PUBLIC LECTURE SERIES

Recycle Your Used Pulsars: Explaining the Extra Gamma-Radiation from the Central Milky Way

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Featuring Guest Speaker:

Christopher Britt

1
00:00:08,660 --> 00:00:04,999
is the butterfly nebula NGC 6302 which

2
00:00:10,220 --> 00:00:08,670
in fact is not the butterfly nebula it

3
00:00:13,129 --> 00:00:10,230
is the bug nebula

4
00:00:15,799 --> 00:00:13,139
however in our press release of this

5
00:00:18,410 --> 00:00:15,809
image we said it resembled a butterfly

6
00:00:19,970 --> 00:00:18,420
the internet took it over the media took

7
00:00:22,790 --> 00:00:19,980
it over it is an out of the butterfly

8
00:00:25,220 --> 00:00:22,800
nebula okay fun fact of that you will

9
00:00:28,640 --> 00:00:25,230
not learn that fact on the back of the

10
00:00:29,630 --> 00:00:28,650
of the net of the lithograph instead

11
00:00:32,780 --> 00:00:29,640
you'll learn other things about what

12
00:00:34,880 --> 00:00:32,790
this object really is the death of this

13
00:00:37,370 --> 00:00:34,890

star here in the amazing temperature

14
00:00:39,680 --> 00:00:37,380
that's heating the gas flowing away from

15
00:00:42,530 --> 00:00:39,690
it alright for those of you on the

16
00:00:45,799 --> 00:00:42,540
Internet you can see the URL down here

17
00:00:48,680 --> 00:00:45,809
at the bottom amazing space org resource

18
00:00:50,690 --> 00:00:48,690
page number 59 this is one of our

19
00:00:53,660 --> 00:00:50,700
earlier ones on this okay so you can

20
00:00:54,680 --> 00:00:53,670
download it there while you are looking

21
00:00:59,229 --> 00:00:54,690
at your listen graph we're downloading

22
00:01:01,760 --> 00:00:59,239
it please silence your electronics our

23
00:01:04,609 --> 00:01:01,770
AV folks have pointed out to me that I

24
00:01:06,590 --> 00:01:04,619
have been laxed to join the 20th century

25
00:01:08,210 --> 00:01:06,600
and asked my audience to please quiet

26
00:01:10,340 --> 00:01:08,220
their phones silence your cell phones

27
00:01:10,880 --> 00:01:10,350
sorry I don't have one of those big

28
00:01:13,010 --> 00:01:10,890
crazy

29
00:01:15,050 --> 00:01:13,020
mm commercials that they do at the

30
00:01:19,340 --> 00:01:15,060
movies maybe I'll have to fire at one of

31
00:01:21,670 --> 00:01:19,350
those for next month okay ah tonight we

32
00:01:24,289 --> 00:01:21,680
have recycle your used pulsars

33
00:01:26,749 --> 00:01:24,299
explaining the extra gamma radiation

34
00:01:28,190 --> 00:01:26,759
from the Central Milky Way and how have

35
00:01:29,690 --> 00:01:28,200
you looked at this is that I have no

36
00:01:32,179 --> 00:01:29,700
idea what that is but it sounds real

37
00:01:34,160 --> 00:01:32,189
cool well this man down here is gonna

38
00:01:38,330 --> 00:01:34,170

explain all about it that's Christopher

39
00:01:40,490 --> 00:01:38,340
Britt upcoming on July 2nd the art and

40
00:01:44,179 --> 00:01:40,500
science of astronomical image processing

41
00:01:47,480 --> 00:01:44,189
from Joe de Pascua our senior image

42
00:01:51,620 --> 00:01:47,490
processor here an August we have the

43
00:01:53,630 --> 00:01:51,630
exciting topic of TBA I talked to Trisha

44
00:01:55,280 --> 00:01:53,640
and she said well I've got two really

45
00:01:57,109 --> 00:01:55,290
good topic sent him and she wasn't ready

46
00:01:59,030 --> 00:01:57,119
to commit to any one of them I said just

47
00:02:01,399 --> 00:01:59,040
choose one and she said well I'll let

48
00:02:04,910 --> 00:02:01,409
you know she didn't let me know so she's

49
00:02:07,429 --> 00:02:04,920
TVA and Brandon Lawton on September 3rd

50
00:02:09,859 --> 00:02:07,439
he's also in the same situation he and I

51
00:02:12,020 --> 00:02:09,869
discussed today and he goes well I yeah

52
00:02:13,100 --> 00:02:12,030
he also has two topics that he wants to

53
00:02:16,460 --> 00:02:13,110
talk about

54
00:02:19,280 --> 00:02:16,470
maybe I have to twist some arms to get

55
00:02:20,840 --> 00:02:19,290
some number names some titles but at

56
00:02:23,600 --> 00:02:20,850
least you know we have speakers for

57
00:02:25,910 --> 00:02:23,610
August and September if you want to see

58
00:02:29,090 --> 00:02:25,920
their titles they can find this webpage

59
00:02:32,870 --> 00:02:29,100
about our upcoming lectures over here on

60
00:02:35,210 --> 00:02:32,880
the right the links to our webcasting

61
00:02:37,910 --> 00:02:35,220
here on the left you can watch the past

62
00:02:42,740 --> 00:02:37,920
lectures on YouTube and in the STScI

63
00:02:46,790 --> 00:02:42,750

webcast all the way back to 2005 so wow

64
00:02:50,930 --> 00:02:46,800
that's 14 years worth of universal

65
00:02:52,520 --> 00:02:50,940
cosmic knowledge who if you want to sign

66
00:02:54,140 --> 00:02:52,530
up for email this is the easiest way to

67
00:02:56,780 --> 00:02:54,150
do it right here enter your email you

68
00:03:00,290 --> 00:02:56,790
can also unsubscribe okay although why

69
00:03:01,580 --> 00:03:00,300
would you want to do that as for those

70
00:03:03,050 --> 00:03:01,590
announcements you can sign if you don't

71
00:03:04,970 --> 00:03:03,060
like to sign at the website you can just

72
00:03:07,880 --> 00:03:04,980
write your email address on a piece of

73
00:03:10,550 --> 00:03:07,890
paper hand it to me by the old-fashioned

74
00:03:13,490 --> 00:03:10,560
paper method and I will make sure you

75
00:03:15,140 --> 00:03:13,500
get signed up if you have comments and

76
00:03:19,850 --> 00:03:15,150
questions you can send them to public

77
00:03:21,470 --> 00:03:19,860
lecture at stsci edu for those of us

78
00:03:24,020 --> 00:03:21,480
those of you who like to follow social

79
00:03:26,480 --> 00:03:24,030
media we have a variety of accounts on

80
00:03:28,940 --> 00:03:26,490
Facebook Twitter YouTube and Instagram

81
00:03:30,860 --> 00:03:28,950
not only for Hubble not only for the

82
00:03:31,880 --> 00:03:30,870
James Webb Space Telescope but also for

83
00:03:35,270 --> 00:03:31,890
our Institute the Space Telescope

84
00:03:37,220 --> 00:03:35,280
Science Institute myself I do I do a

85
00:03:39,070 --> 00:03:37,230
little bit of social media on Facebook

86
00:03:43,040 --> 00:03:39,080
and Twitter

87
00:03:44,630 --> 00:03:43,050
tonight the observatory has said they're

88
00:03:46,760 --> 00:03:44,640

going to be open hi did anybody look up

89
00:03:49,400 --> 00:03:46,770
was it was it clear when we came in yes

90
00:03:50,540 --> 00:03:49,410
alright so we are looking good for the

91
00:03:53,720 --> 00:03:50,550
observer American Space Grant

92
00:03:55,610 --> 00:03:53,730
Observatory being open if you can't do

93
00:03:57,050 --> 00:03:55,620
it too if at the end of the lecture you

94
00:03:57,620 --> 00:03:57,060
want to go across and look through the

95
00:04:00,080 --> 00:03:57,630
telescope

96
00:04:02,360 --> 00:04:00,090
we'll meet down here on the right at the

97
00:04:03,980 --> 00:04:02,370
end if I forget somebody to remind me or

98
00:04:08,470 --> 00:04:03,990
araignee if she's here we'll probably

99
00:04:11,240 --> 00:04:08,480
slappy and say wake up Frank and if you

100
00:04:12,260 --> 00:04:11,250
do not get to do it tonight or you can't

101
00:04:14,120 --> 00:04:12,270
do it tonight and want to do it some

102
00:04:17,090 --> 00:04:14,130
other time they have open houses on

103
00:04:20,990 --> 00:04:17,100
Friday evenings go to MD space grant go

104
00:04:23,590 --> 00:04:21,000
RG now our news from the universe for

105
00:04:26,230 --> 00:04:23,600
June 2019

106
00:04:31,480 --> 00:04:26,240
our first story

107
00:04:34,480 --> 00:04:31,490
lopsided star formation in NGC 44

108
00:04:36,960 --> 00:04:34,490
oh yes 44 85 I remember it well of

109
00:04:39,490 --> 00:04:36,970
course I have no idea what it is but

110
00:04:42,100 --> 00:04:39,500
first thing we got to talk about normal

111
00:04:44,860 --> 00:04:42,110
star formation okay so this is a very

112
00:04:46,420 --> 00:04:44,870
famous galaxy Messier 51 also called the

113
00:04:48,700 --> 00:04:46,430

Whirlpool Galaxy and you can see it's

114
00:04:50,860 --> 00:04:48,710
got this beautiful symmetric spiral

115
00:04:54,400 --> 00:04:50,870
pattern okay call this a grand design

116
00:04:56,890 --> 00:04:54,410
spiral the one of the really striking

117
00:04:59,800 --> 00:04:56,900
features of this image is all of those

118
00:05:02,529 --> 00:04:59,810
red dots around it so you see all these

119
00:05:06,909 --> 00:05:02,539
red star four regions that swirl around

120
00:05:09,430 --> 00:05:06,919
along the spiral arms these are the

121
00:05:12,909 --> 00:05:09,440
places where stars are just forming okay

122
00:05:15,010 --> 00:05:12,919
the red is a hydrogen alpha which is a

123
00:05:17,020 --> 00:05:15,020
hydrogen gas heated to about three of

124
00:05:18,850 --> 00:05:17,030
these star forming regions but you

125
00:05:20,680 --> 00:05:18,860
notice how they're smoothly spread out

126
00:05:22,629 --> 00:05:20,690
throughout this galaxy and this is what

127
00:05:24,370 --> 00:05:22,639
we sort of expect because you know the

128
00:05:25,809 --> 00:05:24,380
density waves that produce star

129
00:05:28,809 --> 00:05:25,819
formation just you know flow throughout

130
00:05:32,080 --> 00:05:28,819
an entire galaxy and you see them well

131
00:05:32,800 --> 00:05:32,090
we released an image last month of NGC

132
00:05:37,930 --> 00:05:32,810
44

133
00:05:39,670 --> 00:05:37,940
and tell me what you don't see here you

134
00:05:42,760 --> 00:05:39,680
don't see that same sort of symmetry

135
00:05:44,950 --> 00:05:42,770
okay you see that all of the star

136
00:05:47,379 --> 00:05:44,960
forming regions are over here on the

137
00:05:49,480 --> 00:05:47,389
right side of this galaxy and the left

138
00:05:52,629 --> 00:05:49,490

side looks kind of like non strong

139
00:05:54,600 --> 00:05:52,639
forming regions okay old stars and a

140
00:05:57,909 --> 00:05:54,610
little bit of you know young blue stars

141
00:06:01,209 --> 00:05:57,919
so what's going on here what does this

142
00:06:03,640 --> 00:06:01,219
indicate anybody have a guess on this

143
00:06:08,939 --> 00:06:03,650
you've got a disturbance on one side

144
00:06:13,390 --> 00:06:11,110
good resolve of galaxy collision not

145
00:06:16,060 --> 00:06:13,400
quite a collision but an interaction

146
00:06:17,499 --> 00:06:16,070
okay when you see that gravitate that

147
00:06:19,209 --> 00:06:17,509
star formation that means that something

148
00:06:21,999 --> 00:06:19,219
funky is happening on that side and that

149
00:06:24,010 --> 00:06:22,009
side only and if you take a larger view

150
00:06:27,219 --> 00:06:24,020
from a ground-based this is where the

151
00:06:33,430 --> 00:06:27,229
Hubble image is within this larger view

152
00:06:35,680 --> 00:06:33,440
and this is NGC 4490 and 44 85 as taken

153
00:06:37,839 --> 00:06:35,690
by the internet named Jay Schulman five

154
00:06:39,070 --> 00:06:37,849
five five I couldn't actually find out

155
00:06:39,999 --> 00:06:39,080
what this person's name is I'm assuming

156
00:06:44,189 --> 00:06:40,009
it's

157
00:06:47,320 --> 00:06:44,199
somebody Sherman and here you see that

158
00:06:50,639 --> 00:06:47,330
4490 which is in the center here has the

159
00:06:54,609 --> 00:06:50,649
title tail stretching back towards 44 85

160
00:06:56,170 --> 00:06:54,619
so as you expected very good intuition

161
00:06:58,779 --> 00:06:56,180
there has been an interaction between

162
00:07:00,969 --> 00:06:58,789
these two galaxies and this star

163
00:07:05,499 --> 00:07:00,979

formation here appears to be the result

164
00:07:08,829 --> 00:07:05,509
of it so that the asymmetry in 44 85 is

165
00:07:10,329 --> 00:07:08,839
that this was a normal galaxy possibly

166
00:07:11,950 --> 00:07:10,339
with starvation ever possible with very

167
00:07:13,209 --> 00:07:11,960
little star formation but at least it

168
00:07:15,999 --> 00:07:13,219
would have been somewhat symmetrical and

169
00:07:18,459 --> 00:07:16,009
that the interaction sweeping past it if

170
00:07:20,110 --> 00:07:18,469
we zoom in on the details of this you

171
00:07:24,010 --> 00:07:20,120
can see that there are some very large

172
00:07:25,749 --> 00:07:24,020
star forming entities here they're

173
00:07:28,269 --> 00:07:25,759
forming thousands upon thousands of

174
00:07:30,700 --> 00:07:28,279
stars and this is one thing that this

175
00:07:34,179 --> 00:07:30,710
teaches us is that interactions between

176
00:07:36,489 --> 00:07:34,189
galaxies create these density ways that

177
00:07:39,249 --> 00:07:36,499
flow across galaxies and can produce

178
00:07:41,079 --> 00:07:39,259
copious amounts of star formation when

179
00:07:44,260 --> 00:07:41,089
you see two galaxies interacting you

180
00:07:48,100 --> 00:07:44,270
often see these large waves of star

181
00:07:50,350 --> 00:07:48,110
formation and this this image

182
00:07:52,179 --> 00:07:50,360
illustrates it here there is no

183
00:07:53,649 --> 00:07:52,189
particular science result of this this

184
00:07:56,230 --> 00:07:53,659
is one of what we call our pretty

185
00:07:58,869 --> 00:07:56,240
picture releases where we have one of

186
00:08:02,019 --> 00:07:58,879
our gorgeous images from the archive and

187
00:08:04,540 --> 00:08:02,029
release it to the public to show off the

188
00:08:07,239 --> 00:08:04,550

beautiful beauty of the universe but you

189
00:08:09,610 --> 00:08:07,249
can see in this one in particular how

190
00:08:13,480 --> 00:08:09,620
the interactions between galaxies can

191
00:08:18,249 --> 00:08:13,490
produce this star formation our second

192
00:08:19,989 --> 00:08:18,259
story mind the gap part two all right so

193
00:08:22,509 --> 00:08:19,999
let's start with our solar system our

194
00:08:25,719 --> 00:08:22,519
solar system we as remarkable because

195
00:08:28,989 --> 00:08:25,729
all of the planets are basically in a

196
00:08:31,239 --> 00:08:28,999
plane right and that sort of suggests to

197
00:08:34,029 --> 00:08:31,249
us that well the planets formed in this

198
00:08:35,949 --> 00:08:34,039
disk that's encircling our Sun right

199
00:08:37,420 --> 00:08:35,959
that seemed very logical and so we

200
00:08:40,750 --> 00:08:37,430
looked out into the universe looking for

201
00:08:41,860 --> 00:08:40,760
that and we did find disks of material

202
00:08:44,559 --> 00:08:41,870
around other stars

203
00:08:47,590 --> 00:08:44,569
this one au microscopy over on the right

204
00:08:50,740 --> 00:08:47,600
HD 107 146 this you can see an edge-on

205
00:08:53,010 --> 00:08:50,750
disc on the left and on the right you

206
00:08:55,470 --> 00:08:53,020
can see a face on disk and so we

207
00:08:58,890 --> 00:08:55,480
did discover these discs around young

208
00:09:03,210 --> 00:08:58,900
stars where stars form and then we got

209
00:09:05,580 --> 00:09:03,220
Alma the Atacama Large millimeter or a

210
00:09:07,290 --> 00:09:05,590
which is able to look in millimeter

211
00:09:11,070 --> 00:09:07,300
wavelengths and see these discs in

212
00:09:14,220 --> 00:09:11,080
unprecedented detail and they saw HL

213
00:09:16,830 --> 00:09:14,230

Tauri seeing this gorgeous disc not just

214
00:09:19,740 --> 00:09:16,840
the disc but also the gaps in the disc

215
00:09:21,990 --> 00:09:19,750
and this tell us is like oh this is a

216
00:09:23,820 --> 00:09:22,000
Holy Grail because this is where we

217
00:09:25,980 --> 00:09:23,830
expect the planets to form in the disk

218
00:09:28,170 --> 00:09:25,990
with these gaps those gaps are going to

219
00:09:30,390 --> 00:09:28,180
be produced by formation of planets

220
00:09:33,150 --> 00:09:30,400
either by the planets themselves sucking

221
00:09:35,250 --> 00:09:33,160
up the material or by residents of

222
00:09:39,450 --> 00:09:35,260
gravitational resonances in it so this

223
00:09:41,010 --> 00:09:39,460
you know just blew us away okay so the

224
00:09:45,810 --> 00:09:41,020
story we're going to tell this week is

225
00:09:48,090 --> 00:09:45,820
about the star pds 70 and this is one of

226
00:09:50,490 --> 00:09:48,100
the early observations of it where you

227
00:09:53,640 --> 00:09:50,500
can see this big whitish blueish thing

228
00:09:54,840 --> 00:09:53,650
is a large disc and this black spot in

229
00:09:57,120 --> 00:09:54,850
the center is where they're blocking out

230
00:09:58,530 --> 00:09:57,130
the light of the star of course and that

231
00:10:00,840 --> 00:09:58,540
you can see just around this black spot

232
00:10:02,520 --> 00:10:00,850
there's a small little disc in here but

233
00:10:04,950 --> 00:10:02,530
in between the outer disk and the inner

234
00:10:07,170 --> 00:10:04,960
disk there is what they called in this

235
00:10:08,400 --> 00:10:07,180
and this thing a giant gap in the disk

236
00:10:13,080 --> 00:10:08,410
all right

237
00:10:15,570 --> 00:10:13,090
whereas the outer disk is around 70s

238
00:10:18,390 --> 00:10:15,580

atomic units in radius 140 in diameter

239
00:10:22,530 --> 00:10:18,400
that's you know a bit twice the distance

240
00:10:26,430 --> 00:10:22,540
of Neptune the inner one there seems to

241
00:10:29,370 --> 00:10:26,440
be at least a 30 or 40 au gap in there

242
00:10:30,810 --> 00:10:29,380
all right and so the question is are we

243
00:10:31,860 --> 00:10:30,820
going to find planets in there well they

244
00:10:34,890 --> 00:10:31,870
did a little bit of follow-up

245
00:10:37,200 --> 00:10:34,900
observations and yes inside this outer

246
00:10:41,610 --> 00:10:37,210
disk and outside the inner disk they did

247
00:10:45,360 --> 00:10:41,620
find an object and this is Planet pds 70

248
00:10:47,880 --> 00:10:45,370
B but this hasn't gotten the Alma

249
00:10:50,040 --> 00:10:47,890
treatment yet then it got the Alma

250
00:10:53,520 --> 00:10:50,050
treatment and you see all this fuzziness

251
00:10:54,060 --> 00:10:53,530
it goes away boom that's Alma for you

252
00:10:57,510 --> 00:10:54,070
okay

253
00:11:00,330 --> 00:10:57,520
behinds just like boom see that you can

254
00:11:02,610 --> 00:11:00,340
see the detail in the Alma observation

255
00:11:03,960 --> 00:11:02,620
of the outer disk and if you blow it up

256
00:11:06,480 --> 00:11:03,970
on the right-hand side you can see also

257
00:11:06,820 --> 00:11:06,490
the inner disk you can see the spot

258
00:11:10,060 --> 00:11:06,830
where

259
00:11:11,680 --> 00:11:10,070
PDS 7tb should should be but it doesn't

260
00:11:15,420 --> 00:11:11,690
show up in the Alma thing but you also

261
00:11:17,699 --> 00:11:15,430
see this spur here that spur right there

262
00:11:20,650 --> 00:11:17,709
indicates that there might be another

263
00:11:24,130 --> 00:11:20,660

gravitational presence pulling on that

264
00:11:26,680 --> 00:11:24,140
outer disk so what the folks at the

265
00:11:30,069 --> 00:11:26,690
European Southern Observatory did was

266
00:11:32,430 --> 00:11:30,079
they did a targeted campaign on PDS 70

267
00:11:34,750 --> 00:11:32,440
and they had to use incredible

268
00:11:37,449 --> 00:11:34,760
sophisticated computer algorithms to

269
00:11:40,480 --> 00:11:37,459
block the light of the star and try and

270
00:11:42,790 --> 00:11:40,490
pull out and enhance the planets that

271
00:11:45,610 --> 00:11:42,800
could be there searching to see the

272
00:11:50,079 --> 00:11:45,620
details of PDS 7tb and if there was

273
00:11:54,100 --> 00:11:50,089
anything else there they succeeded here

274
00:11:57,850 --> 00:11:54,110
is one of the two existing images of a

275
00:12:00,579 --> 00:11:57,860
multi-planet observation two planets

276
00:12:03,910 --> 00:12:00,589
around the star PDS 70 there's only one

277
00:12:07,000 --> 00:12:03,920
other HR 58 at 99 which is a four planet

278
00:12:09,400 --> 00:12:07,010
system this is the second planetary

279
00:12:14,949 --> 00:12:09,410
system where we have to direct images

280
00:12:17,050 --> 00:12:14,959
PDS 7tb PDS 70c to planets around

281
00:12:18,790 --> 00:12:17,060
another star and we can see them both we

282
00:12:21,460 --> 00:12:18,800
can see the light we gave it a pull out

283
00:12:23,980 --> 00:12:21,470
that faint light of those planets around

284
00:12:25,840 --> 00:12:23,990
that star now this is of course

285
00:12:27,610 --> 00:12:25,850
scientific data it's kind of ratty and

286
00:12:30,579 --> 00:12:27,620
ugly and what do we do here so

287
00:12:34,420 --> 00:12:30,589
beautifully we create cool graphics all

288
00:12:37,329 --> 00:12:34,430

right so this is an artist's rendition

289
00:12:39,760 --> 00:12:37,339
of the pds 70 system you can see the

290
00:12:43,720 --> 00:12:39,770
star in the center PDS 70 you can see

291
00:12:46,960 --> 00:12:43,730
the inner disk here you have a PDS 70 B

292
00:12:48,819 --> 00:12:46,970
at the top you have PDS 70 C here in the

293
00:12:51,280 --> 00:12:48,829
foreground and you have material

294
00:12:52,870 --> 00:12:51,290
streaming onto them why is there

295
00:12:56,019 --> 00:12:52,880
material streaming onto them because

296
00:12:59,500 --> 00:12:56,029
this system is only six million years

297
00:13:02,769 --> 00:12:59,510
old okay these two planets are the

298
00:13:05,470 --> 00:13:02,779
jupiter-mass range from between 1 and 14

299
00:13:07,030 --> 00:13:05,480
Jupiter masses both of them and they

300
00:13:09,610 --> 00:13:07,040
would still be forming jupiter-mass

301
00:13:12,009 --> 00:13:09,620
planets take about 10 million years to

302
00:13:14,860 --> 00:13:12,019
form so material is streaming onto it

303
00:13:18,210 --> 00:13:14,870
this is what they believe is happening

304
00:13:21,720 --> 00:13:18,220
in pds 70 is that these two planets

305
00:13:24,150 --> 00:13:21,730
have cleared out this gap right I showed

306
00:13:26,940 --> 00:13:24,160
you that HL Tauri image I said maybe

307
00:13:29,520 --> 00:13:26,950
planets are forming in there in PDS 70

308
00:13:34,230 --> 00:13:29,530
we know there are planets that have

309
00:13:37,080 --> 00:13:34,240
formed inside that gap so I did a news

310
00:13:39,480 --> 00:13:37,090
story called mine the gap before but

311
00:13:43,290 --> 00:13:39,490
this is mine to gap part two because we

312
00:13:46,620 --> 00:13:43,300
have two planets forming inside a gap in

313
00:13:49,500 --> 00:13:46,630

the PDS 70 system our knowledge of

314
00:13:52,200 --> 00:13:49,510
extrasolar planetary systems is truly

315
00:13:53,910 --> 00:13:52,210
developing this is a really great time

316
00:13:56,370 --> 00:13:53,920
to be studying astronomy because we're

317
00:13:58,020 --> 00:13:56,380
learning so much about what solar

318
00:13:59,430 --> 00:13:58,030
systems are like elsewhere in the

319
00:14:02,040 --> 00:13:59,440
universe kind of fun

320
00:14:09,000 --> 00:14:02,050
all right any questions before I move on

321
00:14:10,970 --> 00:14:09,010
yeah the tea tour itself one of the

322
00:14:13,800 --> 00:14:10,980
things that stops the formation of a

323
00:14:16,800 --> 00:14:13,810
giant planet is what's called the T

324
00:14:19,290 --> 00:14:16,810
Tauri wind gust of the star and that

325
00:14:22,080 --> 00:14:19,300
usually kicks in about 10 to 15 million

326
00:14:26,940 --> 00:14:22,090
years after the star has started nuclear

327
00:14:29,010 --> 00:14:26,950
fusion okay so when PDF 70 undergoes its

328
00:14:30,960 --> 00:14:29,020
T Tauri wind and blows away most of the

329
00:14:33,060 --> 00:14:30,970
light of the low-density material and

330
00:14:35,040 --> 00:14:33,070
system there won't be this material to

331
00:14:37,260 --> 00:14:35,050
fall onto these these planets so they

332
00:14:41,220 --> 00:14:37,270
will stop for me okay which is why

333
00:14:43,410 --> 00:14:41,230
actually we believe giant planets like

334
00:14:45,780 --> 00:14:43,420
Jupiter have to form in ten million

335
00:14:47,190 --> 00:14:45,790
first ten million years because the low

336
00:14:49,890 --> 00:14:47,200
Z&C material that would normally fall

337
00:14:57,840 --> 00:14:49,900
onto them is gone after that one other

338
00:14:59,880 --> 00:14:57,850

question before we go yeah you're

339
00:15:03,900 --> 00:14:59,890
talking from PDS 7tb just a little bit

340
00:15:05,040 --> 00:15:03,910
to lower boat lower than that yeah we

341
00:15:07,770 --> 00:15:05,050
recognize that you're trying to pull

342
00:15:11,340 --> 00:15:07,780
signal from a lot of the signal noise

343
00:15:13,440 --> 00:15:11,350
suppression and if that were real they

344
00:15:15,390 --> 00:15:13,450
would have trumpeted it but obviously

345
00:15:17,010 --> 00:15:15,400
the researchers who process this image

346
00:15:18,900 --> 00:15:17,020
said no that's that doesn't have enough

347
00:15:21,510 --> 00:15:18,910
signal-to-noise ratio to indicate that

348
00:15:23,340 --> 00:15:21,520
it's real or they can't follow it you

349
00:15:25,590 --> 00:15:23,350
know usually to confirm planets you want

350
00:15:28,680 --> 00:15:25,600
to follow them moving around so you take

351
00:15:30,180 --> 00:15:28,690
different observations to see their

352
00:15:35,190 --> 00:15:30,190
motions

353
00:15:37,080 --> 00:15:35,200
by the dessert inspector no not yet

354
00:15:40,830 --> 00:15:37,090
this is just the first observations of

355
00:15:43,380 --> 00:15:40,840
it will be able be people are trying to

356
00:15:45,390 --> 00:15:43,390
try and do spectra of things like this

357
00:15:47,700 --> 00:15:45,400
you need a lot more light to be able to

358
00:15:51,090 --> 00:15:47,710
get spectro something like this okay

359
00:15:54,890 --> 00:15:51,100
all right now our featured speaker

360
00:15:56,730 --> 00:15:54,900
tonight dr. Christopher Britt eyes

361
00:15:58,650 --> 00:15:56,740
astronomer here in the office of public

362
00:16:01,680 --> 00:15:58,660
outreach at the Space Telescope Science

363
00:16:05,610 --> 00:16:01,690

Institute he is new to us having joined

364
00:16:07,920 --> 00:16:05,620
last August you said yeah so he is still

365
00:16:10,560 --> 00:16:07,930
learning the ropes and showing us all

366
00:16:15,480 --> 00:16:10,570
the new tricks that he learned he did

367
00:16:17,520 --> 00:16:15,490
his PhD at Louisiana Louisiana State or

368
00:16:20,220 --> 00:16:17,530
is it Louisiana state that's what I

369
00:16:22,700 --> 00:16:20,230
thought okay and then did postdocs at

370
00:16:26,370 --> 00:16:22,710
Texas Tech and Michigan State University

371
00:16:29,250 --> 00:16:26,380
studying old dead stars and non-binary

372
00:16:32,340 --> 00:16:29,260
stars and waste stars die and and do all

373
00:16:33,990 --> 00:16:32,350
these crazy things sometimes they you

374
00:16:34,950 --> 00:16:34,000
know when stars die they become pulsars

375
00:16:37,260 --> 00:16:34,960
which is what I'll talk to you about

376
00:16:39,570 --> 00:16:37,270
tonight Chris and I've gotten to know

377
00:16:42,600 --> 00:16:39,580
each other a little bit because he plays

378
00:16:44,040 --> 00:16:42,610
disc golf and I play disc golf I think I

379
00:16:47,220 --> 00:16:44,050
play it a little bit more seriously than

380
00:16:51,540 --> 00:16:47,230
he does but one other thing in his favor

381
00:16:54,120 --> 00:16:51,550
he also brews his own beer so he has

382
00:16:56,130 --> 00:16:54,130
disc golf and beer got to be one of my

383
00:16:58,440 --> 00:16:56,140
favorite people out there ladies and

384
00:17:28,119 --> 00:16:58,450
gentlemen let us welcome dr. history

385
00:17:54,169 --> 00:17:28,129
bris three doesn't say all right

386
00:17:58,389 --> 00:17:54,179
that's for sorry I touched I must have

387
00:18:00,379 --> 00:17:58,399
pushed the wrong button save me save me

388
00:18:07,070 --> 00:18:00,389

ladies and gentlemen Thomas is coming

389
00:18:08,989 --> 00:18:07,080
down to save us I played this all I'm

390
00:18:10,669 --> 00:18:08,999
getting old I'm looking down here trying

391
00:18:20,680 --> 00:18:10,679
to see which button says change input

392
00:18:23,239 --> 00:18:20,690
and I couldn't read it he's on three

393
00:18:24,240 --> 00:18:23,249
today I hit one of these other buttons

394
00:18:32,750 --> 00:18:24,250
and makes it go

395
00:18:32,760 --> 00:18:42,800
when in doubt turn it off and on again

396
00:18:52,920 --> 00:18:46,890
that's ladies and gentlemen another hand

397
00:18:55,290 --> 00:18:52,930
for Chris with it okay thanks for the

398
00:18:57,840 --> 00:18:55,300
introduction and Frank definitely is

399
00:18:59,730 --> 00:18:57,850
better at disc-off than I am we played

400
00:19:02,910 --> 00:18:59,740
together once and he beat me pretty

401
00:19:05,760 --> 00:19:02,920
soundly so yeah I wanted to talk about

402
00:19:07,230 --> 00:19:05,770
this kind of puzzle and current

403
00:19:08,760 --> 00:19:07,240
astronomy and astrophysics it's

404
00:19:11,370 --> 00:19:08,770
something that's not really solved yet

405
00:19:13,740 --> 00:19:11,380
in part because it involves just a lot

406
00:19:16,020 --> 00:19:13,750
of really cool stuff from all different

407
00:19:17,460 --> 00:19:16,030
parts of astronomy and in part because

408
00:19:20,700 --> 00:19:17,470
it kind of gives a little bit of a

409
00:19:22,470 --> 00:19:20,710
window onto how science has done and how

410
00:19:24,920 --> 00:19:22,480
we go about solving these problems when

411
00:19:27,450 --> 00:19:24,930
the the answer isn't immediately obvious

412
00:19:30,030 --> 00:19:27,460
so I'm going to be talking about kind of

413
00:19:31,590 --> 00:19:30,040

extra gamma radiation coming from the

414
00:19:33,750 --> 00:19:31,600
center of our own galaxy the Milky Way

415
00:19:36,390 --> 00:19:33,760
and when you hear a gamma radiation a

416
00:19:37,950 --> 00:19:36,400
lot of you may have read some Avengers

417
00:19:38,580 --> 00:19:37,960
in the past and be thinking of the Hulk

418
00:19:40,530 --> 00:19:38,590
yeah

419
00:19:43,470 --> 00:19:40,540
gamma radiation famously gave the whole

420
00:19:45,600 --> 00:19:43,480
kiss powers right so far I haven't known

421
00:19:47,160 --> 00:19:45,610
anyone at NASA to turn giant and green

422
00:19:50,460 --> 00:19:47,170
and angry but you never know maybe

423
00:19:52,530 --> 00:19:50,470
they're keeping it quiet so when I talk

424
00:19:54,330 --> 00:19:52,540
about our galaxy in the Milky Way I'm

425
00:19:56,660 --> 00:19:54,340
really just talking about the same thing

426
00:20:00,030 --> 00:19:56,670
you can go out on a dark night and see

427
00:20:02,060 --> 00:20:00,040
so if you go out to a dark sky maybe up

428
00:20:04,350 --> 00:20:02,070
in the mountains in Western Maryland or

429
00:20:06,900 --> 00:20:04,360
wherever you happen to be listening at

430
00:20:09,810 --> 00:20:06,910
home driving out away from the city and

431
00:20:12,570 --> 00:20:09,820
look up a dark sky you can see the Milky

432
00:20:15,330 --> 00:20:12,580
Way with your unaided eye this image in

433
00:20:18,390 --> 00:20:15,340
particular was on a timed exposure with

434
00:20:19,980 --> 00:20:18,400
a camera but your I can still see even

435
00:20:22,470 --> 00:20:19,990
some of these dark clouds and stripes

436
00:20:24,060 --> 00:20:22,480
cutting through the dark stars so it's

437
00:20:26,340 --> 00:20:24,070
really something to do if you can have

438
00:20:28,710 --> 00:20:26,350

the chance to go out to a dark site and

439
00:20:31,650 --> 00:20:28,720
look up you should absolutely take the

440
00:20:32,820 --> 00:20:31,660
time to do it it's well worth it and if

441
00:20:36,440 --> 00:20:32,830
you go and take pictures of the night

442
00:20:39,180 --> 00:20:36,450
sky all over the sky around the earth

443
00:20:41,100 --> 00:20:39,190
the whole sky put together look

444
00:20:42,990 --> 00:20:41,110
something like this so this is like a

445
00:20:45,210 --> 00:20:43,000
globe for the sky it's a global map of

446
00:20:45,450 --> 00:20:45,220
the entire night sky you can see there's

447
00:20:48,450 --> 00:20:45,460
this

448
00:20:50,490 --> 00:20:48,460
plane of dust and stars stretching

449
00:20:52,530 --> 00:20:50,500
across the night sky and that's our

450
00:20:55,080 --> 00:20:52,540
galaxy that's where we live it looks

451
00:20:56,550 --> 00:20:55,090
like a plane like this flatline because

452
00:20:58,320 --> 00:20:56,560
we're inside it we're kind of sitting

453
00:21:00,420 --> 00:20:58,330
out on one of the spiral arms looking at

454
00:21:02,250 --> 00:21:00,430
okay you can see all kinds of other

455
00:21:04,440 --> 00:21:02,260
stuff scattered around you can see these

456
00:21:07,020 --> 00:21:04,450
kind of fuzz balls down here these are

457
00:21:08,970 --> 00:21:07,030
small galaxies orbiting ours called the

458
00:21:11,010 --> 00:21:08,980
Magellanic Clouds and if you're in the

459
00:21:12,840 --> 00:21:11,020
southern hemisphere ever you can look up

460
00:21:15,750 --> 00:21:12,850
in a dark sky and see them with your

461
00:21:17,910 --> 00:21:15,760
naked eyes they look like clouds in the

462
00:21:19,440 --> 00:21:17,920
sky so they're called the Magellanic

463
00:21:21,600 --> 00:21:19,450

Clouds because Magellan was the first

464
00:21:22,980 --> 00:21:21,610
European to see them so of course he got

465
00:21:24,240 --> 00:21:22,990
the name after him never mind the fact

466
00:21:25,560 --> 00:21:24,250
that people have lived in that part of

467
00:21:26,760 --> 00:21:25,570
the world from you know thousands and

468
00:21:27,810 --> 00:21:26,770
thousands of years and have been seeing

469
00:21:31,500 --> 00:21:27,820
them for thousands and thousands of

470
00:21:35,250 --> 00:21:31,510
years but if we look at the night sky in

471
00:21:37,590 --> 00:21:35,260
other wavelengths not just well I hope

472
00:21:40,410 --> 00:21:37,600
that our eyes can see we can see other

473
00:21:42,060 --> 00:21:40,420
kinds of things so you may know that

474
00:21:45,360 --> 00:21:42,070
white light can be broken down into the

475
00:21:47,550 --> 00:21:45,370
different colors blue green and red if

476
00:21:49,650 --> 00:21:47,560
you keep going past blue green and red

477
00:21:52,500 --> 00:21:49,660
on the other side of red there's a color

478
00:21:53,640 --> 00:21:52,510
your eyes can't see called infra red if

479
00:21:55,590 --> 00:21:53,650
you look at the night sky in infrared

480
00:21:58,710 --> 00:21:55,600
light or something like this you can

481
00:22:00,990 --> 00:21:58,720
suddenly see through all of those dust

482
00:22:02,850 --> 00:22:01,000
clouds from before so you can see all

483
00:22:04,770 --> 00:22:02,860
these kind of black dust blocking the

484
00:22:06,450 --> 00:22:04,780
light of the stars when we look down an

485
00:22:09,300 --> 00:22:06,460
infrared we can finally see the stars

486
00:22:12,150 --> 00:22:09,310
underneath this is infrared light that's

487
00:22:14,850 --> 00:22:12,160
very close to what our eyes can see it's

488
00:22:16,530 --> 00:22:14,860

just a little bit longer wavelength so

489
00:22:18,840 --> 00:22:16,540
where our instruments can see it but our

490
00:22:20,610 --> 00:22:18,850
eyes can't we can keep going into

491
00:22:23,190 --> 00:22:20,620
infrared and go into kind of longer and

492
00:22:24,840 --> 00:22:23,200
longer wavelengths and this guy starts

493
00:22:28,260 --> 00:22:24,850
to look like this you can see the blue

494
00:22:30,960 --> 00:22:28,270
here is the Stars and the green is some

495
00:22:32,880 --> 00:22:30,970
of the warm dust in our galaxy but this

496
00:22:36,360 --> 00:22:32,890
is still an infrared image it's just a

497
00:22:38,550 --> 00:22:36,370
little bit further into the infrared if

498
00:22:41,460 --> 00:22:38,560
we keep going to even lower energies of

499
00:22:43,020 --> 00:22:41,470
light even longer wavelengths further

500
00:22:45,780 --> 00:22:43,030
into red we start to crack into

501
00:22:49,770 --> 00:22:45,790
microwave and radio light and that's

502
00:22:52,230 --> 00:22:49,780
what this image shows now radio is very

503
00:22:55,830 --> 00:22:52,240
low energy light and in fact there is

504
00:22:58,460 --> 00:22:55,840
Carl Sagan said in 1980 in the episode

505
00:23:00,440 --> 00:22:58,470
of cosmos that there is more in

506
00:23:03,860 --> 00:23:00,450
in a snowflake falling to the ground

507
00:23:06,049 --> 00:23:03,870
then there is in all of the radio light

508
00:23:08,630 --> 00:23:06,059
that every radio telescope on earth has

509
00:23:11,270 --> 00:23:08,640
ever detected put together now that was

510
00:23:13,340 --> 00:23:11,280
back in 1980 it was a long time ago 40

511
00:23:18,049 --> 00:23:13,350
years gods are pretty good that we're up

512
00:23:19,460 --> 00:23:18,059
to about two snowflakes by now so if we

513
00:23:21,169 --> 00:23:19,470

keep going the other direction

514
00:23:24,169 --> 00:23:21,179
we've gone kind of down in energy if we

515
00:23:26,480 --> 00:23:24,179
go up in energy then we can get up to X

516
00:23:28,490 --> 00:23:26,490
ray light the kind of light that your

517
00:23:30,649 --> 00:23:28,500
doctor will use to look at broken bones

518
00:23:32,390 --> 00:23:30,659
inside your body or that your dentist

519
00:23:34,430 --> 00:23:32,400
will use to look at your teeth the same

520
00:23:37,130 --> 00:23:34,440
kind of light you can see now there's

521
00:23:39,380 --> 00:23:37,140
all these little bright sources of they

522
00:23:42,350 --> 00:23:39,390
look like just bright stars and these

523
00:23:44,450 --> 00:23:42,360
are the kinds of dead stars that I kind

524
00:23:45,620 --> 00:23:44,460
of cut my teeth on that I was most

525
00:23:48,169 --> 00:23:45,630
interested in when I started in

526
00:23:50,029 --> 00:23:48,179
astronomy things like black holes and

527
00:23:53,840 --> 00:23:50,039
neutron stars what's left over after a

528
00:23:57,289 --> 00:23:53,850
star dies and if we keep going up in

529
00:23:58,940 --> 00:23:57,299
energy we get up to gamma ray light so

530
00:24:00,770 --> 00:23:58,950
this is a map of all the gamma-ray light

531
00:24:02,960 --> 00:24:00,780
in the sky that was put together by the

532
00:24:05,360 --> 00:24:02,970
Fermi gamma-ray Observatory which is a

533
00:24:06,799 --> 00:24:05,370
NASA instrument that's up now and

534
00:24:10,130 --> 00:24:06,809
they've been gathering gamma-ray light

535
00:24:12,159 --> 00:24:10,140
since for about 10 years now you can see

536
00:24:15,169 --> 00:24:12,169
the same plane of our Milky Way galaxy

537
00:24:18,250 --> 00:24:15,179
here you can see some bright individual

538
00:24:20,630 --> 00:24:18,260

objects scattered around the sky as well

539
00:24:23,930 --> 00:24:20,640
now when I say it's high-energy light

540
00:24:27,740 --> 00:24:23,940
that doesn't really quite get across how

541
00:24:29,810 --> 00:24:27,750
high-energy this light is it's really

542
00:24:32,090 --> 00:24:29,820
quite extreme it's so extreme right it

543
00:24:34,399 --> 00:24:32,100
gave the Hulk his superpowers right so

544
00:24:37,399 --> 00:24:34,409
to try and put this into perspective of

545
00:24:39,080 --> 00:24:37,409
how high-energy gamma-ray light is I'm

546
00:24:41,029 --> 00:24:39,090
going to compare it to some temperatures

547
00:24:44,330 --> 00:24:41,039
okay there's temperatures or something

548
00:24:47,750 --> 00:24:44,340
we have a better feel for so if we take

549
00:24:50,060 --> 00:24:47,760
something like hot lava say and look at

550
00:24:52,039 --> 00:24:50,070
the temperature of hot lava we can

551
00:24:54,140 --> 00:24:52,049
associate that temperature with a

552
00:24:55,880 --> 00:24:54,150
particular kind of light okay it's

553
00:24:58,250 --> 00:24:55,890
glowing after all we can see some light

554
00:25:00,590 --> 00:24:58,260
coming from it and as we heat it up

555
00:25:04,130 --> 00:25:00,600
it'll glow even more it'll turn than

556
00:25:07,070 --> 00:25:04,140
yellow and then eventually white-hot so

557
00:25:10,909 --> 00:25:07,080
we can associate a temperature to an

558
00:25:11,900 --> 00:25:10,919
energy of light so if we talk about hot

559
00:25:13,730 --> 00:25:11,910
lava

560
00:25:16,190 --> 00:25:13,740
might take a moment just to think about

561
00:25:19,520 --> 00:25:16,200
what kind of light might pair with this

562
00:25:21,890 --> 00:25:19,530
particular temperature okay neither pair

563
00:25:24,320 --> 00:25:21,900

with microwave light visible light or

564
00:25:25,310 --> 00:25:24,330
x-ray light now obviously there's no

565
00:25:26,870 --> 00:25:25,320
grades or anything and just take a

566
00:25:30,289 --> 00:25:26,880
moment to think about what you might

567
00:25:39,740 --> 00:25:30,299
expect the what type of light to match

568
00:25:41,529 --> 00:25:39,750
to this temperature now I bet a lot of

569
00:25:43,340 --> 00:25:41,539
people are probably expecting that it's

570
00:25:45,529 --> 00:25:43,350
visible light because we can see it

571
00:25:49,190 --> 00:25:45,539
glowing but in fact the light that pairs

572
00:25:52,430 --> 00:25:49,200
best with it is infrared so this lava is

573
00:25:54,680 --> 00:25:52,440
glowing most brightly and basically

574
00:25:56,330 --> 00:25:54,690
what's blue in this image is where most

575
00:25:58,159 --> 00:25:56,340
of that light's coming out okay so

576
00:26:00,320 --> 00:25:58,169
something even as hot as hot lava is

577
00:26:04,220 --> 00:26:00,330
still coming up mostly in infrared

578
00:26:07,220 --> 00:26:04,230
wavelengths if we cool down say let's go

579
00:26:09,940 --> 00:26:07,230
to a nice beach day kind of a nice day

580
00:26:12,770 --> 00:26:09,950
outside pleasant sitting in a hammock

581
00:26:14,810 --> 00:26:12,780
breeze coming in we can do the same kind

582
00:26:18,140 --> 00:26:14,820
of thought experiment what kind of light

583
00:26:20,870 --> 00:26:18,150
pairs with that kind of temperature kind

584
00:26:28,820 --> 00:26:20,880
of think about it for a minute make a

585
00:26:30,409 --> 00:26:28,830
prediction and it's again infrared light

586
00:26:31,399 --> 00:26:30,419
so we're still an infrared this now

587
00:26:34,940 --> 00:26:31,409
where we have to move into the green

588
00:26:37,370 --> 00:26:34,950

parts that if we keep cooling off let's

589
00:26:40,610 --> 00:26:37,380
go somewhere more extreme like the poles

590
00:26:43,100 --> 00:26:40,620
of Mars say Mars in the wintertime at

591
00:26:45,380 --> 00:26:43,110
the North and South Pole is extremely

592
00:26:47,779 --> 00:26:45,390
cold it's so cold it's somewhere between

593
00:26:50,750 --> 00:26:47,789
the temperature of dry ice and liquid

594
00:26:52,610 --> 00:26:50,760
nitrogen so in fact a lot of that white

595
00:26:55,700 --> 00:26:52,620
stuff that you can see on the poles is

596
00:26:57,799 --> 00:26:55,710
actually dry ice it's carbon dioxide the

597
00:27:00,560 --> 00:26:57,809
same gas that you breathe out every time

598
00:27:04,039 --> 00:27:00,570
you take a breath frozen solid and it's

599
00:27:06,710 --> 00:27:04,049
even colder than that so this is a

600
00:27:08,270 --> 00:27:06,720
really quite extreme cold so if we had

601
00:27:12,169 --> 00:27:08,280
to think about what kind of light might

602
00:27:14,630 --> 00:27:12,179
pair with that temperature might you

603
00:27:20,320 --> 00:27:14,640
expect it to be on a microwave radio

604
00:27:25,539 --> 00:27:23,740
that's right it's still infrared

605
00:27:27,820 --> 00:27:25,549
so we still haven't even gotten down

606
00:27:31,180 --> 00:27:27,830
into the into the microwave and radio

607
00:27:33,460 --> 00:27:31,190
yet to get down to that kind of energy

608
00:27:36,640 --> 00:27:33,470
we have to keep going in temperature

609
00:27:38,350 --> 00:27:36,650
down to liquid helium so now at four

610
00:27:41,020 --> 00:27:38,360
degrees above absolute zero

611
00:27:44,260 --> 00:27:41,030
is the the warmest liquid helium can be

612
00:27:45,850 --> 00:27:44,270
and now we're finally at the level where

613
00:27:48,700 --> 00:27:45,860

we're just starting to crack into

614
00:27:51,130 --> 00:27:48,710
microwave and radio light comparatively

615
00:27:54,310 --> 00:27:51,140
so even this is why we said you know

616
00:27:56,140 --> 00:27:54,320
radio lights so low energy that even a

617
00:27:58,539 --> 00:27:56,150
snowflake falling to earth has more

618
00:28:01,779 --> 00:27:58,549
energy than everything that we've seen

619
00:28:04,990 --> 00:28:01,789
in radio telescopes is because it's just

620
00:28:06,909 --> 00:28:05,000
such a low energy light if we go the

621
00:28:09,190 --> 00:28:06,919
other way and compare it to temperatures

622
00:28:11,230 --> 00:28:09,200
kinda going up we can use this as a

623
00:28:12,909 --> 00:28:11,240
starting point as liquid helium in a lab

624
00:28:15,340 --> 00:28:12,919
and compare it to something like the

625
00:28:17,409 --> 00:28:15,350
surface of the Sun all right the surface

626
00:28:20,529 --> 00:28:17,419
of the sun's famously a hot place right

627
00:28:22,750 --> 00:28:20,539
and that maps I think probably obviously

628
00:28:24,220 --> 00:28:22,760
to visible light because that's what our

629
00:28:26,140 --> 00:28:24,230
eyes are seeing it's so bright when you

630
00:28:28,810 --> 00:28:26,150
look outside the surface of the Sun you

631
00:28:30,430 --> 00:28:28,820
don't want to look at it directly but

632
00:28:33,190 --> 00:28:30,440
it's mostly emitting its energy at

633
00:28:35,169 --> 00:28:33,200
visible light so the temperature of

634
00:28:37,120 --> 00:28:35,179
liquid helium compared to the

635
00:28:39,820 --> 00:28:37,130
temperature of visible of the surface of

636
00:28:42,390 --> 00:28:39,830
the Sun is about the same as the energy

637
00:28:46,710 --> 00:28:42,400
gap between microwaves and visible light

638
00:28:49,620 --> 00:28:46,720

if we can extend that kind of analogy

639
00:28:52,960 --> 00:28:49,630
that's about the same ratio as the

640
00:28:55,390 --> 00:28:52,970
surface of the Sun to the corona of the

641
00:28:58,419 --> 00:28:55,400
Sun how many people went to the solar

642
00:28:59,770 --> 00:28:58,429
eclipse in 2017 and some people in the

643
00:29:01,990 --> 00:28:59,780
back did you get to see the corona of

644
00:29:03,100 --> 00:29:02,000
the Sun when when you were there yeah

645
00:29:06,730 --> 00:29:03,110
great

646
00:29:08,140 --> 00:29:06,740
yeah so that's a few million degrees is

647
00:29:09,460 --> 00:29:08,150
the surface of the Sun it's about a

648
00:29:12,010 --> 00:29:09,470
thousand times hotter than the surface

649
00:29:13,120 --> 00:29:12,020
of the Sun the surface of the Sun is

650
00:29:17,140 --> 00:29:13,130
about a thousand times hotter than

651
00:29:19,419 --> 00:29:17,150
liquid helium so these ratios are hand

652
00:29:21,730 --> 00:29:19,429
waving ly roughly equivalent okay so

653
00:29:24,399 --> 00:29:21,740
let's keep scaling that up let's now

654
00:29:27,159 --> 00:29:24,409
compare say if this is now emitting

655
00:29:30,130 --> 00:29:27,169
mostly an x-ray light okay go microwave

656
00:29:32,950 --> 00:29:30,140
to visible visible to x-ray let's keep

657
00:29:35,799 --> 00:29:32,960
scaling that up and now we're comparing

658
00:29:36,930 --> 00:29:35,809
microwave to x-ray light liquid helium

659
00:29:41,130 --> 00:29:36,940
to the

660
00:29:44,940 --> 00:29:41,140
the Sun hey that's about the same ratio

661
00:29:48,060 --> 00:29:44,950
as the corona of the Sun to this

662
00:29:49,650 --> 00:29:48,070
gamma-ray light so this is so

663
00:29:50,670 --> 00:29:49,660

high-energy it's really hard to get a

664
00:29:52,530 --> 00:29:50,680
grip on okay

665
00:29:54,390 --> 00:29:52,540
but this difference between the x-ray

666
00:29:56,070 --> 00:29:54,400
light and these gamma rays that Fermi is

667
00:29:57,570 --> 00:29:56,080
emitting it's just so extreme it's about

668
00:30:02,360 --> 00:29:57,580
the same as the corona the Sun compared

669
00:30:05,910 --> 00:30:02,370
to liquid helium scaled up again it's a

670
00:30:09,750 --> 00:30:05,920
factor of a million times more energetic

671
00:30:14,040 --> 00:30:09,760
the light coming out yeah which is why I

672
00:30:15,540 --> 00:30:14,050
can give Hulk his superpowers right so

673
00:30:17,640 --> 00:30:15,550
what could possibly make this kind of

674
00:30:20,280 --> 00:30:17,650
light right what could possibly have so

675
00:30:24,230 --> 00:30:20,290
much energy in it this kind of

676
00:30:26,850 --> 00:30:24,240
unfathomably energetic light coming out

677
00:30:28,490 --> 00:30:26,860
generally what's what happens when you

678
00:30:32,340 --> 00:30:28,500
have charged particles like electrons

679
00:30:34,320 --> 00:30:32,350
that are being rapidly accelerated so

680
00:30:36,660 --> 00:30:34,330
some environments that can do that are

681
00:30:39,930 --> 00:30:36,670
things like supernova remnants so this

682
00:30:41,490 --> 00:30:39,940
image here is an x-ray image of a

683
00:30:44,670 --> 00:30:41,500
supernova called the Crab Nebula

684
00:30:47,400 --> 00:30:44,680
supernova remnant and if you look in

685
00:30:49,500 --> 00:30:47,410
x-ray light at the crab this is what you

686
00:30:52,290 --> 00:30:49,510
see and you can see this motion in it

687
00:30:54,990 --> 00:30:52,300
these ripples kind of coming out from

688
00:30:57,240 --> 00:30:55,000

the center there and a bright central

689
00:30:58,560 --> 00:30:57,250
source in the middle and what's

690
00:31:01,230 --> 00:30:58,570
happening is there's a remnant of the

691
00:31:04,530 --> 00:31:01,240
old dead star in the center there called

692
00:31:07,110 --> 00:31:04,540
it now called a neutron star and it's

693
00:31:09,510 --> 00:31:07,120
spinning around it's giving some of its

694
00:31:11,250 --> 00:31:09,520
energy to the nebula around it and you

695
00:31:14,490 --> 00:31:11,260
can see the motion in that nebula it's

696
00:31:16,620 --> 00:31:14,500
accelerating these particles as it

697
00:31:18,990 --> 00:31:16,630
accelerates those particles they can

698
00:31:22,620 --> 00:31:19,000
flare in this gamma ray light so this is

699
00:31:25,440 --> 00:31:22,630
a gamma ray movie over here taken with

700
00:31:27,750 --> 00:31:25,450
Fermi of the crab pulsar and you can see

701
00:31:29,700 --> 00:31:27,760
when this flare goes off it gets quite

702
00:31:31,830 --> 00:31:29,710
bright and then fades away again and

703
00:31:33,300 --> 00:31:31,840
this is happening very close to the

704
00:31:35,040 --> 00:31:33,310
center of this nebula so something's

705
00:31:37,110 --> 00:31:35,050
going on very close to the old dead

706
00:31:43,380 --> 00:31:37,120
remnant of this star that's creating

707
00:31:45,630 --> 00:31:43,390
this spike in very energetic light so

708
00:31:48,270 --> 00:31:45,640
when we look at this all-sky map we can

709
00:31:49,740 --> 00:31:48,280
find remnants of supernovae in it things

710
00:31:50,520 --> 00:31:49,750
that we know about from other studies

711
00:31:53,820 --> 00:31:50,530
where we know

712
00:31:55,530 --> 00:31:53,830
other supernovae have gone off so we can

713
00:31:57,960 --> 00:31:55,540

see they're mostly in the plane of our

714
00:31:59,100 --> 00:31:57,970
galaxy which makes a lot of sense right

715
00:32:01,830 --> 00:31:59,110
because that's where most of the stars

716
00:32:04,410 --> 00:32:01,840
in our galaxy are so we can find

717
00:32:07,800 --> 00:32:04,420
supernova remnants we can also find

718
00:32:11,400 --> 00:32:07,810
those old dead remnants of stars the

719
00:32:12,780 --> 00:32:11,410
pulsars spinning around and we can see

720
00:32:15,420 --> 00:32:12,790
those kind of scattered through our

721
00:32:16,980 --> 00:32:15,430
galaxy but mostly in that plane and

722
00:32:18,450 --> 00:32:16,990
they're a little bit easier to find up

723
00:32:20,160 --> 00:32:18,460
here and down here than they are in the

724
00:32:22,620 --> 00:32:20,170
middle and I'll talk a little bit about

725
00:32:25,140 --> 00:32:22,630
why that is in a minute we can find some

726
00:32:27,840 --> 00:32:25,150
pulsars we can also find some really

727
00:32:30,810 --> 00:32:27,850
massive black holes in other galaxies

728
00:32:33,960 --> 00:32:30,820
far away now black holes and other

729
00:32:36,330 --> 00:32:33,970
galaxies are greedy they eat all kinds

730
00:32:39,000 --> 00:32:36,340
of gas and dust and they're messy eaters

731
00:32:41,430 --> 00:32:39,010
and some of that gets shot out each end

732
00:32:43,500 --> 00:32:41,440
in these Jets these giant Jets and when

733
00:32:45,840 --> 00:32:43,510
one of those is pointed at us you can

734
00:32:48,330 --> 00:32:45,850
see see it in the gamma-ray see the

735
00:32:51,360 --> 00:32:48,340
gamma-ray light coming in so these are

736
00:32:53,220 --> 00:32:51,370
really massive engines pointing their

737
00:32:56,940 --> 00:32:53,230
jet right at us and it's showing us

738
00:33:00,510 --> 00:32:56,950

their accelerated particles there's also

739
00:33:01,980 --> 00:33:00,520
a lot of this fuzz right a lot of that

740
00:33:04,260 --> 00:33:01,990
fuzz is what's happening when you have

741
00:33:06,480 --> 00:33:04,270
electrons the colliding with the light

742
00:33:09,210 --> 00:33:06,490
and just like two billiard balls can

743
00:33:11,100 --> 00:33:09,220
collide and give its energy to the other

744
00:33:13,410 --> 00:33:11,110
billiard ball that happens with

745
00:33:15,900 --> 00:33:13,420
electrons and photons and light light

746
00:33:19,800 --> 00:33:15,910
can gain energy from a fast-moving

747
00:33:22,920 --> 00:33:19,810
electron so if we take all that stuff we

748
00:33:25,050 --> 00:33:22,930
know about and try and take it away from

749
00:33:26,850 --> 00:33:25,060
our map of the gamma ray light coming

750
00:33:29,070 --> 00:33:26,860
from the galaxy subtract it all off

751
00:33:32,490 --> 00:33:29,080
account for all the pulsars all the

752
00:33:36,540 --> 00:33:32,500
supernovae that we know about we're left

753
00:33:38,390 --> 00:33:36,550
with something extra at the end it's

754
00:33:41,430 --> 00:33:38,400
concentrated in the center of our galaxy

755
00:33:45,210 --> 00:33:41,440
takes up a couple degrees you know not a

756
00:33:47,670 --> 00:33:45,220
big area and but we're not really sure

757
00:33:51,930 --> 00:33:47,680
what the cause of it is there's this

758
00:33:53,580 --> 00:33:51,940
extra super high-energy radiation coming

759
00:33:56,550 --> 00:33:53,590
from the very center of our galaxy and

760
00:34:00,780 --> 00:33:56,560
the area around it we don't really know

761
00:34:02,520 --> 00:34:00,790
why there are a few ideas one of them

762
00:34:03,490 --> 00:34:02,530
relies on the fact that we've now

763
00:34:05,350 --> 00:34:03,500

removed

764
00:34:08,260 --> 00:34:05,360
all of the known sources of the gamma

765
00:34:10,960 --> 00:34:08,270
radiation so what if there's a type of

766
00:34:12,879 --> 00:34:10,970
thing that we can't see what else can

767
00:34:14,950 --> 00:34:12,889
make that kind of light if you remember

768
00:34:17,560 --> 00:34:14,960
Einstein's famous equation e equals MC

769
00:34:18,490 --> 00:34:17,570
squared right energy is mass times the

770
00:34:21,669 --> 00:34:18,500
speed of light squared

771
00:34:24,129 --> 00:34:21,679
something with mass carries energy with

772
00:34:27,419 --> 00:34:24,139
it just inherently so if we could

773
00:34:29,379 --> 00:34:27,429
liberate some of that mass into photons

774
00:34:30,820 --> 00:34:29,389
then we could create some of this

775
00:34:31,530 --> 00:34:30,830
gamma-ray light and that can happen with

776
00:34:36,280 --> 00:34:31,540
antimatter

777
00:34:39,250 --> 00:34:36,290
the galactic center we can annihilate

778
00:34:42,369 --> 00:34:39,260
some regular matter and create this

779
00:34:44,560 --> 00:34:42,379
high-energy light but we already remove

780
00:34:47,710 --> 00:34:44,570
the matter we knew about we remove the

781
00:34:49,540 --> 00:34:47,720
stuff we could see so what else is left

782
00:34:51,580 --> 00:34:49,550
well maybe it's stuff we can't see

783
00:34:56,290 --> 00:34:51,590
things like dark matter which kind of by

784
00:34:58,150 --> 00:34:56,300
definition we can't see right now dark

785
00:35:00,160 --> 00:34:58,160
matter sounds like it's kind of a tooth

786
00:35:02,220 --> 00:35:00,170
fairy that people inject into the world

787
00:35:05,410 --> 00:35:02,230
because they can't explain everything

788
00:35:08,530 --> 00:35:05,420

but there are really good reasons to

789
00:35:10,079 --> 00:35:08,540
think that Dark Matter exists and there

790
00:35:13,450 --> 00:35:10,089
have been for some time

791
00:35:15,730 --> 00:35:13,460
it started off through a totally

792
00:35:18,010 --> 00:35:15,740
different approach from just noticing

793
00:35:19,390 --> 00:35:18,020
that orbits don't work the way where

794
00:35:21,880 --> 00:35:19,400
they that we think they should in

795
00:35:24,120 --> 00:35:21,890
galaxies if you look at our solar system

796
00:35:26,800 --> 00:35:24,130
and look at how fast planets move around

797
00:35:30,040 --> 00:35:26,810
stuff close to the Sun moves fast like

798
00:35:32,500 --> 00:35:30,050
mercury right the messenger god mercury

799
00:35:34,960 --> 00:35:32,510
from Roman mythology moves very quickly

800
00:35:38,140 --> 00:35:34,970
the stuff way further out like Neptune

801
00:35:40,089 --> 00:35:38,150
and Pluto moves very slowly but if you

802
00:35:43,329 --> 00:35:40,099
look at galaxies and the velocity of

803
00:35:45,160 --> 00:35:43,339
stars you don't see that kind of fall

804
00:35:47,500 --> 00:35:45,170
off if you move away from the center of

805
00:35:51,339 --> 00:35:47,510
the galaxy the stars don't go any slower

806
00:35:54,730 --> 00:35:51,349
they stay the same speed now that

807
00:35:56,530 --> 00:35:54,740
suggests that there's matter that's

808
00:35:59,560 --> 00:35:56,540
still pulling on the star that we can't

809
00:36:01,089 --> 00:35:59,570
see so that's the kind of the origin of

810
00:36:04,120 --> 00:36:01,099
dark matter so the structure of our

811
00:36:07,089 --> 00:36:04,130
galaxy then is we're living out here on

812
00:36:08,920 --> 00:36:07,099
this kind of outer spiral arm and the

813
00:36:12,970 --> 00:36:08,930

unfashionable end of the spiral galaxy

814
00:36:14,920 --> 00:36:12,980
right it's flat with us in the middle

815
00:36:17,109 --> 00:36:14,930
and we can see that on the sky but

816
00:36:19,239 --> 00:36:17,119
surrounding us is this

817
00:36:22,450 --> 00:36:19,249
a low of dark matter invisible to our

818
00:36:25,809 --> 00:36:22,460
eyes and to our instruments but the

819
00:36:27,940 --> 00:36:25,819
influence of its gravity is not so the

820
00:36:32,200 --> 00:36:27,950
idea that we could maybe detect it

821
00:36:34,049 --> 00:36:32,210
directly is pretty tantalizing there are

822
00:36:37,930 --> 00:36:34,059
some theories about what dark matter is

823
00:36:40,359 --> 00:36:37,940
well some of those theories think that

824
00:36:42,999 --> 00:36:40,369
dark matter is a type of massive

825
00:36:44,620 --> 00:36:43,009
particle that interacts through the weak

826
00:36:45,819 --> 00:36:44,630
nuclear force is what it's called so

827
00:36:49,599 --> 00:36:45,829
they call it a weakly interacting

828
00:36:51,910 --> 00:36:49,609
massive particle or a wimp

829
00:36:54,160 --> 00:36:51,920
astronomers really love terrible

830
00:36:57,849 --> 00:36:54,170
terrible acronyms and wimps are one of

831
00:37:00,180 --> 00:36:57,859
them but some theories of WIPP Dark

832
00:37:02,200 --> 00:37:00,190
Matter thinks that they're their own

833
00:37:04,029 --> 00:37:02,210
antiparticle so if you have lots of dark

834
00:37:05,529 --> 00:37:04,039
matter concentrated you would expect

835
00:37:08,319 --> 00:37:05,539
those particles of dark matter to run

836
00:37:11,170 --> 00:37:08,329
into each other and when they do create

837
00:37:13,509 --> 00:37:11,180
gamma ray light because a equals MC

838
00:37:16,089 --> 00:37:13,519

squared so maybe the reason that we see

839
00:37:17,980 --> 00:37:16,099
this extra stuff is because that's where

840
00:37:19,960 --> 00:37:17,990
the dark matter is most concentrated and

841
00:37:23,739 --> 00:37:19,970
that's where we see the these particle

842
00:37:27,819 --> 00:37:23,749
annihilations coming from so that's one

843
00:37:29,829 --> 00:37:27,829
idea there are other ideas that don't

844
00:37:31,299 --> 00:37:29,839
involve invoking new kinds of matter

845
00:37:34,749 --> 00:37:31,309
even matter that we have a really good

846
00:37:36,729 --> 00:37:34,759
reason to think exists okay and that's

847
00:37:39,670 --> 00:37:36,739
based on the fact that there are analogs

848
00:37:42,700 --> 00:37:39,680
of this excess in other places and that

849
00:37:44,890 --> 00:37:42,710
this guy is really crowded if we look at

850
00:37:47,019 --> 00:37:44,900
the Galactic bulge there are so many

851
00:37:49,720 --> 00:37:47,029
stars there it's very difficult to tell

852
00:37:51,309 --> 00:37:49,730
them apart this is an image that I took

853
00:37:53,349 --> 00:37:51,319
as part of my research when I was in

854
00:37:56,049 --> 00:37:53,359
grad school of a part of the Galactic

855
00:37:58,569 --> 00:37:56,059
bulge all of the white bits in here are

856
00:38:01,450 --> 00:37:58,579
stars the black is the gap in between

857
00:38:03,579 --> 00:38:01,460
them and this image was taken with a

858
00:38:05,650 --> 00:38:03,589
resolution about 70 times better than

859
00:38:08,019 --> 00:38:05,660
what your eye can see so this is really

860
00:38:11,950 --> 00:38:08,029
a quite a detailed image from the ground

861
00:38:15,579 --> 00:38:11,960
and it's just chock full of stars and an

862
00:38:18,640 --> 00:38:15,589
instrument like Fermi doesn't have the

863
00:38:21,549 --> 00:38:18,650

resolution to tell these stars apart any

864
00:38:23,819 --> 00:38:21,559
more than your eye does so maybe there's

865
00:38:25,989 --> 00:38:23,829
a population of stuff blending together

866
00:38:28,690 --> 00:38:25,999
now just to give you a sense of how

867
00:38:31,599 --> 00:38:28,700
crowded this is this whole

868
00:38:34,240 --> 00:38:31,609
thing would fit on the size of your

869
00:38:36,190 --> 00:38:34,250
pinkie nail held a certain distance away

870
00:38:38,380 --> 00:38:36,200
that's how much of this guy it takes up

871
00:38:39,819 --> 00:38:38,390
let's see if we can guess how how much

872
00:38:41,170 --> 00:38:39,829
how far away you'd have to hold your

873
00:38:44,170 --> 00:38:41,180
pinkie nail to take up that amount of

874
00:38:46,300 --> 00:38:44,180
this guy think you'd have to hold it in

875
00:38:49,660 --> 00:38:46,310
front of your nose kind of out at arm's

876
00:38:51,180 --> 00:38:49,670
length about ten feet away or about 50

877
00:38:53,710 --> 00:38:51,190
feet away

878
00:39:06,480 --> 00:38:53,720
what patch of this guy do you think that

879
00:39:08,560 --> 00:39:06,490
fits in it make your final guesses here

880
00:39:11,380 --> 00:39:08,570
it would have to be about 50 feet away

881
00:39:13,210 --> 00:39:11,390
so if you those of you in the back of

882
00:39:16,990 --> 00:39:13,220
the room or about 50 feet away from me

883
00:39:20,710 --> 00:39:17,000
my pinky nail would contain everything

884
00:39:23,170 --> 00:39:20,720
in that image and that's tiled over the

885
00:39:25,270 --> 00:39:23,180
center of our galaxy so it's just chock

886
00:39:27,910 --> 00:39:25,280
full of stars and some of those stars

887
00:39:32,280 --> 00:39:27,920
have died and some of those stars are

888
00:39:35,650 --> 00:39:32,290

now pulsars and since Fermi is

889
00:39:37,990 --> 00:39:35,660
relatively blurry it's possible that

890
00:39:41,559 --> 00:39:38,000
those could blend together into

891
00:39:44,400 --> 00:39:41,569
something else so I don't know if

892
00:39:48,579 --> 00:39:44,410
anybody recognizes what this is so far

893
00:39:51,460 --> 00:39:48,589
no so there's a style of art where you

894
00:39:53,980 --> 00:39:51,470
draw kind of large colored dots on the

895
00:39:57,040 --> 00:39:53,990
canvas and when you stand far enough

896
00:40:00,190 --> 00:39:57,050
away they blend together into a new

897
00:40:01,990 --> 00:40:00,200
image so here we're standing kind of

898
00:40:03,430 --> 00:40:02,000
close enough to the painting that we

899
00:40:05,980 --> 00:40:03,440
can't tell what it is it's just a bunch

900
00:40:09,099 --> 00:40:05,990
of colored dots as we zoom out and

901
00:40:13,300 --> 00:40:09,109
things blur together a shape starts to

902
00:40:18,370 --> 00:40:13,310
emerge until finally the full piece of

903
00:40:20,410 --> 00:40:18,380
art is revealed so something similar

904
00:40:22,510 --> 00:40:20,420
could be happening with the stars in the

905
00:40:24,130 --> 00:40:22,520
Galactic bulge where individually if you

906
00:40:26,099 --> 00:40:24,140
had the resolution you could pull them

907
00:40:29,140 --> 00:40:26,109
apart into the individual colored dots

908
00:40:31,960 --> 00:40:29,150
but with an instrument that has less

909
00:40:37,300 --> 00:40:31,970
resolution like Fermi they blur together

910
00:40:38,980 --> 00:40:37,310
into kind of the smooth looking art so

911
00:40:41,040 --> 00:40:38,990
could these gamma rays be coming from

912
00:40:42,109 --> 00:40:41,050
lots of small things that blend together

913
00:40:45,579 --> 00:40:42,119

well

914
00:40:49,339 --> 00:40:45,589
we have examples of when this happens

915
00:40:53,210 --> 00:40:49,349
this is a star cluster okay called

916
00:40:55,819 --> 00:40:53,220
Tarzan five and it's in our Milky Way so

917
00:40:56,690 --> 00:40:55,829
called a globular cluster this image was

918
00:40:58,999 --> 00:40:56,700
taken with the Hubble Space Telescope

919
00:41:02,239 --> 00:40:59,009
and you can see lots of individual stars

920
00:41:06,259 --> 00:41:02,249
here right and if we look at that

921
00:41:09,170 --> 00:41:06,269
cluster in gamma rays this is what it

922
00:41:13,069 --> 00:41:09,180
looks like so you can see that it just

923
00:41:15,200 --> 00:41:13,079
looks like one solid blob okay you can't

924
00:41:18,680 --> 00:41:15,210
tell the individual stars apart anymore

925
00:41:20,870 --> 00:41:18,690
in the gamma ray so maybe whatever is

926
00:41:23,059 --> 00:41:20,880
responsible for those gamma rays in the

927
00:41:24,650 --> 00:41:23,069
cluster which is the same kind of thing

928
00:41:27,349 --> 00:41:24,660
that's responsible for the gamma rays in

929
00:41:29,359 --> 00:41:27,359
the galactic center globular clusters

930
00:41:32,680 --> 00:41:29,369
don't have dark matter

931
00:41:35,299 --> 00:41:32,690
okay we've kind of studied lots of them

932
00:41:37,220 --> 00:41:35,309
measured the velocity of their stars

933
00:41:39,319 --> 00:41:37,230
moving around and they behave like you

934
00:41:41,150 --> 00:41:39,329
would expect them to if all of the mass

935
00:41:43,789 --> 00:41:41,160
is coming from the stars they don't seem

936
00:41:45,470 --> 00:41:43,799
to have any dark matter so if the same

937
00:41:47,479 --> 00:41:45,480
thing is responsible for the gamma rays

938
00:41:49,279 --> 00:41:47,489

in the cluster as in the galactic center

939
00:41:51,130 --> 00:41:49,289
then it's not dark matter it's something

940
00:41:53,839 --> 00:41:51,140
else

941
00:41:57,049 --> 00:41:53,849
there are these objects in these

942
00:41:58,519 --> 00:41:57,059
clusters these old dead remnants of

943
00:42:01,220 --> 00:41:58,529
stars that can give you high-energy

944
00:42:03,319 --> 00:42:01,230
light this is an x-ray image taken of

945
00:42:05,210 --> 00:42:03,329
Tarzan 5 and with the Chandra x-ray

946
00:42:07,640 --> 00:42:05,220
Observatory and you can see these

947
00:42:11,390 --> 00:42:07,650
individual points sitting around in the

948
00:42:13,870 --> 00:42:11,400
core of the cluster these are what

949
00:42:16,160 --> 00:42:13,880
happens when you have an old dead star

950
00:42:20,870 --> 00:42:16,170
feeding on something kind of a zombie

951
00:42:25,489 --> 00:42:20,880
star right so what happens is as the

952
00:42:29,059 --> 00:42:25,499
star dies what's left is it's shrunken

953
00:42:30,650 --> 00:42:29,069
core okay called a neutron star so to

954
00:42:33,559 --> 00:42:30,660
give you a kind of a quick primer on how

955
00:42:35,950 --> 00:42:33,569
neutron stars how small they are and how

956
00:42:38,989 --> 00:42:35,960
dense they are after they've shrunk down

957
00:42:40,519 --> 00:42:38,999
and we can compare it to something that

958
00:42:43,009 --> 00:42:40,529
maybe most even familiar with the city

959
00:42:45,380 --> 00:42:43,019
of Baltimore okay so if we put a neutron

960
00:42:47,690 --> 00:42:45,390
star down on top of Baltimore see how

961
00:42:50,930 --> 00:42:47,700
big it's gonna be it fits pretty neatly

962
00:42:53,599 --> 00:42:50,940
inside the loop around the city okay

963
00:42:55,430 --> 00:42:53,609

there's somewhere between 10 and 15

964
00:42:57,470 --> 00:42:55,440
kilometers

965
00:43:00,470 --> 00:42:57,480
in radius okay the one I've drawn here

966
00:43:03,859 --> 00:43:00,480
is 11 kilometers in radius it's pretty

967
00:43:04,819 --> 00:43:03,869
well okay these spin around really

968
00:43:06,710 --> 00:43:04,829
rapidly

969
00:43:08,690 --> 00:43:06,720
most of them spin around about once a

970
00:43:13,520 --> 00:43:08,700
second take about a second to make the

971
00:43:17,630 --> 00:43:13,530
entire loop around Baltimore so if you'd

972
00:43:21,170 --> 00:43:17,640
also weigh more than the Sun does just

973
00:43:23,270 --> 00:43:21,180
for comparison 99.5% of all the mass in

974
00:43:25,279 --> 00:43:23,280
the solar system is wrapped up in the

975
00:43:28,160 --> 00:43:25,289
Sun and most of what's left is in

976
00:43:29,510 --> 00:43:28,170
Jupiter so weighing more than the Sun

977
00:43:32,599 --> 00:43:29,520
and fitting into something the size of

978
00:43:36,740 --> 00:43:32,609
Baltimore is really quite dense she had

979
00:43:38,000 --> 00:43:36,750
to guess a teaspoon of neutron star how

980
00:43:39,620 --> 00:43:38,010
much do you think that would weigh if

981
00:43:47,359 --> 00:43:39,630
you just dipped a little teaspoon of

982
00:43:50,380 --> 00:43:47,369
neutron star out yeah BC yeah 10 million

983
00:43:55,970 --> 00:43:50,390
tons from one teaspoon of neutron star

984
00:43:58,279 --> 00:43:55,980
are fantastically dense something

985
00:44:00,170 --> 00:43:58,289
interesting can happen when you get it

986
00:44:01,670 --> 00:44:00,180
close to another star it can start to

987
00:44:04,730 --> 00:44:01,680
eat it and that happens a lot in these

988
00:44:07,730 --> 00:44:04,740

globular clusters okay deep in the core

989
00:44:12,260 --> 00:44:07,740
this is a really dense environment this

990
00:44:14,599 --> 00:44:12,270
whole area here is about the size of the

991
00:44:17,420 --> 00:44:14,609
distance between the Sun and the nearest

992
00:44:20,299 --> 00:44:17,430
star to the Sun so where we are we'd

993
00:44:22,370 --> 00:44:20,309
have the Sun and then Alpha Centauri the

994
00:44:24,859 --> 00:44:22,380
closest star in the same image here we

995
00:44:25,940 --> 00:44:24,869
packed hundreds of thousands of stars so

996
00:44:28,430 --> 00:44:25,950
they're so close they can really

997
00:44:31,069 --> 00:44:28,440
interact and have a lot of cool things

998
00:44:33,710 --> 00:44:31,079
going on so this is a simulation of a

999
00:44:34,940 --> 00:44:33,720
way that they can interact there's a

1000
00:44:37,370 --> 00:44:34,950
binary up here

1001
00:44:39,200 --> 00:44:37,380
two stars orbiting each other ones green

1002
00:44:41,720 --> 00:44:39,210
ones blue and there's another one down

1003
00:44:44,690 --> 00:44:41,730
here another pair of stars orbiting each

1004
00:44:47,450 --> 00:44:44,700
other ones yellow ones red so keep your

1005
00:44:51,319 --> 00:44:47,460
eye on the green one and the yellow one

1006
00:44:53,809 --> 00:44:51,329
these two pairs of stars are gonna going

1007
00:44:59,150 --> 00:44:53,819
to go by each other and watch what

1008
00:45:00,589 --> 00:44:59,160
happens to now you see how close

1009
00:45:06,630 --> 00:45:00,599
together the green one and the yellow

1010
00:45:08,339 --> 00:45:06,640
and get at the end and how

1011
00:45:12,229 --> 00:45:08,349
fast they end up spiraling around each

1012
00:45:16,079 --> 00:45:12,239
other so when they get so close together

1013
00:45:18,359 --> 00:45:16,089

it becomes important that something else

1014
00:45:20,910 --> 00:45:18,369
happens to stars as they age stars

1015
00:45:23,819 --> 00:45:20,920
expand as they age so once you've gotten

1016
00:45:25,470 --> 00:45:23,829
a neutron star and another star close

1017
00:45:28,829 --> 00:45:25,480
together when that star starts to age

1018
00:45:31,289 --> 00:45:28,839
and get old stars much you know like

1019
00:45:34,229 --> 00:45:31,299
people pass you know I'm starting to get

1020
00:45:38,880 --> 00:45:34,239
there myself have to regulate the intake

1021
00:45:40,410 --> 00:45:38,890
of beer and start to expand and when

1022
00:45:44,249 --> 00:45:40,420
that happens the material at the edge

1023
00:45:46,829 --> 00:45:44,259
can start to fall off of the star and

1024
00:45:47,450 --> 00:45:46,839
onto the neutron star looks something

1025
00:45:50,670 --> 00:45:47,460
like that

1026
00:45:54,870 --> 00:45:50,680
okay so here we've got a neutron star

1027
00:45:58,109 --> 00:45:54,880
here at the very center and this kind of

1028
00:46:00,809 --> 00:45:58,119
starting to age and expand star dumping

1029
00:46:02,160 --> 00:46:00,819
the material out onto the neutron star

1030
00:46:05,039 --> 00:46:02,170
and when it happens it forms this

1031
00:46:07,620 --> 00:46:05,049
whirlpool of material hey have you ever

1032
00:46:09,900 --> 00:46:07,630
gone to the zoo or a museum or something

1033
00:46:13,019 --> 00:46:09,910
like that and they've got those little

1034
00:46:15,120 --> 00:46:13,029
coin drop things that spiral the coin

1035
00:46:16,950 --> 00:46:15,130
around into the donation bucket in the

1036
00:46:19,019 --> 00:46:16,960
middle it's the same sort of thing

1037
00:46:20,609 --> 00:46:19,029
happens you drop the coins and they

1038
00:46:22,380 --> 00:46:20,619

spiral around until they finally reach

1039
00:46:26,880 --> 00:46:22,390
the center going faster and faster the

1040
00:46:28,829 --> 00:46:26,890
closer they get to the center okay all

1041
00:46:30,930 --> 00:46:28,839
that stuff moving faster and faster as

1042
00:46:32,519 --> 00:46:30,940
it gets to the center when it lands on

1043
00:46:34,289 --> 00:46:32,529
the neutron star it's going pretty fast

1044
00:46:38,009 --> 00:46:34,299
it's going faster than the neutron star

1045
00:46:43,440 --> 00:46:38,019
is spinning and it that spins up the

1046
00:46:45,900 --> 00:46:43,450
neutron star so responsible binaries

1047
00:46:47,729 --> 00:46:45,910
recycle their old neutron stars and all

1048
00:46:49,400 --> 00:46:47,739
that material starts to spin it up

1049
00:46:51,870 --> 00:46:49,410
faster and faster and faster

1050
00:46:54,120 --> 00:46:51,880
so instead of a neutron star spinning

1051
00:46:57,660 --> 00:46:54,130
every one second or every two seconds

1052
00:46:59,819 --> 00:46:57,670
these will spend hundreds of times every

1053
00:47:01,890 --> 00:46:59,829
second so if you could imagine traveling

1054
00:47:04,019 --> 00:47:01,900
the outer loop of Baltimore hundreds of

1055
00:47:05,430 --> 00:47:04,029
times in one second you'll get the kind

1056
00:47:10,019 --> 00:47:05,440
of a feel for how quickly these things

1057
00:47:13,200 --> 00:47:10,029
are going okay so what's left at the end

1058
00:47:15,479 --> 00:47:13,210
eventually this accretion stops this

1059
00:47:17,430 --> 00:47:15,489
robbing of material stops and you're

1060
00:47:20,460 --> 00:47:17,440
left with this really fast spinning

1061
00:47:23,970 --> 00:47:20,470
neutron star at the end okay

1062
00:47:25,290 --> 00:47:23,980
that's spun spinning up so quickly this

1063
00:47:30,059 --> 00:47:25,300

is the kind of thing that you can see

1064
00:47:32,790 --> 00:47:30,069
now as a pulsar so every time these

1065
00:47:35,190 --> 00:47:32,800
magnetic poles of the spinning neutron

1066
00:47:37,079 --> 00:47:35,200
star sweep past you you see a bright

1067
00:47:40,920 --> 00:47:37,089
flash of radio light that's what it

1068
00:47:44,670 --> 00:47:40,930
means to be a pulsar a milli second

1069
00:47:47,150 --> 00:47:44,680
pulsar a recycled pulsar is one that has

1070
00:47:50,700 --> 00:47:47,160
been spun up to these fantastic speeds

1071
00:47:54,809 --> 00:47:50,710
and you see a pulse hundreds of times

1072
00:47:57,660 --> 00:47:54,819
every second these are known to be gamma

1073
00:47:59,849 --> 00:47:57,670
ray emitters we can identify them out

1074
00:48:03,450 --> 00:47:59,859
loose in the galaxy we can see that

1075
00:48:07,650 --> 00:48:03,460
they're emitting gamma rays so one

1076
00:48:09,780 --> 00:48:07,660
hypothesis then for the gamma ray excess

1077
00:48:11,490 --> 00:48:09,790
in the center of our galaxy is that

1078
00:48:13,170 --> 00:48:11,500
there's a whole bunch of these really

1079
00:48:15,960 --> 00:48:13,180
rapidly spinning neutron stars hanging

1080
00:48:18,180 --> 00:48:15,970
out in the center of the galaxy each of

1081
00:48:21,240 --> 00:48:18,190
them emitting gamma rays and blending

1082
00:48:26,099 --> 00:48:21,250
together just like a pointillist artwork

1083
00:48:29,040 --> 00:48:26,109
okay so we've got these two ideas right

1084
00:48:31,109 --> 00:48:29,050
oh yeah sorry so there is a a hang-up

1085
00:48:34,829 --> 00:48:31,119
and that we should see some pulsars

1086
00:48:37,290 --> 00:48:34,839
right we can see them in the radio why

1087
00:48:39,900 --> 00:48:37,300
don't we see them in the center of the

1088
00:48:43,200 --> 00:48:39,910

galaxy if they're there why do we miss

1089
00:48:46,230 --> 00:48:43,210
them we should actually be able to point

1090
00:48:49,440 --> 00:48:46,240
a radio telescope at them right and see

1091
00:48:52,319 --> 00:48:49,450
the pulses coming but we don't there are

1092
00:48:55,260 --> 00:48:52,329
some reasons that might happen there are

1093
00:48:58,170 --> 00:48:55,270
hot electrons or just free electrons in

1094
00:49:00,620 --> 00:48:58,180
the galaxies loose and whenever a radio

1095
00:49:04,079 --> 00:49:00,630
wave passes by those it slows it down

1096
00:49:06,540 --> 00:49:04,089
and when it slows it down it smears the

1097
00:49:09,270 --> 00:49:06,550
radio pulse out so whereas the radio

1098
00:49:11,910 --> 00:49:09,280
pulse might start out as this really

1099
00:49:14,099 --> 00:49:11,920
coherent single thing at different

1100
00:49:16,230 --> 00:49:14,109
frequencies the pulse is being delayed

1101
00:49:17,819 --> 00:49:16,240
by different amounts so when you look

1102
00:49:20,130 --> 00:49:17,829
with the radio telescope instead of

1103
00:49:22,800 --> 00:49:20,140
seeing one nice neat pulse you're

1104
00:49:28,220 --> 00:49:22,810
getting a smeared out pulse and that

1105
00:49:34,440 --> 00:49:32,490
inconveniently this smearing is worse at

1106
00:49:36,120 --> 00:49:34,450
the center of the galaxy

1107
00:49:38,339 --> 00:49:36,130
if you measure how much smearing there

1108
00:49:40,440 --> 00:49:38,349
is as a function of the Galactic

1109
00:49:42,240 --> 00:49:40,450
latitude and how far away from the plane

1110
00:49:45,030 --> 00:49:42,250
you move right in the middle of the

1111
00:49:46,530 --> 00:49:45,040
plane it's terrible right now towards

1112
00:49:48,569 --> 00:49:46,540
the edges it's fine and you can see the

1113
00:49:49,620 --> 00:49:48,579

pulsars no problem looking right towards

1114
00:49:51,000 --> 00:49:49,630
the center there's all these free

1115
00:49:54,150 --> 00:49:51,010
electrons and the pulses just get

1116
00:49:56,910 --> 00:49:54,160
hopelessly smeared that's worst at low

1117
00:49:58,950 --> 00:49:56,920
frequency which is a problem because

1118
00:50:00,630 --> 00:49:58,960
pulsars are brightest at low frequency

1119
00:50:03,750 --> 00:50:00,640
so if you want to find pulsars you want

1120
00:50:05,270 --> 00:50:03,760
to go to really low energy radio because

1121
00:50:07,260 --> 00:50:05,280
that's where they're really bright and

1122
00:50:08,880 --> 00:50:07,270
but that's also where they're smearing

1123
00:50:10,650 --> 00:50:08,890
the most and as you move to where the

1124
00:50:13,050 --> 00:50:10,660
smearing is less severe at high

1125
00:50:16,319 --> 00:50:13,060
frequencies then you're running into

1126
00:50:19,829 --> 00:50:16,329
problems with how bright the Pulsar is

1127
00:50:23,880 --> 00:50:19,839
and it's just hard to see so we've got

1128
00:50:26,339 --> 00:50:23,890
these two scenarios to explain kind of

1129
00:50:28,530 --> 00:50:26,349
this puzzle one is that there are

1130
00:50:31,500 --> 00:50:28,540
particles we can't see dark matter and

1131
00:50:34,740 --> 00:50:31,510
the other is that there are pulsars we

1132
00:50:37,670 --> 00:50:34,750
can't see which one is it is it either

1133
00:50:39,480 --> 00:50:37,680
of them is there some way to find out oh

1134
00:50:42,300 --> 00:50:39,490
there are a couple of different ways you

1135
00:50:44,870 --> 00:50:42,310
could approach it there are groups out

1136
00:50:47,940 --> 00:50:44,880
at the Large Hadron Collider in Geneva

1137
00:50:49,530 --> 00:50:47,950
in Switzerland looking for these dark

1138
00:50:51,450 --> 00:50:49,540

matter particles looking to see if they

1139
00:50:54,180 --> 00:50:51,460
can find something that looks like it

1140
00:50:57,660 --> 00:50:54,190
would be responsible for this excess of

1141
00:50:58,890 --> 00:50:57,670
gamma rays I'm not part of that effort

1142
00:51:03,420 --> 00:50:58,900
so I'm not going to talk about it

1143
00:51:06,359 --> 00:51:03,430
anymore the other ways we can go about

1144
00:51:08,609 --> 00:51:06,369
looking for new pulsars see if we can

1145
00:51:10,470 --> 00:51:08,619
find them where it has been difficult to

1146
00:51:11,940 --> 00:51:10,480
find them before and we can take

1147
00:51:14,370 --> 00:51:11,950
advantage of a couple of things one

1148
00:51:17,819 --> 00:51:14,380
pulsars are small all right they fit

1149
00:51:19,410 --> 00:51:17,829
inside the loop around Baltimore the

1150
00:51:21,510 --> 00:51:19,420
other thing we can take advantage of to

1151
00:51:22,950 --> 00:51:21,520
see if we can find them is that they're

1152
00:51:26,550 --> 00:51:22,960
bright at low frequencies we know these

1153
00:51:30,059 --> 00:51:26,560
two facts about pulsars so what we can

1154
00:51:31,950 --> 00:51:30,069
do is go out and look with radio

1155
00:51:34,230 --> 00:51:31,960
telescopes and see if we can separate

1156
00:51:35,940 --> 00:51:34,240
things that are small and bright at low

1157
00:51:38,099 --> 00:51:35,950
frequencies from the rest of the stuff

1158
00:51:40,109 --> 00:51:38,109
we can see some of the rest of the stuff

1159
00:51:45,000 --> 00:51:40,119
we can see are these massive galaxies

1160
00:51:47,130 --> 00:51:45,010
shooting out Jets of particles from a

1161
00:51:48,300 --> 00:51:47,140
central source black hole eating

1162
00:51:52,020 --> 00:51:48,310
gobbling up

1163
00:51:55,080 --> 00:51:52,030

material as rapidly as it can these big

1164
00:51:58,170 --> 00:51:55,090
jets that are large on the sky they're

1165
00:52:00,960 --> 00:51:58,180
not small so we can we can see them they

1166
00:52:02,220 --> 00:52:00,970
are much brighter at low frequencies but

1167
00:52:04,380 --> 00:52:02,230
they don't fulfill both requirements

1168
00:52:07,290 --> 00:52:04,390
right they're bright at low frequencies

1169
00:52:11,580 --> 00:52:07,300
but they're not small that central

1170
00:52:13,980 --> 00:52:11,590
source is very small but it's not super

1171
00:52:16,590 --> 00:52:13,990
bright at low frequencies pulsars are

1172
00:52:19,620 --> 00:52:16,600
much brighter relatively so by combining

1173
00:52:23,370 --> 00:52:19,630
these two facts we can try and separate

1174
00:52:26,670 --> 00:52:23,380
out the pulsars from kind of distant

1175
00:52:30,480 --> 00:52:26,680
black holes and other sources that might

1176
00:52:31,830 --> 00:52:30,490
cause confusion so we need lots of radio

1177
00:52:37,170 --> 00:52:31,840
dishes to make a really high-resolution

1178
00:52:40,560 --> 00:52:37,180
image to really zoom in on the the small

1179
00:52:42,000 --> 00:52:40,570
small things so this is the the VLA the

1180
00:52:43,920 --> 00:52:42,010
Very Large Array out in Socorro New

1181
00:52:46,500 --> 00:52:43,930
Mexico if anybody's seen the movie

1182
00:52:49,470 --> 00:52:46,510
contact yeah I was in the movie contact

1183
00:52:51,360 --> 00:52:49,480
Jodie Foster was out there on a CB radio

1184
00:52:56,940 --> 00:52:51,370
while she was trying to take radio data

1185
00:52:58,890 --> 00:52:56,950
right not a not a good call yeah so this

1186
00:53:00,060 --> 00:52:58,900
is an aerial photo of the VLA just try

1187
00:53:02,610 --> 00:53:00,070
and give you a sense of how big it is

1188
00:53:05,040 --> 00:53:02,620

you can't really see very well the arms

1189
00:53:06,660 --> 00:53:05,050
here so I'll highlight them this is

1190
00:53:08,940 --> 00:53:06,670
where all the different antennae can go

1191
00:53:10,500 --> 00:53:08,950
they can spread out over ten miles

1192
00:53:12,720 --> 00:53:10,510
across

1193
00:53:17,250 --> 00:53:12,730
I think 22 kilometers is the length of

1194
00:53:19,380 --> 00:53:17,260
the arms maybe 21 I'm not right so your

1195
00:53:21,150 --> 00:53:19,390
size of the telescope basically becomes

1196
00:53:25,290 --> 00:53:21,160
the size of these arms when you link

1197
00:53:27,570 --> 00:53:25,300
them all up so using data from the VLA I

1198
00:53:29,100 --> 00:53:27,580
got to go out which is a lot of fun they

1199
00:53:32,730 --> 00:53:29,110
let me climb into one of the dishes for

1200
00:53:36,510 --> 00:53:32,740
some reason you get to use some data

1201
00:53:41,160 --> 00:53:36,520
there they taught me how to use it to

1202
00:53:43,770 --> 00:53:41,170
look for these compact radio sources so

1203
00:53:46,350 --> 00:53:43,780
this is just a small section of one of

1204
00:53:50,100 --> 00:53:46,360
the images we took with the VLA looking

1205
00:53:51,690 --> 00:53:50,110
for small objects that are bright at low

1206
00:53:52,350 --> 00:53:51,700
frequency and not very bright at high

1207
00:53:53,850 --> 00:53:52,360
frequency

1208
00:53:56,550 --> 00:53:53,860
and you can see that there are these

1209
00:53:58,890 --> 00:53:56,560
I've circled some very small point like

1210
00:54:01,840 --> 00:53:58,900
objects and you can also see here

1211
00:54:05,020 --> 00:54:01,850
something extended

1212
00:54:06,970 --> 00:54:05,030
clearer on my screen but the this is a

1213
00:54:10,230 --> 00:54:06,980

supermassive black hole kind of shooting

1214
00:54:12,990 --> 00:54:10,240
out some jets of material out around it

1215
00:54:14,560 --> 00:54:13,000
which is kind of cool to find

1216
00:54:16,000 --> 00:54:14,570
accidentally right because we're not

1217
00:54:19,360 --> 00:54:16,010
really looking for those but it's there

1218
00:54:21,430 --> 00:54:19,370
and it's neat the then after we've got

1219
00:54:23,920 --> 00:54:21,440
all those point sources of small objects

1220
00:54:25,060 --> 00:54:23,930
we can look at how bright they are at

1221
00:54:27,460 --> 00:54:25,070
low frequencies compared to high

1222
00:54:30,280 --> 00:54:27,470
frequencies so stuff further down on

1223
00:54:33,640 --> 00:54:30,290
this plot is bright at low frequencies

1224
00:54:35,110 --> 00:54:33,650
stuff around zero here is about the same

1225
00:54:37,720 --> 00:54:35,120
brightness at high frequencies as to

1226
00:54:40,600 --> 00:54:37,730
visit low frequencies we've plotted up

1227
00:54:41,950 --> 00:54:40,610
just three different fields of where we

1228
00:54:44,110 --> 00:54:41,960
observe three different parts of the

1229
00:54:46,320 --> 00:54:44,120
Milky Way and we can see that there are

1230
00:54:48,550 --> 00:54:46,330
several sources here that are points and

1231
00:54:50,440 --> 00:54:48,560
very bright at low frequencies compared

1232
00:54:52,420 --> 00:54:50,450
to high frequencies so we've got all

1233
00:54:55,990 --> 00:54:52,430
these candidates now things that look

1234
00:54:58,000 --> 00:54:56,000
like pulsars but the smoking gun really

1235
00:55:01,360 --> 00:54:58,010
is to search these candidates so these

1236
00:55:04,210 --> 00:55:01,370
two were bright at low frequencies and

1237
00:55:05,740 --> 00:55:04,220
not at high frequencies this one was not

1238
00:55:06,840 --> 00:55:05,750

so we throw it out we're not going to

1239
00:55:09,940 --> 00:55:06,850
look at it anymore

1240
00:55:12,130 --> 00:55:09,950
but we can now go and look at these

1241
00:55:14,500 --> 00:55:12,140
objects with something like the Green

1242
00:55:17,680 --> 00:55:14,510
Bank Observatory this is out in West

1243
00:55:21,400 --> 00:55:17,690
Virginia not too far away from here and

1244
00:55:23,890 --> 00:55:21,410
we can point this massive dish at each

1245
00:55:26,530 --> 00:55:23,900
of these candidates and look for pulses

1246
00:55:29,320 --> 00:55:26,540
you might say well you didn't find

1247
00:55:31,420 --> 00:55:29,330
pulses earlier why would you find pulses

1248
00:55:33,730 --> 00:55:31,430
now what what's better about having done

1249
00:55:36,070 --> 00:55:33,740
this right and the thing is if you look

1250
00:55:39,010 --> 00:55:36,080
at where these are on the sky the red

1251
00:55:41,650 --> 00:55:39,020
dots here the red circles are where the

1252
00:55:44,350 --> 00:55:41,660
pulsar candidates are the blue circles

1253
00:55:47,050 --> 00:55:44,360
are the part of the sky that this dish

1254
00:55:49,690 --> 00:55:47,060
can see okay and you might notice

1255
00:55:51,610 --> 00:55:49,700
there's a lot of the sky here that we

1256
00:55:54,130 --> 00:55:51,620
don't have to look at anymore we can

1257
00:55:56,740 --> 00:55:54,140
ignore it that means that we don't have

1258
00:55:59,320 --> 00:55:56,750
to search for pulsars kind of blindly in

1259
00:56:01,060 --> 00:55:59,330
the dark we can direct our search we

1260
00:56:04,270 --> 00:56:01,070
don't have to waste the time here and

1261
00:56:06,250 --> 00:56:04,280
instead we can put all of that time into

1262
00:56:07,930 --> 00:56:06,260
the center or into the onto the Pulsar

1263
00:56:10,060 --> 00:56:07,940

candidates trying to build up some

1264
00:56:12,340 --> 00:56:10,070
signal right because if you want to find

1265
00:56:15,310 --> 00:56:12,350
something real you need enough signals

1266
00:56:15,960 --> 00:56:15,320
and noise okay so by focusing our Pulsar

1267
00:56:20,470 --> 00:56:15,970
searches

1268
00:56:22,870 --> 00:56:20,480
we can find some real pulsars and not

1269
00:56:24,640 --> 00:56:22,880
have to hamstring ourselves by searching

1270
00:56:29,020 --> 00:56:24,650
where we know pretty well there aren't

1271
00:56:30,190 --> 00:56:29,030
any so pretty soon we'll be in a

1272
00:56:31,720 --> 00:56:30,200
position where we'll have so many

1273
00:56:33,370 --> 00:56:31,730
pulsars we won't know what to do with

1274
00:56:37,360 --> 00:56:33,380
them right I won't know what to do with

1275
00:56:44,320 --> 00:56:37,370
them all okay so that point will I'll go

1276
00:56:44,330 --> 00:57:05,940
[Applause]

1277
00:57:05,950 --> 00:57:14,220
[Music]

1278
00:57:23,440 --> 00:57:21,130
yeah other than just timing the beam can

1279
00:57:27,330 --> 00:57:23,450
they do anything with it like shadow

1280
00:57:31,300 --> 00:57:27,340
other objects or it's a good question

1281
00:57:33,040 --> 00:57:31,310
so in general sometimes it is neat to be

1282
00:57:34,660 --> 00:57:33,050
able to see light being emitted from

1283
00:57:36,510 --> 00:57:34,670
something strongly bounced off another

1284
00:57:38,890 --> 00:57:36,520
object nearby structure and come to you

1285
00:57:41,380 --> 00:57:38,900
and that that kind of thing has been

1286
00:57:44,490 --> 00:57:41,390
done with other sorts of objects I don't

1287
00:57:48,070 --> 00:57:44,500
think it's ever been done with pulsars

1288
00:57:50,530 --> 00:57:48,080

maybe some of the x-ray pulsars some of

1289
00:57:53,590 --> 00:57:50,540
the x-rays could be bounced like that

1290
00:57:55,090 --> 00:57:53,600
I'm not aware of that but it's the kind

1291
00:57:56,890 --> 00:57:55,100
of thing that someone might already have

1292
00:58:01,960 --> 00:57:56,900
done and then now fuss at me for not

1293
00:58:05,680 --> 00:58:01,970
knowing about it but let's see we have a

1294
00:58:15,580 --> 00:58:05,690
question way in the back gonna make you

1295
00:58:19,090 --> 00:58:15,590
gonna make your work grant Oh oh good

1296
00:58:24,250 --> 00:58:19,100
catch alright so I was just wondering if

1297
00:58:26,340 --> 00:58:24,260
I was wondering if that there were what

1298
00:58:29,770 --> 00:58:26,350
I was actually at the Green Bank

1299
00:58:33,400 --> 00:58:29,780
listening to a lecture there

1300
00:58:36,460 --> 00:58:33,410
they talked about a source of radio

1301
00:58:39,030 --> 00:58:36,470
waves that they didn't know so you

1302
00:58:42,310 --> 00:58:39,040
talked about how this could also

1303
00:58:44,140 --> 00:58:42,320
generate waves and lower frequencies so

1304
00:58:47,860 --> 00:58:44,150
I was just wondering if they're sort of

1305
00:58:51,280 --> 00:58:47,870
the same mystery they are called fast

1306
00:58:53,380 --> 00:58:51,290
radio bursts ah yeah fast radio bursts

1307
00:58:55,570 --> 00:58:53,390
are something a little bit different

1308
00:58:58,300 --> 00:58:55,580
though they're also something that is

1309
00:59:01,450 --> 00:58:58,310
not really explained and is really

1310
00:59:03,910 --> 00:59:01,460
interesting fast radio bursts pop off

1311
00:59:07,690 --> 00:59:03,920
kind of all over the sky so here we have

1312
00:59:09,070 --> 00:59:07,700
kind of a sky map of just the Milky Way

1313
00:59:11,710 --> 00:59:09,080

and everything if we were to draw a

1314
00:59:15,130 --> 00:59:11,720
circle around every fast radio bursts

1315
00:59:17,470 --> 00:59:15,140
that has been seen we would they kind of

1316
00:59:18,790 --> 00:59:17,480
scatter around right they're not coming

1317
00:59:22,630 --> 00:59:18,800
from just the the center of the galaxy

1318
00:59:26,020 --> 00:59:22,640
here so that's a good it's a good

1319
00:59:28,330 --> 00:59:26,030
question and neutron stars probably have

1320
00:59:29,830 --> 00:59:28,340
something to do with fast radio bursts

1321
00:59:31,900 --> 00:59:29,840
they're probably tied because they're

1322
00:59:34,330 --> 00:59:31,910
happening so quickly you need a lot of

1323
00:59:38,040 --> 00:59:34,340
energy on a very small scale for those

1324
00:59:40,840 --> 00:59:38,050
fast radio bursts so neutron stars and

1325
00:59:45,730 --> 00:59:40,850
pulsars more generally yes probably are

1326
00:59:48,130 --> 00:59:45,740
tied into that somehow yeah okay we have

1327
00:59:49,660 --> 00:59:48,140
a question from online which is

1328
00:59:51,790 --> 00:59:49,670
intriguing I haven't thought about this

1329
00:59:55,090 --> 00:59:51,800
before can one use pulsars for

1330
00:59:57,460 --> 00:59:55,100
gravitational lensing and I'm not sure

1331
01:00:00,370 --> 00:59:57,470
because that that strikes two questions

1332
01:00:01,630 --> 01:00:00,380
in me the lensing around a pulsar yeah

1333
01:00:04,600 --> 01:00:01,640
but you'd have to have a really fine

1334
01:00:07,510 --> 01:00:04,610
resolution but if you get a pulsar that

1335
01:00:09,520 --> 01:00:07,520
gets lens multiple sources then you can

1336
01:00:11,620 --> 01:00:09,530
see the timing difference between the

1337
01:00:13,780 --> 01:00:11,630
multiple sources and that would be cool

1338
01:00:15,310 --> 01:00:13,790

would be really cool yeah so I'm not

1339
01:00:17,800 --> 01:00:15,320
aware that that's ever happened but that

1340
01:00:19,930 --> 01:00:17,810
that's a good idea yeah yeah there is a

1341
01:00:22,750 --> 01:00:19,940
supernova the kind of thing that makes a

1342
01:00:25,420 --> 01:00:22,760
pulsar that was lens by a distant galaxy

1343
01:00:28,150 --> 01:00:25,430
you could see the supernova arrive at

1344
01:00:29,380 --> 01:00:28,160
different times I've gotta explain make

1345
01:00:31,780 --> 01:00:29,390
sure everyone knows gravitational

1346
01:00:34,390 --> 01:00:31,790
lensing okay you want to take it yeah so

1347
01:00:36,820 --> 01:00:34,400
gravitational lensing is just when light

1348
01:00:39,190 --> 01:00:36,830
gets bent by gravity so if you have a

1349
01:00:41,290 --> 01:00:39,200
massive object like a neutron star or

1350
01:00:42,690 --> 01:00:41,300
another galaxy as the light is passing

1351
01:00:45,329 --> 01:00:42,700
by

1352
01:00:46,920 --> 01:00:45,339
the gravity curves the space around the

1353
01:00:49,800 --> 01:00:46,930
object and that light traveling through

1354
01:00:51,569 --> 01:00:49,810
that curved space gets bent so it just

1355
01:00:54,000 --> 01:00:51,579
acts like a big magnifying glass the

1356
01:00:55,319 --> 01:00:54,010
path of the light gets diverted right

1357
01:00:57,240 --> 01:00:55,329
and the point I was making is that

1358
01:00:59,010 --> 01:00:57,250
sometimes the light comes this way

1359
01:01:00,180 --> 01:00:59,020
around it and sometimes it goes this way

1360
01:01:01,890 --> 01:01:00,190
around it and the time that I would go

1361
01:01:04,980 --> 01:01:01,900
this way and you can actually see three

1362
01:01:07,079 --> 01:01:04,990
different paths to the same object and

1363
01:01:09,300 --> 01:01:07,089

so if there's a timing event going on

1364
01:01:10,980 --> 01:01:09,310
here it can take different amounts of

1365
01:01:14,010 --> 01:01:10,990
time to pass through these three

1366
01:01:15,630 --> 01:01:14,020
different curvatures around the object

1367
01:01:17,040 --> 01:01:15,640
and then you can tell the timing

1368
01:01:19,740 --> 01:01:17,050
difference to measure the gravitational

1369
01:01:20,910 --> 01:01:19,750
lensing that's going on yeah as you said

1370
01:01:22,319 --> 01:01:20,920
we think we've done it was a supernova

1371
01:01:23,940 --> 01:01:22,329
and maybe a couple of one or two other

1372
01:01:25,380 --> 01:01:23,950
things yeah but I'm kind of wondering if

1373
01:01:29,730 --> 01:01:25,390
there could be like micro lensing of

1374
01:01:32,370 --> 01:01:29,740
pulsars or something like that all right

1375
01:01:33,750 --> 01:01:32,380
questions from the live audience yes we

1376
01:01:35,400 --> 01:01:33,760
do go ahead so you've left us all

1377
01:01:38,339 --> 01:01:35,410
hanging because you've gotten only as

1378
01:01:40,500 --> 01:01:38,349
far as you've gotten and if you were to

1379
01:01:43,290 --> 01:01:40,510
get all the data that you wanted and you

1380
01:01:46,290 --> 01:01:43,300
were going towards your Holy Grail what

1381
01:01:47,910 --> 01:01:46,300
would you altima know yeah so we

1382
01:01:49,890 --> 01:01:47,920
actually have the data from the Green

1383
01:01:54,150 --> 01:01:49,900
Bank telescope in hand and we're working

1384
01:01:58,470 --> 01:01:54,160
on it now but we don't have the answers

1385
01:02:01,170 --> 01:01:58,480
yet we have found enough candidates to

1386
01:02:03,120 --> 01:02:01,180
explain the Fermi gamma-ray excess it's

1387
01:02:05,040 --> 01:02:03,130
entirely possible that those know that

1388
01:02:06,870 --> 01:02:05,050

all those candidates are not pulsars so

1389
01:02:11,099 --> 01:02:06,880
it's too early to say that you know it's

1390
01:02:14,430 --> 01:02:11,109
done but we have found enough small

1391
01:02:16,380 --> 01:02:14,440
point-like objects with really steep

1392
01:02:17,910 --> 01:02:16,390
radio spectra that are very bright at

1393
01:02:22,230 --> 01:02:17,920
low frequencies and not at high

1394
01:02:24,150 --> 01:02:22,240
frequencies they don't have like

1395
01:02:25,470 --> 01:02:24,160
counterparts and infrared and other type

1396
01:02:25,740 --> 01:02:25,480
where you can identify it as something

1397
01:02:28,950 --> 01:02:25,750
else

1398
01:02:30,300 --> 01:02:28,960
so screening out all the contaminants we

1399
01:02:33,240 --> 01:02:30,310
soar left with enough candidates to

1400
01:02:35,670 --> 01:02:33,250
explain it it's still premature to say

1401
01:02:39,270 --> 01:02:35,680
that it's explained but I think I'm I am

1402
01:02:46,650 --> 01:02:39,280
personally optimistic maybe about as far

1403
01:02:48,440 --> 01:02:46,660
as I can go yeah question Jocelyn Bell

1404
01:02:52,829 --> 01:02:48,450
yes thank you

1405
01:02:54,329 --> 01:02:52,839
67 was is credited with discovering

1406
01:02:56,520 --> 01:02:54,339
pulsars yes

1407
01:02:59,099 --> 01:02:56,530
how how is it

1408
01:03:03,319 --> 01:02:59,109
I think I had a picture of her Pulsar

1409
01:03:07,680 --> 01:03:03,329
there - yeah there was it how is it that

1410
01:03:12,569 --> 01:03:07,690
somebody they could find did discover

1411
01:03:16,829 --> 01:03:12,579
something new she was did she was denied

1412
01:03:18,750 --> 01:03:16,839
the the Nobel Prize correct yes how does

1413
01:03:20,700 --> 01:03:18,760

how did that happen her she was a grad

1414
01:03:23,069 --> 01:03:20,710
student right was it red student yes I

1415
01:03:28,730 --> 01:03:23,079
mean her PhD adviser got the prize yeah

1416
01:03:31,260 --> 01:03:28,740
how did how did that hat but yeah yeah

1417
01:03:33,270 --> 01:03:31,270
so I actually got to meet Jocelyn Bernal

1418
01:03:40,079 --> 01:03:33,280
when I was at Texas Tech and Jocelyn

1419
01:03:46,250 --> 01:03:40,089
Bell Burnell and she was very easygoing

1420
01:03:48,839 --> 01:03:46,260
about it she was not at all bitter or

1421
01:03:50,490 --> 01:03:48,849
upset about what had happened even

1422
01:03:57,180 --> 01:03:50,500
though I think she might have every

1423
01:03:59,339 --> 01:03:57,190
right to be but her attitude was that it

1424
01:04:03,170 --> 01:03:59,349
was not traditional for graduate

1425
01:04:04,980 --> 01:04:03,180
students to receive the prize I don't

1426
01:04:08,970 --> 01:04:04,990
personally I think it would've been fine

1427
01:04:13,109 --> 01:04:08,980
to give it to her but she was the one

1428
01:04:14,880 --> 01:04:13,119
who first you know identified it her PhD

1429
01:04:17,280 --> 01:04:14,890
adviser also did a lot of work on the

1430
01:04:19,460 --> 01:04:17,290
object so I'm not trying to say that he

1431
01:04:23,250 --> 01:04:19,470
didn't deserve the Nobel Prize as well

1432
01:04:24,390 --> 01:04:23,260
but I think it would have been I agree

1433
01:04:27,150 --> 01:04:24,400
it would have been good to include her

1434
01:04:37,770 --> 01:04:27,160
that I think she personally I would say

1435
01:04:39,510 --> 01:04:37,780
that she deserved it but yeah it is if

1436
01:04:41,849 --> 01:04:39,520
she made an enormous contribution that

1437
01:04:45,210 --> 01:04:41,859
discovery of hers this object in fact of

1438
01:04:49,050 --> 01:04:45,220

the regular pulse is arriving every once

1439
01:04:51,329 --> 01:04:49,060
a second or so birth the whole new field

1440
01:04:55,319 --> 01:04:51,339
of astronomy and it was something that

1441
01:04:58,050 --> 01:04:55,329
we didn't write yeah exactly and so it's

1442
01:04:59,700 --> 01:04:58,060
it's not every day that someone burst an

1443
01:05:04,500 --> 01:04:59,710
entirely new field of study in the

1444
01:05:06,359 --> 01:05:04,510
Natural Sciences so yeah I think it

1445
01:05:07,950 --> 01:05:06,369
would have you know it merited it

1446
01:05:11,219 --> 01:05:07,960
clearly did merit a Nobel Prize because

1447
01:05:15,670 --> 01:05:11,229
they awarded one for the discovery

1448
01:05:17,170 --> 01:05:15,680
yeah I agree with you the online

1449
01:05:19,120 --> 01:05:17,180
audience it was referenced that we have

1450
01:05:21,670 --> 01:05:19,130
a picture of Jocelyn hanging here at the

1451
01:05:26,920 --> 01:05:21,680
Space Telescope Institute yeah all right

1452
01:05:29,289 --> 01:05:26,930
other questions months going twice

1453
01:05:33,339 --> 01:05:29,299
alright and ireenie arrives right on

1454
01:05:35,679 --> 01:05:33,349
time okay ladies and gentlemen that is

1455
01:05:37,539 --> 01:05:35,689
Ari Neil and Bradys and she will be

1456
01:05:39,969 --> 01:05:37,549
taking people across the street to the

1457
01:05:41,049 --> 01:05:39,979
Maryland Space Grant observatory where

1458
01:05:43,089 --> 01:05:41,059
would you like to hang out you want to

1459
01:05:45,640 --> 01:05:43,099
hang out over here by the door okay so

1460
01:05:46,809 --> 01:05:45,650
if you would like to see they'll use the

1461
01:05:50,949 --> 01:05:46,819
telescopes across the street

1462
01:05:53,529 --> 01:05:50,959
please join rainy over here next month

1463
01:05:57,249 --> 01:05:53,539

the art and science of astronomical

1464
01:05:58,630 --> 01:05:57,259
image processing please join us and let

1465
01:06:00,400 --> 01:05:58,640
us give one more big hand for dr.