching uh from from the

616
00:22:57,510 --> 00:22:56,159
public today and there's like there's a

617
00:22:59,350 --> 00:22:57,520
core concept that i want to make sure

618
00:23:00,870 --> 00:22:59,360
people understand because i know it'll

619
00:23:03,350 --> 00:23:00,880
be adventures particularly for the 3 p.m

620
00:23:05,110 --> 00:23:03,360
eastern time web chat today and that's

621
00:23:06,470 --> 00:23:05,120
reionization so for those of us who

622
00:23:08,230 --> 00:23:06,480
aren't quite familiar with what this

623
00:23:09,990 --> 00:23:08,240
process would have been like from the

624
00:23:11,430 --> 00:23:10,000
big bang up to the point that you're

625
00:23:13,029 --> 00:23:11,440
talking about what these black holes may

626
00:23:14,390 --> 00:23:13,039
have affected can maybe we'll start with

627
00:23:16,149 --> 00:23:14,400
priya could you just kind of explain the

628
00:23:17,190 --> 00:23:16,159
concept of reionization

629
00:23:18,470 --> 00:23:17,200
for us

630
00:23:20,070 --> 00:23:18,480
sure so

631
00:23:22,789 --> 00:23:20,080
reionization

632
00:23:24,549 --> 00:23:22,799
refers to the particular phenomenon that

633
00:23:27,110 --> 00:23:24,559
occurs in the um

634
00:23:30,149 --> 00:23:27,120
slightly late universe

635
00:23:32,070 --> 00:23:30,159
when the universe was essentially opaque

636
00:23:34,950 --> 00:23:32,080
to radiation and then suddenly starts

637
00:23:36,549 --> 00:23:34,960
becoming transparent to light so right

638
00:23:39,270 --> 00:23:36,559

after the big bang the universe is

639
00:23:40,549 --> 00:23:39,280
filled with plasma and it's transparent

640
00:23:43,029 --> 00:23:40,559
to radiation

641
00:23:45,350 --> 00:23:43,039
hydrogen recombines and you form neutral

642
00:23:47,990 --> 00:23:45,360
hydrogen that forms this fog and the

643
00:23:49,830 --> 00:23:48,000
universe becomes opaque to all radiation

644
00:23:51,750 --> 00:23:49,840
and eventually when the first store

645
00:23:53,990 --> 00:23:51,760
sources the first sources of light form

646
00:23:57,110 --> 00:23:54,000
in the universe be it growing black

647
00:23:58,710 --> 00:23:57,120
holes or stars should start opening up

648
00:24:00,950 --> 00:23:58,720
this fog and should start destroying

649
00:24:03,430 --> 00:24:00,960
this fog and so that process is called

650
00:24:05,430 --> 00:24:03,440
reionization we expect it to be not

651
00:24:08,070 --> 00:24:05,440
instantaneous but rather a gradual

652
00:24:09,510 --> 00:24:08,080
process and the details of that process

653
00:24:12,230 --> 00:24:09,520
really depend

654
00:24:13,990 --> 00:24:12,240
first on whether stars form first or

655
00:24:16,870 --> 00:24:14,000
black holes accreting black holes form

656
00:24:19,430 --> 00:24:16,880
first or they may occur concurrently

657
00:24:21,350 --> 00:24:19,440
evenly so the sequence of how things

658
00:24:23,350 --> 00:24:21,360
happen in the universe are very critical

659
00:24:26,549 --> 00:24:23,360
to our understanding of how the process

660
00:24:29,350 --> 00:24:26,559
of reionization occurs so it's if you

661
00:24:31,990 --> 00:24:29,360
will it is a lifting of the veil of the

662
00:24:34,470 --> 00:24:32,000
dark ages of the universe and bringing

663
00:24:36,230 --> 00:24:34,480

sort of transparency

664
00:24:38,149 --> 00:24:36,240
thank you very much let me do a last

665
00:24:42,789 --> 00:24:38,159
check in the audience and and by phone

666
00:24:47,110 --> 00:24:45,190
okay well with that uh we will close

667
00:24:49,110 --> 00:24:47,120
today's event and i just want to thank

668
00:24:51,190 --> 00:24:49,120
our panelists for joining us today and

669
00:24:52,549 --> 00:24:51,200
for those of you online watching again

670
00:24:55,590 --> 00:24:52,559
you can find out more information about

671
00:24:59,269 --> 00:24:55,600
today's results and assorted multimedia