PUBLIC LECTURE SERIES

Shaping Galaxies with Supermassive Black Hole Winds

Featuring Guest Speaker:

Mitchell Revalski

1
00:00:06,309 --> 00:00:04,870
hello and welcome to the space telescope

2
00:00:08,230 --> 00:00:06,319
public lecture series

3
00:00:10,709 --> 00:00:08,240
i'm your host dr frank summers of the

4
00:00:13,669 --> 00:00:10,719
space telescope science institute

5
00:00:15,749 --> 00:00:13,679
tonight's talk shaping galaxies with

6
00:00:19,429 --> 00:00:15,759
supermassive black hole wins

7
00:00:25,189 --> 00:00:22,710
i want to thank our amazing tech team

8
00:00:26,150 --> 00:00:25,199
thomas marufu and grant justice they

9
00:00:28,470 --> 00:00:26,160
have been helping us

10
00:00:29,589 --> 00:00:28,480
transform from our live audience in the

11
00:00:32,709 --> 00:00:29,599
auditorium

12
00:00:34,470 --> 00:00:32,719
to our online only and i will say that

13
00:00:35,510 --> 00:00:34,480

our lecture series will continue to be

14
00:00:40,470 --> 00:00:35,520
online only

15
00:00:44,310 --> 00:00:42,869
next month we have a special date it

16
00:00:46,950 --> 00:00:44,320
will be on january

17
00:00:48,869 --> 00:00:46,960
19th we're skipping the first one first

18
00:00:50,470 --> 00:00:48,879
tuesday because it's around new year's

19
00:00:52,950 --> 00:00:50,480
we're skipping the second tuesday

20
00:00:54,150 --> 00:00:52,960
because it's the american astronomical

21
00:00:56,709 --> 00:00:54,160
society meeting

22
00:00:59,270 --> 00:00:56,719
and we're going to the third tuesday

23
00:01:00,150 --> 00:00:59,280
january 19th in which we have an amazing

24
00:01:03,110 --> 00:01:00,160
talk for you

25
00:01:04,549 --> 00:01:03,120
the darkest secrets of the universe from

26
00:01:07,350 --> 00:01:04,559
rajya muhat the curta

27
00:01:07,910 --> 00:01:07,360
from university of santa cruz this is

28
00:01:10,550 --> 00:01:07,920
one

29
00:01:11,670 --> 00:01:10,560
you're really gonna enjoy this i know in

30
00:01:14,390 --> 00:01:11,680
february and

31
00:01:15,830 --> 00:01:14,400
in march we will both be meeting on the

32
00:01:18,950 --> 00:01:15,840
second of the month

33
00:01:21,190 --> 00:01:18,960
and because we were quite sure how long

34
00:01:22,789 --> 00:01:21,200
all this coronavirus stuff would last we

35
00:01:25,030 --> 00:01:22,799
hadn't scheduled yet

36
00:01:26,469 --> 00:01:25,040
but it's now time to start scheduling

37
00:01:29,030 --> 00:01:26,479
all throughout 2021

38
00:01:30,390 --> 00:01:29,040

so don't worry as always i will make

39
00:01:33,109 --> 00:01:30,400
sure we have speakers

40
00:01:34,950 --> 00:01:33,119
in february and march where can you find

41
00:01:38,230 --> 00:01:34,960
out that information when it pops up

42
00:01:41,429 --> 00:01:38,240
well of course you can go to our website

43
00:01:44,389 --> 00:01:41,439
this if you just go to sdsci.edu

44
00:01:46,630 --> 00:01:44,399
public hyphen lectures you will find

45
00:01:49,990 --> 00:01:46,640
this webpage talking about it

46
00:01:53,429 --> 00:01:50,000
um you can see in the lower left

47
00:01:56,630 --> 00:01:53,439
there is the um links to our webcast

48
00:01:58,870 --> 00:01:56,640
both our youtube playlist as well as our

49
00:01:59,670 --> 00:01:58,880
webcast archive on the space telescope

50
00:02:01,910 --> 00:01:59,680
site

51
00:02:03,670 --> 00:02:01,920
um and in the lower right you can see

52
00:02:05,670 --> 00:02:03,680
how you can subscribe to our

53
00:02:08,389 --> 00:02:05,680
announcements and get an email

54
00:02:09,910 --> 00:02:08,399
once or twice a month about the public

55
00:02:12,309 --> 00:02:09,920
lectures

56
00:02:13,030 --> 00:02:12,319
also on the website are the links to the

57
00:02:15,190 --> 00:02:13,040
individual

58
00:02:17,589 --> 00:02:15,200
lectures and if you click on one of

59
00:02:19,830 --> 00:02:17,599
those lectures you get the full detail

60
00:02:21,190 --> 00:02:19,840
about it after it's been recorded you

61
00:02:24,229 --> 00:02:21,200
can view the webcast

62
00:02:26,070 --> 00:02:24,239
on the stsci webcast site or down bottom

63
00:02:27,510 --> 00:02:26,080

on the youtube site and get all the

64
00:02:32,790 --> 00:02:27,520
information about the speaker

65
00:02:35,110 --> 00:02:32,800
and the um and the abstract

66
00:02:36,710 --> 00:02:35,120
for email well the announcements you can

67
00:02:37,910 --> 00:02:36,720
just sign up at the website as i showed

68
00:02:40,710 --> 00:02:37,920
you previously

69
00:02:41,350 --> 00:02:40,720
you can also subscribe to our youtube

70
00:02:44,630 --> 00:02:41,360
channel

71
00:02:45,990 --> 00:02:44,640
uh youtube.com hubble space telescope

72
00:02:48,150 --> 00:02:46,000
all one word

73
00:02:49,430 --> 00:02:48,160
uh if you do subscribe to our youtube

74
00:02:51,750 --> 00:02:49,440
channel you'll get

75
00:02:54,470 --> 00:02:51,760
new notices of new videos as well as

76
00:02:56,070 --> 00:02:54,480
reminders of these live events

77
00:02:57,910 --> 00:02:56,080
finally if you have comments or

78
00:02:58,630 --> 00:02:57,920
questions you can send them to public

79
00:03:02,390 --> 00:02:58,640
lecture

80
00:03:05,190 --> 00:03:02,400
at stsci.edu

81
00:03:06,550 --> 00:03:05,200
on social media we do social media for

82
00:03:08,309 --> 00:03:06,560
the hubble space telescope

83
00:03:10,550 --> 00:03:08,319
for the upcoming james webb space

84
00:03:11,750 --> 00:03:10,560
telescope and for the space telescope

85
00:03:14,710 --> 00:03:11,760
science institute

86
00:03:16,229 --> 00:03:14,720
and those platf those institutions are

87
00:03:19,350 --> 00:03:16,239
represented on facebook

88
00:03:21,270 --> 00:03:19,360

twitter youtube and instagram so

89
00:03:22,790 --> 00:03:21,280
a whole lot of social media uh

90
00:03:26,309 --> 00:03:22,800
presentation for you

91
00:03:28,229 --> 00:03:26,319
myself i do a tiny tiny bit on facebook

92
00:03:31,990 --> 00:03:28,239
and twitter if you want to follow me

93
00:03:34,550 --> 00:03:32,000
please do so and now

94
00:03:37,509 --> 00:03:34,560
the news from the universe for december

95
00:03:46,710 --> 00:03:40,869
our first story tonight the fading glory

96
00:03:51,149 --> 00:03:46,720
of supernova 2018 gv

97
00:03:54,309 --> 00:03:51,159
this is the this is the galaxy ngc

98
00:03:55,670 --> 00:03:54,319
2525 and as you can see it's a nice

99
00:03:58,070 --> 00:03:55,680
spiral galaxy

100
00:04:00,070 --> 00:03:58,080
this is a ground-based observation from

101
00:04:01,509 --> 00:04:00,080
uh the carnegie observatory

102
00:04:03,350 --> 00:04:01,519
and you can see that's got some

103
00:04:04,390 --> 00:04:03,360
interesting spiral structure and

104
00:04:07,830 --> 00:04:04,400
everything

105
00:04:12,309 --> 00:04:07,840
but ground-based doesn't quite capture

106
00:04:15,509 --> 00:04:12,319
the real detail in there this

107
00:04:17,509 --> 00:04:15,519
that's the hubble image yeah isn't that

108
00:04:19,349 --> 00:04:17,519
amazing that you get the resolution

109
00:04:21,030 --> 00:04:19,359
by getting up above earth's atmosphere

110
00:04:21,830 --> 00:04:21,040
you get an amazing resolution let me go

111
00:04:24,870 --> 00:04:21,840
back

112
00:04:28,150 --> 00:04:24,880
here is ground-based and here is

113
00:04:30,790 --> 00:04:28,160

hubble ah yeah kind of great

114
00:04:31,909 --> 00:04:30,800
but there's also one thing kind of

115
00:04:33,270 --> 00:04:31,919
interesting

116
00:04:34,550 --> 00:04:33,280
i don't know if you guys saw it watch

117
00:04:35,670 --> 00:04:34,560
carefully all right we'll go back to the

118
00:04:37,749 --> 00:04:35,680
ground based

119
00:04:39,189 --> 00:04:37,759
now see if you can see something pop on

120
00:04:42,550 --> 00:04:39,199
when we go to the

121
00:04:45,909 --> 00:04:42,560
hubble to catch it it's

122
00:04:49,990 --> 00:04:45,919
right up here that is not

123
00:04:53,909 --> 00:04:50,000
a star that is an exploded star

124
00:04:56,310 --> 00:04:53,919
supernova 2018 gv

125
00:04:56,950 --> 00:04:56,320
now it looks like a star but really it's

126
00:04:58,629 --> 00:04:56,960
it's not

127
00:05:01,029 --> 00:04:58,639
it's a supernova explosion which is

128
00:05:02,310 --> 00:05:01,039
extremely bright all the other stars you

129
00:05:05,350 --> 00:05:02,320
see in this image

130
00:05:07,990 --> 00:05:05,360
they're not in the galaxy ngc 2525

131
00:05:09,749 --> 00:05:08,000
they're in our own milky way galaxy

132
00:05:11,110 --> 00:05:09,759
remember as we look out through our

133
00:05:13,670 --> 00:05:11,120
milky way galaxy at

134
00:05:15,029 --> 00:05:13,680
distant galaxies beyond we have we go

135
00:05:16,950 --> 00:05:15,039
through this screen of stars so the

136
00:05:19,189 --> 00:05:16,960
stars you're seeing in this image

137
00:05:21,189 --> 00:05:19,199
are actually very close to us they're

138
00:05:24,550 --> 00:05:21,199

inside the milky way

139
00:05:29,270 --> 00:05:24,560
whereas 2018 gv is

140
00:05:32,550 --> 00:05:29,280
actually located in ngc 2525

141
00:05:34,070 --> 00:05:32,560
millions of light years away it has to

142
00:05:37,270 --> 00:05:34,080
be incredibly

143
00:05:39,270 --> 00:05:37,280
bright so that we can see it that far

144
00:05:41,430 --> 00:05:39,280
across the universe and that's one of

145
00:05:44,310 --> 00:05:41,440
the important things about supernovae

146
00:05:45,510 --> 00:05:44,320
is that we can see them occur in other

147
00:05:48,310 --> 00:05:45,520
galaxies

148
00:05:50,310 --> 00:05:48,320
and so this one was was first observed

149
00:05:51,510 --> 00:05:50,320
with a ground-based telescope in january

150
00:05:53,909 --> 00:05:51,520
2018

151
00:05:56,150 --> 00:05:53,919
and hubble started following in in

152
00:05:59,670 --> 00:05:56,160
february of 2018

153
00:06:00,950 --> 00:05:59,680
and hubble was able to watch as it faded

154
00:06:04,230 --> 00:06:00,960
away

155
00:06:07,510 --> 00:06:04,240
so this is a a close-up of

156
00:06:08,790 --> 00:06:07,520
a supernova 2018 starting in about

157
00:06:12,309 --> 00:06:08,800
february 2000 uh

158
00:06:13,189 --> 00:06:12,319
2018 going for about one year and it's a

159
00:06:14,629 --> 00:06:13,199
movie

160
00:06:17,590 --> 00:06:14,639
so we're gonna play it through and you

161
00:06:19,189 --> 00:06:17,600
can watch the star fade away

162
00:06:20,790 --> 00:06:19,199
and go back and looking it's like a

163
00:06:21,350 --> 00:06:20,800

small one this is only over a course of

164
00:06:23,350 --> 00:06:21,360
a year

165
00:06:25,590 --> 00:06:23,360
supernova actually fade over the course

166
00:06:27,350 --> 00:06:25,600
of about three or four years

167
00:06:29,110 --> 00:06:27,360
at least for uh for astronomers to

168
00:06:31,029 --> 00:06:29,120
follow them and you can watch and you

169
00:06:34,390 --> 00:06:31,039
can see we plotted a graph

170
00:06:37,510 --> 00:06:34,400
to show you the brightness um at peak

171
00:06:38,550 --> 00:06:37,520
and then following and fading down over

172
00:06:40,950 --> 00:06:38,560
time

173
00:06:42,550 --> 00:06:40,960
that's actually kind of important

174
00:06:45,749 --> 00:06:42,560
because

175
00:06:46,390 --> 00:06:45,759
the way a supernova decreases in its

176
00:06:49,670 --> 00:06:46,400
light curve

177
00:06:52,309 --> 00:06:49,680
from its peak magnitude down uh

178
00:06:53,430 --> 00:06:52,319
as it fades away actually tells us a lot

179
00:06:55,510 --> 00:06:53,440
about the physics

180
00:06:58,070 --> 00:06:55,520
of the supernova there are different

181
00:07:01,270 --> 00:06:58,080
types type 1a type 1b

182
00:07:03,189 --> 00:07:01,280
type 2b type 2 n i've never heard

183
00:07:05,110 --> 00:07:03,199
i hadn't heard of that until i looked at

184
00:07:06,950 --> 00:07:05,120
this chart earlier today

185
00:07:08,710 --> 00:07:06,960
um that's the hypernova stuff and you

186
00:07:10,870 --> 00:07:08,720
can see how there are various

187
00:07:12,790 --> 00:07:10,880
ways of involved that tells you and

188
00:07:16,309 --> 00:07:12,800

there are certain supernovae

189
00:07:19,990 --> 00:07:16,319
that are really important for cosmology

190
00:07:21,990 --> 00:07:20,000
these are the the type 1a supernovae

191
00:07:24,790 --> 00:07:22,000
and here are two others that occurred in

192
00:07:28,390 --> 00:07:24,800
other galaxies supernova 1994 d

193
00:07:31,430 --> 00:07:28,400
and supernova 2011 fe

194
00:07:33,430 --> 00:07:31,440
and by looking at these supernovae and

195
00:07:35,029 --> 00:07:33,440
finding out how they how how they

196
00:07:36,710 --> 00:07:35,039
decrease and

197
00:07:38,070 --> 00:07:36,720
understanding that gives us their

198
00:07:39,830 --> 00:07:38,080
maximum brightness

199
00:07:41,749 --> 00:07:39,840
which gives us distances to these

200
00:07:43,430 --> 00:07:41,759
galaxies which when we measure the

201
00:07:46,550 --> 00:07:43,440
redshifts of these galaxies

202
00:07:47,510 --> 00:07:46,560
helps us refine the expansion rate of

203
00:07:49,430 --> 00:07:47,520
the universe

204
00:07:50,790 --> 00:07:49,440
right this is actually part of a large

205
00:07:53,909 --> 00:07:50,800
project called

206
00:07:54,390 --> 00:07:53,919
shoes which is some convoluted acronym

207
00:07:56,150 --> 00:07:54,400
about

208
00:07:58,150 --> 00:07:56,160
supernova with hubble to measure the

209
00:08:00,309 --> 00:07:58,160
expansion rate of the universe all right

210
00:08:01,670 --> 00:08:00,319
and so it's a very large project

211
00:08:03,749 --> 00:08:01,680
looking for these different distant

212
00:08:06,469 --> 00:08:03,759
supernovae in these distant

213
00:08:07,189 --> 00:08:06,479

galaxies to measure the distances and

214
00:08:09,589 --> 00:08:07,199
the redshifts

215
00:08:10,629 --> 00:08:09,599
and measure the expansion rate of the

216
00:08:13,350 --> 00:08:10,639
universe

217
00:08:14,309 --> 00:08:13,360
so this is just one more piece in that

218
00:08:16,070 --> 00:08:14,319
puzzle

219
00:08:17,990 --> 00:08:16,080
but it's very nice that hubble was able

220
00:08:18,950 --> 00:08:18,000
to observe it many times over the course

221
00:08:22,469 --> 00:08:18,960
of a year

222
00:08:25,990 --> 00:08:22,479
to truly watch and see the fading glory

223
00:08:29,270 --> 00:08:26,000
of that supernova

224
00:08:33,670 --> 00:08:29,280
our second story arecibo over

225
00:08:36,949 --> 00:08:33,680
and out this is a sad story to tell

226
00:08:38,709 --> 00:08:36,959
because it's about the arecibo radio

227
00:08:40,949 --> 00:08:38,719
observatory which is located

228
00:08:42,550 --> 00:08:40,959
as you might guess in arecibo puerto

229
00:08:45,269 --> 00:08:42,560
rico

230
00:08:46,230 --> 00:08:45,279
arecibo is located in the mountains of

231
00:08:48,949 --> 00:08:46,240
puerto rico

232
00:08:50,470 --> 00:08:48,959
in a natural sinkhole and using the

233
00:08:52,630 --> 00:08:50,480
natural sinkhole which

234
00:08:54,870 --> 00:08:52,640
already does most of the shaping for it

235
00:08:58,710 --> 00:08:54,880
they were able to create a radio dish

236
00:09:00,790 --> 00:08:58,720
one thousand feet across uh it was built

237
00:09:03,030 --> 00:09:00,800
in the 1960s it started operation in

238
00:09:06,070 --> 00:09:03,040

november 1963.

239
00:09:08,550 --> 00:09:06,080
um so it is the has been the

240
00:09:09,670 --> 00:09:08,560
largest rate single dish radio

241
00:09:13,269 --> 00:09:09,680
observatory

242
00:09:13,990 --> 00:09:13,279
until 2016. for over 50 years it was the

243
00:09:17,430 --> 00:09:14,000
largest

244
00:09:19,269 --> 00:09:17,440
single aperture radio telescope

245
00:09:20,949 --> 00:09:19,279
it's been used for radio astronomy it's

246
00:09:22,710 --> 00:09:20,959
been used for radar astronomy

247
00:09:24,310 --> 00:09:22,720
they can actually send out signals with

248
00:09:26,470 --> 00:09:24,320
it um they

249
00:09:28,310 --> 00:09:26,480
have been used for atmospheric science

250
00:09:30,310 --> 00:09:28,320
um and it's also been used for the

251
00:09:33,269 --> 00:09:30,320
search for extraterrestrial intelligence

252
00:09:33,750 --> 00:09:33,279
they actually sent out a signal um out

253
00:09:36,470 --> 00:09:33,760
that

254
00:09:37,430 --> 00:09:36,480
maybe somebody somewhere will actually

255
00:09:41,110 --> 00:09:37,440
see

256
00:09:44,790 --> 00:09:41,120
extra

257
00:09:47,670 --> 00:09:44,800
in the movie contact

258
00:09:50,230 --> 00:09:47,680
starring jody foster that movie came out

259
00:09:53,110 --> 00:09:50,240
in 1997.

260
00:09:55,670 --> 00:09:53,120
of course that's sort of a geeky movie

261
00:09:57,990 --> 00:09:55,680
it was based on a book by carl sagan

262
00:09:59,509 --> 00:09:58,000
i'm sure most people remember the

263
00:10:01,990 --> 00:09:59,519

receiver radio observatory

264
00:10:03,670 --> 00:10:02,000
for its appearance in the james bond

265
00:10:06,069 --> 00:10:03,680
film goldeneye

266
00:10:08,150 --> 00:10:06,079
where pierce brosnan and sean bean had

267
00:10:11,350 --> 00:10:08,160
this big fight out on the radio

268
00:10:14,389 --> 00:10:11,360
uh array in the center of the dish okay

269
00:10:17,750 --> 00:10:14,399
uh yeah that never actually happened

270
00:10:20,230 --> 00:10:17,760
but you know people uh uh

271
00:10:23,110 --> 00:10:20,240
they actually filmed it while uh arecibo

272
00:10:25,750 --> 00:10:23,120
was under undergoing um

273
00:10:27,110 --> 00:10:25,760
uh undergoing repairs but the scene that

274
00:10:28,550 --> 00:10:27,120
they filmed was actually filmed with

275
00:10:29,829 --> 00:10:28,560
green screen around it so they didn't

276
00:10:30,389 --> 00:10:29,839
actually get out there in front of they

277
00:10:33,069 --> 00:10:30,399
did

278
00:10:34,630 --> 00:10:33,079
various scenes all right so

279
00:10:37,750 --> 00:10:34,640
unfortunately

280
00:10:40,949 --> 00:10:37,760
not even james bond can save the arecibo

281
00:10:43,670 --> 00:10:40,959
observatory from the ravages of time

282
00:10:43,990 --> 00:10:43,680
and this year has been particularly bad

283
00:10:45,910 --> 00:10:44,000
uh

284
00:10:47,829 --> 00:10:45,920
in august of this year one of the

285
00:10:48,790 --> 00:10:47,839
auxiliary cables you see this structure

286
00:10:51,190 --> 00:10:48,800
that's holding up

287
00:10:52,150 --> 00:10:51,200
uh the main radio platform uh receiver

288
00:10:54,870 --> 00:10:52,160

platform

289
00:10:55,269 --> 00:10:54,880
um one of the auxiliary cables snapped

290
00:11:04,790 --> 00:10:55,279
in

291
00:11:05,990 --> 00:11:04,800
uh and then you know they did the

292
00:11:07,670 --> 00:11:06,000
analysis and they said okay the

293
00:11:08,389 --> 00:11:07,680
remaining cable should be able to hold

294
00:11:11,509 --> 00:11:08,399
it

295
00:11:12,310 --> 00:11:11,519
but in on november 6th of this year one

296
00:11:13,990 --> 00:11:12,320
of the main

297
00:11:16,470 --> 00:11:14,000
cables not an auxiliary cable one of the

298
00:11:18,550 --> 00:11:16,480
main cables snapped

299
00:11:20,150 --> 00:11:18,560
and there was a significant damage which

300
00:11:22,949 --> 00:11:20,160
you can see in this big picture

301
00:11:26,069 --> 00:11:22,959
but let me bring up a close-up and you

302
00:11:28,790 --> 00:11:26,079
can see the kind of damage that was done

303
00:11:29,829 --> 00:11:28,800
and in mid-november around november 19th

304
00:11:31,670 --> 00:11:29,839
i think it was

305
00:11:33,269 --> 00:11:31,680
the national science foundation which

306
00:11:34,470 --> 00:11:33,279
runs this observatory

307
00:11:36,470 --> 00:11:34,480
announced that it would be dis

308
00:11:38,470 --> 00:11:36,480
decommissioned that they would not

309
00:11:39,910 --> 00:11:38,480
um be able to repair it it would cost

310
00:11:40,389 --> 00:11:39,920
too much they didn't have the budget for

311
00:11:43,590 --> 00:11:40,399
it

312
00:11:46,630 --> 00:11:43,600
um and that the world's one of these

313
00:11:47,910 --> 00:11:46,640

iconic telescopes uh would be would be

314
00:11:51,590 --> 00:11:47,920
mothball

315
00:11:53,990 --> 00:11:51,600
um however it still kept

316
00:11:55,190 --> 00:11:54,000
things still kept happening over the

317
00:11:58,069 --> 00:11:55,200
weekend

318
00:11:58,470 --> 00:11:58,079
several wires within cables snapped and

319
00:12:02,629 --> 00:11:58,480
around

320
00:12:03,750 --> 00:12:02,639
8 am this morning there was catastrophic

321
00:12:06,870 --> 00:12:03,760
failure

322
00:12:12,389 --> 00:12:06,880
the whole main

323
00:12:16,310 --> 00:12:12,399
array fell into the dish uh 900 tons

324
00:12:20,310 --> 00:12:16,320
of receiver platform fell over 400 feet

325
00:12:22,870 --> 00:12:20,320
down and smashed into the radio dish

326
00:12:24,629 --> 00:12:22,880
the news of this spread like a wildfire

327
00:12:25,350 --> 00:12:24,639
across the astronomical community this

328
00:12:27,110 --> 00:12:25,360
morning

329
00:12:28,710 --> 00:12:27,120
and i finally found this observe this

330
00:12:33,269 --> 00:12:28,720
image from um

331
00:12:37,030 --> 00:12:33,279
the science magazine and it's just

332
00:12:40,069 --> 00:12:37,040
yeah it's uh 57 years of this telescope

333
00:12:43,509 --> 00:12:40,079
it's in dirt hurricanes and earthquakes

334
00:12:46,470 --> 00:12:43,519
and unfortunately that is it

335
00:12:48,150 --> 00:12:46,480
so i will always remember the arab civil

336
00:12:50,230 --> 00:12:48,160
observatory like this

337
00:12:52,069 --> 00:12:50,240
uh in its heyday while it was producing

338
00:12:56,629 --> 00:12:52,079

amazing science across

339
00:12:59,509 --> 00:12:56,639
many fields started in 1963

340
00:13:01,670 --> 00:12:59,519
decommissioned in 2020 the arecibo

341
00:13:03,269 --> 00:13:01,680
observatory has had its last radio

342
00:13:08,710 --> 00:13:03,279
transmission

343
00:13:13,509 --> 00:13:11,990
and now to our featured speaker

344
00:13:16,629 --> 00:13:13,519
our featured speaker is mitchell

345
00:13:18,790 --> 00:13:16,639
robolsky and he has been with the space

346
00:13:20,710 --> 00:13:18,800
telescope science institute

347
00:13:22,470 --> 00:13:20,720
for about a year a little longer than a

348
00:13:24,389 --> 00:13:22,480
year uh he is a

349
00:13:25,829 --> 00:13:24,399
post-doc which is what you do after

350
00:13:26,949 --> 00:13:25,839
you've finished your graduate work you

351
00:13:29,190 --> 00:13:26,959
get your phd

352
00:13:31,110 --> 00:13:29,200
and then you do some post-docking before

353
00:13:33,910 --> 00:13:31,120
you then get your faculty job

354
00:13:35,670 --> 00:13:33,920
so uh this is actually probably the most

355
00:13:36,790 --> 00:13:35,680
productive time of your career where

356
00:13:39,430 --> 00:13:36,800
you're able to sit there

357
00:13:41,750 --> 00:13:39,440
really do your research right he got his

358
00:13:44,470 --> 00:13:41,760
phd at georgia state

359
00:13:46,150 --> 00:13:44,480
and his undergraduate work at the uh did

360
00:13:49,030 --> 00:13:46,160
his undergraduate work at the college of

361
00:13:49,990 --> 00:13:49,040
new jersey and he and i were chatting

362
00:13:53,030 --> 00:13:50,000
earlier today

363
00:13:56,150 --> 00:13:53,040

uh he does uh rock climbing

364
00:13:59,670 --> 00:13:56,160
and he also does swing dancing which

365
00:14:01,670 --> 00:13:59,680
puts him he and i have something really

366
00:14:03,110 --> 00:14:01,680
interesting in common because i did

367
00:14:05,110 --> 00:14:03,120
ballroom dancing at the university of

368
00:14:08,870 --> 00:14:05,120
california berkeley

369
00:14:11,990 --> 00:14:08,880
and both of us met our wives

370
00:14:13,189 --> 00:14:12,000
at the dance club all right so

371
00:14:15,430 --> 00:14:13,199
you never know where you're going to run

372
00:14:17,590 --> 00:14:15,440
into an astrophysicist but

373
00:14:20,230 --> 00:14:17,600
it turns out that maybe a dance club is

374
00:14:22,629 --> 00:14:20,240
a place to find one

375
00:14:24,629 --> 00:14:22,639
i can't guarantee you care your mileage

376
00:14:26,069 --> 00:14:24,639
may vary on things like that

377
00:14:28,629 --> 00:14:26,079
ladies and gentlemen dr mitchell

378
00:14:30,230 --> 00:14:28,639
rawalski

379
00:14:32,150 --> 00:14:30,240
all right thank you so much frank for

380
00:14:32,949 --> 00:14:32,160
that kind introduction and also to

381
00:14:35,269 --> 00:14:32,959
everyone for

382
00:14:36,470 --> 00:14:35,279
joining us online this evening uh

383
00:14:38,949 --> 00:14:36,480
hopefully after the

384
00:14:40,470 --> 00:14:38,959
sad news of arecibo i can uplift your

385
00:14:43,990 --> 00:14:40,480
mood a little bit by giving you

386
00:14:46,870 --> 00:14:44,000
a tour of supermassive black hole winds

387
00:14:49,590 --> 00:14:46,880
and show how they basically shape nearly

388
00:14:51,509 --> 00:14:49,600

every scale of the observable universe

389
00:14:53,670 --> 00:14:51,519
so in the background here we have this

390
00:14:55,829 --> 00:14:53,680
stunning multi-wavelength image that

391
00:14:57,030 --> 00:14:55,839
shows different facets of these black

392
00:14:58,629 --> 00:14:57,040
hole winds

393
00:15:00,870 --> 00:14:58,639
and it's my hope that by the end of the

394
00:15:02,150 --> 00:15:00,880
talk you'll have a strong conceptual

395
00:15:04,389 --> 00:15:02,160
picture of how

396
00:15:06,389 --> 00:15:04,399
supermassive black holes interact with

397
00:15:07,509 --> 00:15:06,399
the galaxies that they live in

398
00:15:09,430 --> 00:15:07,519
so i'll start with a little bit of

399
00:15:11,910 --> 00:15:09,440
background on supermassive black holes

400
00:15:12,389 --> 00:15:11,920
and galaxies and how we study them and

401
00:15:14,230 --> 00:15:12,399
then

402
00:15:15,990 --> 00:15:14,240
go ahead and examine the role of

403
00:15:17,750 --> 00:15:16,000
supermassive black holes in shaping

404
00:15:19,030 --> 00:15:17,760
their galaxy starting from the very

405
00:15:27,590 --> 00:15:19,040
smallest scales

406
00:15:28,949 --> 00:15:27,600
moving out to the very largest scales

407
00:15:30,790 --> 00:15:28,959
so starting at the beginning when we

408
00:15:34,150 --> 00:15:30,800
look out into the universe we see

409
00:15:35,509 --> 00:15:34,160
galaxies almost everywhere and so this

410
00:15:37,430 --> 00:15:35,519
image that you're seeing is the

411
00:15:39,829 --> 00:15:37,440
hubble ultra deep field which is one of

412
00:15:41,110 --> 00:15:39,839
the deepest views of the universe ever

413
00:15:43,509 --> 00:15:41,120

captured by humanity

414
00:15:45,749 --> 00:15:43,519
it required the hubble space telescope

415
00:15:47,749 --> 00:15:45,759
to cumulatively look at the same patch

416
00:15:51,030 --> 00:15:47,759
of the sky for nearly 11

417
00:15:51,910 --> 00:15:51,040
days which is about 400 orbits around

418
00:15:53,829 --> 00:15:51,920
the earth

419
00:15:55,509 --> 00:15:53,839
and so in this image we see galaxies

420
00:15:57,430 --> 00:15:55,519
that are relatively close to us

421
00:15:59,110 --> 00:15:57,440
and we see galaxies at the very furthest

422
00:16:00,949 --> 00:15:59,120
extents of the universe

423
00:16:03,430 --> 00:16:00,959
and so in astronomy we're in this very

424
00:16:06,389 --> 00:16:03,440
unique position because we can actually

425
00:16:08,310 --> 00:16:06,399
look back in time and see these galaxies

426
00:16:08,870 --> 00:16:08,320
as they're growing the further away we

427
00:16:10,790 --> 00:16:08,880
look

428
00:16:12,230 --> 00:16:10,800
it takes the light longer and longer to

429
00:16:13,110 --> 00:16:12,240
reach us and so we're seeing these

430
00:16:16,470 --> 00:16:13,120
galaxies

431
00:16:18,949 --> 00:16:16,480
as they were a very long time ago

432
00:16:20,790 --> 00:16:18,959
now despite all these different types of

433
00:16:22,470 --> 00:16:20,800
galaxies you see in this image

434
00:16:25,030 --> 00:16:22,480
they're all made of the same fundamental

435
00:16:28,310 --> 00:16:25,040
building blocks and that's stars

436
00:16:31,430 --> 00:16:28,320
gas dust and more exotic components like

437
00:16:33,829 --> 00:16:31,440
black holes and dark matter

438
00:16:35,910 --> 00:16:33,839

so we have all these components we can

439
00:16:37,749 --> 00:16:35,920
still classify galaxies into different

440
00:16:39,910 --> 00:16:37,759
types depending on how much they have of

441
00:16:42,069 --> 00:16:39,920
these components on their appearance

442
00:16:43,829 --> 00:16:42,079
such as spiral galaxies elliptical

443
00:16:45,590 --> 00:16:43,839
galaxies irregulars we'll talk about

444
00:16:47,509 --> 00:16:45,600
that a little bit more in a minute

445
00:16:50,069 --> 00:16:47,519
but despite the apparent kind of

446
00:16:52,550 --> 00:16:50,079
emptiness in between these galaxies

447
00:16:55,030 --> 00:16:52,560
there really is gas everywhere we have

448
00:16:55,910 --> 00:16:55,040
gas within galaxies we have gas around

449
00:16:57,829 --> 00:16:55,920
galaxies

450
00:17:00,069 --> 00:16:57,839
and we have gas in the spaces between

451
00:17:01,990 --> 00:17:00,079
galaxies and so depending

452
00:17:03,590 --> 00:17:02,000
on the temperature and the density of

453
00:17:05,270 --> 00:17:03,600
that gas we might need to use different

454
00:17:06,789 --> 00:17:05,280
types of telescopes to see it

455
00:17:08,789 --> 00:17:06,799
but i want you to keep in mind this

456
00:17:09,909 --> 00:17:08,799
picture where galaxies are just filled

457
00:17:12,390 --> 00:17:09,919
and surrounded

458
00:17:14,470 --> 00:17:12,400
with different types of gas and in order

459
00:17:15,909 --> 00:17:14,480
to study the connection between galaxies

460
00:17:16,789 --> 00:17:15,919
and their gas and their supermassive

461
00:17:17,909 --> 00:17:16,799
black holes

462
00:17:19,990 --> 00:17:17,919
we're going to use two of the most

463
00:17:20,789 --> 00:17:20,000

fundamental tools of astronomy which are

464
00:17:23,990 --> 00:17:20,799
imaging

465
00:17:25,350 --> 00:17:24,000
and spectroscopy so those of you who

466
00:17:27,110 --> 00:17:25,360
frequent these public lectures have

467
00:17:28,870 --> 00:17:27,120
probably seen many representations of

468
00:17:30,630 --> 00:17:28,880
the electromagnetic spectrum

469
00:17:32,549 --> 00:17:30,640
and i really like this image because

470
00:17:35,990 --> 00:17:32,559
we're looking at the same galaxy

471
00:17:37,029 --> 00:17:36,000
m51 the famous whirlpool galaxy at each

472
00:17:39,750 --> 00:17:37,039
different section

473
00:17:41,510 --> 00:17:39,760
of the electromagnetic spectrum so light

474
00:17:43,990 --> 00:17:41,520
comes out in the form of photons we can

475
00:17:46,549 --> 00:17:44,000
specify its energy by a wavelength

476
00:17:48,549 --> 00:17:46,559
so starting up here at the top left

477
00:17:49,669 --> 00:17:48,559
we're looking at the longest wavelengths

478
00:17:51,909 --> 00:17:49,679
the radio

479
00:17:53,350 --> 00:17:51,919
moving to the right to the shortest most

480
00:17:56,630 --> 00:17:53,360
energetic wave ranks

481
00:17:58,549 --> 00:17:56,640
at gamma rays so as we sweep through the

482
00:17:59,510 --> 00:17:58,559
electromagnetic spectrum with different

483
00:18:01,510 --> 00:17:59,520
telescopes

484
00:18:03,029 --> 00:18:01,520
we're probing different portions of the

485
00:18:04,630 --> 00:18:03,039
galaxy and its gas

486
00:18:06,630 --> 00:18:04,640
so starting here on the left in the

487
00:18:09,990 --> 00:18:06,640
radio we're probing the very

488
00:18:12,150 --> 00:18:10,000

cold cool dense gas that is basically

489
00:18:14,549 --> 00:18:12,160
the reservoir from which stars can

490
00:18:16,310 --> 00:18:14,559
form and as we'll see the radio will

491
00:18:18,549 --> 00:18:16,320
actually also be useful for probing some

492
00:18:20,230 --> 00:18:18,559
of that most energetic phenomenon within

493
00:18:22,070 --> 00:18:20,240
galaxies

494
00:18:23,990 --> 00:18:22,080
as we move over to the right we're

495
00:18:25,510 --> 00:18:24,000
looking at the infrared and here we're

496
00:18:28,230 --> 00:18:25,520
starting to probe the warm

497
00:18:29,669 --> 00:18:28,240
dust and the cool stars within galaxies

498
00:18:32,470 --> 00:18:29,679
and this has been most famously done

499
00:18:34,230 --> 00:18:32,480
using the spitzer space telescope

500
00:18:35,990 --> 00:18:34,240
as we continue on into the center we're

501
00:18:37,669 --> 00:18:36,000
looking at optical or visible

502
00:18:39,430 --> 00:18:37,679
wavelengths and these are the colors

503
00:18:40,549 --> 00:18:39,440
that our eyes are sensitive to that

504
00:18:43,430 --> 00:18:40,559
we're able to

505
00:18:45,990 --> 00:18:43,440
detect and perceive and this is probing

506
00:18:48,150 --> 00:18:46,000
gas that's maybe a few thousand degrees

507
00:18:49,669 --> 00:18:48,160
looking at some of the hotter stars and

508
00:18:51,430 --> 00:18:49,679
by far one of the most famous and

509
00:18:53,270 --> 00:18:51,440
successful observatories for doing this

510
00:18:54,549 --> 00:18:53,280
type of astronomy is the hubble space

511
00:18:56,390 --> 00:18:54,559
telescope

512
00:18:58,390 --> 00:18:56,400
as we continue on moving to higher

513
00:19:00,870 --> 00:18:58,400

energies looking at the ultraviolet and

514
00:19:02,630 --> 00:19:00,880
x-rays we're looking at gas that's tens

515
00:19:04,789 --> 00:19:02,640
of thousands or even hundreds of

516
00:19:06,310 --> 00:19:04,799
thousands or millions of degrees

517
00:19:08,150 --> 00:19:06,320
and so this is often done in the

518
00:19:09,990 --> 00:19:08,160
ultraviolet and the x-rays

519
00:19:12,549 --> 00:19:10,000
using instruments such as the chandra

520
00:19:15,029 --> 00:19:12,559
x-ray observatory

521
00:19:15,590 --> 00:19:15,039
so this is the first tool in our kit in

522
00:19:17,909 --> 00:19:15,600
order to

523
00:19:19,830 --> 00:19:17,919
understand the universe we have an image

524
00:19:21,750 --> 00:19:19,840
we open our telescope up we allow the

525
00:19:23,590 --> 00:19:21,760
light to hit a detector and it shows us

526
00:19:25,350 --> 00:19:23,600
the distribution of gas and dust and

527
00:19:26,549 --> 00:19:25,360
stars within galaxies

528
00:19:28,710 --> 00:19:26,559
the second tool of course is

529
00:19:30,549 --> 00:19:28,720
spectroscopy and so

530
00:19:32,390 --> 00:19:30,559
a famous saying is that if a picture is

531
00:19:34,150 --> 00:19:32,400
worth a thousand words then a spectrum

532
00:19:36,390 --> 00:19:34,160
is worth a thousand pictures

533
00:19:37,669 --> 00:19:36,400
meaning that we can get an enormous

534
00:19:39,510 --> 00:19:37,679
amount of information

535
00:19:41,350 --> 00:19:39,520
from the spectrum of an object we can

536
00:19:43,430 --> 00:19:41,360
learn a lot more than we could

537
00:19:45,270 --> 00:19:43,440
by simply having an image so

538
00:19:47,190 --> 00:19:45,280

spectroscopy is the process of taking

539
00:19:48,230 --> 00:19:47,200
light from a galaxy or a portion of a

540
00:19:50,390 --> 00:19:48,240
galaxy

541
00:19:52,070 --> 00:19:50,400
we pass it through a spectrograph on

542
00:19:54,549 --> 00:19:52,080
board of our telescope in this case

543
00:19:56,070 --> 00:19:54,559
i have a little hubble space telescope

544
00:19:57,990 --> 00:19:56,080
and then we spread it out

545
00:19:59,830 --> 00:19:58,000
as a function of wavelength or color so

546
00:20:01,430 --> 00:19:59,840
either by passing it through a prism or

547
00:20:03,110 --> 00:20:01,440
bouncing it off a grating

548
00:20:06,230 --> 00:20:03,120
we spread that light out and then we

549
00:20:07,830 --> 00:20:06,240
record the intensity of the light as a

550
00:20:09,750 --> 00:20:07,840
function of wavelength

551
00:20:11,510 --> 00:20:09,760
so we do this we can take this spectrum

552
00:20:12,950 --> 00:20:11,520
on the right and we can measure the

553
00:20:15,190 --> 00:20:12,960
intensity of each color

554
00:20:16,070 --> 00:20:15,200
and we get a more familiar spectrum and

555
00:20:17,350 --> 00:20:16,080
this has a couple

556
00:20:19,350 --> 00:20:17,360
key features that are really going to

557
00:20:21,350 --> 00:20:19,360
help us in our studies

558
00:20:23,110 --> 00:20:21,360
first we just have the underlying level

559
00:20:25,029 --> 00:20:23,120
of light at all colors this is the

560
00:20:25,669 --> 00:20:25,039
continuum emission this is primarily

561
00:20:28,630 --> 00:20:25,679
coming

562
00:20:30,070 --> 00:20:28,640
from hot stars and dust within a galaxy

563
00:20:31,350 --> 00:20:30,080

and then on top of that we can have

564
00:20:34,070 --> 00:20:31,360
these very

565
00:20:34,549 --> 00:20:34,080
straight narrow features called emission

566
00:20:36,630 --> 00:20:34,559
lines

567
00:20:38,070 --> 00:20:36,640
so we have this excess of light at a

568
00:20:39,909 --> 00:20:38,080
very specific color

569
00:20:42,070 --> 00:20:39,919
and this is coming from the gas this is

570
00:20:43,909 --> 00:20:42,080
coming from individual atoms which have

571
00:20:45,990 --> 00:20:43,919
electrons going around them

572
00:20:47,830 --> 00:20:46,000
and as those electrons are excited and

573
00:20:48,710 --> 00:20:47,840
de-excited they jump between very

574
00:20:50,789 --> 00:20:48,720
discrete

575
00:20:52,950 --> 00:20:50,799
very well-known energy levels and so you

576
00:20:56,390 --> 00:20:52,960
get a very specific color a very

577
00:20:58,950 --> 00:20:56,400
specific wavelength of that photon

578
00:21:00,390 --> 00:20:58,960
the converse of this is absorption lines

579
00:21:01,510 --> 00:21:00,400
we're basically absorbing a very

580
00:21:03,190 --> 00:21:01,520
specific color

581
00:21:04,950 --> 00:21:03,200
and all these features are very

582
00:21:06,390 --> 00:21:04,960
important because they tell us a lot of

583
00:21:08,549 --> 00:21:06,400
information about the gas

584
00:21:10,549 --> 00:21:08,559
most specifically they tell us about the

585
00:21:12,630 --> 00:21:10,559
velocity of this material

586
00:21:14,310 --> 00:21:12,640
so the locations of these emission lines

587
00:21:15,270 --> 00:21:14,320
are very well known for measuring them

588
00:21:17,510 --> 00:21:15,280

in the lab

589
00:21:19,270 --> 00:21:17,520
but due to the doppler effect if objects

590
00:21:22,070 --> 00:21:19,280
are moving either toward

591
00:21:23,510 --> 00:21:22,080
or away from us the lines will be blue

592
00:21:25,510 --> 00:21:23,520
shifted or red shifted

593
00:21:26,549 --> 00:21:25,520
moving to shorter or longer wavelengths

594
00:21:28,390 --> 00:21:26,559
within the spectrum

595
00:21:30,630 --> 00:21:28,400
so basically we can use the positions of

596
00:21:32,549 --> 00:21:30,640
these lines to measure the velocities of

597
00:21:34,230 --> 00:21:32,559
things in space

598
00:21:36,630 --> 00:21:34,240
so we're going to go ahead and apply

599
00:21:37,669 --> 00:21:36,640
these tools to the different portions of

600
00:21:39,590 --> 00:21:37,679
galaxies

601
00:21:40,789 --> 00:21:39,600
and so here we have on the left an

602
00:21:43,029 --> 00:21:40,799
example of a more of an

603
00:21:45,669 --> 00:21:43,039
edge on spiral galaxy and on the right

604
00:21:47,669 --> 00:21:45,679
we have more of a face on spiral galaxy

605
00:21:49,510 --> 00:21:47,679
and down in the very center we have the

606
00:21:50,390 --> 00:21:49,520
nucleus this is the very center of the

607
00:21:52,549 --> 00:21:50,400
galaxy

608
00:21:53,750 --> 00:21:52,559
and around that we have the bulge and

609
00:21:56,390 --> 00:21:53,760
this is basically kind of a

610
00:21:59,029 --> 00:21:56,400
semi-spherical distribution of stars

611
00:22:00,950 --> 00:21:59,039
that are all orbiting around the nucleus

612
00:22:01,669 --> 00:22:00,960
typically made up of older stars as

613
00:22:04,870 --> 00:22:01,679

compared to

614
00:22:06,549 --> 00:22:04,880
hotter younger stars in this case we

615
00:22:08,710 --> 00:22:06,559
also have spiral arms

616
00:22:09,590 --> 00:22:08,720
and these are regions that are slightly

617
00:22:11,830 --> 00:22:09,600
more dense

618
00:22:12,630 --> 00:22:11,840
in hot stars and gas and dust and they

619
00:22:14,230 --> 00:22:12,640
make these very

620
00:22:15,669 --> 00:22:14,240
intricate shapes that we can see in

621
00:22:16,870 --> 00:22:15,679
these spiral galaxies

622
00:22:18,470 --> 00:22:16,880
now of course these are not the only

623
00:22:20,149 --> 00:22:18,480
type there's also ellipticals which you

624
00:22:20,950 --> 00:22:20,159
can almost think of as just one giant

625
00:22:23,590 --> 00:22:20,960
bulge with

626
00:22:25,590 --> 00:22:23,600
much less gas and much less dust as well

627
00:22:27,430 --> 00:22:25,600
as irregulars and types like that

628
00:22:28,710 --> 00:22:27,440
but a profound discovery to come out of

629
00:22:30,789 --> 00:22:28,720
the last few decades

630
00:22:31,990 --> 00:22:30,799
is that almost all massive galaxies at

631
00:22:34,909 --> 00:22:32,000
their centers have

632
00:22:36,710 --> 00:22:34,919
a super massive black hole abbreviated

633
00:22:38,710 --> 00:22:36,720
smbh

634
00:22:40,070 --> 00:22:38,720
now in this case i've drawn these dots

635
00:22:41,669 --> 00:22:40,080
and they're actually much too

636
00:22:43,350 --> 00:22:41,679
large for the scale of the galaxy

637
00:22:45,270 --> 00:22:43,360
supermassive black holes are actually

638
00:22:47,510 --> 00:22:45,280

very small at the distances of these

639
00:22:48,070 --> 00:22:47,520
galaxies and so a logical question might

640
00:22:49,590 --> 00:22:48,080
be well

641
00:22:52,149 --> 00:22:49,600
how do we actually know that they're

642
00:22:53,990 --> 00:22:52,159
even there and so the best evidence of

643
00:22:56,630 --> 00:22:54,000
this comes from looking at the center

644
00:22:58,390 --> 00:22:56,640
of our very own galaxy so here we're

645
00:23:00,549 --> 00:22:58,400
looking at the center of our galaxy and

646
00:23:01,590 --> 00:23:00,559
we're tracing the motions of stars

647
00:23:04,470 --> 00:23:01,600
around the center

648
00:23:06,230 --> 00:23:04,480
over the course of about 20 years and by

649
00:23:06,870 --> 00:23:06,240
doing this we can see that all of these

650
00:23:09,190 --> 00:23:06,880
stars are

651
00:23:11,110 --> 00:23:09,200
orbiting around the central point marked

652
00:23:13,430 --> 00:23:11,120
by a star

653
00:23:14,789 --> 00:23:13,440
however when we point the majority of

654
00:23:17,590 --> 00:23:14,799
our telescopes there

655
00:23:19,430 --> 00:23:17,600
we don't really see anything so based on

656
00:23:21,190 --> 00:23:19,440
the physics that we know we can see how

657
00:23:22,390 --> 00:23:21,200
fast these stars are moving how tight

658
00:23:24,549 --> 00:23:22,400
their orbits are

659
00:23:25,909 --> 00:23:24,559
and we can calculate how much mass has

660
00:23:28,149 --> 00:23:25,919
to be there to actually

661
00:23:29,590 --> 00:23:28,159
hold those stars in those tight orbits

662
00:23:32,070 --> 00:23:29,600
and it turns out to be

663
00:23:33,110 --> 00:23:32,080

millions of times the mass of our own

664
00:23:35,350 --> 00:23:33,120
sun

665
00:23:36,230 --> 00:23:35,360
so we have something that is very very

666
00:23:38,149 --> 00:23:36,240
massive

667
00:23:40,310 --> 00:23:38,159
not really emitting any light and it's

668
00:23:41,750 --> 00:23:40,320
very very dense because these stars are

669
00:23:43,669 --> 00:23:41,760
orbiting very close

670
00:23:46,230 --> 00:23:43,679
and so the only objects that we know of

671
00:23:48,870 --> 00:23:46,240
that can be that dense and that massive

672
00:23:50,070 --> 00:23:48,880
are supermassive black holes these are

673
00:23:52,390 --> 00:23:50,080
objects that range from

674
00:23:54,149 --> 00:23:52,400
millions to even billions of times the

675
00:23:56,630 --> 00:23:54,159
mass of our own sun

676
00:23:58,310 --> 00:23:56,640
and it's all crushed down into a volume

677
00:24:00,630 --> 00:23:58,320
about the size of the solar system

678
00:24:02,870 --> 00:24:00,640
depending on its mass

679
00:24:04,070 --> 00:24:02,880
so this is incredible result that was

680
00:24:06,630 --> 00:24:04,080
finally really

681
00:24:07,510 --> 00:24:06,640
fully solidified and recognized just

682
00:24:10,310 --> 00:24:07,520
this year with the

683
00:24:11,830 --> 00:24:10,320
2020 nobel prize in physics which was

684
00:24:13,990 --> 00:24:11,840
recently awarded to these three

685
00:24:16,230 --> 00:24:14,000
individuals for their pioneering work

686
00:24:18,630 --> 00:24:16,240
to prove beyond a reasonable doubt that

687
00:24:20,230 --> 00:24:18,640
supermassive black holes exist

688
00:24:22,230 --> 00:24:20,240

and are at the centers of the majority

689
00:24:23,510 --> 00:24:22,240
of galaxies

690
00:24:25,430 --> 00:24:23,520
so for the most part when we look at

691
00:24:27,590 --> 00:24:25,440
galaxies we have this kind of invisible

692
00:24:28,549 --> 00:24:27,600
or indirect view of supermassive black

693
00:24:30,230 --> 00:24:28,559
holes

694
00:24:31,990 --> 00:24:30,240
but that changes when we look at

695
00:24:35,110 --> 00:24:32,000
supermassive black holes that are

696
00:24:38,310 --> 00:24:35,120
actively growing or eating material

697
00:24:40,390 --> 00:24:38,320
and these are active galaxies or active

698
00:24:42,230 --> 00:24:40,400
galactic nuclei

699
00:24:44,950 --> 00:24:42,240
so here on the right we have an artist

700
00:24:46,070 --> 00:24:44,960
conception of basically a supermassive

701
00:24:48,149 --> 00:24:46,080
black hole

702
00:24:49,590 --> 00:24:48,159
material in the galaxy works its way

703
00:24:51,750 --> 00:24:49,600
down into the center

704
00:24:53,669 --> 00:24:51,760
and as it starts to fall into the strong

705
00:24:54,310 --> 00:24:53,679
gravitational potential of the black

706
00:24:56,630 --> 00:24:54,320
hole

707
00:24:58,230 --> 00:24:56,640
it will become compressed will form an

708
00:24:59,029 --> 00:24:58,240
accretion disk of material that's

709
00:25:01,269 --> 00:24:59,039
accreting

710
00:25:03,909 --> 00:25:01,279
to the supermassive black hole it will

711
00:25:04,950 --> 00:25:03,919
heat up and it'll emit an immense amount

712
00:25:07,110 --> 00:25:04,960
of radiation

713
00:25:07,990 --> 00:25:07,120

all across the electromagnetic spectrum

714
00:25:09,750 --> 00:25:08,000
from the radio

715
00:25:13,350 --> 00:25:09,760
to the infrared the visible the

716
00:25:15,669 --> 00:25:13,360
ultraviolet the x-rays and onward

717
00:25:16,789 --> 00:25:15,679
so the way that we kind of characterize

718
00:25:18,549 --> 00:25:16,799
this process

719
00:25:20,710 --> 00:25:18,559
that we talk about different active

720
00:25:22,390 --> 00:25:20,720
galaxies that we compare their power

721
00:25:24,230 --> 00:25:22,400
is through what's called the luminosity

722
00:25:27,029 --> 00:25:24,240
and so this is the total amount of

723
00:25:28,149 --> 00:25:27,039
energy that's being emitted at one time

724
00:25:30,789 --> 00:25:28,159
due to this process

725
00:25:32,230 --> 00:25:30,799
of material falling onto the black hole

726
00:25:35,029 --> 00:25:32,240
and

727
00:25:37,110 --> 00:25:35,039
this ranges from about a million times

728
00:25:39,190 --> 00:25:37,120
the luminosity of our own sun

729
00:25:41,430 --> 00:25:39,200
which is about the same as one really

730
00:25:43,350 --> 00:25:41,440
bright massive o star the largest stars

731
00:25:45,990 --> 00:25:43,360
we see in most galaxies

732
00:25:48,549 --> 00:25:46,000
all the way up to hundreds of trillions

733
00:25:51,590 --> 00:25:48,559
of times the luminosity of our own sun

734
00:25:53,830 --> 00:25:51,600
so in the most powerful active galaxies

735
00:25:55,430 --> 00:25:53,840
the amount of radiation coming from very

736
00:25:57,350 --> 00:25:55,440
near the supermassive black hole can

737
00:26:00,230 --> 00:25:57,360
actually outshine the light of

738
00:26:01,830 --> 00:26:00,240

all the stars in the entire galaxy so

739
00:26:03,510 --> 00:26:01,840
this is going to be a very fundamental

740
00:26:04,870 --> 00:26:03,520
parameter that we're going to use

741
00:26:07,190 --> 00:26:04,880
when we're talking about these active

742
00:26:08,070 --> 00:26:07,200
galaxies the luminosity the total amount

743
00:26:10,470 --> 00:26:08,080
of energy

744
00:26:13,190 --> 00:26:10,480
that's being radiated by this process of

745
00:26:15,510 --> 00:26:13,200
material falling onto the black hole

746
00:26:17,029 --> 00:26:15,520
now all this energy has to go somewhere

747
00:26:19,190 --> 00:26:17,039
it doesn't just disappear

748
00:26:21,510 --> 00:26:19,200
and so this is where our supermassive

749
00:26:23,430 --> 00:26:21,520
black hole winds come into play

750
00:26:24,710 --> 00:26:23,440
this energy in the form of light in the

751
00:26:27,830 --> 00:26:24,720
form of photons

752
00:26:29,750 --> 00:26:27,840
is traveling out back into the galaxy

753
00:26:31,909 --> 00:26:29,760
it can interact with the gas it can

754
00:26:33,190 --> 00:26:31,919
excite it it can ionize it cause it to

755
00:26:35,269 --> 00:26:33,200
glow like a neon

756
00:26:36,950 --> 00:26:35,279
sign and more than that we have such

757
00:26:38,070 --> 00:26:36,960
intense radiation that it's actually

758
00:26:40,470 --> 00:26:38,080
exerting a force

759
00:26:41,830 --> 00:26:40,480
actually inverted in it's actually

760
00:26:44,870 --> 00:26:41,840
imparting momentum

761
00:26:47,029 --> 00:26:44,880
onto this gas and pushing it potentially

762
00:26:48,789 --> 00:26:47,039
away from the supermassive black hole

763
00:26:50,870 --> 00:26:48,799

and so this is what we call mass

764
00:26:53,990 --> 00:26:50,880
outflows or winds i'm going to use those

765
00:26:56,470 --> 00:26:54,000
two phrases somewhat interchangeably

766
00:26:57,269 --> 00:26:56,480
now these appear in kind of two main

767
00:26:59,510 --> 00:26:57,279
forms

768
00:27:01,590 --> 00:26:59,520
the first is these mass outflows where

769
00:27:03,510 --> 00:27:01,600
we have radiation that's traveling out

770
00:27:05,110 --> 00:27:03,520
into the galaxy it's finding gas

771
00:27:06,390 --> 00:27:05,120
somewhere exciting it

772
00:27:08,870 --> 00:27:06,400
and then moving it away from the

773
00:27:09,590 --> 00:27:08,880
supermassive black hole and then we also

774
00:27:11,990 --> 00:27:09,600
have

775
00:27:13,269 --> 00:27:12,000
radio jets and so this is a somewhat

776
00:27:15,190 --> 00:27:13,279
different phenomenon

777
00:27:17,029 --> 00:27:15,200
and so here what we have is very close

778
00:27:18,630 --> 00:27:17,039
to the supermassive black hole

779
00:27:20,630 --> 00:27:18,640
there's an immense amount of energy we

780
00:27:21,909 --> 00:27:20,640
have twisting magnetic fields all sorts

781
00:27:23,990 --> 00:27:21,919
of intense physics

782
00:27:25,190 --> 00:27:24,000
and this is basically able to launch a

783
00:27:27,669 --> 00:27:25,200
potential beam of

784
00:27:30,149 --> 00:27:27,679
particles away from the supermassive

785
00:27:31,750 --> 00:27:30,159
black hole at very very high velocities

786
00:27:33,590 --> 00:27:31,760
and so these are much narrower they're

787
00:27:35,669 --> 00:27:33,600
much more directed but they

788
00:27:37,350 --> 00:27:35,679

may have much less material so these are

789
00:27:39,350 --> 00:27:37,360
kind of the two main types of

790
00:27:41,110 --> 00:27:39,360
outflows that i'm going to be focusing

791
00:27:42,950 --> 00:27:41,120
on tonight

792
00:27:44,389 --> 00:27:42,960
so with this we have nearly everything

793
00:27:46,310 --> 00:27:44,399
that we need to investigate the

794
00:27:48,070 --> 00:27:46,320
supermassive black hole winds

795
00:27:49,909 --> 00:27:48,080
let's go ahead and just paint the big

796
00:27:51,990 --> 00:27:49,919
picture so here

797
00:27:53,750 --> 00:27:52,000
on the right we have an artist kind of

798
00:27:56,870 --> 00:27:53,760
version of a typical

799
00:27:58,549 --> 00:27:56,880
say milky way like galaxy and

800
00:28:00,789 --> 00:27:58,559
we like to measure distances in

801
00:28:01,350 --> 00:28:00,799
astronomy using parsecs where a parsec

802
00:28:03,190 --> 00:28:01,360
is about

803
00:28:05,350 --> 00:28:03,200
three light years so anytime you hear a

804
00:28:08,070 --> 00:28:05,360
parsec you can think three light years

805
00:28:09,350 --> 00:28:08,080
and just like grams and kilograms we use

806
00:28:11,909 --> 00:28:09,360
suffixes to give

807
00:28:14,310 --> 00:28:11,919
larger distances so a thousand parsecs

808
00:28:16,149 --> 00:28:14,320
is a kiloparsec

809
00:28:18,149 --> 00:28:16,159
so everything i've shown you so far the

810
00:28:20,389 --> 00:28:18,159
supermassive black hole it's accretion

811
00:28:22,789 --> 00:28:20,399
disk this whole energetic environment

812
00:28:23,909 --> 00:28:22,799
is all contained down at the very center

813
00:28:25,510 --> 00:28:23,919

of the galaxy

814
00:28:28,230 --> 00:28:25,520
if you look at this image on the right

815
00:28:30,710 --> 00:28:28,240
i'll highlight the center most portion

816
00:28:32,230 --> 00:28:30,720
so all of this is contained on scales of

817
00:28:34,149 --> 00:28:32,240
less than a parsec

818
00:28:36,310 --> 00:28:34,159
nearly less than a light year so i've

819
00:28:38,310 --> 00:28:36,320
highlighted that with a single red pixel

820
00:28:40,230 --> 00:28:38,320
on this image and that's actually too

821
00:28:42,389 --> 00:28:40,240
large it should be even smaller than

822
00:28:45,990 --> 00:28:42,399
that and so that's just to highlight

823
00:28:47,669 --> 00:28:46,000
just how tiny these very massive dense

824
00:28:49,110 --> 00:28:47,679
objects are on the scales of their

825
00:28:50,870 --> 00:28:49,120
galaxies

826
00:28:52,230 --> 00:28:50,880
the next scale as we move out is the

827
00:28:54,230 --> 00:28:52,240
galaxy bulge

828
00:28:56,149 --> 00:28:54,240
and so this is on scales of about one

829
00:28:58,870 --> 00:28:56,159
thousand to three thousand parsecs or

830
00:29:01,190 --> 00:28:58,880
one to three kiloparsecs

831
00:29:03,029 --> 00:29:01,200
continuing on past that we have the

832
00:29:04,710 --> 00:29:03,039
stellar disk of the galaxy

833
00:29:06,950 --> 00:29:04,720
and so this is basically the extent of

834
00:29:08,710 --> 00:29:06,960
the galaxy as traced by the stars

835
00:29:10,549 --> 00:29:08,720
and this varies depending on the type of

836
00:29:12,630 --> 00:29:10,559
galaxy but it might be something on the

837
00:29:13,510 --> 00:29:12,640
order of say 30 kiloparsecs which is

838
00:29:16,470 --> 00:29:13,520

about a hundred

839
00:29:18,389 --> 00:29:16,480
thousand light years and finally in the

840
00:29:20,149 --> 00:29:18,399
region outside of the galaxy where we

841
00:29:21,590 --> 00:29:20,159
might not see many stars but we still

842
00:29:24,070 --> 00:29:21,600
have lots of gas

843
00:29:25,430 --> 00:29:24,080
this is the circum galactic medium where

844
00:29:28,149 --> 00:29:25,440
the circum galactic region

845
00:29:28,789 --> 00:29:28,159
around these galaxies so these are kind

846
00:29:30,389 --> 00:29:28,799
of the four

847
00:29:32,230 --> 00:29:30,399
fundamental scales that we're going to

848
00:29:34,549 --> 00:29:32,240
focus on when looking at these

849
00:29:36,070 --> 00:29:34,559
supermassive black hole winds

850
00:29:37,750 --> 00:29:36,080
so now you have all the background you

851
00:29:39,669 --> 00:29:37,760
need we can dive in

852
00:29:42,070 --> 00:29:39,679
and we can tackle this from two points

853
00:29:44,870 --> 00:29:42,080
of view we can look at these wins from

854
00:29:49,350 --> 00:29:44,880
simulations or we can look at them from

855
00:29:53,350 --> 00:29:51,430
so simulations and observations both

856
00:29:55,110 --> 00:29:53,360
tell us something somewhat different

857
00:29:57,430 --> 00:29:55,120
but they're complementary by learning

858
00:29:58,549 --> 00:29:57,440
from one we can use that information to

859
00:30:00,230 --> 00:29:58,559
inform the other

860
00:30:02,149 --> 00:30:00,240
and then rotate through to try to

861
00:30:03,510 --> 00:30:02,159
understand the physics at work

862
00:30:05,750 --> 00:30:03,520
so we're going to go ahead and start

863
00:30:06,470 --> 00:30:05,760

with simulations so let's take the

864
00:30:09,029 --> 00:30:06,480
universe

865
00:30:10,470 --> 00:30:09,039
let's put it in a box let's apply all

866
00:30:13,029 --> 00:30:10,480
the physics that we know

867
00:30:14,549 --> 00:30:13,039
and let's see how it evolves over time

868
00:30:16,630 --> 00:30:14,559
so in this simulation

869
00:30:18,789 --> 00:30:16,640
we're looking at the temperature of gas

870
00:30:19,269 --> 00:30:18,799
in the universe from the very earliest

871
00:30:21,909 --> 00:30:19,279
times

872
00:30:23,510 --> 00:30:21,919
moving towards the present day and so

873
00:30:26,549 --> 00:30:23,520
what you see here is this

874
00:30:28,789 --> 00:30:26,559
long filamentary like structure

875
00:30:30,789 --> 00:30:28,799
all these different pieces of gas and we

876
00:30:33,430 --> 00:30:30,799
have the very cool gas in blue

877
00:30:34,549 --> 00:30:33,440
warmer gas and green and the hottest gas

878
00:30:36,230 --> 00:30:34,559
in red

879
00:30:38,549 --> 00:30:36,240
so these big structures here these are

880
00:30:39,990 --> 00:30:38,559
whole groups of galaxies clusters of

881
00:30:41,350 --> 00:30:40,000
galaxies we're looking at the very

882
00:30:43,190 --> 00:30:41,360
biggest scales

883
00:30:44,950 --> 00:30:43,200
and what you start to see are these

884
00:30:46,710 --> 00:30:44,960
pockets of red basically

885
00:30:48,870 --> 00:30:46,720
exploding out of these groups of

886
00:30:51,510 --> 00:30:48,880
galaxies and so these are

887
00:30:52,230 --> 00:30:51,520
our agn these are super massive black

888
00:30:55,350 --> 00:30:52,240

holes

889
00:30:57,430 --> 00:30:55,360
that are eating material and pushing an

890
00:30:59,990 --> 00:30:57,440
immense amount of energy and radiation

891
00:31:02,310 --> 00:31:00,000
out beyond the galaxy and heating up and

892
00:31:04,630 --> 00:31:02,320
moving this gas

893
00:31:06,149 --> 00:31:04,640
so this is these simulations are

894
00:31:07,509 --> 00:31:06,159
absolutely incredible this one

895
00:31:10,870 --> 00:31:07,519
in particular is from the illustrious

896
00:31:12,870 --> 00:31:10,880
group and so these allow us to control

897
00:31:15,110 --> 00:31:12,880
the different aspects of what's going on

898
00:31:17,190 --> 00:31:15,120
and understand the physics in detail

899
00:31:18,870 --> 00:31:17,200
despite how incredible these simulations

900
00:31:20,470 --> 00:31:18,880
are we still just don't have the

901
00:31:22,950 --> 00:31:20,480
computational power

902
00:31:24,230 --> 00:31:22,960
to simulate all the different scales

903
00:31:26,149 --> 00:31:24,240
that we just talked about

904
00:31:27,830 --> 00:31:26,159
so if you want to simulate material

905
00:31:29,909 --> 00:31:27,840
falling into a black hole

906
00:31:31,509 --> 00:31:29,919
simulate individual galaxies and then

907
00:31:33,269 --> 00:31:31,519
simulate the entire universe we just

908
00:31:33,909 --> 00:31:33,279
don't have the computational power to do

909
00:31:35,350 --> 00:31:33,919
that

910
00:31:37,669 --> 00:31:35,360
and so what we do here is we use

911
00:31:39,029 --> 00:31:37,679
different numerical recipes

912
00:31:41,269 --> 00:31:39,039
basically we say okay on the smallest

913
00:31:43,269 --> 00:31:41,279

scales let's just say that we know how

914
00:31:44,149 --> 00:31:43,279
much energy is being injected by these

915
00:31:45,750 --> 00:31:44,159
agn

916
00:31:48,149 --> 00:31:45,760
and then we'll follow it and watch what

917
00:31:49,590 --> 00:31:48,159
happens and so

918
00:31:51,830 --> 00:31:49,600
one of the things that's very critical

919
00:31:54,149 --> 00:31:51,840
here is the result that you get

920
00:31:55,590 --> 00:31:54,159
depends very strongly on how you tweak

921
00:31:56,870 --> 00:31:55,600
those parameters

922
00:31:59,190 --> 00:31:56,880
so here towards the end of the

923
00:32:00,549 --> 00:31:59,200
simulation you can see that we have all

924
00:32:02,710 --> 00:32:00,559
this hot gas

925
00:32:03,750 --> 00:32:02,720
that's permeating all throughout between

926
00:32:06,149 --> 00:32:03,760
these different

927
00:32:07,669 --> 00:32:06,159
galaxies and clusters of galaxies but

928
00:32:09,029 --> 00:32:07,679
now if we go ahead and update the

929
00:32:11,669 --> 00:32:09,039
physics a little bit

930
00:32:14,389 --> 00:32:11,679
and we look at what happens if we try to

931
00:32:16,389 --> 00:32:14,399
understand the efficiency of how this

932
00:32:18,070 --> 00:32:16,399
radiation is produced and how it moves

933
00:32:19,750 --> 00:32:18,080
out and couples with gas

934
00:32:22,070 --> 00:32:19,760
if we go ahead and fine-tune those

935
00:32:23,909 --> 00:32:22,080
parameters based on what we know now

936
00:32:25,590 --> 00:32:23,919
we see that in just a few years these

937
00:32:26,389 --> 00:32:25,600
simulations give somewhat different

938
00:32:29,269 --> 00:32:26,399

answers

939
00:32:30,950 --> 00:32:29,279
so we still have this hot excited gas

940
00:32:32,789 --> 00:32:30,960
but now on the right we can see that

941
00:32:34,630 --> 00:32:32,799
it's very hot but more condensed it's

942
00:32:36,870 --> 00:32:34,640
more it's held more closely to these

943
00:32:38,870 --> 00:32:36,880
clusters these groups of galaxies

944
00:32:40,149 --> 00:32:38,880
and so the overall picture is somewhat

945
00:32:42,549 --> 00:32:40,159
different

946
00:32:44,230 --> 00:32:42,559
and so the way that we can improve these

947
00:32:46,070 --> 00:32:44,240
simulations and inform them

948
00:32:47,909 --> 00:32:46,080
is by going ahead and actually doing

949
00:32:50,630 --> 00:32:47,919
detailed observations

950
00:32:51,269 --> 00:32:50,640
of the supermassive black hole winds to

951
00:32:54,710 --> 00:32:51,279
understand

952
00:32:56,070 --> 00:32:54,720
just how they work

953
00:32:57,990 --> 00:32:56,080
and then we can iterate between

954
00:33:00,230 --> 00:32:58,000
simulations and observations to learn

955
00:33:02,389 --> 00:33:00,240
all the physics involved

956
00:33:04,549 --> 00:33:02,399
so now we're ready to transition to

957
00:33:05,430 --> 00:33:04,559
observations starting here with our big

958
00:33:07,430 --> 00:33:05,440
picture

959
00:33:09,590 --> 00:33:07,440
we're going to go ahead at the closest

960
00:33:11,190 --> 00:33:09,600
in scales right near the supermassive

961
00:33:13,750 --> 00:33:11,200
black hole in the accretion disk

962
00:33:15,190 --> 00:33:13,760
on scales of less than a light year and

963
00:33:16,870 --> 00:33:15,200

so because we're so close to the

964
00:33:19,669 --> 00:33:16,880
supermassive black hole we're generally

965
00:33:21,909 --> 00:33:19,679
looking at the highest energy radiation

966
00:33:23,590 --> 00:33:21,919
which is most often observed in the

967
00:33:28,630 --> 00:33:23,600
x-rays

968
00:33:30,870 --> 00:33:28,640
showed some sort of signature in the

969
00:33:33,269 --> 00:33:30,880
spectra there was something going on

970
00:33:33,990 --> 00:33:33,279
but x-ray spectroscopy is really

971
00:33:36,549 --> 00:33:34,000
difficult

972
00:33:37,750 --> 00:33:36,559
x-rays are very high energy if you try

973
00:33:39,269 --> 00:33:37,760
to bounce them off a

974
00:33:40,950 --> 00:33:39,279
normal type of mirror that you're used

975
00:33:41,909 --> 00:33:40,960
to looking at they'll just go right

976
00:33:43,430 --> 00:33:41,919
through it

977
00:33:45,830 --> 00:33:43,440
and so you have to build a very

978
00:33:47,669 --> 00:33:45,840
specialized telescope with a series of

979
00:33:49,830 --> 00:33:47,679
ring-like mirrors that will basically

980
00:33:51,669 --> 00:33:49,840
bounce that photon and get it down

981
00:33:53,110 --> 00:33:51,679
onto the detector where you want to

982
00:33:55,830 --> 00:33:53,120
analyze it

983
00:33:57,750 --> 00:33:55,840
and so this was really revolutionized by

984
00:33:59,830 --> 00:33:57,760
newer space missions such as the chandra

985
00:34:01,750 --> 00:33:59,840
x-ray observatory suzaku

986
00:34:03,990 --> 00:34:01,760
and the x-ray multi-mirror mission

987
00:34:06,149 --> 00:34:04,000
telescope shown here on the right

988
00:34:07,909 --> 00:34:06,159

and so after looking at more and more of

989
00:34:10,710 --> 00:34:07,919
these active galaxies

990
00:34:13,270 --> 00:34:10,720
and looking at um a large archive of

991
00:34:14,710 --> 00:34:13,280
data really just in the last 10 years

992
00:34:16,470 --> 00:34:14,720
is when we've been able to establish

993
00:34:18,550 --> 00:34:16,480
that there is indeed these

994
00:34:20,710 --> 00:34:18,560
winds very close to the supermassive

995
00:34:21,909 --> 00:34:20,720
black hole and as the title alludes to

996
00:34:25,510 --> 00:34:21,919
these are called

997
00:34:27,669 --> 00:34:25,520
ultra fast outflows or ufos yes that is

998
00:34:29,669 --> 00:34:27,679
actually the acronym

999
00:34:31,190 --> 00:34:29,679
so you can see here on the right is one

1000
00:34:33,349 --> 00:34:31,200
of these x-ray spectra

1001
00:34:35,190 --> 00:34:33,359
so we're looking on the horizontal axis

1002
00:34:37,270 --> 00:34:35,200
at the energy of the light

1003
00:34:38,310 --> 00:34:37,280
and on the vertical axis the brightness

1004
00:34:39,990 --> 00:34:38,320
of that light

1005
00:34:41,829 --> 00:34:40,000
and we can see here that we have this

1006
00:34:42,869 --> 00:34:41,839
emission line feature which is coming

1007
00:34:44,710 --> 00:34:42,879
from very close

1008
00:34:46,790 --> 00:34:44,720
to the supermassive black hole turns out

1009
00:34:48,389 --> 00:34:46,800
to be from iron k alpha very highly

1010
00:34:50,310 --> 00:34:48,399
ionized iron

1011
00:34:52,950 --> 00:34:50,320
and then we see here this absorption

1012
00:34:54,149 --> 00:34:52,960
feature and so with some very detailed

1013
00:34:56,069 --> 00:34:54,159

and careful modeling

1014
00:34:58,150 --> 00:34:56,079
we can figure out that this absorption

1015
00:34:59,829 --> 00:34:58,160
line is coming from the same excited

1016
00:35:02,550 --> 00:34:59,839
state as this emission line

1017
00:35:05,190 --> 00:35:02,560
and this corresponds to a very very

1018
00:35:06,870 --> 00:35:05,200
large shift a very large doppler shift

1019
00:35:08,790 --> 00:35:06,880
so as we talked about we can use those

1020
00:35:12,230 --> 00:35:08,800
shifts to determine the velocity

1021
00:35:14,630 --> 00:35:12,240
and in this case it works out to be 15

1022
00:35:16,470 --> 00:35:14,640
of the speed of light which is

1023
00:35:18,310 --> 00:35:16,480
absolutely insane

1024
00:35:20,550 --> 00:35:18,320
so by looking at more of these objects

1025
00:35:23,510 --> 00:35:20,560
we've found that ultra fast outflows

1026
00:35:24,390 --> 00:35:23,520
can move at up to 30 percent the speed

1027
00:35:27,430 --> 00:35:24,400
of light

1028
00:35:27,990 --> 00:35:27,440
that's something like 60 000 miles per

1029
00:35:31,030 --> 00:35:28,000
second

1030
00:35:32,390 --> 00:35:31,040
that is one serious speeding ticket so

1031
00:35:33,990 --> 00:35:32,400
what we're seeing is we have

1032
00:35:35,349 --> 00:35:34,000
this artist conception on the right with

1033
00:35:36,310 --> 00:35:35,359
the supermassive black hole in the

1034
00:35:38,069 --> 00:35:36,320
accretion disk

1035
00:35:39,670 --> 00:35:38,079
and this material is being launched from

1036
00:35:41,430 --> 00:35:39,680
very close to the accretion disk and

1037
00:35:42,550 --> 00:35:41,440
then it's absorbing some of the light as

1038
00:35:43,589 --> 00:35:42,560

it's moving

1039
00:35:46,150 --> 00:35:43,599
and that's what we see as that

1040
00:35:48,710 --> 00:35:46,160
absorption feature in the spectrum

1041
00:35:49,990 --> 00:35:48,720
another interesting feature of ufos is

1042
00:35:52,069 --> 00:35:50,000
that when we look at them

1043
00:35:53,349 --> 00:35:52,079
and we revisit the same galaxies we see

1044
00:35:55,430 --> 00:35:53,359
that they change

1045
00:35:56,630 --> 00:35:55,440
on time scales of months to years or

1046
00:35:58,150 --> 00:35:56,640
even faster

1047
00:36:00,470 --> 00:35:58,160
and so this is telling us that these are

1048
00:36:02,550 --> 00:36:00,480
not nice steady

1049
00:36:04,310 --> 00:36:02,560
constant types of phenomena but they're

1050
00:36:06,630 --> 00:36:04,320
very chaotic and tumultuous they're

1051
00:36:07,910 --> 00:36:06,640
constantly changing

1052
00:36:09,510 --> 00:36:07,920
and this could be really important

1053
00:36:10,550 --> 00:36:09,520
because we have gas that's moving very

1054
00:36:12,550 --> 00:36:10,560
very fast

1055
00:36:13,750 --> 00:36:12,560
and so it may actually be able to sweep

1056
00:36:16,069 --> 00:36:13,760
material out

1057
00:36:18,390 --> 00:36:16,079
and regulate how fast the black hole is

1058
00:36:20,710 --> 00:36:18,400
growing as the black hole is eating

1059
00:36:22,790 --> 00:36:20,720
it's actually generating the energy that

1060
00:36:24,550 --> 00:36:22,800
is pushing away its fuel it's pushing

1061
00:36:26,710 --> 00:36:24,560
away its supply of gas that it would

1062
00:36:29,109 --> 00:36:26,720
otherwise try to accrete

1063
00:36:30,710 --> 00:36:29,119

and so the question is well is there any

1064
00:36:31,910 --> 00:36:30,720
evidence that this is what's really

1065
00:36:34,710 --> 00:36:31,920
happening

1066
00:36:36,950 --> 00:36:34,720
and indeed there is so looking here on

1067
00:36:38,950 --> 00:36:36,960
the vertical axis we have the mass

1068
00:36:41,190 --> 00:36:38,960
of these supermassive black holes in

1069
00:36:44,470 --> 00:36:41,200
terms of mass of the sun moving from

1070
00:36:47,190 --> 00:36:44,480
a million to 10 billion and then we have

1071
00:36:49,109 --> 00:36:47,200
the mass of the bulge that large

1072
00:36:50,790 --> 00:36:49,119
semi-spherical distribution of stars

1073
00:36:53,270 --> 00:36:50,800
around the center of the galaxy

1074
00:36:54,790 --> 00:36:53,280
and the velocity of those stars and what

1075
00:36:56,230 --> 00:36:54,800
we can see is that these two things are

1076
00:36:57,430 --> 00:36:56,240
correlated meaning if we have a

1077
00:36:59,190 --> 00:36:57,440
measurement of one

1078
00:37:01,190 --> 00:36:59,200
then we have a reasonable estimate of

1079
00:37:02,310 --> 00:37:01,200
the other and now you might say well

1080
00:37:04,470 --> 00:37:02,320
that makes sense right

1081
00:37:05,910 --> 00:37:04,480
larger galaxy larger bulge larger

1082
00:37:07,750 --> 00:37:05,920
supermassive black hole

1083
00:37:09,750 --> 00:37:07,760
but there's no necessity for it to be

1084
00:37:11,349 --> 00:37:09,760
that way and what i mean is

1085
00:37:13,030 --> 00:37:11,359
that even though supermassive black

1086
00:37:14,790 --> 00:37:13,040
holes are so dense and have such a

1087
00:37:16,630 --> 00:37:14,800
strong gravitational pull

1088
00:37:17,990 --> 00:37:16,640

it's only when you get really close to

1089
00:37:18,790 --> 00:37:18,000
them that their gravity starts to

1090
00:37:20,710 --> 00:37:18,800
dominate

1091
00:37:22,390 --> 00:37:20,720
so within a galaxy the supermassive

1092
00:37:24,310 --> 00:37:22,400
black hole is only dominating the

1093
00:37:26,310 --> 00:37:24,320
gravity in a region maybe a few light

1094
00:37:27,990 --> 00:37:26,320
years or smaller around it

1095
00:37:30,069 --> 00:37:28,000
whereas the bulge of these galaxies is

1096
00:37:31,910 --> 00:37:30,079
on scales of thousands of light years

1097
00:37:33,109 --> 00:37:31,920
and so they're just not gravitationally

1098
00:37:34,630 --> 00:37:33,119
aware of each other

1099
00:37:36,470 --> 00:37:34,640
it's kind of like holding a magnet at a

1100
00:37:38,470 --> 00:37:36,480
paper clip a mile away the effect is

1101
00:37:40,230 --> 00:37:38,480
just too weak to really matter

1102
00:37:41,990 --> 00:37:40,240
and so this is one piece of evidence

1103
00:37:44,150 --> 00:37:42,000
that maybe these two

1104
00:37:45,670 --> 00:37:44,160
individual entities basically evolve

1105
00:37:47,270 --> 00:37:45,680
together maybe the black hole in the

1106
00:37:49,190 --> 00:37:47,280
bulge grew up together

1107
00:37:50,710 --> 00:37:49,200
exchanging energy and information

1108
00:37:52,710 --> 00:37:50,720
through these winds

1109
00:37:53,990 --> 00:37:52,720
and through this exchange of material

1110
00:37:56,310 --> 00:37:54,000
that's being pushed out

1111
00:37:58,069 --> 00:37:56,320
to larger radii that's not the only

1112
00:37:59,349 --> 00:37:58,079
interpretation of this result there are

1113
00:38:00,950 --> 00:37:59,359

other ways that you might be able to

1114
00:38:09,030 --> 00:38:00,960
generate this but this is one piece of

1115
00:38:12,630 --> 00:38:10,710
so the second stop on our tour of

1116
00:38:15,270 --> 00:38:12,640
supermassive black hole winds

1117
00:38:17,109 --> 00:38:15,280
is now looking within the galaxy bulge

1118
00:38:18,870 --> 00:38:17,119
so now we're looking on scales of a few

1119
00:38:21,510 --> 00:38:18,880
thousand light years

1120
00:38:22,630 --> 00:38:21,520
and so early studies in this uh regime

1121
00:38:24,710 --> 00:38:22,640
kind of showed that there were

1122
00:38:25,910 --> 00:38:24,720
non-rotational motions so it was clear

1123
00:38:28,230 --> 00:38:25,920
that gas was doing

1124
00:38:30,069 --> 00:38:28,240
something that wasn't just nice and

1125
00:38:31,910 --> 00:38:30,079
simple galaxy rotation

1126
00:38:33,829 --> 00:38:31,920
but it was really revolutionized with

1127
00:38:35,670 --> 00:38:33,839
data from the hubble space telescope

1128
00:38:36,710 --> 00:38:35,680
because as frank mentioned we get above

1129
00:38:39,510 --> 00:38:36,720
the atmosphere

1130
00:38:41,109 --> 00:38:39,520
we can see extremely small details and

1131
00:38:42,390 --> 00:38:41,119
the critical piece here is that this is

1132
00:38:44,150 --> 00:38:42,400
the first scale

1133
00:38:46,390 --> 00:38:44,160
as we move away from the black hole that

1134
00:38:47,910 --> 00:38:46,400
we can actually spatially resolve

1135
00:38:49,990 --> 00:38:47,920
meaning when we look at stars they're

1136
00:38:51,190 --> 00:38:50,000
infinitesimal small points of light

1137
00:38:53,190 --> 00:38:51,200
when you look at the moon and planets

1138
00:38:53,829 --> 00:38:53,200

they have a defined physical size on the

1139
00:38:55,829 --> 00:38:53,839
sky

1140
00:38:57,910 --> 00:38:55,839
and so we can actually resolve the

1141
00:38:59,829 --> 00:38:57,920
bulges of galaxies

1142
00:39:02,150 --> 00:38:59,839
so we're going to go ahead and start add

1143
00:39:05,270 --> 00:39:02,160
a galaxy and zoom in on its bulge

1144
00:39:07,190 --> 00:39:05,280
here's an example of ngc 4151

1145
00:39:09,349 --> 00:39:07,200
it's one of the most nearby and well

1146
00:39:10,870 --> 00:39:09,359
studied active galaxies because it is so

1147
00:39:12,950 --> 00:39:10,880
nearby and very bright

1148
00:39:15,589 --> 00:39:12,960
here we can see it has these extended

1149
00:39:17,990 --> 00:39:15,599
spiral arm structures it has this

1150
00:39:19,829 --> 00:39:18,000
ring of hot young stars that are forming

1151
00:39:21,910 --> 00:39:19,839
that are surrounding this yellowish

1152
00:39:23,670 --> 00:39:21,920
older bulge of stars

1153
00:39:25,670 --> 00:39:23,680
now this is an incredible ground-based

1154
00:39:27,190 --> 00:39:25,680
image but as frank mentioned again we're

1155
00:39:28,550 --> 00:39:27,200
just still limited by the earth's

1156
00:39:30,790 --> 00:39:28,560
atmosphere sometimes

1157
00:39:32,950 --> 00:39:30,800
so if we go ahead and zoom in with the

1158
00:39:36,310 --> 00:39:32,960
power of the hubble space telescope

1159
00:39:38,790 --> 00:39:36,320
we get a much clearer picture

1160
00:39:41,430 --> 00:39:38,800
now we can see individual clumps of

1161
00:39:44,150 --> 00:39:41,440
stars that are forming within the galaxy

1162
00:39:46,069 --> 00:39:44,160
we can see these dark spiral dust lanes

1163
00:39:48,230 --> 00:39:46,079

working their way into the center

1164
00:39:49,349 --> 00:39:48,240
around the bulge and we can start to see

1165
00:39:52,150 --> 00:39:49,359
some hint

1166
00:39:54,150 --> 00:39:52,160
of this bright active nucleus now like

1167
00:39:55,990 --> 00:39:54,160
any good criminal investigation show all

1168
00:39:57,109 --> 00:39:56,000
you have to do is hit your magic enhance

1169
00:39:58,310 --> 00:39:57,119
button again

1170
00:40:00,470 --> 00:39:58,320
okay of course it's not quite that

1171
00:40:03,270 --> 00:40:00,480
simple but if we zoom in once again

1172
00:40:04,150 --> 00:40:03,280
we get this incredible image of this

1173
00:40:06,950 --> 00:40:04,160
bulge scale

1174
00:40:08,790 --> 00:40:06,960
outflow produced by judy schmidt and so

1175
00:40:10,309 --> 00:40:08,800
down in the very center here we have

1176
00:40:12,630 --> 00:40:10,319
this supermassive black hole and

1177
00:40:14,870 --> 00:40:12,640
accretion disk our source of energy

1178
00:40:15,990 --> 00:40:14,880
and that radiation is traveling out into

1179
00:40:17,990 --> 00:40:16,000
the galaxy

1180
00:40:19,750 --> 00:40:18,000
it's exciting this gas it's making it

1181
00:40:22,390 --> 00:40:19,760
glow like a neon sign

1182
00:40:22,870 --> 00:40:22,400
and so we can see very clearly here that

1183
00:40:25,030 --> 00:40:22,880
there's an

1184
00:40:26,710 --> 00:40:25,040
impact on the galaxy but what is this

1185
00:40:28,390 --> 00:40:26,720
gas really doing how do we know where

1186
00:40:29,270 --> 00:40:28,400
it's going how do we know what its fate

1187
00:40:30,710 --> 00:40:29,280
is

1188
00:40:32,710 --> 00:40:30,720

and so of course the second piece to

1189
00:40:34,710 --> 00:40:32,720
that is by using spectroscopy

1190
00:40:36,470 --> 00:40:34,720
so if we isolate a portion of it using

1191
00:40:39,349 --> 00:40:36,480
the hubble space telescope looking at

1192
00:40:40,790 --> 00:40:39,359
just a specific portion of the galaxy

1193
00:40:42,550 --> 00:40:40,800
as we showed in some of our earlier

1194
00:40:43,990 --> 00:40:42,560
example spectra well if the gas was just

1195
00:40:45,589 --> 00:40:44,000
sitting there let's say we were looking

1196
00:40:46,150 --> 00:40:45,599
at two emission lines we might just

1197
00:40:48,870 --> 00:40:46,160
expect

1198
00:40:50,950 --> 00:40:48,880
nice straight lines galaxy is generally

1199
00:40:51,990 --> 00:40:50,960
rotating and so one side is moving

1200
00:40:53,910 --> 00:40:52,000
towards us another side

1201
00:40:55,829 --> 00:40:53,920
is moving away from us and so we'd

1202
00:40:58,309 --> 00:40:55,839
expect some sort of redshift and blue

1203
00:41:00,630 --> 00:40:58,319
shift on either side of the galaxy

1204
00:41:01,349 --> 00:41:00,640
when we look at the actual data for this

1205
00:41:03,349 --> 00:41:01,359
target

1206
00:41:05,349 --> 00:41:03,359
we see indeed some of the gas is

1207
00:41:07,349 --> 00:41:05,359
rotating but there's also this gas

1208
00:41:09,190 --> 00:41:07,359
moving at much higher velocities at

1209
00:41:11,270 --> 00:41:09,200
higher blue shifts and redshifts

1210
00:41:13,030 --> 00:41:11,280
so while the galaxy might be rotating at

1211
00:41:14,710 --> 00:41:13,040
a few hundred kilometers a second this

1212
00:41:16,630 --> 00:41:14,720
gas is moving at maybe a thousand

1213
00:41:18,950 --> 00:41:16,640

kilometers per second

1214
00:41:20,069 --> 00:41:18,960
so this is that clear signature that on

1215
00:41:21,829 --> 00:41:20,079
one side of galaxy

1216
00:41:24,630 --> 00:41:21,839
gas is moving towards you on the other

1217
00:41:27,270 --> 00:41:24,640
side gas is moving away from you

1218
00:41:27,670 --> 00:41:27,280
now this is an incredible result but

1219
00:41:29,670 --> 00:41:27,680
it's

1220
00:41:31,349 --> 00:41:29,680
kind of tough to picture the geometry

1221
00:41:32,950 --> 00:41:31,359
here what's really going on

1222
00:41:34,390 --> 00:41:32,960
so let's look at a model of this

1223
00:41:36,069 --> 00:41:34,400
starting down

1224
00:41:38,150 --> 00:41:36,079
right near the supermassive black hole

1225
00:41:40,309 --> 00:41:38,160
where all this radiation is coming out

1226
00:41:42,069 --> 00:41:40,319
and then let's zoom out onto scales of

1227
00:41:42,710 --> 00:41:42,079
the galaxy so we can see here we have

1228
00:41:45,270 --> 00:41:42,720
this blue

1229
00:41:46,309 --> 00:41:45,280
disk of the galaxy rotating around and

1230
00:41:48,790 --> 00:41:46,319
this radiation is

1231
00:41:50,950 --> 00:41:48,800
traveling out into the galaxy it's

1232
00:41:53,190 --> 00:41:50,960
exciting it's ionizing it and then it's

1233
00:41:54,710 --> 00:41:53,200
pushing it away from the supermassive

1234
00:41:56,309 --> 00:41:54,720
black hole

1235
00:41:57,829 --> 00:41:56,319
so this is an area of research that i've

1236
00:41:59,430 --> 00:41:57,839
been very interested in

1237
00:42:01,750 --> 00:41:59,440
and we've learned a number of things for

1238
00:42:02,550 --> 00:42:01,760

these types of supermassive black hole

1239
00:42:04,390 --> 00:42:02,560
winds

1240
00:42:05,589 --> 00:42:04,400
so the first is that the gas can

1241
00:42:07,030 --> 00:42:05,599
probably be launched

1242
00:42:08,790 --> 00:42:07,040
at a bunch of different distances

1243
00:42:10,630 --> 00:42:08,800
meaning it's not all coming from right

1244
00:42:12,950 --> 00:42:10,640
near the supermassive black hole

1245
00:42:14,550 --> 00:42:12,960
but as this radiation travels out it

1246
00:42:16,630 --> 00:42:14,560
sees the gas there it excites it and

1247
00:42:18,790 --> 00:42:16,640
then it starts pushing it

1248
00:42:20,710 --> 00:42:18,800
now while these are not moving nearly as

1249
00:42:22,309 --> 00:42:20,720
fast as the ultra fast outflows they're

1250
00:42:24,150 --> 00:42:22,319
moving at less than one percent of the

1251
00:42:25,750 --> 00:42:24,160
speed of light as compared to nearly 30

1252
00:42:27,430 --> 00:42:25,760
percent of the speed of light

1253
00:42:29,750 --> 00:42:27,440
because they're spatially resolved we

1254
00:42:30,710 --> 00:42:29,760
can work out how much material is there

1255
00:42:32,790 --> 00:42:30,720
in detail

1256
00:42:34,150 --> 00:42:32,800
and it turns out that these outflows can

1257
00:42:36,390 --> 00:42:34,160
carry several

1258
00:42:38,390 --> 00:42:36,400
million or even tens of millions of

1259
00:42:41,030 --> 00:42:38,400
solar masses worth of gas

1260
00:42:42,230 --> 00:42:41,040
it's a lot of material and so the impact

1261
00:42:44,390 --> 00:42:42,240
here is that this

1262
00:42:45,990 --> 00:42:44,400
may reduce star formation in the inner

1263
00:42:47,670 --> 00:42:46,000

regions of the galaxy because we're

1264
00:42:49,670 --> 00:42:47,680
evacuating the gas

1265
00:42:50,870 --> 00:42:49,680
which would otherwise be available to

1266
00:42:52,790 --> 00:42:50,880
form stars

1267
00:42:55,430 --> 00:42:52,800
in addition we're also heating that gas

1268
00:42:57,510 --> 00:42:55,440
up gas needs to start to cool down to

1269
00:42:58,790 --> 00:42:57,520
collapse under gravity in order to form

1270
00:43:00,630 --> 00:42:58,800
stars

1271
00:43:02,150 --> 00:43:00,640
now this is kind of a general picture

1272
00:43:03,670 --> 00:43:02,160
and it's not the case for every single

1273
00:43:05,910 --> 00:43:03,680
galaxy in some cases

1274
00:43:07,990 --> 00:43:05,920
gas is actually driven out impacts other

1275
00:43:10,069 --> 00:43:08,000
gas and then may trigger star formation

1276
00:43:11,750 --> 00:43:10,079
so it's not a one size fits all in terms

1277
00:43:12,710 --> 00:43:11,760
of what we see the impact of these

1278
00:43:14,309 --> 00:43:12,720
outflows being

1279
00:43:17,270 --> 00:43:14,319
but this is kind of a general picture

1280
00:43:21,109 --> 00:43:18,950
so with that we're ready to move to the

1281
00:43:23,190 --> 00:43:21,119
third out of four spatial scales of our

1282
00:43:24,710 --> 00:43:23,200
tour of supermassive black hole winds

1283
00:43:27,190 --> 00:43:24,720
and that is scales

1284
00:43:28,069 --> 00:43:27,200
of the galaxy stellar disk so these are

1285
00:43:31,270 --> 00:43:28,079
basically

1286
00:43:33,109 --> 00:43:31,280
on scales of the entire galaxy

1287
00:43:34,230 --> 00:43:33,119
now you might mention earlier might

1288
00:43:35,910 --> 00:43:34,240

remember from earlier that i mentioned

1289
00:43:37,349 --> 00:43:35,920
that the luminosity of these active

1290
00:43:39,430 --> 00:43:37,359
galaxies is a key

1291
00:43:41,910 --> 00:43:39,440
factor and so if we're looking for

1292
00:43:44,710 --> 00:43:41,920
outflows on the scales of galaxies

1293
00:43:46,470 --> 00:43:44,720
we generally need more luminous active

1294
00:43:48,710 --> 00:43:46,480
galaxies because we need more

1295
00:43:50,630 --> 00:43:48,720
energy to push gas at these large

1296
00:43:51,510 --> 00:43:50,640
distances and to push large amounts of

1297
00:43:53,990 --> 00:43:51,520
gas

1298
00:43:55,589 --> 00:43:54,000
and so this is more commonly observed

1299
00:43:57,030 --> 00:43:55,599
further back in the more distant

1300
00:43:58,950 --> 00:43:57,040
universe

1301
00:44:00,390 --> 00:43:58,960
and so studies of this type have been

1302
00:44:01,190 --> 00:44:00,400
done with a number of telescopes and

1303
00:44:04,950 --> 00:44:01,200
instruments

1304
00:44:06,950 --> 00:44:04,960
really revolutionized this is the

1305
00:44:09,030 --> 00:44:06,960
atacama large millimeter and sub

1306
00:44:10,470 --> 00:44:09,040
millimeter array or alma

1307
00:44:12,710 --> 00:44:10,480
and so that's shown on the right here

1308
00:44:15,030 --> 00:44:12,720
this is basically a series of radio

1309
00:44:16,870 --> 00:44:15,040
and millimeter dishes that are all

1310
00:44:18,150 --> 00:44:16,880
pointed at the same object

1311
00:44:19,990 --> 00:44:18,160
and we're basically taking the

1312
00:44:21,990 --> 00:44:20,000
information from each of them

1313
00:44:23,990 --> 00:44:22,000

and through a process of interferometry

1314
00:44:24,870 --> 00:44:24,000
or interference we're bringing that data

1315
00:44:27,589 --> 00:44:24,880
together

1316
00:44:28,710 --> 00:44:27,599
in order to get an image that is as good

1317
00:44:31,750 --> 00:44:28,720
as if we had one

1318
00:44:33,349 --> 00:44:31,760
ginormous dish as we saw earlier and so

1319
00:44:36,150 --> 00:44:33,359
in this case you can separate these

1320
00:44:38,390 --> 00:44:36,160
telescopes by up to 16 kilometers and so

1321
00:44:41,910 --> 00:44:38,400
we're getting an image as if we had one

1322
00:44:43,510 --> 00:44:41,920
massive telescope so let's go ahead and

1323
00:44:46,309 --> 00:44:43,520
look at one of these so

1324
00:44:48,069 --> 00:44:46,319
this is an example of a galaxy now it's

1325
00:44:50,150 --> 00:44:48,079
much more distant and so we don't get

1326
00:44:51,030 --> 00:44:50,160
that fine exquisite detail in the image

1327
00:44:52,950 --> 00:44:51,040
necessarily

1328
00:44:55,109 --> 00:44:52,960
but this is actually quite a large

1329
00:44:56,230 --> 00:44:55,119
galaxy we're looking at excited gas here

1330
00:44:58,870 --> 00:44:56,240
on the scales of

1331
00:44:59,990 --> 00:44:58,880
around 10 kiloparsecs or over 30 000

1332
00:45:01,829 --> 00:45:00,000
light years

1333
00:45:03,670 --> 00:45:01,839
and so what we see looking at these

1334
00:45:05,430 --> 00:45:03,680
galaxies that are further away

1335
00:45:08,069 --> 00:45:05,440
in this case it's looking back nearly 10

1336
00:45:11,109 --> 00:45:08,079
billion years to a red shift of two

1337
00:45:12,710 --> 00:45:11,119
is that it's not very simple to figure

1338
00:45:14,230 --> 00:45:12,720

out what's going on it's not just the

1339
00:45:16,309 --> 00:45:14,240
supermassive black hole

1340
00:45:17,750 --> 00:45:16,319
that's necessarily driving these this

1341
00:45:19,829 --> 00:45:17,760
these winds

1342
00:45:21,829 --> 00:45:19,839
and what we found out is that stars

1343
00:45:23,990 --> 00:45:21,839
actually make a very large contribution

1344
00:45:25,190 --> 00:45:24,000
sometimes the dominant contribution in

1345
00:45:26,470 --> 00:45:25,200
these galaxies

1346
00:45:28,550 --> 00:45:26,480
and so what that's happening is

1347
00:45:29,349 --> 00:45:28,560
basically stars are either forming very

1348
00:45:30,950 --> 00:45:29,359
rapidly

1349
00:45:33,270 --> 00:45:30,960
and their immense radiation is

1350
00:45:35,910 --> 00:45:33,280
contributing to driving these winds

1351
00:45:37,990 --> 00:45:35,920
or as stars die through powerful super

1352
00:45:39,910 --> 00:45:38,000
anova events that frank showed earlier

1353
00:45:41,349 --> 00:45:39,920
they emit an immense amount of radiation

1354
00:45:44,230 --> 00:45:41,359
that can also go ahead

1355
00:45:46,230 --> 00:45:44,240
and excite and move this gas so stellar

1356
00:45:47,750 --> 00:45:46,240
outflows and stellar winds are worthy of

1357
00:45:48,550 --> 00:45:47,760
an entire another talk in and of

1358
00:45:50,230 --> 00:45:48,560
themselves

1359
00:45:52,150 --> 00:45:50,240
so this is just to point out that

1360
00:45:53,430 --> 00:45:52,160
sometimes it's more than one mechanism

1361
00:45:55,510 --> 00:45:53,440
at work

1362
00:45:57,750 --> 00:45:55,520
and this is a key place where we'll

1363
00:45:58,950 --> 00:45:57,760

learn a lot more with the james webb

1364
00:46:00,790 --> 00:45:58,960
space telescope

1365
00:46:03,190 --> 00:46:00,800
because we'll be able to probe these

1366
00:46:04,710 --> 00:46:03,200
galaxies on very small scales

1367
00:46:06,790 --> 00:46:04,720
we'll be able to look at them in great

1368
00:46:08,550 --> 00:46:06,800
detail with high sensitivity

1369
00:46:11,349 --> 00:46:08,560
in different portions of the spectrum

1370
00:46:12,950 --> 00:46:11,359
than we can necessarily look at now

1371
00:46:14,470 --> 00:46:12,960
and so when we look at this galaxy in

1372
00:46:16,069 --> 00:46:14,480
this image

1373
00:46:17,910 --> 00:46:16,079
we can go ahead and take a spectrum of

1374
00:46:19,990 --> 00:46:17,920
it and we have this first strong

1375
00:46:22,150 --> 00:46:20,000
emission line which is basically just

1376
00:46:23,510 --> 00:46:22,160
from the rotation of the galaxy

1377
00:46:25,589 --> 00:46:23,520
and then we can see that we actually

1378
00:46:26,150 --> 00:46:25,599
have a second emission line right next

1379
00:46:27,829 --> 00:46:26,160
to it

1380
00:46:29,670 --> 00:46:27,839
which is coming from the same excited

1381
00:46:31,829 --> 00:46:29,680
state and this is gas that's

1382
00:46:33,510 --> 00:46:31,839
moving at several hundred kilometers per

1383
00:46:35,270 --> 00:46:33,520
second and if we look at where this

1384
00:46:37,190 --> 00:46:35,280
material is relative to the center of

1385
00:46:39,349 --> 00:46:37,200
the galaxy we see this big

1386
00:46:40,230 --> 00:46:39,359
redshifted blob of material that's being

1387
00:46:41,670 --> 00:46:40,240
blown out

1388
00:46:45,990 --> 00:46:41,680

from the center of the galaxy or for

1389
00:46:50,390 --> 00:46:47,990
so finally we've arrived at the last

1390
00:46:51,510 --> 00:46:50,400
stop on our tour of supermassive black

1391
00:46:54,150 --> 00:46:51,520
hole winds and this

1392
00:46:55,270 --> 00:46:54,160
is the circum galactic medium where the

1393
00:46:57,990 --> 00:46:55,280
scales around

1394
00:46:59,510 --> 00:46:58,000
galaxies themselves so here as i

1395
00:47:01,910 --> 00:46:59,520
mentioned there are basically two

1396
00:47:03,670 --> 00:47:01,920
forms of these outflows there are these

1397
00:47:05,030 --> 00:47:03,680
wide angle mass outflows and then there

1398
00:47:07,510 --> 00:47:05,040
are these narrow radio

1399
00:47:09,349 --> 00:47:07,520
jets and so in this case what we're

1400
00:47:11,910 --> 00:47:09,359
often looking at on scales bigger than

1401
00:47:13,910 --> 00:47:11,920
galaxies are these radio jets

1402
00:47:15,589 --> 00:47:13,920
so in this case the particles within

1403
00:47:17,910 --> 00:47:15,599
these jets can be moving

1404
00:47:18,790 --> 00:47:17,920
very very fast typically maybe half the

1405
00:47:21,750 --> 00:47:18,800
speed of light

1406
00:47:23,270 --> 00:47:21,760
but sometimes in excess of 99 percent

1407
00:47:25,750 --> 00:47:23,280
the speed of light these are some of the

1408
00:47:29,510 --> 00:47:25,760
fastest phenomenon in the universe

1409
00:47:31,670 --> 00:47:29,520
so these are extremely fast moving jets

1410
00:47:33,349 --> 00:47:31,680
now again these are often found in more

1411
00:47:34,150 --> 00:47:33,359
luminous and more powerful and often

1412
00:47:36,470 --> 00:47:34,160
more massive

1413
00:47:38,549 --> 00:47:36,480

active galaxies and so here on the right

1414
00:47:41,349 --> 00:47:38,559
is an example of centaurus a

1415
00:47:43,030 --> 00:47:41,359
which is a more nearby active galaxy

1416
00:47:45,109 --> 00:47:43,040
here we can see it has some bright

1417
00:47:45,990 --> 00:47:45,119
emission from stars it has a dust lane

1418
00:47:48,390 --> 00:47:46,000
across it

1419
00:47:49,589 --> 00:47:48,400
and if we zoom in and add in millimeter

1420
00:47:52,069 --> 00:47:49,599
radio data

1421
00:47:52,710 --> 00:47:52,079
we can see these powerful jets so we can

1422
00:47:54,870 --> 00:47:52,720
see these two

1423
00:47:57,109 --> 00:47:54,880
jets here which are pushing their way

1424
00:47:58,870 --> 00:47:57,119
out beyond the galaxy to scales larger

1425
00:48:00,390 --> 00:47:58,880
than the galaxy

1426
00:48:02,710 --> 00:48:00,400
now in this case this is a more nearby

1427
00:48:05,270 --> 00:48:02,720
example let's go to more powerful

1428
00:48:07,910 --> 00:48:05,280
examples in the more distant universe

1429
00:48:09,670 --> 00:48:07,920
in particular the impact of these jets

1430
00:48:11,589 --> 00:48:09,680
is most clearly seen when we look at

1431
00:48:13,750 --> 00:48:11,599
clusters and groups of galaxies where

1432
00:48:15,829 --> 00:48:13,760
they have something to interact with

1433
00:48:17,589 --> 00:48:15,839
so we're going to start out with a

1434
00:48:18,390 --> 00:48:17,599
hubble space telescope image in the

1435
00:48:20,309 --> 00:48:18,400
optical

1436
00:48:21,910 --> 00:48:20,319
and here we can see we have a large

1437
00:48:24,069 --> 00:48:21,920
galaxy in the center

1438
00:48:24,950 --> 00:48:24,079

we have a bunch of smaller galaxies

1439
00:48:26,710 --> 00:48:24,960
around it

1440
00:48:28,150 --> 00:48:26,720
but for the most part it just looks like

1441
00:48:30,390 --> 00:48:28,160
an image of galaxies

1442
00:48:31,510 --> 00:48:30,400
now we go ahead and add in the radio

1443
00:48:34,710 --> 00:48:31,520
information

1444
00:48:35,910 --> 00:48:34,720
in red we can see this long extended

1445
00:48:37,670 --> 00:48:35,920
radio jet

1446
00:48:40,150 --> 00:48:37,680
starting near the center of the galaxy

1447
00:48:41,910 --> 00:48:40,160
and then pushing its way out past

1448
00:48:43,190 --> 00:48:41,920
well beyond some of the galaxies in this

1449
00:48:44,870 --> 00:48:43,200
cluster

1450
00:48:47,430 --> 00:48:44,880
now even with these two pieces of

1451
00:48:48,230 --> 00:48:47,440
information we still can't fully see the

1452
00:48:50,790 --> 00:48:48,240
impact

1453
00:48:51,750 --> 00:48:50,800
until we add in information from the

1454
00:48:54,069 --> 00:48:51,760
x-rays

1455
00:48:56,150 --> 00:48:54,079
and so we add that information in blue

1456
00:48:57,990 --> 00:48:56,160
and put these all together

1457
00:49:00,630 --> 00:48:58,000
and we end up with an image that looks

1458
00:49:02,950 --> 00:49:00,640
like this and so what we're seeing here

1459
00:49:03,990 --> 00:49:02,960
is this radio jet is moving out away

1460
00:49:06,069 --> 00:49:04,000
from the galaxy

1461
00:49:07,990 --> 00:49:06,079
and it's actually carving out these kind

1462
00:49:11,910 --> 00:49:08,000
of bubbles in this very hot

1463
00:49:13,430 --> 00:49:11,920

tenuous x-ray gas so here is the

1464
00:49:15,349 --> 00:49:13,440
the overall view with these three

1465
00:49:16,309 --> 00:49:15,359
different energy and wavelength regimes

1466
00:49:19,430 --> 00:49:16,319
individually

1467
00:49:20,950 --> 00:49:19,440
and what we can learn from them combined

1468
00:49:23,430 --> 00:49:20,960
so the kind of the overall picture

1469
00:49:25,750 --> 00:49:23,440
that's emerging of these big massive

1470
00:49:27,990 --> 00:49:25,760
active galaxies with jets and clusters

1471
00:49:29,670 --> 00:49:28,000
is that the jet is acting to basically

1472
00:49:32,309 --> 00:49:29,680
prevent the gas from cooling

1473
00:49:33,990 --> 00:49:32,319
and falling into galaxies to form stars

1474
00:49:36,309 --> 00:49:34,000
so naturally the gas would want to cool

1475
00:49:37,910 --> 00:49:36,319
the gravity would pull it into galaxies

1476
00:49:39,750 --> 00:49:37,920
it should begin to form stars and so

1477
00:49:42,150 --> 00:49:39,760
this jet is basically keeping the gas

1478
00:49:43,990 --> 00:49:42,160
out there keeping it heating up and in

1479
00:49:46,950 --> 00:49:44,000
some cases it can reduce the rate at

1480
00:49:49,750 --> 00:49:46,960
which stars form by up to a factor of 10

1481
00:49:51,109 --> 00:49:49,760
so it's really quite powerful and this

1482
00:49:53,109 --> 00:49:51,119
is often denoted

1483
00:49:54,870 --> 00:49:53,119
maintenance mode outflows or maintenance

1484
00:49:56,630 --> 00:49:54,880
mode feedback basically as the

1485
00:49:58,309 --> 00:49:56,640
black hole is feeding and delivering

1486
00:50:01,190 --> 00:49:58,319
feedback to its environment

1487
00:50:02,710 --> 00:50:01,200
rather than actually pushing gas well

1488
00:50:03,030 --> 00:50:02,720

outside the galaxies we're basically

1489
00:50:05,109 --> 00:50:03,040
just

1490
00:50:06,790 --> 00:50:05,119
keeping it there and keeping it warm and

1491
00:50:10,309 --> 00:50:06,800
that way it can't collapse down

1492
00:50:12,710 --> 00:50:10,319
to form stars so with that

1493
00:50:14,470 --> 00:50:12,720
to kind of pull all of this together i

1494
00:50:15,589 --> 00:50:14,480
hope i've shown you that supermassive

1495
00:50:18,390 --> 00:50:15,599
black holes

1496
00:50:20,630 --> 00:50:18,400
and the agn that they power have the

1497
00:50:21,510 --> 00:50:20,640
potential to significantly impact their

1498
00:50:23,430 --> 00:50:21,520
galaxies

1499
00:50:25,109 --> 00:50:23,440
so this may be on scales of the

1500
00:50:26,950 --> 00:50:25,119
supermassive black hole

1501
00:50:28,710 --> 00:50:26,960
and the bulge of the galaxy with these

1502
00:50:31,109 --> 00:50:28,720
ultra fast outflows

1503
00:50:32,790 --> 00:50:31,119
it can be within the bulge and on the

1504
00:50:35,349 --> 00:50:32,800
scales of the galaxy disk

1505
00:50:37,349 --> 00:50:35,359
looking at the rates at which stars form

1506
00:50:38,390 --> 00:50:37,359
and it can be on even larger scales on

1507
00:50:40,790 --> 00:50:38,400
entire

1508
00:50:43,030 --> 00:50:40,800
groups and clusters of galaxies where

1509
00:50:45,349 --> 00:50:43,040
we're keeping lots of gas hot and moving

1510
00:50:48,230 --> 00:50:45,359
around so that way it can't form stars

1511
00:50:50,309 --> 00:50:48,240
and is impacting the overall formation

1512
00:50:52,069 --> 00:50:50,319
of galaxy structure

1513
00:50:54,069 --> 00:50:52,079

so i'd like to end by coming back to

1514
00:50:57,349 --> 00:50:54,079
where we started with this image

1515
00:50:59,430 --> 00:50:57,359
of ngc 1275 and i hope now that this

1516
00:51:01,349 --> 00:50:59,440
gives you a little more awe inspire

1517
00:51:03,430 --> 00:51:01,359
as it does to me what we have down in

1518
00:51:04,069 --> 00:51:03,440
the center is this supermassive black

1519
00:51:06,069 --> 00:51:04,079
hole

1520
00:51:07,589 --> 00:51:06,079
that's eating material and putting an

1521
00:51:10,630 --> 00:51:07,599
immense amount of radiation

1522
00:51:12,549 --> 00:51:10,640
out into the galaxy and beyond in this

1523
00:51:13,829 --> 00:51:12,559
case it's exciting that gas

1524
00:51:15,670 --> 00:51:13,839
it's pushing it away from the

1525
00:51:16,470 --> 00:51:15,680
supermassive black hole out beyond the

1526
00:51:18,069 --> 00:51:16,480
galaxy

1527
00:51:20,390 --> 00:51:18,079
and we can see even here that we're

1528
00:51:22,950 --> 00:51:20,400
lighting up gas within the cluster in

1529
00:51:24,950 --> 00:51:22,960
these long red filaments and strings

1530
00:51:26,950 --> 00:51:24,960
which contain millions and tens of

1531
00:51:27,750 --> 00:51:26,960
millions or even more solar masses worth

1532
00:51:30,230 --> 00:51:27,760
of gas

1533
00:51:32,710 --> 00:51:30,240
it's keeping it hot and it's impacting

1534
00:51:34,710 --> 00:51:32,720
the entire environment around it

1535
00:51:35,990 --> 00:51:34,720
so if there's one real takeaway here is

1536
00:51:38,790 --> 00:51:36,000
that the supermassive black

1537
00:51:39,190 --> 00:51:38,800
hole resides at the very center on the

1538
00:51:42,309 --> 00:51:39,200

very

1539
00:51:44,150 --> 00:51:42,319
smallest scales of galaxies and yet it

1540
00:51:47,030 --> 00:51:44,160
has the potential

1541
00:51:48,150 --> 00:51:47,040
to impact nearly every scale that we can

1542
00:51:50,710 --> 00:51:48,160
observe

1543
00:51:53,910 --> 00:51:50,720
and with that i would be happy to take

1544
00:51:56,950 --> 00:51:55,990
all right thank you mitchell that was

1545
00:51:59,270 --> 00:51:56,960
wonderful it was

1546
00:52:00,150 --> 00:51:59,280
great um especially the way that you

1547
00:52:02,549 --> 00:52:00,160
worked um

1548
00:52:03,349 --> 00:52:02,559
and got across the idea that it does

1549
00:52:06,549 --> 00:52:03,359
really go

1550
00:52:08,230 --> 00:52:06,559
from you know parsec scales and down to

1551
00:52:09,910 --> 00:52:08,240
the supermassive black hole is a parsec

1552
00:52:12,870 --> 00:52:09,920
scale object out

1553
00:52:13,990 --> 00:52:12,880
to millions of parsecs uh when you get

1554
00:52:17,190 --> 00:52:14,000
their giant radio

1555
00:52:17,990 --> 00:52:17,200
jets uh we had a lot of interesting

1556
00:52:20,230 --> 00:52:18,000
discussion

1557
00:52:21,750 --> 00:52:20,240
in the chat um but one of the things

1558
00:52:25,349 --> 00:52:21,760
that uh people talked about

1559
00:52:26,309 --> 00:52:25,359
was the correlation between the bulge

1560
00:52:31,270 --> 00:52:26,319
mass

1561
00:52:32,549 --> 00:52:31,280
and you sort of answered it a bit but

1562
00:52:34,870 --> 00:52:32,559
you know given that the

1563
00:52:35,589 --> 00:52:34,880

the formation time scale of the two that

1564
00:52:38,230 --> 00:52:35,599
obviously

1565
00:52:38,870 --> 00:52:38,240
means how quickly do they form and you

1566
00:52:41,510 --> 00:52:38,880
know

1567
00:52:43,670 --> 00:52:41,520
do do do they form in the same time

1568
00:52:45,430 --> 00:52:43,680
scale type thing

1569
00:52:46,790 --> 00:52:45,440
that's a great question so as i

1570
00:52:48,390 --> 00:52:46,800
mentioned when we look back at more

1571
00:52:49,030 --> 00:52:48,400
distant galaxies we're looking back in

1572
00:52:50,790 --> 00:52:49,040
time but

1573
00:52:52,549 --> 00:52:50,800
these are kind of snapshots so how does

1574
00:52:54,630 --> 00:52:52,559
this evolve over time

1575
00:52:56,470 --> 00:52:54,640
so in the very distant universe when

1576
00:52:57,349 --> 00:52:56,480
galaxies are basically just starting to

1577
00:52:59,510 --> 00:52:57,359
be built

1578
00:53:00,710 --> 00:52:59,520
that's when we have gas collapsing down

1579
00:53:04,870 --> 00:53:00,720
it's starting to form

1580
00:53:05,430 --> 00:53:04,880
that's when the bulge really begins to

1581
00:53:06,870 --> 00:53:05,440
form

1582
00:53:08,309 --> 00:53:06,880
and so it's really from the very

1583
00:53:10,309 --> 00:53:08,319
earliest portions of the universe where

1584
00:53:12,309 --> 00:53:10,319
we can see that supermassive black holes

1585
00:53:14,309 --> 00:53:12,319
and galaxies are beginning to form

1586
00:53:15,430 --> 00:53:14,319
that these energetic phenomena are

1587
00:53:17,270 --> 00:53:15,440
happening so

1588
00:53:18,630 --> 00:53:17,280

a important question is well how long

1589
00:53:20,870 --> 00:53:18,640
does it really take to

1590
00:53:22,230 --> 00:53:20,880
necessarily do this that's not a

1591
00:53:23,990 --> 00:53:22,240
question an answer a question that i

1592
00:53:25,910 --> 00:53:24,000
have a very sharp answer for but what i

1593
00:53:27,589 --> 00:53:25,920
can tell you is that it's time scales

1594
00:53:29,910 --> 00:53:27,599
on the order of millions of years or

1595
00:53:31,510 --> 00:53:29,920
more and so we get that basically from

1596
00:53:33,670 --> 00:53:31,520
looking at how long

1597
00:53:34,790 --> 00:53:33,680
active galaxies are basically turned on

1598
00:53:36,549 --> 00:53:34,800
for so

1599
00:53:37,910 --> 00:53:36,559
the majority of galaxies in the universe

1600
00:53:39,349 --> 00:53:37,920
are basically quiescent their black

1601
00:53:40,549 --> 00:53:39,359
holes are kind of hidden they're not

1602
00:53:42,309 --> 00:53:40,559
really eating

1603
00:53:44,150 --> 00:53:42,319
but by looking at lots and lots of

1604
00:53:46,069 --> 00:53:44,160
galaxies we can figure out that

1605
00:53:47,349 --> 00:53:46,079
almost every galaxy should become an

1606
00:53:49,109 --> 00:53:47,359
active galaxy for

1607
00:53:50,710 --> 00:53:49,119
maybe 10 percent of its life or

1608
00:53:52,390 --> 00:53:50,720
something on that order and so we're

1609
00:53:52,950 --> 00:53:52,400
talking about time scales of millions of

1610
00:53:55,910 --> 00:53:52,960
years

1611
00:53:56,870 --> 00:53:55,920
sometimes maybe a bit more for sure okay

1612
00:53:59,510 --> 00:53:56,880
great

1613
00:54:01,589 --> 00:53:59,520

um grant justice has been monitoring the

1614
00:54:03,190 --> 00:54:01,599
chat more than i've been able to

1615
00:54:05,190 --> 00:54:03,200
uh grant why don't you turn on your

1616
00:54:05,910 --> 00:54:05,200
video and join us and bring us some of

1617
00:54:08,870 --> 00:54:05,920
the

1618
00:54:10,950 --> 00:54:08,880
best questions from our chat sure

1619
00:54:13,030 --> 00:54:10,960
absolutely

1620
00:54:15,910 --> 00:54:13,040
so yes the chat has been very active for

1621
00:54:18,069 --> 00:54:15,920
this one black holes are always one of

1622
00:54:19,670 --> 00:54:18,079
both online and our favorite subjects

1623
00:54:22,390 --> 00:54:19,680
when we get it so

1624
00:54:25,270 --> 00:54:22,400
um the first one that i picked out was

1625
00:54:26,549 --> 00:54:25,280
is the length of the ultra fast outflows

1626
00:54:29,589 --> 00:54:26,559
an indication of

1627
00:54:31,910 --> 00:54:29,599
age or formation activation time for

1628
00:54:33,349 --> 00:54:31,920
black holes

1629
00:54:35,670 --> 00:54:33,359
uh that's a good question so basically

1630
00:54:37,589 --> 00:54:35,680
these ultra fast outflows are very very

1631
00:54:39,750 --> 00:54:37,599
close to the supermassive black hole

1632
00:54:40,630 --> 00:54:39,760
so we can't necessarily measure how far

1633
00:54:42,230 --> 00:54:40,640
they extend

1634
00:54:44,309 --> 00:54:42,240
but we can figure out how long they've

1635
00:54:45,510 --> 00:54:44,319
been there by looking at these galaxies

1636
00:54:48,630 --> 00:54:45,520
again and again

1637
00:54:50,549 --> 00:54:48,640
and so in that context often we see them

1638
00:54:52,309 --> 00:54:50,559

sometimes appearing and disappearing on

1639
00:54:53,990 --> 00:54:52,319
week or month time scales

1640
00:54:55,990 --> 00:54:54,000
but the real tricky part here this is

1641
00:54:57,750 --> 00:54:56,000
where things get almost kind of ghostly

1642
00:54:59,270 --> 00:54:57,760
is that sometimes they're appearing and

1643
00:55:00,950 --> 00:54:59,280
disappearing just because

1644
00:55:03,190 --> 00:55:00,960
we can't actually see them with our

1645
00:55:05,670 --> 00:55:03,200
x-ray telescopes and what i mean is

1646
00:55:07,190 --> 00:55:05,680
each type of telescope is is sensitive

1647
00:55:08,390 --> 00:55:07,200
to a different wavelength range a

1648
00:55:10,549 --> 00:55:08,400
different energy range

1649
00:55:12,870 --> 00:55:10,559
and so if that outflow becomes so

1650
00:55:15,109 --> 00:55:12,880
incredibly ionized and excited

1651
00:55:16,549 --> 00:55:15,119
it may still be there but it disappears

1652
00:55:17,510 --> 00:55:16,559
from our telescope and we basically just

1653
00:55:19,109 --> 00:55:17,520
can't see it

1654
00:55:21,030 --> 00:55:19,119
or on the other side of that the outflow

1655
00:55:21,750 --> 00:55:21,040
can get so dense and mass loaded with

1656
00:55:23,190 --> 00:55:21,760
material

1657
00:55:25,030 --> 00:55:23,200
that it's basically blocking the view

1658
00:55:26,549 --> 00:55:25,040
all together and so

1659
00:55:28,549 --> 00:55:26,559
in terms of what these ultra fast

1660
00:55:30,309 --> 00:55:28,559
outflows do we know that they're close

1661
00:55:31,910 --> 00:55:30,319
to the center of galaxies but there's

1662
00:55:33,750 --> 00:55:31,920
actually been some recent evidence that

1663
00:55:35,910 --> 00:55:33,760

maybe they travel out further

1664
00:55:37,589 --> 00:55:35,920
and then they push gas on the scales of

1665
00:55:39,829 --> 00:55:37,599
galaxies on galactic scale so there

1666
00:55:41,510 --> 00:55:39,839
might be some interaction

1667
00:55:43,910 --> 00:55:41,520
okay and that brings up another question

1668
00:55:45,270 --> 00:55:43,920
that was sort of referenced is that

1669
00:55:47,270 --> 00:55:45,280
the you talk about the speed of the

1670
00:55:49,030 --> 00:55:47,280
ultra fast ones right the ufos

1671
00:55:51,190 --> 00:55:49,040
um and then you talked about the speed

1672
00:55:52,789 --> 00:55:51,200
of this the stellar disc scale ones

1673
00:55:54,390 --> 00:55:52,799
but the ones that go all the way up i

1674
00:55:56,950 --> 00:55:54,400
mean does speed

1675
00:55:57,910 --> 00:55:56,960
correlate to the distance away is it you

1676
00:55:59,589 --> 00:55:57,920
know

1677
00:56:01,750 --> 00:55:59,599
how much of it is just the density of

1678
00:56:04,069 --> 00:56:01,760
the material it gets to plow through

1679
00:56:06,309 --> 00:56:04,079
versus how much this is the speed of the

1680
00:56:08,069 --> 00:56:06,319
uh up flow

1681
00:56:09,670 --> 00:56:08,079
absolutely that's a great question so

1682
00:56:11,670 --> 00:56:09,680
yeah so for those kind of bulge scale

1683
00:56:13,030 --> 00:56:11,680
outflows and galaxy scale outflows we're

1684
00:56:15,270 --> 00:56:13,040
generally looking at you know a few

1685
00:56:16,069 --> 00:56:15,280
hundred to a few thousand kilometers per

1686
00:56:18,069 --> 00:56:16,079
second

1687
00:56:19,829 --> 00:56:18,079
and since we can spatially resolve them

1688
00:56:21,190 --> 00:56:19,839

we can actually kind of see how they

1689
00:56:23,589 --> 00:56:21,200
change as they move throughout the

1690
00:56:24,950 --> 00:56:23,599
galaxy and so in a lot of cases we'll

1691
00:56:26,950 --> 00:56:24,960
see that it basically looks like

1692
00:56:28,789 --> 00:56:26,960
the gas is moving faster and faster and

1693
00:56:30,789 --> 00:56:28,799
faster and then at some point

1694
00:56:31,990 --> 00:56:30,799
it turns over and begins to slow down

1695
00:56:33,589 --> 00:56:32,000
and slow down and so

1696
00:56:35,670 --> 00:56:33,599
there's kind of two interpretations

1697
00:56:37,589 --> 00:56:35,680
either the gas is being accelerated and

1698
00:56:39,349 --> 00:56:37,599
then decelerated because you're running

1699
00:56:41,589 --> 00:56:39,359
out of energy to push it

1700
00:56:43,270 --> 00:56:41,599
or that gas is being driven from

1701
00:56:43,990 --> 00:56:43,280
wherever it was in the galaxy and the

1702
00:56:45,990 --> 00:56:44,000
further away

1703
00:56:47,510 --> 00:56:46,000
you get you just have less radiation so

1704
00:56:49,670 --> 00:56:47,520
you can't push it as fast

1705
00:56:51,910 --> 00:56:49,680
so these definitely change in velocity

1706
00:56:55,030 --> 00:56:51,920
as you move throughout a galaxy

1707
00:56:58,549 --> 00:56:55,040
okay grant what's in what's up next

1708
00:57:01,109 --> 00:56:58,559
yeah um so next up is do supermassive

1709
00:57:02,549 --> 00:57:01,119
black holes always begin as stars

1710
00:57:04,309 --> 00:57:02,559
is there any other way that they can

1711
00:57:06,870 --> 00:57:04,319
form

1712
00:57:08,870 --> 00:57:06,880
that is an excellent question if i had a

1713
00:57:10,150 --> 00:57:08,880

full answer to that i'd probably have a

1714
00:57:12,470 --> 00:57:10,160
nobel prize

1715
00:57:13,750 --> 00:57:12,480
um so the further back we look in the

1716
00:57:15,270 --> 00:57:13,760
universe we still see

1717
00:57:17,190 --> 00:57:15,280
evidence of these supermassive black

1718
00:57:20,230 --> 00:57:17,200
holes and how they can possibly

1719
00:57:22,069 --> 00:57:20,240
form so quickly so early in the universe

1720
00:57:23,829 --> 00:57:22,079
is definitely still a mystery

1721
00:57:26,069 --> 00:57:23,839
and so this is one of those things there

1722
00:57:27,589 --> 00:57:26,079
are certainly many great ideas out there

1723
00:57:29,190 --> 00:57:27,599
it's been worked on for some time and

1724
00:57:30,950 --> 00:57:29,200
this is definitely one of the key

1725
00:57:33,670 --> 00:57:30,960
questions to push after with the james

1726
00:57:35,829 --> 00:57:33,680
webb space telescope

1727
00:57:37,109 --> 00:57:35,839
so the answer is we don't know but we're

1728
00:57:38,710 --> 00:57:37,119
going to find out

1729
00:57:41,910 --> 00:57:38,720
that is correct yes quintessential

1730
00:57:46,069 --> 00:57:44,630
what trade of black holes surprised or

1731
00:57:49,670 --> 00:57:46,079
surprises you

1732
00:57:52,390 --> 00:57:49,680
the most ah what an

1733
00:57:54,470 --> 00:57:52,400
interesting question what trait of

1734
00:57:55,349 --> 00:57:54,480
supermassive black holes surprises me

1735
00:57:57,190 --> 00:57:55,359
the most

1736
00:57:58,470 --> 00:57:57,200
i think the trait that surprises me the

1737
00:58:01,829 --> 00:57:58,480
most

1738
00:58:04,630 --> 00:58:01,839

is how we picture these as having this

1739
00:58:06,710 --> 00:58:04,640
immense gravitational field that just

1740
00:58:08,069 --> 00:58:06,720
eats everything around it which if you

1741
00:58:11,270 --> 00:58:08,079
get close to the black hole

1742
00:58:12,470 --> 00:58:11,280
is very true however if you're very far

1743
00:58:14,309 --> 00:58:12,480
from the black hole

1744
00:58:16,150 --> 00:58:14,319
it's basically the same gravity as you

1745
00:58:17,589 --> 00:58:16,160
might feel from a star or any other body

1746
00:58:18,230 --> 00:58:17,599
and so for example if you were to take

1747
00:58:19,990 --> 00:58:18,240
the sun

1748
00:58:21,910 --> 00:58:20,000
and pluck it out of the solar system and

1749
00:58:23,030 --> 00:58:21,920
put a black hole with the same mass

1750
00:58:25,589 --> 00:58:23,040
which would be very small

1751
00:58:27,030 --> 00:58:25,599
few kilometers in size for the most part

1752
00:58:28,710 --> 00:58:27,040
all the planets would just keep going on

1753
00:58:30,470 --> 00:58:28,720
in their orbits as they were

1754
00:58:31,750 --> 00:58:30,480
things very close like mercury might get

1755
00:58:33,990 --> 00:58:31,760
perturbed a little bit

1756
00:58:35,510 --> 00:58:34,000
but in general it's just a point source

1757
00:58:37,349 --> 00:58:35,520
of gravity and so that is one of the

1758
00:58:38,789 --> 00:58:37,359
most surprising things to me is that

1759
00:58:40,630 --> 00:58:38,799
they're not just these monsters eating

1760
00:58:42,150 --> 00:58:40,640
necessarily everything all around them

1761
00:58:44,390 --> 00:58:42,160
but once you get very close

1762
00:58:45,430 --> 00:58:44,400
things do you get very intense yeah

1763
00:58:46,870 --> 00:58:45,440

that's one of the

1764
00:58:48,549 --> 00:58:46,880
hardest things to get across to the

1765
00:58:51,109 --> 00:58:48,559
public because

1766
00:58:52,069 --> 00:58:51,119
mass media has created them as oh

1767
00:58:54,950 --> 00:58:52,079
they're sucking in

1768
00:58:55,990 --> 00:58:54,960
everything around it uh no black holes

1769
00:58:59,670 --> 00:58:56,000
don't suck guys

1770
00:59:02,630 --> 00:58:59,680
okay they're just gravitational entities

1771
00:59:02,950 --> 00:59:02,640
so it's uh it's and that we will we will

1772
00:59:04,710 --> 00:59:02,960
be

1773
00:59:06,390 --> 00:59:04,720
explaining that for the rest of our

1774
00:59:07,829 --> 00:59:06,400
careers unfortunately

1775
00:59:09,670 --> 00:59:07,839
it's less of a headline if it's not

1776
00:59:12,870 --> 00:59:09,680
trying to kill us all immediately

1777
00:59:16,829 --> 00:59:12,880
or impending doom so

1778
00:59:19,190 --> 00:59:16,839
but so is it possible for emissions to

1779
00:59:19,829 --> 00:59:19,200
restart because one of the theories that

1780
00:59:23,190 --> 00:59:19,839
you mentioned

1781
00:59:24,150 --> 00:59:23,200
was black holes having a potential to

1782
00:59:26,470 --> 00:59:24,160
freeze

1783
00:59:27,670 --> 00:59:26,480
as it were is it possible for emissions

1784
00:59:30,950 --> 00:59:27,680
to come from a

1785
00:59:32,230 --> 00:59:30,960
frozen black hole absolutely this is a

1786
00:59:34,309 --> 00:59:32,240
fantastic question

1787
00:59:35,750 --> 00:59:34,319
so thank you for bringing this up so in

1788
00:59:37,270 --> 00:59:35,760

this picture i've kind of painted the

1789
00:59:38,789 --> 00:59:37,280
active galaxy is basically just

1790
00:59:40,789 --> 00:59:38,799
continuously putting out

1791
00:59:42,150 --> 00:59:40,799
energy it's exciting this gas and

1792
00:59:44,710 --> 00:59:42,160
driving it but

1793
00:59:46,390 --> 00:59:44,720
that all relies on material getting down

1794
00:59:46,870 --> 00:59:46,400
into the black hole and so that can

1795
00:59:49,109 --> 00:59:46,880
happen

1796
00:59:51,270 --> 00:59:49,119
from gas just working its way in from

1797
00:59:51,750 --> 00:59:51,280
minor mergers where little galaxies come

1798
00:59:53,270 --> 00:59:51,760
in

1799
00:59:54,789 --> 00:59:53,280
and so it's possible for these active

1800
00:59:57,030 --> 00:59:54,799
galaxies basically to turn

1801
00:59:58,309 --> 00:59:57,040
on and off so we can look at an active

1802
00:59:59,670 --> 00:59:58,319
galaxy today

1803
01:00:01,829 --> 00:59:59,680
and say well there's barely anything

1804
01:00:03,750 --> 01:00:01,839
going on but if we look at the larger

1805
01:00:05,829 --> 01:00:03,760
scales we'll see these echoes these kind

1806
01:00:08,950 --> 01:00:05,839
of light echoes or these remnants

1807
01:00:09,990 --> 01:00:08,960
of much more excited gas at larger radii

1808
01:00:11,589 --> 01:00:10,000
that tells us

1809
01:00:13,990 --> 01:00:11,599
that at some point in the past the

1810
01:00:15,670 --> 01:00:14,000
active galaxy was much more powerful

1811
01:00:17,030 --> 01:00:15,680
and we've also seen the converse of that

1812
01:00:18,789 --> 01:00:17,040
where basically it looks like something

1813
01:00:20,630 --> 01:00:18,799

is restarting where we have this

1814
01:00:22,470 --> 01:00:20,640
old radio jet that's basically

1815
01:00:24,150 --> 01:00:22,480
dissipating and then a new jet

1816
01:00:28,789 --> 01:00:24,160
that is being launched much closer to

1817
01:00:32,309 --> 01:00:28,799
the black hole

1818
01:00:35,510 --> 01:00:32,319
all right so on the online questions

1819
01:00:40,309 --> 01:00:35,520
that's more or less where i had um

1820
01:00:42,630 --> 01:00:40,319
i'm checking to see if there are any um

1821
01:00:43,430 --> 01:00:42,640
and he came in during the uh yeah

1822
01:00:45,910 --> 01:00:43,440
there's one about

1823
01:00:46,710 --> 01:00:45,920
chemical makeup of the gas is the

1824
01:00:49,750 --> 01:00:46,720
chemical makeup

1825
01:00:50,950 --> 01:00:49,760
of gas similar among galaxies or is the

1826
01:00:52,630 --> 01:00:50,960
proportion of elements

1827
01:00:55,430 --> 01:00:52,640
significantly different different from

1828
01:00:58,390 --> 01:00:55,440
one galaxy to the next

1829
01:01:00,150 --> 01:00:58,400
a very interesting question so all the

1830
01:01:01,190 --> 01:01:00,160
gas and dust and stars in these galaxies

1831
01:01:02,230 --> 01:01:01,200
are made up of all the different

1832
01:01:04,710 --> 01:01:02,240
elements we can see

1833
01:01:06,309 --> 01:01:04,720
primarily hydrogen and helium but traces

1834
01:01:07,829 --> 01:01:06,319
of everything else such as carbon

1835
01:01:10,150 --> 01:01:07,839
nitrogen and oxygen

1836
01:01:11,910 --> 01:01:10,160
and so depending on which distance

1837
01:01:13,829 --> 01:01:11,920
you're looking at from the galaxy

1838
01:01:15,349 --> 01:01:13,839

those relative abundances of the

1839
01:01:17,270 --> 01:01:15,359
elements do change

1840
01:01:19,349 --> 01:01:17,280
and so often we see near the centers of

1841
01:01:21,670 --> 01:01:19,359
galaxies where stars have formed in the

1842
01:01:23,990 --> 01:01:21,680
past and they process that material

1843
01:01:25,670 --> 01:01:24,000
we have higher metallicity basically

1844
01:01:26,470 --> 01:01:25,680
elements that are heavier than hydrogen

1845
01:01:28,710 --> 01:01:26,480
helium

1846
01:01:30,789 --> 01:01:28,720
whereas at much larger distances we

1847
01:01:33,270 --> 01:01:30,799
might see much lower metallicity so we

1848
01:01:35,270 --> 01:01:33,280
have much less of those heavy elements

1849
01:01:36,870 --> 01:01:35,280
and this is another reason i didn't have

1850
01:01:37,990 --> 01:01:36,880
a chance to touch on as to why these

1851
01:01:40,069 --> 01:01:38,000
winds and outflows are so

1852
01:01:41,910 --> 01:01:40,079
important because then we're taking some

1853
01:01:44,150 --> 01:01:41,920
of that enriched material

1854
01:01:45,990 --> 01:01:44,160
and we're moving it out onto much larger

1855
01:01:47,270 --> 01:01:46,000
scales where it may not normally be and

1856
01:01:48,230 --> 01:01:47,280
so that's going to affect the way that

1857
01:01:52,230 --> 01:01:48,240
stars form

1858
01:01:54,309 --> 01:01:52,240
gas cools and all those sorts of details

1859
01:01:55,670 --> 01:01:54,319
okay i actually have a pretty good one

1860
01:01:56,309 --> 01:01:55,680
that just came in right now i'm gonna

1861
01:01:58,470 --> 01:01:56,319
say there's

1862
01:01:59,910 --> 01:01:58,480
that that's a good good last question

1863
01:02:03,270 --> 01:01:59,920

yep

1864
01:02:07,510 --> 01:02:03,280
do black holes die and if so

1865
01:02:11,029 --> 01:02:07,520
how do black holes die

1866
01:02:12,630 --> 01:02:11,039
so theoretically there is a process

1867
01:02:14,870 --> 01:02:12,640
known as hawking radiation where black

1868
01:02:16,230 --> 01:02:14,880
holes could very very very slowly

1869
01:02:18,230 --> 01:02:16,240
evaporate

1870
01:02:20,470 --> 01:02:18,240
for supermassive black holes the amount

1871
01:02:22,549 --> 01:02:20,480
of time that that would take is

1872
01:02:23,510 --> 01:02:22,559
many times longer than the age of the

1873
01:02:25,589 --> 01:02:23,520
universe

1874
01:02:26,710 --> 01:02:25,599
even for small black holes made from

1875
01:02:28,789 --> 01:02:26,720
smaller stars

1876
01:02:30,309 --> 01:02:28,799
it's still an exceedingly long time and

1877
01:02:32,870 --> 01:02:30,319
so we don't have any direct

1878
01:02:34,470 --> 01:02:32,880
measurement of that but otherwise in

1879
01:02:36,630 --> 01:02:34,480
theory the black hole will just

1880
01:02:40,230 --> 01:02:36,640
sit there forever until something comes

1881
01:02:45,349 --> 01:02:43,510
ah well yeah black holes will

1882
01:02:46,829 --> 01:02:45,359
for at least for as far as we're

1883
01:02:48,470 --> 01:02:46,839
concerned black holes will be around

1884
01:02:51,109 --> 01:02:48,480
forever

1885
01:02:52,870 --> 01:02:51,119
and i probably think at least for my

1886
01:02:53,750 --> 01:02:52,880
lifetime will continually be learning

1887
01:02:56,710 --> 01:02:53,760
about them

1888
01:02:58,870 --> 01:02:56,720

uh there's just uh yeah the the amount

1889
01:03:00,789 --> 01:02:58,880
that radio astronomy and telescopes like

1890
01:03:03,190 --> 01:03:00,799
arecibo we talked about earlier

1891
01:03:04,630 --> 01:03:03,200
have contributed to our understanding of

1892
01:03:06,309 --> 01:03:04,640
what goes on in the cores of these

1893
01:03:09,190 --> 01:03:06,319
galaxies it's just been

1894
01:03:09,990 --> 01:03:09,200
amazing to watch over the decades

1895
01:03:11,829 --> 01:03:10,000
absolutely we've

1896
01:03:13,109 --> 01:03:11,839
learned so much and yet we still have so

1897
01:03:14,870 --> 01:03:13,119
much to learn and so

1898
01:03:16,230 --> 01:03:14,880
if we knew it all then astronomy would

1899
01:03:17,910 --> 01:03:16,240
not be fun and so that's one of the most

1900
01:03:19,600 --> 01:03:17,920
exciting things in astronomy

1901
01:03:19,700 --> 01:03:19,610
we knew it all we'd be out of jobs

1902
01:03:22,630 --> 01:03:19,710
[Music]

1903
01:03:24,309 --> 01:03:22,640
[Laughter]

1904
01:03:25,670 --> 01:03:24,319
to see as well like hubble's the same

1905
01:03:28,470 --> 01:03:25,680
age as i am so

1906
01:03:30,630 --> 01:03:28,480
we have the same lifespan thus far i

1907
01:03:31,589 --> 01:03:30,640
can't wait for jwst to get into some of

1908
01:03:32,950 --> 01:03:31,599
these

1909
01:03:34,950 --> 01:03:32,960
i didn't want to mention it during the

1910
01:03:37,349 --> 01:03:34,960
news summary but arecibo

1911
01:03:39,190 --> 01:03:37,359
was launched it was what started

1912
01:03:41,349 --> 01:03:39,200
operation the year i was born

1913
01:03:46,470 --> 01:03:41,359

um so it looks like i have a little bit

1914
01:03:50,309 --> 01:03:48,309
all right well thank you very much

1915
01:03:51,910 --> 01:03:50,319
appreciate all of your help

1916
01:03:53,829 --> 01:03:51,920
grant in getting the comments out of

1917
01:03:57,109 --> 01:03:53,839
this everybody next month

1918
01:03:59,190 --> 01:03:57,119
remember it's january 19th special date

1919
01:04:02,230 --> 01:03:59,200
we're skipping the first couple tuesdays

1920
01:04:05,510 --> 01:04:02,240
uh for for various reasons it will be

1921
01:04:08,549 --> 01:04:05,520
the darkest secrets of the universe

1922
01:04:10,470 --> 01:04:08,559
raja kuhatukurta from the uc santa cruz

1923
01:04:11,589 --> 01:04:10,480
we'll see you then thank you all for