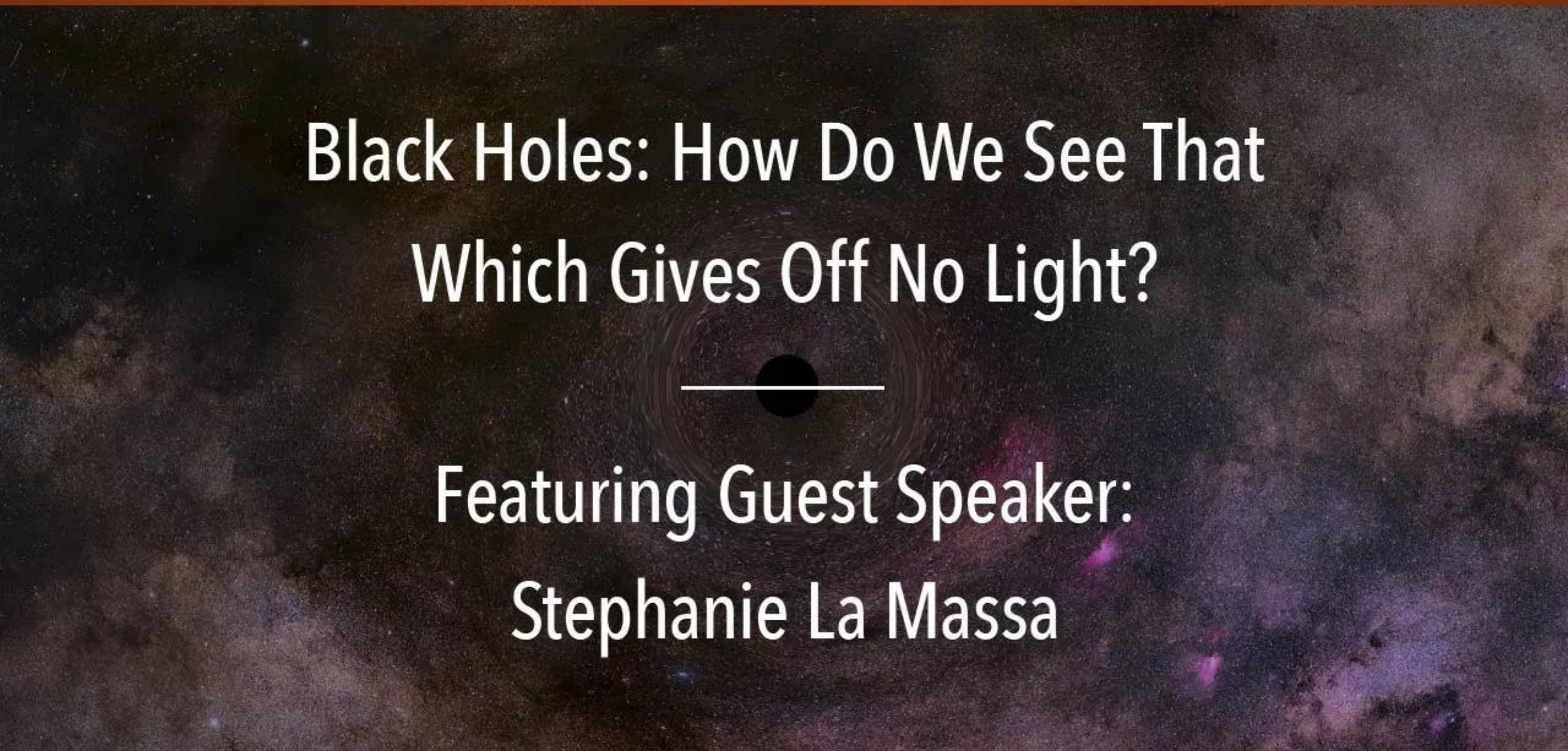
PUBLIC LECTURE SERIES



Black Holes: How Do We See That Which Gives Off No Light?

Featuring Guest Speaker: Stephanie La Massa

1
00:00:08,570 --> 00:00:05,510
welcome to the Space Telescope public

2
00:00:11,450 --> 00:00:08,580
lecture series tonight's topic black

3
00:00:14,270 --> 00:00:11,460
holes how do we see that which gives off

4
00:00:17,450 --> 00:00:14,280
no light from Stephanie lamasa of the

5
00:00:19,910 --> 00:00:17,460
Space Telescope Science Institute

6
00:00:23,150 --> 00:00:19,920
I'm your host Dr Frank Summers of the

7
00:00:25,250 --> 00:00:23,160
Office of Public Outreach here at stsci

8
00:00:27,830 --> 00:00:25,260
I will remind you that our public liquor

9
00:00:32,569 --> 00:00:27,840
series will be online only throughout

10
00:00:35,630 --> 00:00:32,579
the rest of 2022 and into 2023.

11
00:00:38,030 --> 00:00:35,640
as always I like to thank our wonderful

12
00:00:40,790 --> 00:00:38,040
tech team Thomas marufu and Grant

13
00:00:42,709 --> 00:00:40,800

Justice who bring you these uh these

14
00:00:43,549 --> 00:00:42,719
pictures bring you the bring you the

15
00:00:47,389 --> 00:00:43,559
lectures

16
00:00:49,250 --> 00:00:47,399
our upcoming talks uh next month high

17
00:00:51,350 --> 00:00:49,260
energy astronomy with a swift

18
00:00:54,290 --> 00:00:51,360
Observatory and this is a brand new

19
00:00:56,330 --> 00:00:54,300
topic for us we've never discussed this

20
00:00:58,670 --> 00:00:56,340
in our lecture Series so this is going

21
00:01:02,150 --> 00:00:58,680
to be great uh Steve Kirby from Penn

22
00:01:04,729 --> 00:01:02,160
State University and for January and

23
00:01:07,550 --> 00:01:04,739
February I'm a little behind in actually

24
00:01:09,770 --> 00:01:07,560
nailing down a speaker for those so we

25
00:01:12,050 --> 00:01:09,780
will have fascinating topics insightful

26
00:01:14,149 --> 00:01:12,060
speakers or insightful topics with

27
00:01:16,550 --> 00:01:14,159
fascinating speakers for both January

28
00:01:18,710 --> 00:01:16,560
and February uh if you would like to

29
00:01:21,050 --> 00:01:18,720
know what those are going to be you can

30
00:01:25,090 --> 00:01:21,060
check back on our website where they

31
00:01:31,010 --> 00:01:28,609
www.stsei.edu public hyphen lectures

32
00:01:33,469 --> 00:01:31,020
this is where you will find all the

33
00:01:37,190 --> 00:01:33,479
information on the left hand side you

34
00:01:39,410 --> 00:01:37,200
will see links to our webcast both on

35
00:01:43,429 --> 00:01:39,420
our YouTube playlist and the webcast

36
00:01:46,429 --> 00:01:43,439
archive here at stsci on the right you

37
00:01:48,469 --> 00:01:46,439
will see our email which is basically

38
00:01:50,990 --> 00:01:48,479

two emails a month reminding you about

39
00:01:53,389 --> 00:01:51,000
the lectures upcoming you just enter

40
00:01:54,649 --> 00:01:53,399
your email address and hit the Subscribe

41
00:01:56,990 --> 00:01:54,659
button

42
00:01:59,149 --> 00:01:57,000
and as promised all of the information

43
00:02:01,789 --> 00:01:59,159
about our upcoming lectures is posted

44
00:02:04,310 --> 00:02:01,799
here if you click on one of those

45
00:02:07,310 --> 00:02:04,320
lectures you get the full details

46
00:02:09,770 --> 00:02:07,320
including the description of it and

47
00:02:13,790 --> 00:02:09,780
after it has been recorded the link to

48
00:02:15,830 --> 00:02:13,800
the stsci webcast as well as it's uh

49
00:02:19,130 --> 00:02:15,840
recording on YouTube

50
00:02:21,589 --> 00:02:19,140
uh for our email as I said the easiest

51
00:02:24,170 --> 00:02:21,599
way is just to sign up uh for our

52
00:02:26,210 --> 00:02:24,180
announcements on our website but you can

53
00:02:30,229 --> 00:02:26,220
also subscribe to our YouTube channel

54
00:02:32,390 --> 00:02:30,239
youtube.com Hubble Space Telescope and

55
00:02:35,150 --> 00:02:32,400
if you sign up for that you will get new

56
00:02:37,010 --> 00:02:35,160
video notices and reminders of Live

57
00:02:38,690 --> 00:02:37,020
Events such as this

58
00:02:40,670 --> 00:02:38,700
finally if you have comments or

59
00:02:44,140 --> 00:02:40,680
questions you can send them to the email

60
00:02:45,949 --> 00:02:44,150
address public lecture at stsci.edu

61
00:02:48,830 --> 00:02:45,959
[Music]

62
00:02:51,650 --> 00:02:48,840
as always I remind you of our social

63
00:02:55,009 --> 00:02:51,660

media uh we are on Facebook Twitter

64
00:02:56,809 --> 00:02:55,019
Youtube and Instagram uh for the Hubble

65
00:02:59,330 --> 00:02:56,819
Space Telescope for the web Space

66
00:03:01,970 --> 00:02:59,340
Telescope and for the Space Telescope

67
00:03:03,290 --> 00:03:01,980
Science Institute at all of the

68
00:03:05,390 --> 00:03:03,300
addresses there

69
00:03:06,949 --> 00:03:05,400
I myself do a tiny little bit of social

70
00:03:09,830 --> 00:03:06,959
media and you can find me on Facebook

71
00:03:12,589 --> 00:03:09,840
and Twitter

72
00:03:15,170 --> 00:03:12,599
and now our news from the universe for

73
00:03:17,330 --> 00:03:15,180
November 2022

74
00:03:20,750 --> 00:03:17,340
I'm only going to do one story tonight

75
00:03:24,610 --> 00:03:20,760
but it's quite the story it is The

76
00:03:28,729 --> 00:03:24,620
Pillars of Creation now you may remember

77
00:03:31,910 --> 00:03:28,739
that way back in the 1990s we produced

78
00:03:33,890 --> 00:03:31,920
an iconic image from Hubble the pillars

79
00:03:36,890 --> 00:03:33,900
in the Eagle Nebula that got the

80
00:03:38,630 --> 00:03:36,900
nickname The Pillars of Creation and

81
00:03:40,309 --> 00:03:38,640
these pillars I think though the one on

82
00:03:44,089 --> 00:03:40,319
the left hand side is about three light

83
00:03:46,910 --> 00:03:44,099
years long these are there are there is

84
00:03:49,369 --> 00:03:46,920
energy streaming down from above that's

85
00:03:52,009 --> 00:03:49,379
blowing away the the low density gas

86
00:03:53,630 --> 00:03:52,019
leaving Behind These pillars and in the

87
00:03:56,270 --> 00:03:53,640
tops of these pillars and along the

88
00:03:59,809 --> 00:03:56,280

pillars are places where stars are being

89
00:04:02,330 --> 00:03:59,819
born and this was one of the very first

90
00:04:05,210 --> 00:04:02,340
Hubble images that really caught the

91
00:04:08,509 --> 00:04:05,220
Public's attention and said wow this

92
00:04:10,910 --> 00:04:08,519
telescope produces amazing imagery and

93
00:04:11,809 --> 00:04:10,920
the public started following um on the

94
00:04:15,890 --> 00:04:11,819
attention

95
00:04:18,590 --> 00:04:15,900
well 20 years later we took this image

96
00:04:20,509 --> 00:04:18,600
of The Pillars of Creation with a new

97
00:04:23,270 --> 00:04:20,519
camera that was on Hubble wide field

98
00:04:26,570 --> 00:04:23,280
camera three uh the first one was taken

99
00:04:29,390 --> 00:04:26,580
with Widefield planetary camera two and

100
00:04:31,610 --> 00:04:29,400
it was a much larger image more detail

101
00:04:35,450 --> 00:04:31,620
because it was a newer camera and again

102
00:04:37,189 --> 00:04:35,460
this amazing image of these pillars uh

103
00:04:39,950 --> 00:04:37,199
inside this nebula

104
00:04:43,430 --> 00:04:39,960
but Widefield camera 3 had an improved

105
00:04:46,610 --> 00:04:43,440
infrared mode on it so we were also able

106
00:04:49,490 --> 00:04:46,620
to get a near infrared view of the

107
00:04:52,909 --> 00:04:49,500
pillars and as you can see from this

108
00:04:55,670 --> 00:04:52,919
that the pillars that appear solid and

109
00:04:57,710 --> 00:04:55,680
dense invisible actually appeared a

110
00:05:00,650 --> 00:04:57,720
little bit more wispy because infrared

111
00:05:02,570 --> 00:05:00,660
sees into the pillars the longer

112
00:05:05,629 --> 00:05:02,580
wavelengths of infrared see through some

113
00:05:07,850 --> 00:05:05,639

of the gas and dust uh into the uh and

114
00:05:10,850 --> 00:05:07,860
through the pillars you also notice the

115
00:05:12,890 --> 00:05:10,860
tremendous number of stars that you see

116
00:05:16,249 --> 00:05:12,900
here that you don't see in the visible

117
00:05:19,310 --> 00:05:16,259
light image so that's the setup

118
00:05:22,310 --> 00:05:19,320
and now we have the web Space Telescope

119
00:05:25,249 --> 00:05:22,320
up there and it looks in the near

120
00:05:28,249 --> 00:05:25,259
infrared and the mid infrared so of

121
00:05:31,370 --> 00:05:28,259
course web is going to look at this so

122
00:05:33,830 --> 00:05:31,380
this month we released this near

123
00:05:38,810 --> 00:05:33,840
infrared view from web

124
00:05:41,629 --> 00:05:38,820
boom yeah yeah look at all that detail

125
00:05:44,210 --> 00:05:41,639
in that gas and dust that you do not see

126
00:05:47,210 --> 00:05:44,220
in the Hubble image but comes across

127
00:05:49,850 --> 00:05:47,220
really strongly when you look at it with

128
00:05:53,330 --> 00:05:49,860
web web has higher resolution higher

129
00:05:55,490 --> 00:05:53,340
spatial resolution and also web can get

130
00:05:59,029 --> 00:05:55,500
more

131
00:06:01,490 --> 00:05:59,039
um photons it's light Gathering Power is

132
00:06:03,890 --> 00:06:01,500
stronger also the other thing that makes

133
00:06:06,350 --> 00:06:03,900
this more colorful is Webb has many more

134
00:06:09,469 --> 00:06:06,360
filters in the infrared than Hubble does

135
00:06:11,689 --> 00:06:09,479
so it can create a wider Spectrum view

136
00:06:15,110 --> 00:06:11,699
in the near infrared

137
00:06:18,469 --> 00:06:15,120
but this is just the near infrared as a

138
00:06:21,950 --> 00:06:18,479

special Halloween treat last Friday we

139
00:06:25,309 --> 00:06:21,960
released the mid-infrared because

140
00:06:28,189 --> 00:06:25,319
that looks like a bunch of ghosts it has

141
00:06:30,050 --> 00:06:28,199
a ghostly feel to it now you'll notice

142
00:06:32,450 --> 00:06:30,060
one thing that there aren't that many

143
00:06:34,370 --> 00:06:32,460
stars in the mid infrared if we go come

144
00:06:37,249 --> 00:06:34,380
to the near infrared you see a ton of

145
00:06:40,730 --> 00:06:37,259
stars you go to the mid infrared you see

146
00:06:43,249 --> 00:06:40,740
fewer Stars that's because uh the

147
00:06:44,990 --> 00:06:43,259
emissions from Starlight Fades away as

148
00:06:47,809 --> 00:06:45,000
you go to the mid-infrared not that many

149
00:06:51,050 --> 00:06:47,819
stars actually shine in the mid infrared

150
00:06:53,330 --> 00:06:51,060
but the gas and dust shines really

151
00:06:55,309 --> 00:06:53,340
really well in the mid infrared

152
00:06:57,650 --> 00:06:55,319
um so you have even more detail in the

153
00:06:59,150 --> 00:06:57,660
mid infrared than you do in the near

154
00:07:00,409 --> 00:06:59,160
infrared

155
00:07:02,510 --> 00:07:00,419
but

156
00:07:06,050 --> 00:07:02,520
what I've showed you is all of the

157
00:07:08,450 --> 00:07:06,060
images co-aligned and basically all five

158
00:07:10,670 --> 00:07:08,460
of these images on the same spatial

159
00:07:13,010 --> 00:07:10,680
scale so that we can blink back and

160
00:07:14,689 --> 00:07:13,020
forth between them and see them but one

161
00:07:17,330 --> 00:07:14,699
of the things I want you to understand

162
00:07:18,730 --> 00:07:17,340
is that these different instruments that

163
00:07:21,730 --> 00:07:18,740

have done these different observations

164
00:07:26,029 --> 00:07:21,740
have actually very different resolutions

165
00:07:28,189 --> 00:07:26,039
so here is actually these five images on

166
00:07:31,129 --> 00:07:28,199
the same pixel scale

167
00:07:33,170 --> 00:07:31,139
and you can see that the near infrared

168
00:07:35,930 --> 00:07:33,180
image that web what we released from web

169
00:07:40,070 --> 00:07:35,940
this month has as many pixels more

170
00:07:44,210 --> 00:07:40,080
pixels than all the other four combined

171
00:07:46,610 --> 00:07:44,220
yeah so the amount of of uh pixel

172
00:07:50,930 --> 00:07:46,620
information we got from the web near

173
00:07:53,809 --> 00:07:50,940
infrared is amazing right and you will

174
00:07:56,870 --> 00:07:53,819
notice that the very first with pick 2

175
00:07:58,909 --> 00:07:56,880
image up in the top left that doesn't

176
00:08:02,150 --> 00:07:58,919
have that many pixels compared to things

177
00:08:04,510 --> 00:08:02,160
right and so that going to the uh the

178
00:08:07,309 --> 00:08:04,520
whiff C3 was a huge Improvement

179
00:08:09,050 --> 00:08:07,319
then you've got the near infrared and

180
00:08:11,330 --> 00:08:09,060
the mid infrared then you're in from

181
00:08:14,990 --> 00:08:11,340
Hubble in the mid infrared from web

182
00:08:18,409 --> 00:08:15,000
those are actually smaller because as

183
00:08:21,890 --> 00:08:18,419
you go to longer wavelengths you lose

184
00:08:23,629 --> 00:08:21,900
resolution okay the resolving power of a

185
00:08:25,610 --> 00:08:23,639
telescope is proportional to the

186
00:08:27,469 --> 00:08:25,620
wavelength you're looking at so that

187
00:08:29,570 --> 00:08:27,479
mirror image which looks so small down

188
00:08:31,550 --> 00:08:29,580

there in the bottom left left is

189
00:08:35,389 --> 00:08:31,560
actually looking at wavelengths that are

190
00:08:38,510 --> 00:08:35,399
10 to 20 times longer than the Hubble

191
00:08:40,190 --> 00:08:38,520
visible light image therefore its

192
00:08:42,409 --> 00:08:40,200
resolution is going to be much much

193
00:08:44,810 --> 00:08:42,419
smaller so although it's an amazing

194
00:08:48,710 --> 00:08:44,820
image it doesn't it has only just a bit

195
00:08:50,990 --> 00:08:48,720
more pixels than the uh original Hubble

196
00:08:53,449 --> 00:08:51,000
image from 1995.

197
00:08:56,690 --> 00:08:53,459
so knowing that let's take a look at a

198
00:08:59,750 --> 00:08:56,700
detail on a high resolution part of it

199
00:09:01,910 --> 00:08:59,760
so let's take a look at the top of this

200
00:09:04,490 --> 00:09:01,920
pillar here right let's take a look at

201
00:09:07,190 --> 00:09:04,500
the top of that pillar and this is the

202
00:09:09,350 --> 00:09:07,200
Hubble 1995 image and this had these

203
00:09:10,670 --> 00:09:09,360
little fingers sticking up which was

204
00:09:13,790 --> 00:09:10,680
really cool

205
00:09:15,230 --> 00:09:13,800
um as as the the gas is being eaten away

206
00:09:17,570 --> 00:09:15,240
and you're thinking these are the dense

207
00:09:19,250 --> 00:09:17,580
globules Where Stars might be forming

208
00:09:22,550 --> 00:09:19,260
the other thing I'll draw your attention

209
00:09:24,230 --> 00:09:22,560
to is this jet here okay there's a star

210
00:09:27,410 --> 00:09:24,240
that is formed here and there's a jet

211
00:09:30,190 --> 00:09:27,420
going off this way and this way all

212
00:09:32,949 --> 00:09:30,200
right and so when we got to the Hubble

213
00:09:36,769 --> 00:09:32,959

2015 20 years later

214
00:09:39,410 --> 00:09:36,779
you can see the resolution improvement

215
00:09:42,050 --> 00:09:39,420
from hubbells all right going from with

216
00:09:44,750 --> 00:09:42,060
pick two to with C3

217
00:09:47,090 --> 00:09:44,760
kind of cool the Improvement but you

218
00:09:50,870 --> 00:09:47,100
also notice if you look at this jet here

219
00:09:52,910 --> 00:09:50,880
that the jet actually extended over the

220
00:09:55,130 --> 00:09:52,920
course of 20 years

221
00:09:57,230 --> 00:09:55,140
that's kind of cool right

222
00:10:00,230 --> 00:09:57,240
then we go from Hubble

223
00:10:02,750 --> 00:10:00,240
visible to the Hubble infrared this is

224
00:10:04,610 --> 00:10:02,760
again near infrared all right and you

225
00:10:07,250 --> 00:10:04,620
can see how the resolution goes down and

226
00:10:10,070 --> 00:10:07,260
how it is so many more stars come out

227
00:10:12,829 --> 00:10:10,080
right because we're seeing into it uh

228
00:10:16,370 --> 00:10:12,839
you can see things like over here where

229
00:10:19,070 --> 00:10:16,380
uh the it looks relatively solid and

230
00:10:21,170 --> 00:10:19,080
Hubble over here and over here but

231
00:10:23,210 --> 00:10:21,180
actually the infrared view shows that

232
00:10:25,009 --> 00:10:23,220
there's not much there you see the

233
00:10:27,170 --> 00:10:25,019
really dense pieces with the infrared

234
00:10:29,930 --> 00:10:27,180
and here's where we can get to compare

235
00:10:32,389 --> 00:10:29,940
apples and apples Hubble to web here is

236
00:10:35,449 --> 00:10:32,399
Hubble's near infrared and here is

237
00:10:38,329 --> 00:10:35,459
Webb's near infrared I hope it comes

238
00:10:40,190 --> 00:10:38,339

across on the on the uh the video that's

239
00:10:42,290 --> 00:10:40,200
that there is a significant difference

240
00:10:45,050 --> 00:10:42,300
and look at the resolution difference

241
00:10:47,990 --> 00:10:45,060
that you get going to the web Space

242
00:10:51,230 --> 00:10:48,000
Telescope you also see a lot more

243
00:10:52,970 --> 00:10:51,240
texturing along the gas in here uh with

244
00:10:56,750 --> 00:10:52,980
web again because it has many more

245
00:10:59,690 --> 00:10:56,760
filters to pull out that detail and

246
00:11:02,930 --> 00:10:59,700
finally we go to the web mid infrared

247
00:11:04,250 --> 00:11:02,940
say goodbye to most of those stars and

248
00:11:06,590 --> 00:11:04,260
you can see that it's slightly

249
00:11:09,170 --> 00:11:06,600
significantly lower resolution in the

250
00:11:13,250 --> 00:11:09,180
mid infrared but you get all sorts of

251
00:11:15,650 --> 00:11:13,260
interesting detail again in the gas

252
00:11:17,870 --> 00:11:15,660
one thing I want to point out to you is

253
00:11:20,930 --> 00:11:17,880
if I go back to the Hubble visible image

254
00:11:24,889 --> 00:11:20,940
look at the surface of this brown gas

255
00:11:28,009 --> 00:11:24,899
here right as we go to the near infrared

256
00:11:30,530 --> 00:11:28,019
it shrinks a little bit all right and in

257
00:11:33,110 --> 00:11:30,540
the near infrared it's a lower level

258
00:11:35,889 --> 00:11:33,120
there and when you go to the mid

259
00:11:39,650 --> 00:11:35,899
infrared it gets even lower still right

260
00:11:42,650 --> 00:11:39,660
so what we are seeing is the rate the

261
00:11:45,889 --> 00:11:42,660
wavelengths looking deeper inside the

262
00:11:49,069 --> 00:11:45,899
nebula so that it grows as you go to the

263
00:11:52,730 --> 00:11:49,079

visible and it shrinks away

264
00:11:54,170 --> 00:11:52,740
as you go to the mid infrared now I

265
00:11:56,030 --> 00:11:54,180
could probably talk on this for hours

266
00:11:59,030 --> 00:11:56,040
because there's just so much detail in

267
00:12:01,670 --> 00:11:59,040
this but let me just leave it there and

268
00:12:04,190 --> 00:12:01,680
we will show you that there are two new

269
00:12:06,949 --> 00:12:04,200
images of the pillars in Eagle Nebula

270
00:12:08,990 --> 00:12:06,959
from the web Space Telescope these will

271
00:12:11,329 --> 00:12:09,000
tell us a lot more about the stars in

272
00:12:14,090 --> 00:12:11,339
there because uh the near infrared sees

273
00:12:16,310 --> 00:12:14,100
many many more stars invisible and the

274
00:12:20,810 --> 00:12:16,320
gas and dust how much gas and dust is

275
00:12:29,810 --> 00:12:25,370
all right our speaker tonight

276
00:12:32,389 --> 00:12:29,820
um is Stephanie lamasa and Stephanie

277
00:12:34,730 --> 00:12:32,399
um is a scientist at the Space Telescope

278
00:12:37,490 --> 00:12:34,740
Science Institute working on the James

279
00:12:39,410 --> 00:12:37,500
Webb Space Telescope she got her

280
00:12:42,829 --> 00:12:39,420
undergraduate degree from Boston

281
00:12:45,170 --> 00:12:42,839
University and after that she worked as

282
00:12:48,410 --> 00:12:45,180
a mission planner for the Chandra x-ray

283
00:12:49,490 --> 00:12:48,420
Observatory which is run out of

284
00:12:52,690 --> 00:12:49,500
um

285
00:12:57,290 --> 00:12:52,700
the Harvard Smithsonian in Boston

286
00:13:00,490 --> 00:12:57,300
she then went on to get her PhD here in

287
00:13:03,530 --> 00:13:00,500
Baltimore at Johns Hopkins University

288
00:13:06,889 --> 00:13:03,540

and after the John Johns Hopkins she did

289
00:13:10,730 --> 00:13:06,899
a post-doctoral uh studies up at Yale

290
00:13:12,889 --> 00:13:10,740
University and then a fellowship at

291
00:13:14,930 --> 00:13:12,899
Goddard space flight center so she's

292
00:13:17,810 --> 00:13:14,940
been she's been going up and down the

293
00:13:19,970 --> 00:13:17,820
East Coast throughout her uh throughout

294
00:13:21,410 --> 00:13:19,980
her career she's been here at Space

295
00:13:23,650 --> 00:13:21,420
Telescope we've been lucky enough to

296
00:13:26,389 --> 00:13:23,660
have her for five years

297
00:13:29,090 --> 00:13:26,399
and when I asked her what does she do

298
00:13:31,190 --> 00:13:29,100
that's a little offbeat well she says

299
00:13:33,590 --> 00:13:31,200
she does some panelists at sci-fi

300
00:13:36,769 --> 00:13:33,600
conventions uh she has been several

301
00:13:40,250 --> 00:13:36,779
times to both Dragon Con and to awesome

302
00:13:42,650 --> 00:13:40,260
Khan so we're expecting an awesome talk

303
00:13:45,230 --> 00:13:42,660
here today Stephanie sorry had to do it

304
00:13:46,670 --> 00:13:45,240
uh ladies and gentlemen's Dr Stephanie

305
00:13:48,769 --> 00:13:46,680
lamasa

306
00:13:50,509 --> 00:13:48,779
all right thanks a lot for that

307
00:13:52,970 --> 00:13:50,519
introduction Frank and thanks to

308
00:13:54,590 --> 00:13:52,980
everyone for tuning in to hear about

309
00:13:56,030 --> 00:13:54,600
black holes

310
00:14:00,110 --> 00:13:56,040
okay

311
00:14:03,230 --> 00:14:00,120
so black holes are probably the most

312
00:14:06,110 --> 00:14:03,240
enigmatic objects in the universe

313
00:14:09,710 --> 00:14:06,120

and they are objects that I think

314
00:14:12,110 --> 00:14:09,720
rightfully Captivate the imagination

315
00:14:14,889 --> 00:14:12,120
and though they serve as an inspiration

316
00:14:17,690 --> 00:14:14,899
for a myriad of Science Fiction media

317
00:14:19,850 --> 00:14:17,700
they very much have their basis in

318
00:14:22,730 --> 00:14:19,860
science fact

319
00:14:25,190 --> 00:14:22,740
black holes are a natural consequence of

320
00:14:27,710 --> 00:14:25,200
the description of phys of gravity

321
00:14:32,750 --> 00:14:27,720
through the theory of general relativity

322
00:14:35,509 --> 00:14:32,760
which says that mass itself curves space

323
00:14:38,569 --> 00:14:35,519
so motions of objects whether they be

324
00:14:41,629 --> 00:14:38,579
planets moons comets even lighted

325
00:14:45,129 --> 00:14:41,639
stealth can be understood through its

326
00:14:49,670 --> 00:14:45,139
interaction with curved space-time

327
00:14:53,750 --> 00:14:49,680
and the more massive an object is the

328
00:14:57,050 --> 00:14:53,760
more that space-time itself bends

329
00:15:00,410 --> 00:14:57,060
so take into an extreme you can have an

330
00:15:02,990 --> 00:15:00,420
object so massive in such a small region

331
00:15:06,410 --> 00:15:03,000
of space that the density becomes

332
00:15:08,150 --> 00:15:06,420
infinite and that causes a singularity

333
00:15:12,230 --> 00:15:08,160
and this has interesting consequences

334
00:15:15,110 --> 00:15:12,240
for the Escape speed which is the

335
00:15:17,269 --> 00:15:15,120
velocity that an object needs to have in

336
00:15:18,829 --> 00:15:17,279
order to escape the gravitational pull

337
00:15:21,410 --> 00:15:18,839
of a body

338
00:15:23,990 --> 00:15:21,420

and that escape velocity depends on that

339
00:15:26,750 --> 00:15:24,000
body's mass and that body's radius

340
00:15:30,350 --> 00:15:26,760
so let's take the Earth as an example

341
00:15:32,210 --> 00:15:30,360
the Escape speed of the earth is 11.2

342
00:15:35,150 --> 00:15:32,220
kilometers per second

343
00:15:38,329 --> 00:15:35,160
so if our little rocket ship here wants

344
00:15:40,970 --> 00:15:38,339
to lift off into space it has to be able

345
00:15:43,670 --> 00:15:40,980
to travel faster than that speed and if

346
00:15:48,350 --> 00:15:43,680
it's able to do so it travels merrily

347
00:15:53,889 --> 00:15:51,050
if we replace the Earth with a

348
00:15:56,689 --> 00:15:53,899
singularity then the Escape speed

349
00:16:00,410 --> 00:15:56,699
becomes the speed of light

350
00:16:02,449 --> 00:16:00,420
and nothing can travel faster than light

351
00:16:04,970 --> 00:16:02,459
and so this is what we mean when we say

352
00:16:07,910 --> 00:16:04,980
that there's a black hole

353
00:16:10,370 --> 00:16:07,920
now if our little spaceship here happens

354
00:16:13,250 --> 00:16:10,380
to cross the Event Horizon of the black

355
00:16:15,110 --> 00:16:13,260
hole that defines the region where the

356
00:16:16,250 --> 00:16:15,120
Escape speed is equal to the speed of

357
00:16:19,009 --> 00:16:16,260
light

358
00:16:22,069 --> 00:16:19,019
and no matter how much our little rocket

359
00:16:24,110 --> 00:16:22,079
ship fires its thrusters it cannot go

360
00:16:28,970 --> 00:16:24,120
fast enough to escape the gravitational

361
00:16:31,930 --> 00:16:28,980
pull and our poor spaceship is doomed

362
00:16:35,569 --> 00:16:31,940
so how do we get black holes

363
00:16:37,150 --> 00:16:35,579

they are an end product of Stellar

364
00:16:40,490 --> 00:16:37,160
evolution

365
00:16:42,769 --> 00:16:40,500
stars that are at least several times

366
00:16:46,069 --> 00:16:42,779
more massive than our sun

367
00:16:48,590 --> 00:16:46,079
go through life and end their lives in

368
00:16:50,389 --> 00:16:48,600
an energetic Supernova explosion that

369
00:16:52,370 --> 00:16:50,399
since the shock wave careening into

370
00:16:55,249 --> 00:16:52,380
Interstellar space

371
00:16:59,509 --> 00:16:55,259
heating the gas up to high temperatures

372
00:17:02,629 --> 00:16:59,519
what's left is the core of that star

373
00:17:05,150 --> 00:17:02,639
and if that Remnant is dense enough it

374
00:17:06,770 --> 00:17:05,160
can then collapse on itself to become a

375
00:17:12,590 --> 00:17:06,780
black hole

376
00:17:15,530 --> 00:17:12,600
light can escape it then how do we

377
00:17:17,390 --> 00:17:15,540
actually see these objects

378
00:17:19,130 --> 00:17:17,400
and to answer that question we first

379
00:17:21,829 --> 00:17:19,140
have to Define what it is that we mean

380
00:17:28,370 --> 00:17:25,010
for those of us with sight all the rich

381
00:17:30,789 --> 00:17:28,380
colors that we can see it's just an

382
00:17:33,169 --> 00:17:30,799
overall small part of the

383
00:17:36,350 --> 00:17:33,179
electromagnetic spectrum

384
00:17:38,990 --> 00:17:36,360
there's light at higher energies and

385
00:17:40,789 --> 00:17:39,000
light at lower Energies

386
00:17:43,909 --> 00:17:40,799
and most of this light we can't see with

387
00:17:46,970 --> 00:17:43,919
our eyes but we could build telescopes

388
00:17:49,549 --> 00:17:46,980

to detect that light and that becomes

389
00:17:51,830 --> 00:17:49,559
really important because objects

390
00:17:54,710 --> 00:17:51,840
throughout the Universe give off light

391
00:17:56,450 --> 00:17:54,720
across the electromagnetic spectrum

392
00:17:58,669 --> 00:17:56,460
so if we really want to understand the

393
00:18:00,890 --> 00:17:58,679
universe in our place in it we have to

394
00:18:03,950 --> 00:18:00,900
build a telescopes that's sensitive to

395
00:18:06,350 --> 00:18:03,960
all these wavelengths of light

396
00:18:08,810 --> 00:18:06,360
this also becomes really important for

397
00:18:11,330 --> 00:18:08,820
understanding black holes because though

398
00:18:13,610 --> 00:18:11,340
we can't see them directly we can see

399
00:18:16,190 --> 00:18:13,620
the effects that they have on their

400
00:18:19,430 --> 00:18:16,200
environment and their surroundings

401
00:18:22,010 --> 00:18:19,440
and oftentimes those effects can't be

402
00:18:25,909 --> 00:18:22,020
seen in visible light but in other parts

403
00:18:27,950 --> 00:18:25,919
of the electromagnetic spectrum

404
00:18:31,730 --> 00:18:27,960
and here's one example

405
00:18:33,409 --> 00:18:31,740
many stars live in binary systems so

406
00:18:35,570 --> 00:18:33,419
these are two stars that orbit around

407
00:18:37,970 --> 00:18:35,580
each other around a Common Center of

408
00:18:40,909 --> 00:18:37,980
mass our sun slope of an outlier being

409
00:18:43,490 --> 00:18:40,919
in a single star system

410
00:18:46,130 --> 00:18:43,500
now if both of these stars are much

411
00:18:48,650 --> 00:18:46,140
heavier than our own Sun then they will

412
00:18:50,510 --> 00:18:48,660
eventually end their lives as black

413
00:18:52,730 --> 00:18:50,520

holes

414
00:18:54,710 --> 00:18:52,740
one star is likely going to be bigger

415
00:18:57,169 --> 00:18:54,720
than the other so it's going to go

416
00:18:59,570 --> 00:18:57,179
through its life quicker

417
00:19:01,370 --> 00:18:59,580
it'll go to a stage where it expands as

418
00:19:04,610 --> 00:19:01,380
a red giant

419
00:19:07,370 --> 00:19:04,620
it'll go supernova and then it'll

420
00:19:09,830 --> 00:19:07,380
collapse into a black hole

421
00:19:11,570 --> 00:19:09,840
now at this point the companion star is

422
00:19:13,970 --> 00:19:11,580
just merely living it's a good life

423
00:19:16,310 --> 00:19:13,980
converting hydrogen into helium in its

424
00:19:18,289 --> 00:19:16,320
core doing what stars do

425
00:19:20,510 --> 00:19:18,299
and just part of that its atmosphere

426
00:19:23,150 --> 00:19:20,520
expands into space through Stellar winds

427
00:19:26,870 --> 00:19:23,160
and some of that material will find its

428
00:19:29,570 --> 00:19:26,880
way over to its companion black hole

429
00:19:32,029 --> 00:19:29,580
we could fast forward this film and that

430
00:19:35,210 --> 00:19:32,039
star will eventually become a red giant

431
00:19:37,669 --> 00:19:35,220
so it'll expand sending even more

432
00:19:40,070 --> 00:19:37,679
material out that will find its way to

433
00:19:41,690 --> 00:19:40,080
the black hole and if we want to zoom in

434
00:19:43,730 --> 00:19:41,700
on what that looks like we could see

435
00:19:46,669 --> 00:19:43,740
that in this right panel

436
00:19:49,130 --> 00:19:46,679
where this material that comes out

437
00:19:52,490 --> 00:19:49,140
combed close enough to the black hole

438
00:19:56,390 --> 00:19:52,500

starts to spiral into the black hole it

439
00:19:59,210 --> 00:19:56,400
forms a disc to due to conservation of

440
00:20:01,070 --> 00:19:59,220
angular momentum and as that material

441
00:20:04,370 --> 00:20:01,080
spirals closer and closer to the black

442
00:20:07,490 --> 00:20:04,380
hole it eventually Falls in in a process

443
00:20:09,950 --> 00:20:07,500
where the black hole grows in Mass we

444
00:20:11,990 --> 00:20:09,960
call this process accretion and we call

445
00:20:14,529 --> 00:20:12,000
that disk of material that feeds a black

446
00:20:17,450 --> 00:20:14,539
hole and accretion disk

447
00:20:20,690 --> 00:20:17,460
now this process of accretion gives off

448
00:20:23,210 --> 00:20:20,700
a lot of energy the material rubs

449
00:20:26,150 --> 00:20:23,220
against each other releasing lots of

450
00:20:30,470 --> 00:20:26,160
friction which gives off energy and

451
00:20:31,970 --> 00:20:30,480
reaches temperatures that reach into the

452
00:20:34,610 --> 00:20:31,980
X-ray regime

453
00:20:36,950 --> 00:20:34,620
so these objects do a great job of

454
00:20:41,029 --> 00:20:36,960
giving off x-ray light

455
00:20:43,610 --> 00:20:41,039
and in fact in the 1960s this is one of

456
00:20:45,590 --> 00:20:43,620
the first x-ray objects from outer space

457
00:20:47,510 --> 00:20:45,600
that was detected

458
00:20:49,789 --> 00:20:47,520
at this time there were experiments that

459
00:20:51,890 --> 00:20:49,799
had x-ray detectors that were launched

460
00:20:54,049 --> 00:20:51,900
onto Rockets to get above the atmosphere

461
00:20:55,909 --> 00:20:54,059
our atmosphere does a really great job

462
00:20:57,590 --> 00:20:55,919
of blocking out x-ray light from space

463
00:20:59,270 --> 00:20:57,600

which is really good for our own health

464
00:21:01,370 --> 00:20:59,280
a little bit challenging for x-ray

465
00:21:03,770 --> 00:21:01,380
astronomy because you need to get above

466
00:21:06,770 --> 00:21:03,780
the atmosphere to see x-rays

467
00:21:10,190 --> 00:21:06,780
one of the first sources of X-ray light

468
00:21:13,130 --> 00:21:10,200
detected was in the cygnus constellation

469
00:21:16,970 --> 00:21:13,140
this object was called cygnus excellent

470
00:21:19,549 --> 00:21:16,980
x-ray source and cygnus and we now know

471
00:21:22,789 --> 00:21:19,559
as quickly learned afterwards that what

472
00:21:26,150 --> 00:21:22,799
was being observed was x-rays from an

473
00:21:29,990 --> 00:21:26,160
accreting black hole that was stealing

474
00:21:31,850 --> 00:21:30,000
material from its companion star

475
00:21:33,590 --> 00:21:31,860
we could go back to our picture of

476
00:21:36,770 --> 00:21:33,600
Stellar Evolution and turn the clock

477
00:21:39,890 --> 00:21:36,780
forward eventually that companion itself

478
00:21:42,950 --> 00:21:39,900
is going to go supernova and then you're

479
00:21:45,350 --> 00:21:42,960
left with two black holes

480
00:21:48,470 --> 00:21:45,360
now at this point There's No Object

481
00:21:50,930 --> 00:21:48,480
around to feed either of the black holes

482
00:21:54,110 --> 00:21:50,940
to let them shine in light

483
00:21:56,210 --> 00:21:54,120
so these black holes are now proper dark

484
00:21:58,430 --> 00:21:56,220
how do we find these

485
00:22:00,590 --> 00:21:58,440
we'll get back to that by the end of the

486
00:22:03,890 --> 00:22:00,600
talk

487
00:22:06,770 --> 00:22:03,900
so this is a picture that explains black

488
00:22:09,649 --> 00:22:06,780

holes that are several times heavier

489
00:22:12,110 --> 00:22:09,659
than our own sun to maybe around a

490
00:22:13,070 --> 00:22:12,120
hundred times or so heavier than our own

491
00:22:17,029 --> 00:22:13,080
Sun

492
00:22:19,370 --> 00:22:17,039
we call these Stellar Mass black holes

493
00:22:21,830 --> 00:22:19,380
and where we have found Stellar Mass

494
00:22:25,490 --> 00:22:21,840
black holes are in these binary star

495
00:22:27,710 --> 00:22:25,500
systems that are giving off x-ray light

496
00:22:30,409 --> 00:22:27,720
we see this in the center of our own

497
00:22:33,890 --> 00:22:30,419
Milky Way galaxy here's the beautiful

498
00:22:36,710 --> 00:22:33,900
image of the Milky Way Center and x-rays

499
00:22:39,350 --> 00:22:36,720
and we also see this in other galaxies

500
00:22:41,930 --> 00:22:39,360
that are relatively nearby where we're

501
00:22:44,630 --> 00:22:41,940
measuring here the distance to galaxies

502
00:22:47,510 --> 00:22:44,640
in units of the amount of time it takes

503
00:22:48,890 --> 00:22:47,520
for light to travel from that galaxy to

504
00:22:51,289 --> 00:22:48,900
us

505
00:22:54,230 --> 00:22:51,299
so these are x-ray images of two

506
00:22:56,270 --> 00:22:54,240
beautiful nearby galaxies and you might

507
00:22:58,310 --> 00:22:56,280
see these points of light

508
00:23:00,110 --> 00:22:58,320
um in these images

509
00:23:02,930 --> 00:23:00,120
some of those points are other x-ray

510
00:23:06,230 --> 00:23:02,940
sources it might be neutron stars but

511
00:23:09,830 --> 00:23:06,240
some of these are black holes in binary

512
00:23:16,070 --> 00:23:12,890
there's another class of objects that we

513
00:23:18,890 --> 00:23:16,080

call supermassive black holes these are

514
00:23:21,289 --> 00:23:18,900
millions to billions of times heavier

515
00:23:24,529 --> 00:23:21,299
than our own Sun

516
00:23:25,789 --> 00:23:24,539
and these live in the centers of

517
00:23:30,250 --> 00:23:25,799
galaxies

518
00:23:33,890 --> 00:23:30,260
black holes live in they're really small

519
00:23:35,930 --> 00:23:33,900
it could be anywhere of a factor of tens

520
00:23:39,169 --> 00:23:35,940
of thousands of times less massive than

521
00:23:41,750 --> 00:23:39,179
the Galaxy to up to a million times less

522
00:23:43,370 --> 00:23:41,760
massive than the Galaxy

523
00:23:45,110 --> 00:23:43,380
and most of the time these black holes

524
00:23:46,730 --> 00:23:45,120
are dormant

525
00:23:49,070 --> 00:23:46,740
but sometimes

526
00:23:52,370 --> 00:23:49,080
we catch them in a phase where they're

527
00:23:55,970 --> 00:23:52,380
actively are creating matter like their

528
00:23:59,090 --> 00:23:55,980
Stellar masks x-ray binary cousins

529
00:24:02,270 --> 00:23:59,100
and when we observe galaxies hosting

530
00:24:06,350 --> 00:24:02,280
these actively growing black holes we

531
00:24:08,510 --> 00:24:06,360
call them active Galactic nuclei or AGN

532
00:24:10,510 --> 00:24:08,520
and these are the types of objects that

533
00:24:14,330 --> 00:24:10,520
I study

534
00:24:18,169 --> 00:24:14,340
so again like their Stellar Mass uh

535
00:24:21,409 --> 00:24:18,179
cousins these AGN do a really good job

536
00:24:22,909 --> 00:24:21,419
of giving off x-ray light as well as

537
00:24:24,230 --> 00:24:22,919
light across the electromagnetic

538
00:24:27,250 --> 00:24:24,240

spectrum

539
00:24:31,070 --> 00:24:27,260
and because this process is so energetic

540
00:24:33,830 --> 00:24:31,080
we could detect galaxies hosting these

541
00:24:37,450 --> 00:24:33,840
growing black holes from nearby galaxies

542
00:24:40,669 --> 00:24:37,460
to galaxies to the edge of the universe

543
00:24:43,909 --> 00:24:40,679
so an example of how we could use x-ray

544
00:24:49,130 --> 00:24:43,919
light to find an AGN in your bike Galaxy

545
00:24:51,409 --> 00:24:49,140
is um NGC 1365 which is the Galaxy 80

546
00:24:53,450 --> 00:24:51,419
million light years away and this

547
00:24:56,630 --> 00:24:53,460
visible light image is just absolutely

548
00:24:59,090 --> 00:24:56,640
stunning it's this barred spiral

549
00:25:02,090 --> 00:24:59,100
if you were to observe the center of

550
00:25:04,970 --> 00:25:02,100
this galaxy an x-ray light you see some

551
00:25:07,789 --> 00:25:04,980
of this like diffuse-ish emission that's

552
00:25:10,310 --> 00:25:07,799
from hot gas but you see this bright

553
00:25:12,830 --> 00:25:10,320
point of light in the center

554
00:25:18,169 --> 00:25:12,840
and that is showing us where this

555
00:25:21,789 --> 00:25:20,750
and we could also do this Across the

556
00:25:25,310 --> 00:25:21,799
Universe

557
00:25:28,549 --> 00:25:25,320
on the right is a visible light image of

558
00:25:31,430 --> 00:25:28,559
the Hubble Deep Field so it's a little

559
00:25:34,490 --> 00:25:31,440
piece of Sky about 1 12 the size of the

560
00:25:38,330 --> 00:25:34,500
Moon that Hubble observed for 10 days

561
00:25:41,450 --> 00:25:38,340
detecting thousands of galaxies

562
00:25:44,390 --> 00:25:41,460
the Chandra x-ray Observatory also

563
00:25:47,330 --> 00:25:44,400

looked at this region of sky and that is

564
00:25:51,169 --> 00:25:47,340
the image that is shown on the left

565
00:25:53,630 --> 00:25:51,179
and in that image over a thousand uh

566
00:25:58,430 --> 00:25:53,640
x-ray sources were detected

567
00:26:01,070 --> 00:25:58,440
many of which are growing black holes in

568
00:26:05,870 --> 00:26:01,080
other galaxies

569
00:26:09,350 --> 00:26:05,880
so another way to experience the Chandra

570
00:26:11,990 --> 00:26:09,360
x-ray Deep Field is through sonification

571
00:26:14,570 --> 00:26:12,000
which is a process where data is

572
00:26:18,289 --> 00:26:14,580
translated into sound

573
00:26:20,510 --> 00:26:18,299
so the colors of these points that you

574
00:26:22,669 --> 00:26:20,520
see here encode information about the

575
00:26:26,210 --> 00:26:22,679
energy of the X-ray source

576
00:26:29,210 --> 00:26:26,220
the red colors are lower x-ray energies

577
00:26:32,269 --> 00:26:29,220
and the blue and purple colors are

578
00:26:35,269 --> 00:26:32,279
higher x-ray Energies

579
00:26:37,909 --> 00:26:35,279
in the sonification process those colors

580
00:26:43,130 --> 00:26:37,919
were converted into tones

581
00:26:45,350 --> 00:26:43,140
so the low tones are for the red sources

582
00:26:49,010 --> 00:26:45,360
which are lower energy

583
00:26:53,090 --> 00:26:49,020
and the high tones are for the purple

584
00:26:54,830 --> 00:26:53,100
and blue sources which are higher energy

585
00:26:58,370 --> 00:26:54,840
so when I play this we'll see a bar

586
00:27:00,590 --> 00:26:58,380
sweep up through the image and uh that

587
00:27:03,049 --> 00:27:00,600
will tell you uh what what the sources

588
00:27:07,240 --> 00:27:03,059

are that are producing the sound that

589
00:27:25,610 --> 00:27:17,530
[Music]

590
00:27:25,620 --> 00:27:32,860
foreign

591
00:27:32,870 --> 00:27:52,730
[Music]

592
00:27:57,049 --> 00:27:55,010
so this provides another way of

593
00:27:59,690 --> 00:27:57,059
interpreting the data a way that could

594
00:28:01,789 --> 00:27:59,700
be accessible for those who who are

595
00:28:04,070 --> 00:28:01,799
blind or who have other types of

596
00:28:07,850 --> 00:28:04,080
problems with vision

597
00:28:11,269 --> 00:28:07,860
so while x-rays provide a great probe

598
00:28:13,430 --> 00:28:11,279
for identifying supermassive black holes

599
00:28:16,250 --> 00:28:13,440
there's a lot that we learn from

600
00:28:17,269 --> 00:28:16,260
observations across the electromagnetic

601
00:28:19,310 --> 00:28:17,279
spectrum

602
00:28:22,430 --> 00:28:19,320
and they complement each other to

603
00:28:25,850 --> 00:28:22,440
highlight different physical processes

604
00:28:29,390 --> 00:28:25,860
and this is well Illustrated in a nearby

605
00:28:31,010 --> 00:28:29,400
Galaxy Centaurus a which probably no

606
00:28:33,470 --> 00:28:31,020
surprise because I'm talking about it

607
00:28:34,669 --> 00:28:33,480
Centaurus a hosts a growing supermassive

608
00:28:37,250 --> 00:28:34,679
black hole

609
00:28:40,430 --> 00:28:37,260
so again striking image of the Galaxy

610
00:28:43,370 --> 00:28:40,440
with a very dramatic dust Lane that cuts

611
00:28:45,710 --> 00:28:43,380
through the center of the Galaxy

612
00:28:49,010 --> 00:28:45,720
if we observe this galaxy in infrared

613
00:28:52,190 --> 00:28:49,020

light the dust lights up

614
00:28:54,529 --> 00:28:52,200
and we can start seeing behind that veil

615
00:28:57,950 --> 00:28:54,539
of dust in particular the point of light

616
00:29:00,230 --> 00:28:57,960
in the galactic nucleus showing us where

617
00:29:02,630 --> 00:29:00,240
the black hole lies

618
00:29:04,810 --> 00:29:02,640
and in fact as you probably got from um

619
00:29:07,970 --> 00:29:04,820
Frank's presentation at the beginning

620
00:29:10,190 --> 00:29:07,980
for the news updates this is one of the

621
00:29:11,750 --> 00:29:10,200
reasons why infrared is such a powerful

622
00:29:14,630 --> 00:29:11,760
probe to learn about the universe

623
00:29:17,630 --> 00:29:14,640
because it gives us that ability to peer

624
00:29:19,909 --> 00:29:17,640
through a Dusty Veil

625
00:29:21,909 --> 00:29:19,919
once we get to x-ray light things start

626
00:29:25,190 --> 00:29:21,919
looking a little bit different

627
00:29:28,430 --> 00:29:25,200
here's the X-ray image let me see this

628
00:29:31,190 --> 00:29:28,440
long thin filament cutting through the

629
00:29:33,409 --> 00:29:31,200
Galaxy and then once we go to Radio

630
00:29:36,590 --> 00:29:33,419
light we see a thin filament that ends

631
00:29:39,830 --> 00:29:36,600
in these fluffy lobes

632
00:29:42,590 --> 00:29:39,840
what the x-rays and radio are showing us

633
00:29:45,830 --> 00:29:42,600
are jets that are being launched from

634
00:29:49,130 --> 00:29:45,840
the AGN these are accelerating particles

635
00:29:51,470 --> 00:29:49,140
to close to the speed of light through a

636
00:29:53,630 --> 00:29:51,480
mechanism that's either

637
00:29:56,090 --> 00:29:53,640
um using magnetic fields to tap the

638
00:29:58,370 --> 00:29:56,100

rotational energy from the black hole

639
00:30:00,529 --> 00:29:58,380
might be coming from the inner edge of

640
00:30:03,649 --> 00:30:00,539
this secretion disk we're still trying

641
00:30:05,570 --> 00:30:03,659
to understand how these Jets form but we

642
00:30:08,990 --> 00:30:05,580
know they're there we know they see the

643
00:30:12,950 --> 00:30:09,000
we see them and we know that they are a

644
00:30:16,669 --> 00:30:12,960
part of some egn that we observe and

645
00:30:20,149 --> 00:30:16,679
that they could be extremely powerful

646
00:30:23,330 --> 00:30:20,159
and when we put this all together one of

647
00:30:27,110 --> 00:30:23,340
the Striking things that jumps out is

648
00:30:30,289 --> 00:30:27,120
just how massive these jets are compared

649
00:30:32,750 --> 00:30:30,299
to the Galaxy in which it lives they're

650
00:30:34,669 --> 00:30:32,760
bigger than the Galaxy

651
00:30:37,250 --> 00:30:34,679
and it's remarkable to think about right

652
00:30:39,649 --> 00:30:37,260
when we compare the black hole to the

653
00:30:42,409 --> 00:30:39,659
Galaxy itself the black hole is just so

654
00:30:44,690 --> 00:30:42,419
much smaller and it's over such a so

655
00:30:46,850 --> 00:30:44,700
much less mess such a tiny area

656
00:30:49,070 --> 00:30:46,860
but it could have this outsized impact

657
00:30:53,090 --> 00:30:49,080
where it's launching these energetic

658
00:30:56,149 --> 00:30:53,100
outflows that outstrips the Galaxy

659
00:30:57,950 --> 00:30:56,159
this is also an example of how when we

660
00:31:00,350 --> 00:30:57,960
could combine data from different

661
00:31:02,450 --> 00:31:00,360
wavelengths we have a more complete

662
00:31:05,330 --> 00:31:02,460
picture of the physical processes at

663
00:31:07,730 --> 00:31:05,340

play in this galaxy and what the black

664
00:31:09,190 --> 00:31:07,740
hole itself is doing

665
00:31:12,649 --> 00:31:09,200
foreign

666
00:31:15,950 --> 00:31:12,659
talked about so far has focused on how

667
00:31:18,529 --> 00:31:15,960
we could use images to identify black

668
00:31:20,630 --> 00:31:18,539
holes and learn a little bit about the

669
00:31:22,850 --> 00:31:20,640
physical processes

670
00:31:24,769 --> 00:31:22,860
there's another technique that we use

671
00:31:26,570 --> 00:31:24,779
that's quite powerful called

672
00:31:34,970 --> 00:31:26,580
spectroscopy

673
00:31:37,070 --> 00:31:34,980
into very fine wavelengths in a process

674
00:31:39,710 --> 00:31:37,080
that's very similar to how a prism

675
00:31:42,169 --> 00:31:39,720
disperses white light into its

676
00:31:45,049 --> 00:31:42,179
constituent colors

677
00:31:48,710 --> 00:31:45,059
so this is a beautiful image of the

678
00:31:51,649 --> 00:31:48,720
Southern Crab Nebula so not a Galaxy not

679
00:31:56,769 --> 00:31:51,659
an egn but an excellent visual

680
00:32:00,649 --> 00:31:56,779
illustration of how spectroscopy works

681
00:32:03,470 --> 00:32:00,659
elements shine at very specific colors

682
00:32:04,970 --> 00:32:03,480
or wavelengths of light and that's

683
00:32:06,950 --> 00:32:04,980
determined by the laws of quantum

684
00:32:10,909 --> 00:32:06,960
mechanics

685
00:32:13,850 --> 00:32:10,919
so in the top panel of images what

686
00:32:17,570 --> 00:32:13,860
you're seeing are images of this of this

687
00:32:20,870 --> 00:32:17,580
nebula taken with filters that are

688
00:32:23,149 --> 00:32:20,880

centered at these specific wavelengths

689
00:32:25,310 --> 00:32:23,159
where these elements shine these are

690
00:32:27,649 --> 00:32:25,320
ionized species of oxygen hydrogen

691
00:32:31,490 --> 00:32:27,659
nitrogen and sulfur

692
00:32:34,669 --> 00:32:31,500
the bottom panel is the Spectrum showing

693
00:32:37,669 --> 00:32:34,679
discrete sharp lines at these very

694
00:32:40,570 --> 00:32:37,679
specific wavelengths again corresponding

695
00:32:44,630 --> 00:32:40,580
to the light coming from these elements

696
00:32:47,090 --> 00:32:44,640
and this is why we could use Spectra as

697
00:32:49,669 --> 00:32:47,100
Fingerprints of elements to determine

698
00:32:51,769 --> 00:32:49,679
the chemical composition of the object

699
00:32:54,409 --> 00:32:51,779
that we're studying

700
00:32:57,110 --> 00:32:54,419
Spectra also tells us what the energy

701
00:33:00,049 --> 00:32:57,120
source is that's lighting up the gas

702
00:33:03,889 --> 00:33:00,059
that we're observing and it does a whole

703
00:33:13,070 --> 00:33:10,430
so here is a spectrum of a class of AGN

704
00:33:14,690 --> 00:33:13,080
very similar conceptually to what we saw

705
00:33:18,529 --> 00:33:14,700
in the previous slide

706
00:33:20,870 --> 00:33:18,539
the x or horizontal axis is showing us

707
00:33:24,350 --> 00:33:20,880
the wavelengths of light

708
00:33:27,769 --> 00:33:24,360
the y or vertical axis is showing us the

709
00:33:29,269 --> 00:33:27,779
amount of energy being given off at each

710
00:33:33,230 --> 00:33:29,279
wavelength

711
00:33:35,990 --> 00:33:33,240
and we see these sharp lines in the

712
00:33:38,389 --> 00:33:36,000
Spectrum these lines correspond to

713
00:33:40,970 --> 00:33:38,399

ionized species of hydrogen carbon

714
00:33:43,909 --> 00:33:40,980
magnesium oxygen

715
00:33:46,430 --> 00:33:43,919
and what the spectrum is telling us is

716
00:33:49,549 --> 00:33:46,440
that the energy source lighting up the

717
00:33:51,049 --> 00:33:49,559
gas is an accreting supermassive black

718
00:33:54,350 --> 00:33:51,059
hole

719
00:33:56,649 --> 00:33:54,360
other processes in galaxies don't cause

720
00:33:58,970 --> 00:33:56,659
these features with these specific

721
00:34:02,029 --> 00:33:58,980
characteristics whether it's the

722
00:34:04,669 --> 00:34:02,039
intensity of the line or the width of

723
00:34:06,649 --> 00:34:04,679
the line or the relative intensities of

724
00:34:09,169 --> 00:34:06,659
the lines compared with each other

725
00:34:11,930 --> 00:34:09,179
so it becomes a very powerful diagnostic

726
00:34:14,089 --> 00:34:11,940
to identify galaxies hosting growing

727
00:34:15,770 --> 00:34:14,099
black holes

728
00:34:18,290 --> 00:34:15,780
and as you might be able to tell some

729
00:34:20,629 --> 00:34:18,300
lines are wider than the others

730
00:34:23,690 --> 00:34:20,639
um and that's because that is those

731
00:34:26,210 --> 00:34:23,700
lines are coming from gas that is closer

732
00:34:27,290 --> 00:34:26,220
to the black hole so it's orbiting more

733
00:34:29,570 --> 00:34:27,300
rapidly

734
00:34:31,669 --> 00:34:29,580
while the lines that are more narrow are

735
00:34:34,010 --> 00:34:31,679
coming from gas that are further away

736
00:34:36,169 --> 00:34:34,020
from the black hole so it's orbiting

737
00:34:40,310 --> 00:34:36,179
slower

738
00:34:43,250 --> 00:34:40,320

so again using Spectra are almost a gold

739
00:34:45,649 --> 00:34:43,260
standard for identifying which galaxies

740
00:34:48,889 --> 00:34:45,659
host growing supermassive black holes

741
00:34:51,050 --> 00:34:48,899
and this is one technique that I use in

742
00:34:53,930 --> 00:34:51,060
my research just this past month I've

743
00:34:56,810 --> 00:34:53,940
been on several observing runs with two

744
00:35:00,890 --> 00:34:56,820
telescopes where I have been taking

745
00:35:04,010 --> 00:35:00,900
Spectra of objects that I believe are

746
00:35:06,770 --> 00:35:04,020
are AGN and the Spectra are what tell me

747
00:35:09,829 --> 00:35:06,780
whether or not that's true

748
00:35:13,190 --> 00:35:09,839
so that's one way to study these objects

749
00:35:16,310 --> 00:35:13,200
is to identify promising sources and

750
00:35:19,370 --> 00:35:16,320
then follow them up with telescopes

751
00:35:22,430 --> 00:35:19,380
another technique that we could use is

752
00:35:25,069 --> 00:35:22,440
to use telescopes that act that act

753
00:35:28,069 --> 00:35:25,079
completely as survey telescopes I mean

754
00:35:30,470 --> 00:35:28,079
that what they do is scan the sky they

755
00:35:32,750 --> 00:35:30,480
take images they take Spectra of what

756
00:35:35,750 --> 00:35:32,760
they observe and they store all that

757
00:35:39,290 --> 00:35:35,760
data in archives that become available

758
00:35:42,349 --> 00:35:39,300
for astronomers to use for analysis

759
00:35:44,569 --> 00:35:42,359
and an example of this is uh the Sloan

760
00:35:47,990 --> 00:35:44,579
digital Sky survey which has been taking

761
00:35:50,390 --> 00:35:48,000
data and what one of any spin through

762
00:35:52,490 --> 00:35:50,400
five iterations since 2000

763
00:35:56,510 --> 00:35:52,500

um but it's been operational in some

764
00:35:58,670 --> 00:35:56,520
format uh for over two decades now

765
00:36:02,329 --> 00:35:58,680
and just from the Sloan digital Sky

766
00:36:05,450 --> 00:36:02,339
survey itself we've discovered over 30

767
00:36:08,150 --> 00:36:05,460
quarters of a million black holes in

768
00:36:12,050 --> 00:36:08,160
other galaxies some from galaxies nearby

769
00:36:14,329 --> 00:36:12,060
and some from galaxies really far away

770
00:36:16,609 --> 00:36:14,339
and Sundial Sky survey holds a special

771
00:36:19,190 --> 00:36:16,619
place in my heart uh because part of my

772
00:36:21,710 --> 00:36:19,200
PhD thesis was based on a sample of

773
00:36:24,770 --> 00:36:21,720
galaxies selected from Sloan and I still

774
00:36:27,710 --> 00:36:24,780
use data from slower my research and uh

775
00:36:32,750 --> 00:36:30,410
so these surveys are a great way to

776
00:36:35,569 --> 00:36:32,760
build up statistical picture of black

777
00:36:36,890 --> 00:36:35,579
holes from early Cosmic times to the

778
00:36:40,250 --> 00:36:36,900
present day

779
00:36:43,730 --> 00:36:40,260
we could also use in-depth spectroscopic

780
00:36:45,829 --> 00:36:43,740
observations of individual objects to

781
00:36:47,329 --> 00:36:45,839
learn about the physical processes in

782
00:36:48,829 --> 00:36:47,339
these systems

783
00:36:51,349 --> 00:36:48,839
and this is something else that we've

784
00:36:54,230 --> 00:36:51,359
been doing for decades using telescopes

785
00:36:56,990 --> 00:36:54,240
from ground and from space

786
00:37:01,250 --> 00:36:57,000
and our newest telescope to join the

787
00:37:03,410 --> 00:37:01,260
family is no different uh jwst the

788
00:37:06,410 --> 00:37:03,420

latest Flagship observatory in space

789
00:37:09,589 --> 00:37:06,420
launched in December studies infrared

790
00:37:11,270 --> 00:37:09,599
universe and this telescope is indeed a

791
00:37:14,329 --> 00:37:11,280
game changer

792
00:37:17,870 --> 00:37:14,339
it's undertaking both surveys like we

793
00:37:20,270 --> 00:37:17,880
saw the Hubble Deep Field jwst is also

794
00:37:23,270 --> 00:37:20,280
doing uh deep surveys

795
00:37:25,069 --> 00:37:23,280
and it's also doing in-depth studies of

796
00:37:28,250 --> 00:37:25,079
individual objects

797
00:37:30,770 --> 00:37:28,260
and from the in-depth spectroscopic

798
00:37:34,250 --> 00:37:30,780
studies we can learn about the chemical

799
00:37:37,010 --> 00:37:34,260
composition of galaxies and identify

800
00:37:38,810 --> 00:37:37,020
which of these are hosting supermassive

801
00:37:42,290 --> 00:37:38,820
black holes

802
00:37:45,170 --> 00:37:42,300
and as a demonstration of this is

803
00:37:47,990 --> 00:37:45,180
Stefan's quintet which is one of the

804
00:37:50,630 --> 00:37:48,000
first science observations released from

805
00:37:52,730 --> 00:37:50,640
jwst in July

806
00:37:54,530 --> 00:37:52,740
now this is a stunning image and it's

807
00:37:56,510 --> 00:37:54,540
just so much that could be said about

808
00:37:58,370 --> 00:37:56,520
this image you're seeing these five

809
00:38:01,310 --> 00:37:58,380
Galaxies for the more gravitationally

810
00:38:03,050 --> 00:38:01,320
bound lots of cool stuff going on in

811
00:38:05,930 --> 00:38:03,060
this image

812
00:38:10,370 --> 00:38:05,940
but I want to focus on this top guy here

813
00:38:12,650 --> 00:38:10,380

NGC 7319 probably no surprise the reason

814
00:38:16,930 --> 00:38:12,660
why is because it hosts a growing black

815
00:38:23,810 --> 00:38:20,710
this galaxy was observed with the jwst

816
00:38:28,370 --> 00:38:23,820
spectroscopy modes as a demonstration of

817
00:38:36,190 --> 00:38:32,450
in the mid-infrared we obtained Spectra

818
00:38:40,609 --> 00:38:36,200
from above the nucleus of the Galaxy

819
00:38:43,550 --> 00:38:40,619
which is gas that is hot and ionized

820
00:38:45,950 --> 00:38:43,560
from the accretion disk this outflowing

821
00:38:50,690 --> 00:38:45,960
wind where we're seeing ionized species

822
00:38:53,210 --> 00:38:50,700
of iron argon neon sulfur oxygen

823
00:38:54,470 --> 00:38:53,220
the bottom spectrum is from the nucleus

824
00:38:57,710 --> 00:38:54,480
itself

825
00:39:01,730 --> 00:38:57,720
where we're probing colder denser dust

826
00:39:07,250 --> 00:39:01,740
that enshrouds the nucleus of seeing

827
00:39:13,490 --> 00:39:10,849
in the near-fread wavelengths we see

828
00:39:17,510 --> 00:39:13,500
Atomic hydrogen which is tracing

829
00:39:20,150 --> 00:39:17,520
structures of this outflowing gas

830
00:39:24,230 --> 00:39:20,160
iron which traces the location of the

831
00:39:27,470 --> 00:39:24,240
hot gas and again the colder dense dust

832
00:39:31,130 --> 00:39:27,480
traced by molecular hydrogen which

833
00:39:35,510 --> 00:39:31,140
itself could may form a reservoir of

834
00:39:37,730 --> 00:39:35,520
material to feed the black hole

835
00:39:40,970 --> 00:39:37,740
from spectroscopy we could also learn

836
00:39:43,130 --> 00:39:40,980
about the gas motion and speed

837
00:39:45,230 --> 00:39:43,140
anything here that's showing a blue

838
00:39:47,270 --> 00:39:45,240

color represents gas that's moving

839
00:39:49,370 --> 00:39:47,280
towards us well anything's showing

840
00:39:52,670 --> 00:39:49,380
yellow color represents gas that's

841
00:39:55,370 --> 00:39:52,680
moving away from us

842
00:39:58,910 --> 00:39:55,380
so from spectroscopic observations like

843
00:40:02,089 --> 00:39:58,920
these we learn about how black holes are

844
00:40:04,970 --> 00:40:02,099
fueled and how they give off energy to

845
00:40:07,790 --> 00:40:04,980
affect their surroundings and maybe even

846
00:40:10,490 --> 00:40:07,800
inject energy that guides the evolution

847
00:40:11,810 --> 00:40:10,500
of the galaxies that they live in and we

848
00:40:15,290 --> 00:40:11,820
do this by mapping out the chemical

849
00:40:19,569 --> 00:40:15,300
composition and the motion of material

850
00:40:21,829 --> 00:40:19,579
both near and far from the black hole

851
00:40:25,130 --> 00:40:21,839
another great thing that we could get

852
00:40:26,690 --> 00:40:25,140
from Spectra is to measure distances to

853
00:40:28,550 --> 00:40:26,700
these galaxies

854
00:40:31,130 --> 00:40:28,560
where we could use the fact that the

855
00:40:33,829 --> 00:40:31,140
universe is expanding and the Doppler

856
00:40:37,670 --> 00:40:33,839
shift to our advantage

857
00:40:41,450 --> 00:40:37,680
so an example of the Doppler shift is if

858
00:40:43,670 --> 00:40:41,460
you hear an ambulance with a siren go by

859
00:40:45,290 --> 00:40:43,680
as that ambulance moves further and

860
00:40:48,230 --> 00:40:45,300
further away from you

861
00:40:50,150 --> 00:40:48,240
the pitch of the siren sounds lower and

862
00:40:53,089 --> 00:40:50,160
lower and lower

863
00:40:55,670 --> 00:40:53,099

and that's because the sound wave coming

864
00:40:57,770 --> 00:40:55,680
from that siren is moving away from you

865
00:41:00,109 --> 00:40:57,780
it's traveling a greater distance so the

866
00:41:04,130 --> 00:41:00,119
wavelength of sound is getting stretched

867
00:41:07,010 --> 00:41:04,140
to longer and longer wavelengths

868
00:41:09,890 --> 00:41:07,020
we know the universe is expanding and as

869
00:41:11,210 --> 00:41:09,900
it expands it takes galaxies along for

870
00:41:13,609 --> 00:41:11,220
the ride

871
00:41:17,690 --> 00:41:13,619
so the light that comes out of these

872
00:41:20,390 --> 00:41:17,700
galaxies travels through space which is

873
00:41:22,790 --> 00:41:20,400
expanding which causes the wavelength of

874
00:41:24,050 --> 00:41:22,800
that light to shift to longer

875
00:41:26,510 --> 00:41:24,060
wavelengths

876
00:41:29,450 --> 00:41:26,520
so galaxies that are closer by will have

877
00:41:31,670 --> 00:41:29,460
a smaller shift in wavelengths galaxies

878
00:41:33,650 --> 00:41:31,680
that are further away will have a larger

879
00:41:35,870 --> 00:41:33,660
shift in wavelengths

880
00:41:38,390 --> 00:41:35,880
and taken to its extreme

881
00:41:41,630 --> 00:41:38,400
you could have galaxies at the farthest

882
00:41:44,569 --> 00:41:41,640
end of the universe that are made up of

883
00:41:48,290 --> 00:41:44,579
stars that are young giving off lots of

884
00:41:51,109 --> 00:41:48,300
energy at ultraviolet wavelengths that

885
00:41:53,270 --> 00:41:51,119
travel through the whole extent of the

886
00:41:55,490 --> 00:41:53,280
universe to get to our telescopes here

887
00:41:58,010 --> 00:41:55,500
on Earth and the because it's traveled

888
00:42:02,030 --> 00:41:58,020

so far the wavelength of the light has

889
00:42:06,109 --> 00:42:02,040
been shifted all the way to the infrared

890
00:42:08,750 --> 00:42:06,119
foreign so when we observe Spectra from

891
00:42:11,750 --> 00:42:08,760
other galaxies we will see that these

892
00:42:14,030 --> 00:42:11,760
emission features will be at redder

893
00:42:16,370 --> 00:42:14,040
wavelengths than they would be if we

894
00:42:19,250 --> 00:42:16,380
were observing them in the lab

895
00:42:23,089 --> 00:42:19,260
so by comparing the wavelengths at which

896
00:42:25,370 --> 00:42:23,099
these lines appear in these galaxies

897
00:42:30,230 --> 00:42:25,380
with where they should be

898
00:42:33,770 --> 00:42:30,240
gives us a measure of how far how much

899
00:42:37,609 --> 00:42:33,780
the universe has expanded which gives us

900
00:42:39,290 --> 00:42:37,619
a distance measurement to that Galaxy

901
00:42:42,349 --> 00:42:39,300
so here's an example

902
00:42:46,370 --> 00:42:42,359
again going to an early release image

903
00:42:49,190 --> 00:42:46,380
from jwst another stunning image jwsc is

904
00:42:51,470 --> 00:42:49,200
just awesome and what it's giving us

905
00:42:54,170 --> 00:42:51,480
um so in the left we are seeing an image

906
00:42:57,950 --> 00:42:54,180
of a galaxy cluster thousands of

907
00:42:59,630 --> 00:42:57,960
galaxies jwst's first Deep Field again

908
00:43:02,750 --> 00:42:59,640
so many amazing things we could talk

909
00:43:08,210 --> 00:43:05,809
this part of the sky was also observed

910
00:43:11,750 --> 00:43:08,220
with one of a couple of the

911
00:43:15,530 --> 00:43:11,760
spectroscopic modes on jwst which being

912
00:43:17,630 --> 00:43:15,540
shown here are some of the galaxies that

913
00:43:18,910 --> 00:43:17,640

were observed with the near spec

914
00:43:22,550 --> 00:43:18,920
instrument

915
00:43:23,690 --> 00:43:22,560
which got Spectra for tens of the

916
00:43:25,370 --> 00:43:23,700
galaxies

917
00:43:27,890 --> 00:43:25,380
in this field

918
00:43:33,050 --> 00:43:27,900
so the middle panel shows close-up

919
00:43:35,569 --> 00:43:33,060
images of four of these galaxies

920
00:43:38,510 --> 00:43:35,579
the right hand panel shows the Spectra

921
00:43:41,150 --> 00:43:38,520
for those galaxies

922
00:43:44,270 --> 00:43:41,160
so when I want to draw your attention to

923
00:43:48,170 --> 00:43:44,280
is this set of features here these lines

924
00:43:51,109 --> 00:43:48,180
what you're seeing is ionized oxygen O3

925
00:43:54,170 --> 00:43:51,119
it's been ionized twice by the way my

926
00:43:56,630 --> 00:43:54,180
favorite emission line and you're seeing

927
00:44:01,490 --> 00:43:56,640
um ionized hydrogen

928
00:44:04,790 --> 00:44:01,500
and as we go down uh panels we see that

929
00:44:07,370 --> 00:44:04,800
these features get shifted to longer and

930
00:44:09,410 --> 00:44:07,380
longer and longer wavelengths

931
00:44:11,750 --> 00:44:09,420
because they're coming from galaxies

932
00:44:13,550 --> 00:44:11,760
that are further and further and further

933
00:44:18,230 --> 00:44:13,560
away from us

934
00:44:20,990 --> 00:44:18,240
the Galaxy on top uh is at a distance

935
00:44:22,490 --> 00:44:21,000
where light has traveled 11.3 billion

936
00:44:25,309 --> 00:44:22,500
years to reach us

937
00:44:26,410 --> 00:44:25,319
and on the bottom the light has been

938
00:44:31,609 --> 00:44:26,420

traveling

939
00:44:38,750 --> 00:44:35,450
so these are galaxies and it's fair to

940
00:44:42,050 --> 00:44:38,760
ask what about AGN what about galaxies

941
00:44:45,650 --> 00:44:42,060
hosting growing supermassive blast coals

942
00:44:48,230 --> 00:44:45,660
what's the most distant AGN that we know

943
00:44:52,430 --> 00:44:48,240
about so far

944
00:44:54,589 --> 00:44:52,440
and so far the record holder is an AGN

945
00:44:57,410 --> 00:44:54,599
where it's taken light 13 billion years

946
00:44:59,809 --> 00:44:57,420
to reach us so not not as far away as

947
00:45:02,329 --> 00:44:59,819
the most distant galaxies

948
00:45:05,030 --> 00:45:02,339
and this is a beautiful artist rendition

949
00:45:06,470 --> 00:45:05,040
of what uh growing supermassive black

950
00:45:11,030 --> 00:45:06,480
hole looks like

951
00:45:12,950 --> 00:45:11,040
the image is perhaps a little bit less

952
00:45:15,109 --> 00:45:12,960
impressive

953
00:45:16,190 --> 00:45:15,119
but it doesn't encode a lot of

954
00:45:18,230 --> 00:45:16,200
information

955
00:45:21,530 --> 00:45:18,240
all right so in the three left panels

956
00:45:23,450 --> 00:45:21,540
we're seeing this object invisible light

957
00:45:26,089 --> 00:45:23,460
the two right panels we're seeing this

958
00:45:29,510 --> 00:45:26,099
object in infrared light the cyan Circle

959
00:45:31,970 --> 00:45:29,520
shows us where the source is

960
00:45:34,370 --> 00:45:31,980
in the visible panels

961
00:45:36,849 --> 00:45:34,380
you see a whole lot of nothing within

962
00:45:40,670 --> 00:45:36,859
that science Circle

963
00:45:42,970 --> 00:45:40,680

infrared panels it gets much brighter we

964
00:45:47,569 --> 00:45:42,980
see an object there

965
00:45:51,650 --> 00:45:47,579
now one explanation for this could be

966
00:45:54,109 --> 00:45:51,660
that this object is so far away that the

967
00:45:57,109 --> 00:45:54,119
ultraviolet to Optical light from this

968
00:45:59,750 --> 00:45:57,119
galaxy has traveled such a long distance

969
00:46:00,950 --> 00:45:59,760
that's been redshifted into the infrared

970
00:46:04,609 --> 00:46:00,960
regime

971
00:46:07,550 --> 00:46:04,619
and to confirm that you need a spectrum

972
00:46:10,970 --> 00:46:07,560
and indeed the spectrum of this object

973
00:46:13,190 --> 00:46:10,980
shows ionized species of carbon and

974
00:46:16,849 --> 00:46:13,200
magnesium and because of the width of

975
00:46:18,349 --> 00:46:16,859
these lines we know that this gas is

976
00:46:20,270 --> 00:46:18,359
being energized by a growing

977
00:46:22,849 --> 00:46:20,280
supermassive black hole

978
00:46:26,510 --> 00:46:22,859
and from these lines you're also able to

979
00:46:28,609 --> 00:46:26,520
measure the distance to the Galaxy

980
00:46:31,309 --> 00:46:28,619
another very interesting thing about

981
00:46:34,190 --> 00:46:31,319
this source is that the black hole in

982
00:46:36,650 --> 00:46:34,200
this galaxy is at about a billion times

983
00:46:38,930 --> 00:46:36,660
heavier than our own Sun

984
00:46:41,750 --> 00:46:38,940
now we've seen black holes that massive

985
00:46:45,230 --> 00:46:41,760
in other galaxies but what's interesting

986
00:46:47,990 --> 00:46:45,240
here is that the universe is only 670

987
00:46:50,569 --> 00:46:48,000
million years old by the time this

988
00:46:52,790 --> 00:46:50,579

galaxy was in existence with the black

989
00:46:56,089 --> 00:46:52,800
hole this massive

990
00:46:57,650 --> 00:46:56,099
how did this black hole get so massive

991
00:46:59,630 --> 00:46:57,660
so quick

992
00:47:01,670 --> 00:46:59,640
it's not going to be from feeding

993
00:47:04,430 --> 00:47:01,680
Stellar Mass black holes because there's

994
00:47:06,890 --> 00:47:04,440
not enough time to dump material on them

995
00:47:10,309 --> 00:47:06,900
to get them this big so there has to be

996
00:47:12,530 --> 00:47:10,319
some other formation mechanism

997
00:47:15,410 --> 00:47:12,540
and indeed that's one of the questions

998
00:47:19,730 --> 00:47:15,420
that we think in jwst will be able to

999
00:47:21,770 --> 00:47:19,740
answer because jwst will find even more

1000
00:47:23,210 --> 00:47:21,780
distant galaxies even more distant black

1001
00:47:25,309 --> 00:47:23,220
holes that will have a better

1002
00:47:27,170 --> 00:47:25,319
statistical picture of the demographics

1003
00:47:29,510 --> 00:47:27,180
of what these first generations of

1004
00:47:30,650 --> 00:47:29,520
galaxies and black holes look like and

1005
00:47:33,230 --> 00:47:30,660
then compare that with different

1006
00:47:35,510 --> 00:47:33,240
theoretical models to understand their

1007
00:47:38,510 --> 00:47:35,520
formation pathways

1008
00:47:44,990 --> 00:47:41,809
as some of you might know astronomers

1009
00:47:47,450 --> 00:47:45,000
are quite excited about jwst data

1010
00:47:50,809 --> 00:47:47,460
finally being available and things

1011
00:47:53,270 --> 00:47:50,819
looking so good and certainly after the

1012
00:47:55,430 --> 00:47:53,280
first couple of months when science data

1013
00:47:59,270 --> 00:47:55,440

were released to the community there has

1014
00:48:02,150 --> 00:47:59,280
been a lot of speculation that some

1015
00:48:04,790 --> 00:48:02,160
really distant galaxies have already

1016
00:48:06,710 --> 00:48:04,800
been detected really early on in the

1017
00:48:09,230 --> 00:48:06,720
life of the mission

1018
00:48:13,809 --> 00:48:09,240
so one thing that I do want to say is

1019
00:48:17,690 --> 00:48:13,819
that those objects are candidates

1020
00:48:21,470 --> 00:48:17,700
they are objects that based on Imaging

1021
00:48:24,109 --> 00:48:21,480
and some model fits could potentially be

1022
00:48:27,050 --> 00:48:24,119
galaxies really far away

1023
00:48:29,450 --> 00:48:27,060
what we need now is spectroscopy of

1024
00:48:32,569 --> 00:48:29,460
these candidates to be able to measure

1025
00:48:35,089 --> 00:48:32,579
the distances to them and confirm if

1026
00:48:37,370 --> 00:48:35,099
they are at the distance that these

1027
00:48:39,470 --> 00:48:37,380
other data seem to indicate

1028
00:48:42,230 --> 00:48:39,480
and it's more interesting for me it's

1029
00:48:45,470 --> 00:48:42,240
not only how far away are they but do

1030
00:48:48,170 --> 00:48:45,480
any of them show signatures of AGN

1031
00:48:50,870 --> 00:48:48,180
activity in their Spectra

1032
00:48:54,410 --> 00:48:50,880
over the next couple of months year

1033
00:48:56,030 --> 00:48:54,420
years will be gain lots of Spectra of a

1034
00:48:59,630 --> 00:48:56,040
whole bunch of galaxies so we'll be

1035
00:49:03,470 --> 00:49:01,430
all right so we've talked about

1036
00:49:08,030 --> 00:49:03,480
supermassive black holes in nearby

1037
00:49:11,210 --> 00:49:08,040
galaxies and in galaxies far far away

1038
00:49:14,390 --> 00:49:11,220

is there anything closer to home

1039
00:49:17,569 --> 00:49:14,400
the answer is yes

1040
00:49:19,490 --> 00:49:17,579
in our own Milky Way galaxy in the

1041
00:49:22,309 --> 00:49:19,500
center 27

1042
00:49:25,069 --> 00:49:22,319
000 light years from where we are their

1043
00:49:27,710 --> 00:49:25,079
lurks a supermassive black hole called

1044
00:49:30,170 --> 00:49:27,720
Sagittarius A star

1045
00:49:35,210 --> 00:49:30,180
unlike these AGN that we've been talking

1046
00:49:39,890 --> 00:49:35,220
about this black hole is largely dormant

1047
00:49:42,349 --> 00:49:39,900
we know about its existence due to years

1048
00:49:44,210 --> 00:49:42,359
and years of dedicated work from a

1049
00:49:46,190 --> 00:49:44,220
couple of research groups one of them

1050
00:49:48,050 --> 00:49:46,200
being the research group led by Andrea

1051
00:49:50,170 --> 00:49:48,060
guest from UCLA

1052
00:49:52,849 --> 00:49:50,180
who have spent years

1053
00:49:55,849 --> 00:49:52,859
measuring the Motions of stars in the

1054
00:49:58,370 --> 00:49:55,859
galactic center mapping out their orbits

1055
00:49:59,510 --> 00:49:58,380
and calculating how fast they're

1056
00:50:01,309 --> 00:49:59,520
orbiting

1057
00:50:02,990 --> 00:50:01,319
now you can't see anything that they're

1058
00:50:06,050 --> 00:50:03,000
orbiting around

1059
00:50:09,410 --> 00:50:06,060
but we have their speeds and just by

1060
00:50:12,470 --> 00:50:09,420
using Kepler's laws you could calculate

1061
00:50:14,150 --> 00:50:12,480
the mass of the object that these stars

1062
00:50:17,410 --> 00:50:14,160
are orbiting around

1063
00:50:22,150 --> 00:50:17,420

when you do that you get a mass that's

1064
00:50:24,829 --> 00:50:22,160
4.3 million times heavier than our sun

1065
00:50:27,109 --> 00:50:24,839
so here we have evidence of a

1066
00:50:30,170 --> 00:50:27,119
supermassive black hole

1067
00:50:32,329 --> 00:50:30,180
so while this black hole is not an AGN

1068
00:50:35,270 --> 00:50:32,339
some of the Stars said to orbit around

1069
00:50:38,270 --> 00:50:35,280
the center give off Stellar winds some

1070
00:50:40,970 --> 00:50:38,280
of those winds do find their way onto

1071
00:50:44,030 --> 00:50:40,980
the black hole so we see some small

1072
00:50:45,410 --> 00:50:44,040
activity there very wimpy compared to

1073
00:50:47,750 --> 00:50:45,420
these growing black holes in other

1074
00:50:50,510 --> 00:50:47,760
galaxies it's like a factor of a billion

1075
00:50:52,430 --> 00:50:50,520
difference but you know some activity

1076
00:50:55,549 --> 00:50:52,440
there

1077
00:50:59,030 --> 00:50:55,559
and in fact we've gotten a closer look

1078
00:51:02,030 --> 00:50:59,040
at Sagittarius A star from the Event

1079
00:51:09,650 --> 00:51:02,040
Horizon telescope

1080
00:51:11,450 --> 00:51:09,660
our closest views humanly possible to a

1081
00:51:15,170 --> 00:51:11,460
black hole

1082
00:51:18,470 --> 00:51:15,180
and they're able to resolve really small

1083
00:51:21,230 --> 00:51:18,480
scales and the reason that they're able

1084
00:51:24,190 --> 00:51:21,240
to have this high resolution is because

1085
00:51:27,049 --> 00:51:24,200
of a technique they use called

1086
00:51:29,349 --> 00:51:27,059
interferometry to build up a large

1087
00:51:32,990 --> 00:51:29,359
virtual telescope

1088
00:51:34,370 --> 00:51:33,000

now in in astronomy if you want to see

1089
00:51:36,890 --> 00:51:34,380
really small scales and have great

1090
00:51:38,750 --> 00:51:36,900
resolution you want to have as big of a

1091
00:51:42,530 --> 00:51:38,760
telescope as possible

1092
00:51:45,589 --> 00:51:42,540
with interferometry you achieve this by

1093
00:51:47,690 --> 00:51:45,599
having an array of telescopes

1094
00:51:49,849 --> 00:51:47,700
and that's Illustrated a bit on this

1095
00:51:52,510 --> 00:51:49,859
view graph it's a little bit busy but

1096
00:51:56,569 --> 00:51:52,520
we'll go through it step by step

1097
00:51:59,690 --> 00:51:56,579
so the top panel shows how when you have

1098
00:52:02,510 --> 00:51:59,700
two radio telescopes and you increase

1099
00:52:04,849 --> 00:52:02,520
the distance between them you've

1100
00:52:06,349 --> 00:52:04,859
increased the Baseline of this virtual

1101
00:52:08,750 --> 00:52:06,359
telescope

1102
00:52:10,670 --> 00:52:08,760
so you get to a larger Baseline the

1103
00:52:13,790 --> 00:52:10,680
image becomes sharper

1104
00:52:16,549 --> 00:52:13,800
the next panel down is showing that

1105
00:52:19,549 --> 00:52:16,559
what's observed by radio telescopes is

1106
00:52:21,890 --> 00:52:19,559
an interference pattern that could be

1107
00:52:24,230 --> 00:52:21,900
analyzed using a mathematical technique

1108
00:52:26,930 --> 00:52:24,240
called a foray transform

1109
00:52:29,630 --> 00:52:26,940
and the bottom panel is showing that as

1110
00:52:32,150 --> 00:52:29,640
you add more and more telescopes to the

1111
00:52:34,730 --> 00:52:32,160
array get more data points and as the

1112
00:52:37,609 --> 00:52:34,740
Earth rotates it fills in the space

1113
00:52:41,089 --> 00:52:37,619

between the data points and then you're

1114
00:52:43,670 --> 00:52:41,099
able to reconstruct a really sharp image

1115
00:52:45,170 --> 00:52:43,680
of the object that you're observing in

1116
00:52:46,490 --> 00:52:45,180
outer space

1117
00:52:49,010 --> 00:52:46,500
foreign

1118
00:52:52,790 --> 00:52:49,020
The Event Horizon telescope uses an

1119
00:52:56,150 --> 00:52:52,800
array of telescopes around the globe to

1120
00:52:57,710 --> 00:52:56,160
create a large virtual telescope so in

1121
00:53:00,230 --> 00:52:57,720
essence they've turned to planet Earth

1122
00:53:01,970 --> 00:53:00,240
and itself into a telescope it's pretty

1123
00:53:03,589 --> 00:53:01,980
awesome

1124
00:53:06,349 --> 00:53:03,599
earlier this year the collaboration

1125
00:53:08,089 --> 00:53:06,359
released this image of Sagittarius A

1126
00:53:09,770 --> 00:53:08,099
star the supermassive black hole in the

1127
00:53:11,710 --> 00:53:09,780
center of our galaxy

1128
00:53:15,170 --> 00:53:11,720
so we see this donut

1129
00:53:18,109 --> 00:53:15,180
with a dark Center

1130
00:53:19,430 --> 00:53:18,119
that dark Center is the black hole

1131
00:53:22,670 --> 00:53:19,440
shadow

1132
00:53:25,069 --> 00:53:22,680
the space around a black hole is Warped

1133
00:53:28,490 --> 00:53:25,079
due to the mass of the black hole again

1134
00:53:31,910 --> 00:53:28,500
a general relativity large masses warp

1135
00:53:34,849 --> 00:53:31,920
space so the light rays from any light

1136
00:53:37,670 --> 00:53:34,859
that's behind it are traveling through

1137
00:53:42,170 --> 00:53:37,680
this warped space-time causing the

1138
00:53:46,790 --> 00:53:44,030

um this uh

1139
00:53:49,069 --> 00:53:46,800
black hole Shadows about two and a half

1140
00:53:52,490 --> 00:53:49,079
times the size of the actual Event

1141
00:53:54,770 --> 00:53:52,500
Horizon but it's as close to a black

1142
00:53:57,170 --> 00:53:54,780
hole that the laws of physics allow us

1143
00:54:00,290 --> 00:53:57,180
to resolve

1144
00:54:02,510 --> 00:54:00,300
you might remember several years earlier

1145
00:54:05,650 --> 00:54:02,520
um The Event Horizon telescope released

1146
00:54:08,569 --> 00:54:05,660
an image where they observed a Galaxy

1147
00:54:10,970 --> 00:54:08,579
m87 that has its own supermassive black

1148
00:54:13,549 --> 00:54:10,980
hole that's launching this jet that's

1149
00:54:14,930 --> 00:54:13,559
thousands of light years long and if you

1150
00:54:16,309 --> 00:54:14,940
want to play the game of the name that

1151
00:54:18,710 --> 00:54:16,319
black hole I mean I can't get the answer

1152
00:54:20,150 --> 00:54:18,720
away I labeled the black holes but it's

1153
00:54:21,950 --> 00:54:20,160
really interesting to do this side by

1154
00:54:23,630 --> 00:54:21,960
side comparison because there's so many

1155
00:54:26,750 --> 00:54:23,640
similarities that we see in these two

1156
00:54:28,970 --> 00:54:26,760
images right we see this circular ring

1157
00:54:31,069 --> 00:54:28,980
that's due to that bending of space-time

1158
00:54:33,230 --> 00:54:31,079
near the black hole we see that the

1159
00:54:36,290 --> 00:54:33,240
Rings are largely symmetric

1160
00:54:38,450 --> 00:54:36,300
we see brighter Parts in both Rings

1161
00:54:41,150 --> 00:54:38,460
those brighter Parts show us where

1162
00:54:43,309 --> 00:54:41,160
matter is moving towards us the darker

1163
00:54:44,930 --> 00:54:43,319

parts are showing where matter is moving

1164
00:54:47,630 --> 00:54:44,940
away from us

1165
00:54:50,390 --> 00:54:47,640
and both of these images represent the

1166
00:54:53,750 --> 00:54:50,400
small scales that we are we can possibly

1167
00:54:55,190 --> 00:54:53,760
see around a black hole and it's kind of

1168
00:54:58,030 --> 00:54:55,200
mind-blowing when you think about it

1169
00:55:00,349 --> 00:54:58,040
when you think about the different

1170
00:55:04,010 --> 00:55:00,359
distances involved

1171
00:55:07,730 --> 00:55:04,020
Sagittarius A star in our galaxy 27

1172
00:55:10,490 --> 00:55:07,740
000 light years away and m87 we are

1173
00:55:14,870 --> 00:55:10,500
resolving these scales at a distance of

1174
00:55:17,270 --> 00:55:14,880
55 million light years away

1175
00:55:21,049 --> 00:55:17,280
what's also interesting is that

1176
00:55:23,870 --> 00:55:21,059
Sagittarius A star this black hole is a

1177
00:55:27,049 --> 00:55:23,880
thousand times smaller and less massive

1178
00:55:29,150 --> 00:55:27,059
than the black hole in m87

1179
00:55:30,410 --> 00:55:29,160
and this is what a factor of a thousand

1180
00:55:34,370 --> 00:55:30,420
means

1181
00:55:38,870 --> 00:55:34,380
our whole solar system could fit within

1182
00:55:41,630 --> 00:55:38,880
the black hole shadow of m87 and again

1183
00:55:43,790 --> 00:55:41,640
think about this we could resolve the

1184
00:55:46,190 --> 00:55:43,800
scale of something the size of our solar

1185
00:55:47,569 --> 00:55:46,200
system in an object is 55 million light

1186
00:55:49,790 --> 00:55:47,579
years away that enough itself is

1187
00:55:52,309 --> 00:55:49,800
mind-blowing

1188
00:55:54,890 --> 00:55:52,319

in Sagittarius A star

1189
00:55:57,770 --> 00:55:54,900
the outer edge of the Ring shows us

1190
00:55:59,750 --> 00:55:57,780
where is the same size as Mercury's

1191
00:56:02,930 --> 00:55:59,760
orbit

1192
00:56:05,450 --> 00:56:02,940
so very different absolute size scales

1193
00:56:06,710 --> 00:56:05,460
very different distances to these

1194
00:56:10,190 --> 00:56:06,720
objects

1195
00:56:12,650 --> 00:56:10,200
but the same physics and we're resolving

1196
00:56:17,270 --> 00:56:12,660
the same scales relative to the size of

1197
00:56:22,010 --> 00:56:19,910
all right so we've found a black holes

1198
00:56:25,790 --> 00:56:22,020
from several times the mass of our sun

1199
00:56:28,910 --> 00:56:25,800
to billions of times the mass of our sun

1200
00:56:30,829 --> 00:56:28,920
from our own galaxy to the furthest

1201
00:56:32,990 --> 00:56:30,839
reaches of space

1202
00:56:35,510 --> 00:56:33,000
we can use spectroscopy to observe black

1203
00:56:38,450 --> 00:56:35,520
holes effects on its environment and how

1204
00:56:39,710 --> 00:56:38,460
material can be fueled into the black

1205
00:56:42,230 --> 00:56:39,720
hole

1206
00:56:44,990 --> 00:56:42,240
and we've resolved the smallest region

1207
00:56:46,670 --> 00:56:45,000
that's possible to see around black

1208
00:56:52,490 --> 00:56:46,680
holes

1209
00:56:58,190 --> 00:56:55,210
there's another messenger of information

1210
00:56:59,210 --> 00:56:58,200
that we could use to learn about black

1211
00:57:03,170 --> 00:56:59,220
holes

1212
00:57:04,790 --> 00:57:03,180
and that's through gravitational waves

1213
00:57:07,069 --> 00:57:04,800

gravitational waves are another

1214
00:57:09,770 --> 00:57:07,079
consequence of general relativity

1215
00:57:13,250 --> 00:57:09,780
there are ripples in space-time from the

1216
00:57:16,490 --> 00:57:13,260
most energetic processes in the universe

1217
00:57:19,190 --> 00:57:16,500
so massive accelerating objects that

1218
00:57:21,710 --> 00:57:19,200
Collide will cause these ripples to

1219
00:57:24,650 --> 00:57:21,720
propagate at the speed of light in all

1220
00:57:26,450 --> 00:57:24,660
directions carrying clues about their

1221
00:57:28,370 --> 00:57:26,460
Origins

1222
00:57:31,130 --> 00:57:28,380
so if you think back to the beginning of

1223
00:57:33,290 --> 00:57:31,140
the presentation where we had this

1224
00:57:35,390 --> 00:57:33,300
binary star system that evolved to the

1225
00:57:38,390 --> 00:57:35,400
point where all that was left were these

1226
00:57:40,010 --> 00:57:38,400
black hole remnants not giving off any

1227
00:57:43,370 --> 00:57:40,020
light

1228
00:57:46,490 --> 00:57:43,380
if those black holes in spiral and

1229
00:57:49,609 --> 00:57:46,500
Collide we could use gravitational waves

1230
00:57:52,670 --> 00:57:49,619
to detect these objects

1231
00:57:56,510 --> 00:57:52,680
and we now have observatories that can

1232
00:57:59,150 --> 00:57:56,520
detect gravitational waves

1233
00:58:01,309 --> 00:57:59,160
The ligo Observatory is made up of two

1234
00:58:03,770 --> 00:58:01,319
detectors in the United States one in

1235
00:58:07,089 --> 00:58:03,780
Washington state one in Louisiana

1236
00:58:09,410 --> 00:58:07,099
and they started taking data in 2015

1237
00:58:11,630 --> 00:58:09,420
with the first gravitational wave

1238
00:58:13,849 --> 00:58:11,640

discoveries announced in February of

1239
00:58:17,930 --> 00:58:13,859
2016.

1240
00:58:20,510 --> 00:58:17,940
and uh about a year later in 2017 the

1241
00:58:22,549 --> 00:58:20,520
Virgo interferometer in Italy came

1242
00:58:24,589 --> 00:58:22,559
online

1243
00:58:27,589 --> 00:58:24,599
now for gravitational wave astronomy

1244
00:58:29,569 --> 00:58:27,599
it's really important to have more than

1245
00:58:31,970 --> 00:58:29,579
one detector

1246
00:58:34,010 --> 00:58:31,980
though that animation I showed on the

1247
00:58:36,230 --> 00:58:34,020
previous slide looked pretty dramatic

1248
00:58:38,630 --> 00:58:36,240
with the ripples coming out from the

1249
00:58:40,490 --> 00:58:38,640
inspiring objects

1250
00:58:43,130 --> 00:58:40,500
the actual

1251
00:58:45,770 --> 00:58:43,140
signal from gravitational waves is

1252
00:58:49,549 --> 00:58:45,780
really really tiny

1253
00:58:53,450 --> 00:58:49,559
so uh they're very challenging to detect

1254
00:58:54,890 --> 00:58:53,460
and sources of noise become the most

1255
00:58:57,289 --> 00:58:54,900
prominent thing they're actually

1256
00:58:59,089 --> 00:58:57,299
detected at these observatories but

1257
00:59:02,270 --> 00:58:59,099
these sources of noise are going to be

1258
00:59:03,710 --> 00:59:02,280
local in origin it could be a Tremor in

1259
00:59:05,990 --> 00:59:03,720
the earth I'm an extremely slight

1260
00:59:09,049 --> 00:59:06,000
earthquake maybe it's traffic traveling

1261
00:59:10,730 --> 00:59:09,059
by Miles and Miles Away

1262
00:59:13,490 --> 00:59:10,740
but you won't have the same source of

1263
00:59:15,650 --> 00:59:13,500

noise detectors that are far apart

1264
00:59:19,609 --> 00:59:15,660
geographically

1265
00:59:22,250 --> 00:59:19,619
so if you detect the same signal in

1266
00:59:23,870 --> 00:59:22,260
multiple detectors with a time delay

1267
00:59:26,690 --> 00:59:23,880
that's consistent with the light travel

1268
00:59:29,450 --> 00:59:26,700
time between those detectors that gives

1269
00:59:34,430 --> 00:59:29,460
you a higher confidence that that signal

1270
00:59:39,410 --> 00:59:37,010
and that signal the frequency of the

1271
00:59:41,630 --> 00:59:39,420
signal that's detected

1272
00:59:44,630 --> 00:59:41,640
tells you about the masses of the

1273
00:59:46,430 --> 00:59:44,640
objects that Collide and the mass of the

1274
00:59:49,250 --> 00:59:46,440
final object

1275
00:59:51,770 --> 00:59:49,260
so here's a way to kind of um that you

1276
00:59:54,589 --> 00:59:51,780
could internalize it because you convert

1277
01:00:00,829 --> 00:59:54,599
you can convert that wave signal into

1278
01:00:00,839 --> 01:00:05,160
foreign

1279
01:00:05,170 --> 01:00:26,530
[Music]

1280
01:00:33,770 --> 01:00:29,870
so the gravitational wave signal from

1281
01:00:35,690 --> 01:00:33,780
December 2015 has a higher pitch than

1282
01:00:37,430 --> 01:00:35,700
that from September

1283
01:00:39,710 --> 01:00:37,440
and that's because

1284
01:00:42,710 --> 01:00:39,720
um the signal from December was

1285
01:00:46,309 --> 01:00:42,720
caused by black holes that have a lower

1286
01:00:49,490 --> 01:00:46,319
Mass than the one from September

1287
01:00:52,250 --> 01:00:49,500
so that frequency of the signal encodes

1288
01:00:56,569 --> 01:00:52,260

information about the masses of objects

1289
01:01:00,530 --> 01:00:56,579
that Collide and that final Mass

1290
01:01:03,770 --> 01:01:00,540
as of now we have about 50 gravitational

1291
01:01:09,230 --> 01:01:03,780
wave signals that have been detected

1292
01:01:15,710 --> 01:01:12,589
um and this graph shows uh the masses of

1293
01:01:18,289 --> 01:01:15,720
compact objects that have been observed

1294
01:01:20,690 --> 01:01:18,299
to date so as you go higher up in the

1295
01:01:24,069 --> 01:01:20,700
graph the mass increases and these are

1296
01:01:26,870 --> 01:01:24,079
in units relative to the mass of our sun

1297
01:01:28,430 --> 01:01:26,880
so the yellow and orange points are

1298
01:01:29,990 --> 01:01:28,440
neutron stars should just ignore those

1299
01:01:31,849 --> 01:01:30,000
we don't care about those I mean maybe

1300
01:01:33,289 --> 01:01:31,859
you care about those I think they're

1301
01:01:34,849 --> 01:01:33,299
kind of cool but really I care more

1302
01:01:35,870 --> 01:01:34,859
about black holes especially for this

1303
01:01:39,130 --> 01:01:35,880
talk

1304
01:01:43,190 --> 01:01:39,140
the yellow um the uh the pink circles

1305
01:01:45,470 --> 01:01:43,200
these are black holes that are in binary

1306
01:01:47,150 --> 01:01:45,480
systems that are giving off X-rays and

1307
01:01:48,950 --> 01:01:47,160
that's how we've detected them

1308
01:01:51,349 --> 01:01:48,960
so these are the black holes that we

1309
01:01:53,870 --> 01:01:51,359
know from x-ray light

1310
01:01:56,030 --> 01:01:53,880
the blue circles are the black holes

1311
01:01:58,670 --> 01:01:56,040
that have been detected through

1312
01:02:01,970 --> 01:01:58,680
gravitational waves and you might see

1313
01:02:05,210 --> 01:02:01,980

that there are three that are connected

1314
01:02:07,430 --> 01:02:05,220
um by by arrows so what that is showing

1315
01:02:09,589 --> 01:02:07,440
you are the masses of the two individual

1316
01:02:11,630 --> 01:02:09,599
objects black holes before they emerged

1317
01:02:13,430 --> 01:02:11,640
and then the final Mass after they

1318
01:02:16,130 --> 01:02:13,440
collided

1319
01:02:19,730 --> 01:02:16,140
so one of the really interesting things

1320
01:02:23,210 --> 01:02:19,740
about these detections and about this

1321
01:02:28,010 --> 01:02:23,220
graph is that the Blue Points by and

1322
01:02:30,289 --> 01:02:28,020
large are above the pink points

1323
01:02:33,109 --> 01:02:30,299
from gravitational waves we are

1324
01:02:35,510 --> 01:02:33,119
detecting black holes that are more

1325
01:02:38,150 --> 01:02:35,520
massive than those that we detect in

1326
01:02:40,370 --> 01:02:38,160
x-ray binaries this is the whole part of

1327
01:02:45,109 --> 01:02:40,380
the population that we were ignorant

1328
01:02:47,150 --> 01:02:45,119
about prior to 2015. and in fact some of

1329
01:02:51,309 --> 01:02:47,160
these detections are challenging some of

1330
01:02:56,230 --> 01:02:55,250
so since March of 2020

1331
01:02:59,569 --> 01:02:56,240
um

1332
01:03:02,329 --> 01:02:59,579
the operations at ligo and Virgo were

1333
01:03:04,970 --> 01:03:02,339
halted because of covid and they've been

1334
01:03:08,630 --> 01:03:04,980
going through a process now of upgrading

1335
01:03:11,809 --> 01:03:08,640
the detectors the next observing run is

1336
01:03:14,450 --> 01:03:11,819
plan to start up again in March of 2023

1337
01:03:17,569 --> 01:03:14,460
and it will be joined by a Japanese

1338
01:03:20,690 --> 01:03:17,579

facility called kagra so now we'll have

1339
01:03:22,730 --> 01:03:20,700
four gravitational wave detectors over

1340
01:03:25,430 --> 01:03:22,740
the globe which is great the more

1341
01:03:29,270 --> 01:03:25,440
detectors you have the better able your

1342
01:03:32,030 --> 01:03:29,280
you can triangulate where on the sky the

1343
01:03:36,170 --> 01:03:32,040
gravitational detection is gravitational

1344
01:03:40,430 --> 01:03:37,549
so

1345
01:03:42,890 --> 01:03:40,440
on the ground we could only

1346
01:03:46,250 --> 01:03:42,900
observe certain frequencies of

1347
01:03:49,130 --> 01:03:48,049
you know I care about supermassive black

1348
01:03:50,770 --> 01:03:49,140
holes

1349
01:03:55,549 --> 01:03:50,780
we can't detect those from the ground

1350
01:03:57,710 --> 01:03:55,559
for that we need to get into space

1351
01:04:01,370 --> 01:03:57,720
the um

1352
01:04:04,630 --> 01:04:01,380
gravitational waves given off by uh

1353
01:04:08,569 --> 01:04:04,640
colliding supermassive black holes

1354
01:04:10,609 --> 01:04:08,579
are much lower frequency than what we

1355
01:04:14,930 --> 01:04:10,619
could detect on the ground

1356
01:04:17,630 --> 01:04:14,940
so the Lisa Observatory uh which is

1357
01:04:19,789 --> 01:04:17,640
slated to launch in the 2030s

1358
01:04:22,430 --> 01:04:19,799
um it is led by the European Space

1359
01:04:26,150 --> 01:04:22,440
Agency with contributions from NASA and

1360
01:04:29,690 --> 01:04:26,160
it is a satellite of three gravitational

1361
01:04:32,569 --> 01:04:29,700
wave detectors each spacecraft separated

1362
01:04:34,490 --> 01:04:32,579
by about one and a half million miles

1363
01:04:37,190 --> 01:04:34,500

which is just mind-boggling to think

1364
01:04:41,030 --> 01:04:37,200
about right jwst is a million miles away

1365
01:04:42,950 --> 01:04:41,040
from us and these three satellites are

1366
01:04:46,490 --> 01:04:42,960
going to be even further away from each

1367
01:04:48,410 --> 01:04:46,500
other but fine in perfect formation to

1368
01:04:51,789 --> 01:04:48,420
detect these teeny tiny ripples from

1369
01:04:54,109 --> 01:04:51,799
colliding supermassive black holes

1370
01:04:56,569 --> 01:04:54,119
these types of observations will be

1371
01:05:00,770 --> 01:04:56,579
really helpful to learn about how

1372
01:05:04,250 --> 01:05:00,780
mergers of galaxies and black holes uh

1373
01:05:06,289 --> 01:05:04,260
play a pivotal role perhaps in some

1374
01:05:10,069 --> 01:05:06,299
forms of Galaxy and black hole

1375
01:05:11,930 --> 01:05:10,079
co-evolution so be very cool once that's

1376
01:05:14,510 --> 01:05:11,940
working

1377
01:05:17,990 --> 01:05:14,520
all right so go back into the question

1378
01:05:20,750 --> 01:05:18,000
that I posed as my talk title how do we

1379
01:05:23,150 --> 01:05:20,760
see that which gives off no light

1380
01:05:25,309 --> 01:05:23,160
well one way is that we can use light we

1381
01:05:28,010 --> 01:05:25,319
could use light to observe black holes

1382
01:05:31,069 --> 01:05:28,020
effects on its surroundings whether it's

1383
01:05:33,170 --> 01:05:31,079
from black holes feeding on any unlucky

1384
01:05:35,210 --> 01:05:33,180
matter that gets too close to it that

1385
01:05:37,730 --> 01:05:35,220
can escape that gives off a bunch of

1386
01:05:39,170 --> 01:05:37,740
energy before it disappears forever into

1387
01:05:42,829 --> 01:05:39,180
the black hole

1388
01:05:46,309 --> 01:05:42,839

or if it's by mapping out the motion of

1389
01:05:49,010 --> 01:05:46,319
nearby stars or gas or dust and using

1390
01:05:53,450 --> 01:05:49,020
orbital mechanics to be able to measure

1391
01:05:55,010 --> 01:05:53,460
the mass of an object that we can't see

1392
01:05:57,829 --> 01:05:55,020
we could use a completely different

1393
01:06:01,250 --> 01:05:57,839
messenger of information gravitational

1394
01:06:03,890 --> 01:06:01,260
waves to learn about objects that in

1395
01:06:06,109 --> 01:06:03,900
spiral and collide

1396
01:06:08,569 --> 01:06:06,119
and really it's this combination of

1397
01:06:11,150 --> 01:06:08,579
multi-messenger astronomy where we have

1398
01:06:13,789 --> 01:06:11,160
a much more comprehensive view of the

1399
01:06:16,130 --> 01:06:13,799
energetic universe

1400
01:06:18,589 --> 01:06:16,140
and there is a lot that we've learned

1401
01:06:21,289 --> 01:06:18,599
about supermassive black holes from

1402
01:06:24,109 --> 01:06:21,299
being mere Curiosities

1403
01:06:28,370 --> 01:06:24,119
um decades and decades ago to now being

1404
01:06:31,190 --> 01:06:28,380
a foundational part of Galaxy Evolution

1405
01:06:34,130 --> 01:06:31,200
and modern day astrophysics

1406
01:06:36,470 --> 01:06:34,140
but there's still some Mysteries

1407
01:06:38,630 --> 01:06:36,480
how did the first supermassive black

1408
01:06:40,970 --> 01:06:38,640
holes form

1409
01:06:43,970 --> 01:06:40,980
what is the full population of black

1410
01:06:46,069 --> 01:06:43,980
holes across all mass ranges including

1411
01:06:48,069 --> 01:06:46,079
those that are really difficult to

1412
01:06:51,289 --> 01:06:48,079
detect

1413
01:06:53,510 --> 01:06:51,299

what role do black holes play in shaping

1414
01:06:55,690 --> 01:06:53,520
the galaxies that they live in what

1415
01:06:59,630 --> 01:06:55,700
controls defeating habits of black holes

1416
01:07:01,849 --> 01:06:59,640
most galaxies that host supermassive

1417
01:07:03,349 --> 01:07:01,859
black holes those black holes are

1418
01:07:06,770 --> 01:07:03,359
dormant

1419
01:07:09,170 --> 01:07:06,780
why do some of them turn on why are

1420
01:07:13,630 --> 01:07:09,180
those feeding how does material get to

1421
01:07:16,549 --> 01:07:13,640
them and why do they stop feeding

1422
01:07:18,109 --> 01:07:16,559
and in the past few years we've learned

1423
01:07:20,270 --> 01:07:18,119
a lot due to an array of

1424
01:07:22,910 --> 01:07:20,280
multi-wavelength telescopes from ground

1425
01:07:26,029 --> 01:07:22,920
and from space as well as observatories

1426
01:07:28,910 --> 01:07:26,039
I could detect gravitational waves

1427
01:07:32,029 --> 01:07:28,920
but the future is even brighter

1428
01:07:35,089 --> 01:07:32,039
the next generation of telescopes will

1429
01:07:37,250 --> 01:07:35,099
really push the field forward and we've

1430
01:07:39,829 --> 01:07:37,260
been saying for years now as a community

1431
01:07:41,690 --> 01:07:39,839
that jwst is going to be awesome it's

1432
01:07:45,230 --> 01:07:41,700
going to tell us so much about the first

1433
01:07:48,710 --> 01:07:45,240
galaxies and the first black holes

1434
01:07:50,270 --> 01:07:48,720
um and after an intense year for those

1435
01:07:53,089 --> 01:07:50,280
of us supporting launch and

1436
01:07:54,710 --> 01:07:53,099
commissioning we are thrilled to say

1437
01:07:57,410 --> 01:07:54,720
that the performance of this telescope

1438
01:07:59,870 --> 01:07:57,420

is phenomenal exceeding some of our even

1439
01:08:02,750 --> 01:07:59,880
most ambitious expectations

1440
01:08:05,150 --> 01:08:02,760
so we know jwst is going to deliver on

1441
01:08:07,789 --> 01:08:05,160
these promises and from those

1442
01:08:09,770 --> 01:08:07,799
observations we're going to understand

1443
01:08:12,410 --> 01:08:09,780
how black holes evolved from early

1444
01:08:13,549 --> 01:08:12,420
Cosmic times to the present day and how

1445
01:08:16,370 --> 01:08:13,559
they shape

1446
01:08:19,490 --> 01:08:16,380
um Galaxy Evolution it's going to be an

1447
01:08:23,809 --> 01:08:19,500
exciting few years so stay tuned for

1448
01:08:30,950 --> 01:08:26,570
oh and thank you Stephanie

1449
01:08:32,809 --> 01:08:30,960
um it has been a joy over my career over

1450
01:08:35,390 --> 01:08:32,819
the years I've been doing astronomy to

1451
01:08:37,610 --> 01:08:35,400
watch black hole talks go from these

1452
01:08:39,410 --> 01:08:37,620
theoretical ideas to a little bit of

1453
01:08:42,050 --> 01:08:39,420
observations and X-ray binaries and

1454
01:08:44,749 --> 01:08:42,060
stuff until we finally have some real

1455
01:08:47,090 --> 01:08:44,759
serious observations to discuss uh

1456
01:08:49,189 --> 01:08:47,100
that's got to be gratifying for a

1457
01:08:51,410 --> 01:08:49,199
researcher in the field as well

1458
01:08:53,510 --> 01:08:51,420
yeah I mean it's just so funny because

1459
01:08:55,970 --> 01:08:53,520
like we we can't think about modern day

1460
01:08:58,910 --> 01:08:55,980
astrophysics without black holes right

1461
01:09:02,030 --> 01:08:58,920
and to think about just how far it came

1462
01:09:05,410 --> 01:09:02,040
from the 1960s when the first Quasar was

1463
01:09:07,610 --> 01:09:05,420

discovered and it was like what is this

1464
01:09:10,010 --> 01:09:07,620
quasi-stellar Source it's giving off

1465
01:09:11,630 --> 01:09:10,020
radios what's this all about and then

1466
01:09:13,729 --> 01:09:11,640
finding out it's like oh well that comes

1467
01:09:16,070 --> 01:09:13,739
from Beyond the Galaxy and we think it

1468
01:09:19,309 --> 01:09:16,080
might be a black hole it's like

1469
01:09:21,110 --> 01:09:19,319
yeah the uh the pathway in science is

1470
01:09:23,390 --> 01:09:21,120
long and it takes lots of twists and

1471
01:09:26,269 --> 01:09:23,400
turns but when you've got something and

1472
01:09:29,870 --> 01:09:26,279
you get the EHT images you go

1473
01:09:32,450 --> 01:09:29,880
yeah we really we've really gotten a uh

1474
01:09:34,249 --> 01:09:32,460
quite an amazing progress over these

1475
01:09:37,430 --> 01:09:34,259
decades

1476
01:09:39,950 --> 01:09:37,440
all right so I get this first question

1477
01:09:41,809 --> 01:09:39,960
um and you showed Agnes and you talked

1478
01:09:42,890 --> 01:09:41,819
about agents and then you showed these

1479
01:09:46,430 --> 01:09:42,900
Jets

1480
01:09:49,910 --> 01:09:46,440
yeah and one of our one of our uh astute

1481
01:09:51,829 --> 01:09:49,920
viewers wanted to know how do the Jets

1482
01:09:54,350 --> 01:09:51,839
from such a small object you emphasized

1483
01:09:56,930 --> 01:09:54,360
how small these black holes are get so

1484
01:09:59,150 --> 01:09:56,940
collimate is that they stay like

1485
01:10:01,130 --> 01:09:59,160
stretching across an entire galaxy how

1486
01:10:03,229 --> 01:10:01,140
do you collimate Jets so so carefully

1487
01:10:07,010 --> 01:10:03,239
how do you collimate just so carefully

1488
01:10:08,990 --> 01:10:07,020

so we think magnetic fields play a role

1489
01:10:11,630 --> 01:10:09,000
um so what we're seeing is particle

1490
01:10:14,150 --> 01:10:11,640
acceleration and so these particles will

1491
01:10:16,669 --> 01:10:14,160
accelerate by rotating around magnetic

1492
01:10:18,229 --> 01:10:16,679
field lines and this is this is one of

1493
01:10:21,050 --> 01:10:18,239
the ways that we could distinguish

1494
01:10:24,410 --> 01:10:21,060
between Jets and outflows it's just by

1495
01:10:26,330 --> 01:10:24,420
how collimated or how thin it is and we

1496
01:10:29,209 --> 01:10:26,340
really think that it's the magnetic

1497
01:10:32,930 --> 01:10:29,219
fields that is so much shaping the jet

1498
01:10:34,850 --> 01:10:32,940
shape to be to be narrow right and also

1499
01:10:36,470 --> 01:10:34,860
I mean the so the magnetic fields are

1500
01:10:38,930 --> 01:10:36,480
wound up by that accretion disk right

1501
01:10:41,330 --> 01:10:38,940
right right okay all right so basically

1502
01:10:42,709 --> 01:10:41,340
I I like I'm not a specialist in this

1503
01:10:44,510 --> 01:10:42,719
but I like to think it is the accretion

1504
01:10:45,709 --> 01:10:44,520
distance is winding this up getting it

1505
01:10:48,169 --> 01:10:45,719
so tight it's almost like you know

1506
01:10:50,390 --> 01:10:48,179
twisting a a little candy you get those

1507
01:10:53,689 --> 01:10:50,400
really tight things and but since it's

1508
01:10:56,090 --> 01:10:53,699
doing this at that at uh at the

1509
01:10:59,570 --> 01:10:56,100
relativistic speeds it can get into a

1510
01:11:01,669 --> 01:10:59,580
really long uh really long jet out of it

1511
01:11:03,890 --> 01:11:01,679
yeah that's cool

1512
01:11:05,149 --> 01:11:03,900
um and as always in astronomy if we

1513
01:11:07,729 --> 01:11:05,159

don't know it's got to be magnetic

1514
01:11:09,350 --> 01:11:07,739
fields right absolutely but here here's

1515
01:11:11,209 --> 01:11:09,360
one place where I if that's not a

1516
01:11:14,090 --> 01:11:11,219
cop-out okay to have that be the answer

1517
01:11:16,689 --> 01:11:14,100
to my first question it feels like no I

1518
01:11:20,090 --> 01:11:16,699
don't think it's really a cop-out guys

1519
01:11:22,070 --> 01:11:20,100
it's actually real all right uh we've

1520
01:11:24,070 --> 01:11:22,080
had a bunch of questions and a bunch of

1521
01:11:26,870 --> 01:11:24,080
compliments on your talk uh in the chat

1522
01:11:29,330 --> 01:11:26,880
uh Grant you want to turn on your video

1523
01:11:30,950 --> 01:11:29,340
and uh see to let us know which

1524
01:11:34,250 --> 01:11:30,960
questions you've picked out from the

1525
01:11:35,570 --> 01:11:34,260
chat welcome yeah absolutely hello

1526
01:11:37,189 --> 01:11:35,580
everyone

1527
01:11:39,110 --> 01:11:37,199
um so yes the chat has been great

1528
01:11:41,570 --> 01:11:39,120
tonight thank thank you everyone for

1529
01:11:45,070 --> 01:11:41,580
tuning in and asking questions

1530
01:11:47,630 --> 01:11:45,080
um we'll start off here

1531
01:11:50,090 --> 01:11:47,640
literally at the beginning what sort of

1532
01:11:52,310 --> 01:11:50,100
effect do you think black holes had on

1533
01:11:56,050 --> 01:11:52,320
Big Bang slash formation of the universe

1534
01:11:58,970 --> 01:11:56,060
like where do they fit into the Giants

1535
01:12:01,910 --> 01:11:58,980
oh okay so yeah primordial black holes

1536
01:12:04,130 --> 01:12:01,920
are a whole other topic

1537
01:12:06,229 --> 01:12:04,140
uh and I know I know some people have

1538
01:12:08,030 --> 01:12:06,239

been working on this I've not

1539
01:12:09,470 --> 01:12:08,040
so it's not one of my fields of research

1540
01:12:12,050 --> 01:12:09,480
so I don't really

1541
01:12:15,530 --> 01:12:12,060
um keep up with that

1542
01:12:17,330 --> 01:12:15,540
um yeah so so the objects that that I

1543
01:12:20,870 --> 01:12:17,340
study by and large are these things that

1544
01:12:23,810 --> 01:12:20,880
are the end products of something that

1545
01:12:25,669 --> 01:12:23,820
formed after the big bang right so for

1546
01:12:28,010 --> 01:12:25,679
the supermassive black holes they

1547
01:12:30,229 --> 01:12:28,020
probably form from larger seeds than the

1548
01:12:32,209 --> 01:12:30,239
Stellar Mass black holes so you had to

1549
01:12:35,330 --> 01:12:32,219
have already gone through the big bang

1550
01:12:38,030 --> 01:12:35,340
and had a dust cloud or something else

1551
01:12:39,770 --> 01:12:38,040
or intermediate Mass black holes that

1552
01:12:41,209 --> 01:12:39,780
merge and combine to form bigger black

1553
01:12:42,470 --> 01:12:41,219
holes

1554
01:12:44,390 --> 01:12:42,480
um when we're thinking about the very

1555
01:12:46,430 --> 01:12:44,400
first generation the primordial ones

1556
01:12:49,370 --> 01:12:46,440
around the big bang that has a whole

1557
01:12:50,950 --> 01:12:49,380
another ball game yeah okay that's you

1558
01:12:53,330 --> 01:12:50,960
know you're not expected to be an expert

1559
01:12:55,550 --> 01:12:53,340
absolutely everything yeah in the

1560
01:12:57,470 --> 01:12:55,560
universe although those of us in the

1561
01:13:01,250 --> 01:12:57,480
Outreach office have to pretend to be

1562
01:13:06,470 --> 01:13:04,729
um uh let's see there was a question

1563
01:13:08,570 --> 01:13:06,480

um oh there was a question sort of

1564
01:13:10,430 --> 01:13:08,580
related to someone like this and I know

1565
01:13:12,229 --> 01:13:10,440
it might be off topic but the uh

1566
01:13:13,790 --> 01:13:12,239
gamma-ray burst that just happened last

1567
01:13:17,090 --> 01:13:13,800
month somebody was asking about that

1568
01:13:22,550 --> 01:13:19,729
um it said to be the biggest of all time

1569
01:13:24,169 --> 01:13:22,560
yeah uh any new information on that or

1570
01:13:26,390 --> 01:13:24,179
do you want to explain it to the to our

1571
01:13:27,950 --> 01:13:26,400
audience a little bit Yeah so I mean

1572
01:13:30,290 --> 01:13:27,960
there's not much more than I know about

1573
01:13:33,410 --> 01:13:30,300
that other than

1574
01:13:35,870 --> 01:13:33,420
Swift detected this super energetic

1575
01:13:37,729 --> 01:13:35,880
gamma-ray burst I think at a time when

1576
01:13:39,709 --> 01:13:37,739
there was like a conference on gamma-ray

1577
01:13:41,030 --> 01:13:39,719
bursts happening like exactly I mean

1578
01:13:42,350 --> 01:13:41,040
which is kind of like it happened on

1579
01:13:45,410 --> 01:13:42,360
Saturday and the conference opened on

1580
01:13:46,790 --> 01:13:45,420
Sunday yeah yeah like oh man to be a fly

1581
01:13:48,470 --> 01:13:46,800
on the wall in that conference it must

1582
01:13:50,750 --> 01:13:48,480
have been amazing

1583
01:13:54,050 --> 01:13:50,760
um so I don't know what the what the

1584
01:13:55,870 --> 01:13:54,060
latest on that is I know that super

1585
01:13:58,310 --> 01:13:55,880
energetic

1586
01:14:00,470 --> 01:13:58,320
very exciting I know I've asked some

1587
01:14:01,729 --> 01:14:00,480
people like what is going on with that I

1588
01:14:03,530 --> 01:14:01,739

think they're still trying to figure it

1589
01:14:05,090 --> 01:14:03,540
out and it was a long gamma-ray burst

1590
01:14:08,990 --> 01:14:05,100
they said they were detecting for like

1591
01:14:11,270 --> 01:14:09,000
10 hours right 10 hours for a gamma ray

1592
01:14:12,830 --> 01:14:11,280
burst is one of the longest I've heard

1593
01:14:14,450 --> 01:14:12,840
of I'm not an expert in this field as

1594
01:14:16,790 --> 01:14:14,460
well

1595
01:14:19,010 --> 01:14:16,800
so okay these things usually last for

1596
01:14:20,570 --> 01:14:19,020
like seconds or minutes that's the

1597
01:14:22,070 --> 01:14:20,580
longest hour that's crazy yeah and the

1598
01:14:23,890 --> 01:14:22,080
other thing I read about it that it was

1599
01:14:26,209 --> 01:14:23,900
uh about two billion light years away

1600
01:14:27,770 --> 01:14:26,219
which you know sometimes for gamma ray

1601
01:14:29,270 --> 01:14:27,780
burst that sounds really really far away

1602
01:14:32,270 --> 01:14:29,280
but for some gamma ray bursts that's

1603
01:14:34,310 --> 01:14:32,280
actually relatively close right so

1604
01:14:36,169 --> 01:14:34,320
um getting this strong all right so

1605
01:14:37,790 --> 01:14:36,179
that's another another question we can

1606
01:14:39,890 --> 01:14:37,800
strike off the list because I didn't

1607
01:14:42,350 --> 01:14:39,900
think we had there was anything new

1608
01:14:45,229 --> 01:14:42,360
um but the observation sure will be

1609
01:14:49,010 --> 01:14:45,239
ongoing all right grant what's your all

1610
01:14:51,350 --> 01:14:49,020
right um at what location in the AGN do

1611
01:14:54,050 --> 01:14:51,360
relativistic outflows originating from

1612
01:14:56,510 --> 01:14:54,060
the active Galaxy get accelerated and

1613
01:14:59,350 --> 01:14:56,520

highly collimated wow we've got some

1614
01:15:07,010 --> 01:15:03,470
well stated yes this might be a ringer

1615
01:15:09,410 --> 01:15:07,020
um okay so so when we think about an AGN

1616
01:15:11,149 --> 01:15:09,420
we think about it kind of like in

1617
01:15:13,430 --> 01:15:11,159
different kind of like in different

1618
01:15:15,410 --> 01:15:13,440
pieces right so you have a black hole

1619
01:15:18,169 --> 01:15:15,420
you have the accretions feeding the

1620
01:15:21,189 --> 01:15:18,179
black hole and then right above and

1621
01:15:23,990 --> 01:15:21,199
below the accretion disk is this region

1622
01:15:26,630 --> 01:15:24,000
where if we think back to that Spectrum

1623
01:15:28,070 --> 01:15:26,640
or we saw these lines in the spectrum

1624
01:15:29,810 --> 01:15:28,080
that were wide

1625
01:15:33,229 --> 01:15:29,820
those lines are broad so we call it the

1626
01:15:35,630 --> 01:15:33,239
Broadline region so this is a gas that's

1627
01:15:37,850 --> 01:15:35,640
close to the black hole that is orbiting

1628
01:15:41,030 --> 01:15:37,860
rapidly and that's causing the lines to

1629
01:15:44,810 --> 01:15:41,040
to get broader and it's from this region

1630
01:15:48,649 --> 01:15:44,820
that we do see winds coming off the

1631
01:15:51,770 --> 01:15:48,659
accretion disk that propagate into the

1632
01:15:54,430 --> 01:15:51,780
host Galaxy so

1633
01:15:56,750 --> 01:15:54,440
um these winds don't necessarily get

1634
01:15:58,570 --> 01:15:56,760
very collimated if we think about

1635
01:16:01,550 --> 01:15:58,580
collimation we're thinking more about

1636
01:16:04,070 --> 01:16:01,560
jets that are getting collimated by the

1637
01:16:05,229 --> 01:16:04,080
magnetic fields but we do kind of see

1638
01:16:08,450 --> 01:16:05,239

that

1639
01:16:10,370 --> 01:16:08,460
these are in in a preferred Direction uh

1640
01:16:11,930 --> 01:16:10,380
because the equation disc is a disk the

1641
01:16:14,149 --> 01:16:11,940
winds are going to come off above and

1642
01:16:15,950 --> 01:16:14,159
below the disc and not from the sides

1643
01:16:19,910 --> 01:16:15,960
another thing that we also think about

1644
01:16:24,830 --> 01:16:19,920
around AGN is that around the accretion

1645
01:16:27,110 --> 01:16:24,840
disk is a a Taurus of dust and gas which

1646
01:16:29,750 --> 01:16:27,120
obscures your view to that central

1647
01:16:32,090 --> 01:16:29,760
region so sometimes we don't see that

1648
01:16:35,030 --> 01:16:32,100
central region of the accretion disk or

1649
01:16:36,169 --> 01:16:35,040
the outflows or the broad emission lines

1650
01:16:38,689 --> 01:16:36,179
because

1651
01:16:40,310 --> 01:16:38,699
this object is oriented such that we're

1652
01:16:43,070 --> 01:16:40,320
looking through that Taurus all that is

1653
01:16:46,250 --> 01:16:43,080
blocked so we only see the stuff that is

1654
01:16:49,070 --> 01:16:46,260
above and below by several parsecs a

1655
01:16:50,810 --> 01:16:49,080
parsec is something like three something

1656
01:16:51,649 --> 01:16:50,820
light years

1657
01:16:54,110 --> 01:16:51,659
um

1658
01:16:56,450 --> 01:16:54,120
so sometimes we could see some activity

1659
01:16:58,729 --> 01:16:56,460
there some type of outflow activity

1660
01:17:01,490 --> 01:16:58,739
though not as rapidly as the stuff

1661
01:17:03,890 --> 01:17:01,500
that's closer to the black hole okay

1662
01:17:05,930 --> 01:17:03,900
yeah that's a really good an important

1663
01:17:07,910 --> 01:17:05,940

point that the there are many different

1664
01:17:10,729 --> 01:17:07,920
scales when you talk about these AGN

1665
01:17:13,010 --> 01:17:10,739
structures and the different uh

1666
01:17:14,810 --> 01:17:13,020
emissions come from different scales and

1667
01:17:16,370 --> 01:17:14,820
you also mentioned that it's blocked and

1668
01:17:19,010 --> 01:17:16,380
so there's the difference between the

1669
01:17:20,930 --> 01:17:19,020
blazars and the qsos and the liners and

1670
01:17:23,630 --> 01:17:20,940
all those uh different emission regions

1671
01:17:25,610 --> 01:17:23,640
for AGN so uh the angle at which you're

1672
01:17:27,290 --> 01:17:25,620
viewing it which is something you know

1673
01:17:29,990 --> 01:17:27,300
you wouldn't necessarily think of it

1674
01:17:31,669 --> 01:17:30,000
plays such a big role in your field yeah

1675
01:17:35,390 --> 01:17:31,679
absolutely that's that would be a whole

1676
01:17:40,510 --> 01:17:35,400
other talk yes that would be I think I

1677
01:17:44,390 --> 01:17:42,709
a good reminder for people in the

1678
01:17:46,010 --> 01:17:44,400
audience we've done lots and lots of

1679
01:17:48,020 --> 01:17:46,020
these if you have a question we've

1680
01:17:50,110 --> 01:17:48,030
probably covered it

1681
01:17:53,270 --> 01:17:50,120
[Music]

1682
01:17:53,990 --> 01:17:53,280
so uh I actually like this one quite a

1683
01:18:00,169 --> 01:17:54,000
bit

1684
01:18:02,270 --> 01:18:00,179
um so black holes can Collide and do the

1685
01:18:03,950 --> 01:18:02,280
and they lose mass in the Collision does

1686
01:18:07,610 --> 01:18:03,960
that mean something actually escapes

1687
01:18:10,250 --> 01:18:07,620
them do they trade material yeah yeah so

1688
01:18:12,470 --> 01:18:10,260

if you do the math right and you think

1689
01:18:15,110 --> 01:18:12,480
about these gravitational wave events

1690
01:18:17,270 --> 01:18:15,120
that we've observed and you add up the

1691
01:18:19,430 --> 01:18:17,280
mass of the two progenitors the two

1692
01:18:21,530 --> 01:18:19,440
black holes that were there and then the

1693
01:18:24,610 --> 01:18:21,540
mass of the final object there's a

1694
01:18:27,290 --> 01:18:24,620
difference some of that goes into energy

1695
01:18:29,209 --> 01:18:27,300
uh equals mc squared so some of that

1696
01:18:32,030 --> 01:18:29,219
Mass gets converted to energy which is

1697
01:18:34,130 --> 01:18:32,040
given off by gravitational waves right

1698
01:18:36,410 --> 01:18:34,140
and and that actually brings up another

1699
01:18:38,149 --> 01:18:36,420
question somebody asked I mean there's a

1700
01:18:40,370 --> 01:18:38,159
tremendous amount of energy from this

1701
01:18:44,030 --> 01:18:40,380
black hole Collision company can get off

1702
01:18:47,149 --> 01:18:44,040
but by the time it gets to our solar

1703
01:18:49,070 --> 01:18:47,159
system it's really diluted

1704
01:18:51,350 --> 01:18:49,080
um so somebody was talking about a Star

1705
01:18:53,390 --> 01:18:51,360
Trek episode where I I guess some sort

1706
01:18:54,709 --> 01:18:53,400
of wave passed over the Enterprise or

1707
01:18:55,669 --> 01:18:54,719
whatever and everything got distorted

1708
01:18:58,189 --> 01:18:55,679
and everything

1709
01:18:59,090 --> 01:18:58,199
um can you clarify that that's not

1710
01:19:00,950 --> 01:18:59,100
really what happens with the

1711
01:19:03,110 --> 01:19:00,960
gravitational waves that we've observed

1712
01:19:05,649 --> 01:19:03,120
I mean this would make detection's so

1713
01:19:07,490 --> 01:19:05,659

much easier right

1714
01:19:09,770 --> 01:19:07,500
you wouldn't have to do these things

1715
01:19:13,850 --> 01:19:09,780
that are 10 to the minus ridiculous like

1716
01:19:15,830 --> 01:19:13,860
yeah you know trying to find instead uh

1717
01:19:17,450 --> 01:19:15,840
yeah it's not actually what happens yeah

1718
01:19:19,970 --> 01:19:17,460
it would make some people's job easier

1719
01:19:21,770 --> 01:19:19,980
but do you happen to know that the

1720
01:19:23,750 --> 01:19:21,780
actual scale is it a femto meter or

1721
01:19:25,149 --> 01:19:23,760
something like that something like that

1722
01:19:28,310 --> 01:19:25,159
I don't remember off the top of my head

1723
01:19:31,070 --> 01:19:28,320
it's really tiny it's ten to the minus

1724
01:19:33,830 --> 01:19:31,080
ridiculous I love that phrase

1725
01:19:36,229 --> 01:19:33,840
so the amount of spatial Distortion is

1726
01:19:39,050 --> 01:19:36,239
immeasurable it's you know on more on

1727
01:19:41,030 --> 01:19:39,060
the atomic scale right yeah okay just

1728
01:19:43,930 --> 01:19:41,040
gonna get that question answered go

1729
01:19:48,649 --> 01:19:43,940
ahead two wonderful phrases tonight

1730
01:19:50,570 --> 01:19:48,659
uh it was 10 to the minus ridiculous and

1731
01:19:53,930 --> 01:19:50,580
uh what was the other one candy candy

1732
01:19:58,790 --> 01:19:55,550
yeah

1733
01:20:00,590 --> 01:19:58,800
I love it I love it all right um less of

1734
01:20:03,830 --> 01:20:00,600
a question and more of a point for

1735
01:20:06,050 --> 01:20:03,840
further discussion

1736
01:20:09,350 --> 01:20:06,060
um let me pull down a little bit here to

1737
01:20:14,870 --> 01:20:12,229
so um if the Jets are collimated by a

1738
01:20:17,030 --> 01:20:14,880

magnetic field would that make them

1739
01:20:20,950 --> 01:20:17,040
ionic which would change the

1740
01:20:26,689 --> 01:20:24,290
so yeah okay so

1741
01:20:32,330 --> 01:20:26,699
I mean it's what we're seeing when we

1742
01:20:34,610 --> 01:20:32,340
observe Jets is synchrotron radiation so

1743
01:20:38,030 --> 01:20:34,620
kind of the the Spectra that I was

1744
01:20:40,669 --> 01:20:38,040
showing of AGN that's not going to be

1745
01:20:43,910 --> 01:20:40,679
from from a jet that's going to be from

1746
01:20:47,570 --> 01:20:43,920
gas like in the Galaxy itself the

1747
01:20:49,490 --> 01:20:47,580
Spectra for jets are they just look

1748
01:20:52,490 --> 01:20:49,500
different it's from a different physical

1749
01:20:53,570 --> 01:20:52,500
process so

1750
01:20:56,870 --> 01:20:53,580
um again it's like it's like it's

1751
01:20:58,430 --> 01:20:56,880
particle acceleration so uh you have to

1752
01:21:00,350 --> 01:20:58,440
start thinking about particle physics a

1753
01:21:02,990 --> 01:21:00,360
little bit and thinking about the

1754
01:21:05,270 --> 01:21:03,000
different Origins for for particles

1755
01:21:07,970 --> 01:21:05,280
right and I'm used to thinking of

1756
01:21:10,250 --> 01:21:07,980
observing Jets and radio waves yeah

1757
01:21:12,050 --> 01:21:10,260
yeah so that's that you're not really

1758
01:21:14,990 --> 01:21:12,060
looking at Spectra in the radio waves

1759
01:21:16,490 --> 01:21:15,000
right right right like you'll get like a

1760
01:21:18,350 --> 01:21:16,500
spectral energy distribution right

1761
01:21:19,790 --> 01:21:18,360
you'll get so you can also see Judson

1762
01:21:22,010 --> 01:21:19,800
x-rays

1763
01:21:24,350 --> 01:21:22,020

um but like kind of a similar like

1764
01:21:25,550 --> 01:21:24,360
you'll have like these seed photons

1765
01:21:27,470 --> 01:21:25,560
probably from the caustic microwave

1766
01:21:30,890 --> 01:21:27,480
background that inverse Compton scatter

1767
01:21:34,970 --> 01:21:30,900
off of plasma causing causing these Jets

1768
01:21:35,870 --> 01:21:34,980
um but so what you would get are

1769
01:21:38,930 --> 01:21:35,880
um

1770
01:21:41,209 --> 01:21:38,940
you would get the amount of energy at

1771
01:21:42,229 --> 01:21:41,219
some discrete wavelength so it won't be

1772
01:21:44,030 --> 01:21:42,239
like the kind of the same information

1773
01:21:46,790 --> 01:21:44,040
that you get from the Spectrum but you

1774
01:21:49,010 --> 01:21:46,800
get like a very very very low resolution

1775
01:21:50,870 --> 01:21:49,020
Spectrum special energy distribution

1776
01:21:53,810 --> 01:21:50,880
that you could fit with different models

1777
01:21:55,490 --> 01:21:53,820
right but I think the original commenter

1778
01:21:57,950 --> 01:21:55,500
is correct you know in saying that all

1779
01:21:59,510 --> 01:21:57,960
right if there are there being

1780
01:22:02,390 --> 01:21:59,520
accelerated by managing Fields they have

1781
01:22:04,970 --> 01:22:02,400
to be charged right oh yeah yeah yeah so

1782
01:22:07,970 --> 01:22:04,980
just clarify on that point

1783
01:22:10,010 --> 01:22:07,980
okay cool I had a question I wanted to

1784
01:22:12,590 --> 01:22:10,020
comment on because you've been using

1785
01:22:14,570 --> 01:22:12,600
Sloan digital Sky survey

1786
01:22:16,669 --> 01:22:14,580
um and a lot of researchers these days

1787
01:22:18,770 --> 01:22:16,679
are using the Hubble archive and they

1788
01:22:22,430 --> 01:22:18,780

will be using the web archive can you

1789
01:22:24,410 --> 01:22:22,440
just make a comment on how this uh the

1790
01:22:26,990 --> 01:22:24,420
development of these very large archives

1791
01:22:29,390 --> 01:22:27,000
that uh researchers can mind has helped

1792
01:22:31,550 --> 01:22:29,400
astronomy or hindered astronomy if you

1793
01:22:32,290 --> 01:22:31,560
think so but I I kind of think it helps

1794
01:22:35,209 --> 01:22:32,300
it

1795
01:22:38,750 --> 01:22:35,219
almost almost too much data to get

1796
01:22:41,149 --> 01:22:38,760
through but no it is it is just so it's

1797
01:22:42,229 --> 01:22:41,159
so amazing because uh I mean there's

1798
01:22:44,209 --> 01:22:42,239
several things that you could think

1799
01:22:45,890 --> 01:22:44,219
about if you think about a survey

1800
01:22:49,070 --> 01:22:45,900
telescope something like the Sloan

1801
01:22:51,350 --> 01:22:49,080
digital Sky survey there will be several

1802
01:22:55,070 --> 01:22:51,360
science questions that are posed that

1803
01:22:56,930 --> 01:22:55,080
you'll say data from this survey will

1804
01:22:59,330 --> 01:22:56,940
help answer and that's why we need to

1805
01:23:01,250 --> 01:22:59,340
observe these types of objects and take

1806
01:23:02,570 --> 01:23:01,260
these data to answer these types of

1807
01:23:05,750 --> 01:23:02,580
questions

1808
01:23:08,750 --> 01:23:05,760
but the applications for what could

1809
01:23:11,630 --> 01:23:08,760
actually be solved with that data set go

1810
01:23:13,550 --> 01:23:11,640
well beyond that original pitch for why

1811
01:23:15,830 --> 01:23:13,560
why you need that telescope or a certain

1812
01:23:18,470 --> 01:23:15,840
observing plan so you're really only

1813
01:23:21,110 --> 01:23:18,480

limit limited by the creativity of

1814
01:23:23,750 --> 01:23:21,120
people of astronomers to

1815
01:23:26,270 --> 01:23:23,760
um to ask big questions and that could

1816
01:23:27,890 --> 01:23:26,280
be anything from statistical studies

1817
01:23:31,610 --> 01:23:27,900
where you need big data and you're

1818
01:23:33,410 --> 01:23:31,620
looking for Trends it could be hey I

1819
01:23:36,649 --> 01:23:33,420
discovered something kind of interesting

1820
01:23:38,270 --> 01:23:36,659
is there any other data out there of

1821
01:23:41,330 --> 01:23:38,280
this object that I didn't even know

1822
01:23:44,630 --> 01:23:41,340
about go through archives and find that

1823
01:23:48,169 --> 01:23:44,640
um and so even for things like the

1824
01:23:51,590 --> 01:23:48,179
Hubble archive or the jwst archive

1825
01:23:54,229 --> 01:23:51,600
those are observations by and large

1826
01:23:56,330 --> 01:23:54,239
where astronomers have said I want to

1827
01:23:59,149 --> 01:23:56,340
look at this object or this patch of sky

1828
01:24:01,669 --> 01:23:59,159
for this reason it's not like these big

1829
01:24:03,590 --> 01:24:01,679
holistic let's just study a whole big

1830
01:24:06,169 --> 01:24:03,600
part of the sky and and just grab all

1831
01:24:08,450 --> 01:24:06,179
the as much data as we can

1832
01:24:11,689 --> 01:24:08,460
um these are kind of to answer very

1833
01:24:13,850 --> 01:24:11,699
specific questions but then the value of

1834
01:24:15,770 --> 01:24:13,860
those data sets to the community who

1835
01:24:18,169 --> 01:24:15,780
might come back a year later two years

1836
01:24:20,930 --> 01:24:18,179
later 20 years later to then look at

1837
01:24:23,450 --> 01:24:20,940
that data to answer other questions I

1838
01:24:25,310 --> 01:24:23,460

mean like it helps in a way is that the

1839
01:24:26,870 --> 01:24:25,320
original observing team probably never

1840
01:24:29,750 --> 01:24:26,880
even thought about

1841
01:24:31,430 --> 01:24:29,760
you know and I I think forward to the um

1842
01:24:34,310 --> 01:24:31,440
the Reuben

1843
01:24:35,689 --> 01:24:34,320
um and we're getting a 10-year monstrous

1844
01:24:37,189 --> 01:24:35,699
data dump

1845
01:24:38,590 --> 01:24:37,199
um that we'll be going through for you

1846
01:24:41,990 --> 01:24:38,600
know probably the rest of this Century

1847
01:24:44,090 --> 01:24:42,000
seriously and I also think about back

1848
01:24:45,890 --> 01:24:44,100
back to the discovery of Uranus and

1849
01:24:47,870 --> 01:24:45,900
Neptune Etc going back into the old

1850
01:24:49,729 --> 01:24:47,880
flamsteed plates to try and see oh

1851
01:24:52,250 --> 01:24:49,739
somebody actually did see this you know

1852
01:24:54,790 --> 01:24:52,260
70 years before the anybody ever thought

1853
01:24:58,550 --> 01:24:54,800
to go look for it so

1854
01:25:01,250 --> 01:24:58,560
you as a benefit beneficiary of of one

1855
01:25:03,229 --> 01:25:01,260
of these great surveys I think uh great

1856
01:25:06,229 --> 01:25:03,239
to hear your review about it yeah okay

1857
01:25:07,850 --> 01:25:06,239
Grant all right two more questions two

1858
01:25:10,189 --> 01:25:07,860
more questions just about right sounds

1859
01:25:12,410 --> 01:25:10,199
good all right um with all the different

1860
01:25:14,270 --> 01:25:12,420
techniques of detecting black holes that

1861
01:25:16,669 --> 01:25:14,280
are available now and what is known

1862
01:25:18,890 --> 01:25:16,679
about their biases can we estimate the

1863
01:25:21,590 --> 01:25:18,900

distribution of black hole masses or

1864
01:25:24,790 --> 01:25:21,600
spins in the universe yeah so that's

1865
01:25:28,330 --> 01:25:24,800
that is a really good question and uh

1866
01:25:31,250 --> 01:25:28,340
yeah seriously and the answer answer is

1867
01:25:33,590 --> 01:25:31,260
yes kind of um there are definitely

1868
01:25:35,750 --> 01:25:33,600
papers published every couple of years

1869
01:25:38,450 --> 01:25:35,760
where people will use survey data to say

1870
01:25:40,970 --> 01:25:38,460
you know again look at patch of Sky

1871
01:25:44,030 --> 01:25:40,980
assume it's representative of a certain

1872
01:25:46,490 --> 01:25:44,040
population and then map out saying you

1873
01:25:47,990 --> 01:25:46,500
know we've detected these many black

1874
01:25:51,410 --> 01:25:48,000
holes at all these different distances

1875
01:25:53,390 --> 01:25:51,420
you could then use that to say here's

1876
01:25:56,390 --> 01:25:53,400
how we think this population has evolved

1877
01:25:58,370 --> 01:25:56,400
over time so getting to that of like

1878
01:26:00,530 --> 01:25:58,380
what's the distribution of black hole

1879
01:26:04,310 --> 01:26:00,540
masses and the more that you could

1880
01:26:07,729 --> 01:26:04,320
combine data from different selection

1881
01:26:10,070 --> 01:26:07,739
techniques perhaps you can mitigate the

1882
01:26:12,410 --> 01:26:10,080
biases with any one technique to get a

1883
01:26:14,570 --> 01:26:12,420
more comprehensive view that being said

1884
01:26:16,729 --> 01:26:14,580
it is complicated because then there you

1885
01:26:18,470 --> 01:26:16,739
know each one has biases so then how do

1886
01:26:19,669 --> 01:26:18,480
you combine stuff knowing that they all

1887
01:26:22,790 --> 01:26:19,679
have biases and they have different

1888
01:26:25,070 --> 01:26:22,800

selection techniques so it's complicated

1889
01:26:28,669 --> 01:26:25,080
and there are some limitations but it's

1890
01:26:31,129 --> 01:26:28,679
definitely stuff that people do work on

1891
01:26:34,370 --> 01:26:31,139
and uh and that's an interesting thing

1892
01:26:36,290 --> 01:26:34,380
to do is to compare what you get using

1893
01:26:38,330 --> 01:26:36,300
one method with a different method and

1894
01:26:40,910 --> 01:26:38,340
just seeing where the consistencies are

1895
01:26:43,250 --> 01:26:40,920
and understanding what it is that you

1896
01:26:45,169 --> 01:26:43,260
might be missing in some studies versus

1897
01:26:46,310 --> 01:26:45,179
other studies

1898
01:26:48,169 --> 01:26:46,320
um which is actually probably going to

1899
01:26:49,970 --> 01:26:48,179
be a paper that I'm co-author of coming

1900
01:26:52,430 --> 01:26:49,980
out sometime within the next few weeks

1901
01:26:55,550 --> 01:26:52,440
that that does this uh we just got the

1902
01:26:58,610 --> 01:26:55,560
referee report on it I think today

1903
01:27:00,709 --> 01:26:58,620
um so uh it is a really cool thing to do

1904
01:27:05,030 --> 01:27:00,719
for getting the spins of black holes

1905
01:27:06,830 --> 01:27:05,040
that is a little bit more challenging

1906
01:27:09,649 --> 01:27:06,840
um just because sometimes it's hard to

1907
01:27:11,090 --> 01:27:09,659
definitively measure the spins of black

1908
01:27:13,370 --> 01:27:11,100
holes

1909
01:27:15,770 --> 01:27:13,380
um and some of the ways that are used

1910
01:27:18,890 --> 01:27:15,780
not everyone agrees that those

1911
01:27:20,270 --> 01:27:18,900
techniques uh uniquely measure spin you

1912
01:27:23,209 --> 01:27:20,280
could get some of these features by

1913
01:27:24,729 --> 01:27:23,219

other processes so that that's a little

1914
01:27:26,930 --> 01:27:24,739
bit more challenging

1915
01:27:29,209 --> 01:27:26,940
well one of the things that I thought

1916
01:27:31,010 --> 01:27:29,219
was fascinating about the Stella

1917
01:27:32,629 --> 01:27:31,020
graveyard like you showed the cellar

1918
01:27:36,830 --> 01:27:32,639
grave I think is that we're getting up

1919
01:27:39,770 --> 01:27:36,840
to actually knowing of math black holes

1920
01:27:41,570 --> 01:27:39,780
at 150 Solar masses right

1921
01:27:43,010 --> 01:27:41,580
um we didn't have evidence for anything

1922
01:27:44,709 --> 01:27:43,020
like that

1923
01:27:47,330 --> 01:27:44,719
um a few years ago so

1924
01:27:50,030 --> 01:27:47,340
our speculation that we could have 300

1925
01:27:52,010 --> 01:27:50,040
solar mass black holes uh might not be

1926
01:27:55,070 --> 01:27:52,020
as so much speculation anymore

1927
01:27:56,930 --> 01:27:55,080
yeah it's really cool like that the big

1928
01:28:01,330 --> 01:27:56,940
one the most massive signal where they

1929
01:28:04,790 --> 01:28:01,340
announced that I think September of 2020

1930
01:28:06,709 --> 01:28:04,800
like it was it was really cool like Not

1931
01:28:08,930 --> 01:28:06,719
only was like this black hole masses he

1932
01:28:11,510 --> 01:28:08,940
said like around 150 times mass of our

1933
01:28:13,310 --> 01:28:11,520
sun but even the masses of the

1934
01:28:15,890 --> 01:28:13,320
progenitors the two things that that

1935
01:28:18,890 --> 01:28:15,900
collided some of those were like how do

1936
01:28:22,610 --> 01:28:18,900
we get black holes exactly right this

1937
01:28:30,370 --> 01:28:24,470
all right last question Grant all right

1938
01:28:36,350 --> 01:28:33,050

so what was it that got you originally

1939
01:28:38,390 --> 01:28:36,360
interested in astrophysics and what path

1940
01:28:40,430 --> 01:28:38,400
would you say someone getting into it

1941
01:28:42,290 --> 01:28:40,440
newly should do I mean you knew it was

1942
01:28:44,450 --> 01:28:42,300
coming okay okay

1943
01:28:46,550 --> 01:28:44,460
discussions all right so like the short

1944
01:28:49,370 --> 01:28:46,560
answer is I always thought outer space

1945
01:28:52,189 --> 01:28:49,380
was cool and then I never grew up and so

1946
01:28:53,629 --> 01:28:52,199
I just kept on uh you know growing up as

1947
01:28:58,070 --> 01:28:53,639
a trap I'm just throwing it out there

1948
01:28:59,330 --> 01:28:58,080
yeah absolutely absolutely so uh when I

1949
01:29:00,890 --> 01:28:59,340
was in high school and looking at

1950
01:29:03,530 --> 01:29:00,900
colleges I was like I want to major in

1951
01:29:05,270 --> 01:29:03,540
astronomy um and so I just applied to

1952
01:29:06,950 --> 01:29:05,280
astronomy programs

1953
01:29:08,090 --> 01:29:06,960
um and just kind of kept on going from

1954
01:29:10,310 --> 01:29:08,100
there

1955
01:29:12,350 --> 01:29:10,320
um so for someone new wanting to get

1956
01:29:14,090 --> 01:29:12,360
into it I'd say there's just like so

1957
01:29:16,189 --> 01:29:14,100
many opportunities out there so much

1958
01:29:17,930 --> 01:29:16,199
more than when I started out because now

1959
01:29:19,970 --> 01:29:17,940
we have the internet and now we have all

1960
01:29:23,810 --> 01:29:19,980
these other things like wonderful

1961
01:29:25,790 --> 01:29:23,820
Outreach activities uh to engage people

1962
01:29:27,350 --> 01:29:25,800
um you mean you couldn't control F your

1963
01:29:29,689 --> 01:29:27,360

dissertation when you were looking for

1964
01:29:31,430 --> 01:29:29,699
things I mean

1965
01:29:33,110 --> 01:29:31,440
well I was thinking more like more

1966
01:29:35,330 --> 01:29:33,120
younger you know when you're a kind of

1967
01:29:37,850 --> 01:29:35,340
like more high school age which was yeah

1968
01:29:40,550 --> 01:29:37,860
I wasn't wearing any dissertations then

1969
01:29:42,470 --> 01:29:40,560
um so one thing said I I would recommend

1970
01:29:44,930 --> 01:29:42,480
is look for

1971
01:29:49,070 --> 01:29:44,940
um in turn opportunities

1972
01:29:52,189 --> 01:29:49,080
um and apply for those there are also

1973
01:29:53,689 --> 01:29:52,199
um websites that have online tutorials

1974
01:29:55,310 --> 01:29:53,699
about

1975
01:29:57,890 --> 01:29:55,320
um you know they'll give you a data set

1976
01:29:59,990 --> 01:29:57,900
to play with and a tutorial of how to

1977
01:30:02,810 --> 01:30:00,000
work through that data set so those

1978
01:30:05,149 --> 01:30:02,820
could be a lot of fun to look at I think

1979
01:30:07,490 --> 01:30:05,159
stsci might have some of these through

1980
01:30:09,590 --> 01:30:07,500
through the their archives

1981
01:30:11,689 --> 01:30:09,600
um I know son digital Sky survey has

1982
01:30:14,090 --> 01:30:11,699
some of those get some experience with

1983
01:30:16,010 --> 01:30:14,100
coding because we do a lot of coding to

1984
01:30:18,350 --> 01:30:16,020
analyze data

1985
01:30:22,250 --> 01:30:18,360
um and yeah just keep on listening to

1986
01:30:24,410 --> 01:30:22,260
cool and fun talks and uh look for

1987
01:30:25,550 --> 01:30:24,420
opportunities for for internships and

1988
01:30:28,430 --> 01:30:25,560

other things

1989
01:30:30,950 --> 01:30:28,440
yeah and you you can't emphasize enough

1990
01:30:33,770 --> 01:30:30,960
the ability to do your mathematics to do

1991
01:30:36,890 --> 01:30:33,780
your coding and I like to say just to

1992
01:30:39,350 --> 01:30:36,900
solve problems okay because astronomy is

1993
01:30:41,810 --> 01:30:39,360
about encountering things that are just

1994
01:30:44,270 --> 01:30:41,820
out there right and so you've got to be

1995
01:30:46,910 --> 01:30:44,280
able to think laterally you've got to be

1996
01:30:49,790 --> 01:30:46,920
able to think outside the box uh for a

1997
01:30:53,510 --> 01:30:49,800
lot of astronomy so yeah a big thing is

1998
01:30:55,910 --> 01:30:53,520
grit right like it gets hard the more

1999
01:30:58,310 --> 01:30:55,920
you you're willing to stick with it and

2000
01:31:00,950 --> 01:30:58,320
work through challenges like that is

2001
01:31:02,450 --> 01:31:00,960
that that's really a good trait to have

2002
01:31:05,390 --> 01:31:02,460
all right

2003
01:31:10,070 --> 01:31:05,400
okay so that's all the time we have

2004
01:31:11,950 --> 01:31:10,080
tonight next month December 6th high

2005
01:31:14,750 --> 01:31:11,960
energy astronomy with the Swift

2006
01:31:16,550 --> 01:31:14,760
Observatory and so that gamma ray burst

2007
01:31:19,070 --> 01:31:16,560
we just talked about discovered by Swift

2008
01:31:22,070 --> 01:31:19,080
you'll hear about that next month Steve

2009
01:31:23,149 --> 01:31:22,080
Kirby from Penn State University until

2010
01:31:25,729 --> 01:31:23,159
then