

1  
00:00:00,000 --> 00:00:08,669  
is the butterfly nebula NGC 6302 which

2  
00:00:05,009 --> 00:00:10,230  
in fact is not the butterfly nebula it

3  
00:00:08,669 --> 00:00:13,138  
is the bug nebula

4  
00:00:10,230 --> 00:00:15,809  
however in our press release of this

5  
00:00:13,138 --> 00:00:18,419  
image we said it resembled a butterfly

6  
00:00:15,808 --> 00:00:19,980  
the internet took it over the media took

7  
00:00:18,420 --> 00:00:22,800  
it over it is an out of the butterfly

8  
00:00:19,980 --> 00:00:25,230  
nebula okay fun fact of that you will

9  
00:00:22,800 --> 00:00:28,649  
not learn that fact on the back of the

10  
00:00:25,230 --> 00:00:29,640  
of the net of the lithograph instead

11  
00:00:28,649 --> 00:00:32,789  
you'll learn other things about what

12  
00:00:29,640 --> 00:00:34,890  
this object really is the death of this

13  
00:00:32,789 --> 00:00:37,379  
star here in the amazing temperature

14  
00:00:34,890 --> 00:00:39,689  
that's heating the gas flowing away from

15  
00:00:37,380 --> 00:00:42,540  
it alright for those of you on the

16  
00:00:39,689 --> 00:00:45,808  
Internet you can see the URL down here

17  
00:00:42,539 --> 00:00:48,689  
at the bottom amazing space org resource

18  
00:00:45,808 --> 00:00:50,699  
page number 59 this is one of our

19  
00:00:48,689 --> 00:00:53,670  
earlier ones on this okay so you can

20  
00:00:50,700 --> 00:00:54,690  
download it there while you are looking

21  
00:00:53,670 --> 00:00:59,239  
at your listen graph we're downloading

22  
00:00:54,689 --> 00:01:01,769  
it please silence your electronics our

23  
00:00:59,238 --> 00:01:04,618  
AV folks have pointed out to me that I

24  
00:01:01,770 --> 00:01:06,600  
have been lax to join the 20th century

25  
00:01:04,618 --> 00:01:08,219  
and asked my audience to please quiet

26  
00:01:06,599 --> 00:01:10,349  
their phones silence your cell phones

27  
00:01:08,219 --> 00:01:10,890  
sorry I don't have one of those big

28  
00:01:10,349 --> 00:01:13,019  
crazy

29

00:01:10,890 --> 00:01:15,060  
mm commercials that they do at the

30  
00:01:13,019 --> 00:01:19,349  
movies maybe I'll have to fire at one of

31  
00:01:15,060 --> 00:01:21,680  
those for next month okay ah tonight we

32  
00:01:19,349 --> 00:01:24,298  
have recycle your used pulsars

33  
00:01:21,680 --> 00:01:26,759  
explaining the extra gamma radiation

34  
00:01:24,299 --> 00:01:28,200  
from the Central Milky Way and how have

35  
00:01:26,759 --> 00:01:29,700  
you looked at this is that I have no

36  
00:01:28,200 --> 00:01:32,189  
idea what that is but it sounds real

37  
00:01:29,700 --> 00:01:34,170  
cool well this man down here is gonna

38  
00:01:32,188 --> 00:01:38,339  
explain all about it that's Christopher

39  
00:01:34,170 --> 00:01:40,500  
Britt upcoming on July 2nd the art and

40  
00:01:38,340 --> 00:01:44,189  
science of astronomical image processing

41  
00:01:40,500 --> 00:01:47,489  
from Joe de Pascua our senior image

42  
00:01:44,188 --> 00:01:51,629  
processor here an August we have the

43  
00:01:47,489 --> 00:01:53,640

exciting topic of TBA I talked to Trisha

44

00:01:51,629 --> 00:01:55,289

and she said well I've got two really

45

00:01:53,640 --> 00:01:57,118

good topic sent him and she wasn't ready

46

00:01:55,290 --> 00:01:59,040

to commit to any one of them I said just

47

00:01:57,118 --> 00:02:01,409

choose one and she said well I'll let

48

00:01:59,040 --> 00:02:04,920

you know she didn't let me know so she's

49

00:02:01,409 --> 00:02:07,439

TVA and Brandon Lawton on September 3rd

50

00:02:04,920 --> 00:02:09,868

he's also in the same situation he and I

51

00:02:07,438 --> 00:02:12,030

discussed today and he goes well I yeah

52

00:02:09,868 --> 00:02:13,110

he also has two topics that he wants to

53

00:02:12,030 --> 00:02:16,469

talk about

54

00:02:13,110 --> 00:02:19,290

maybe I have to twist some arms to get

55

00:02:16,469 --> 00:02:20,849

some number names some titles but at

56

00:02:19,289 --> 00:02:23,609

least you know we have speakers for

57

00:02:20,849 --> 00:02:25,919

August and September if you want to see

58  
00:02:23,610 --> 00:02:29,100  
their titles they can find this webpage

59  
00:02:25,919 --> 00:02:32,879  
about our upcoming lectures over here on

60  
00:02:29,099 --> 00:02:35,219  
the right the links to our webcasting

61  
00:02:32,879 --> 00:02:37,919  
here on the left you can watch the past

62  
00:02:35,219 --> 00:02:42,750  
lectures on YouTube and in the STScI

63  
00:02:37,919 --> 00:02:46,799  
webcast all the way back to 2005 so wow

64  
00:02:42,750 --> 00:02:50,939  
that's 14 years worth of universal

65  
00:02:46,800 --> 00:02:52,530  
cosmic knowledge who if you want to sign

66  
00:02:50,939 --> 00:02:54,150  
up for email this is the easiest way to

67  
00:02:52,530 --> 00:02:56,789  
do it right here enter your email you

68  
00:02:54,150 --> 00:03:00,300  
can also unsubscribe okay although why

69  
00:02:56,789 --> 00:03:01,590  
would you want to do that as for those

70  
00:03:00,300 --> 00:03:03,060  
announcements you can sign if you don't

71  
00:03:01,590 --> 00:03:04,979  
like to sign at the website you can just

72  
00:03:03,060 --> 00:03:07,890  
write your email address on a piece of

73  
00:03:04,979 --> 00:03:10,560  
paper hand it to me by the old-fashioned

74  
00:03:07,889 --> 00:03:13,500  
paper method and I will make sure you

75  
00:03:10,560 --> 00:03:15,150  
get signed up if you have comments and

76  
00:03:13,500 --> 00:03:19,860  
questions you can send them to public

77  
00:03:15,150 --> 00:03:21,480  
lecture at stsci edu for those of us

78  
00:03:19,860 --> 00:03:24,030  
those of you who like to follow social

79  
00:03:21,479 --> 00:03:26,489  
media we have a variety of accounts on

80  
00:03:24,030 --> 00:03:28,949  
Facebook Twitter YouTube and Instagram

81  
00:03:26,490 --> 00:03:30,870  
not only for Hubble not only for the

82  
00:03:28,949 --> 00:03:31,889  
James Webb Space Telescope but also for

83  
00:03:30,870 --> 00:03:35,280  
our Institute the Space Telescope

84  
00:03:31,889 --> 00:03:37,229  
Science Institute myself I do I do a

85  
00:03:35,280 --> 00:03:39,080  
little bit of social media on Facebook

86

00:03:37,229 --> 00:03:43,049  
and Twitter

87  
00:03:39,080 --> 00:03:44,640  
tonight the observatory has said they're

88  
00:03:43,050 --> 00:03:46,770  
going to be open hi did anybody look up

89  
00:03:44,639 --> 00:03:49,409  
was it was it clear when we came in yes

90  
00:03:46,770 --> 00:03:50,550  
alright so we are looking good for the

91  
00:03:49,409 --> 00:03:53,729  
observer American Space Grant

92  
00:03:50,550 --> 00:03:55,620  
Observatory being open if you can't do

93  
00:03:53,729 --> 00:03:57,060  
it too if at the end of the lecture you

94  
00:03:55,620 --> 00:03:57,629  
want to go across and look through the

95  
00:03:57,060 --> 00:04:00,090  
telescope

96  
00:03:57,629 --> 00:04:02,370  
we'll meet down here on the right at the

97  
00:04:00,090 --> 00:04:03,990  
end if I forget somebody to remind me or

98  
00:04:02,370 --> 00:04:08,480  
araignee if she's here we'll probably

99  
00:04:03,990 --> 00:04:11,250  
slappy and say wake up Frank and if you

100  
00:04:08,479 --> 00:04:12,269

do not get to do it tonight or you can't

101

00:04:11,250 --> 00:04:14,129

do it tonight and want to do it some

102

00:04:12,270 --> 00:04:17,100

other time they have open houses on

103

00:04:14,129 --> 00:04:21,000

Friday evenings go to MD space grant go

104

00:04:17,100 --> 00:04:23,600

RG now our news from the universe for

105

00:04:21,000 --> 00:04:26,240

June 2019

106

00:04:23,600 --> 00:04:31,490

our first story

107

00:04:26,240 --> 00:04:34,490

lopsided star formation in NGC 44

108

00:04:31,490 --> 00:04:36,970

oh yes 44 85 I remember it well of

109

00:04:34,490 --> 00:04:39,500

course I have no idea what it is but

110

00:04:36,970 --> 00:04:42,110

first thing we got to talk about normal

111

00:04:39,500 --> 00:04:44,870

star formation okay so this is a very

112

00:04:42,110 --> 00:04:46,430

famous galaxy Messier 51 also called the

113

00:04:44,870 --> 00:04:48,709

Whirlpool Galaxy and you can see it's

114

00:04:46,430 --> 00:04:50,870

got this beautiful symmetric spiral



115  
00:04:48,709 --> 00:04:54,409  
pattern okay call this a grand design

116  
00:04:50,870 --> 00:04:56,899  
spiral the one of the really striking

117  
00:04:54,410 --> 00:04:59,810  
features of this image is all of those

118  
00:04:56,899 --> 00:05:02,538  
red dots around it so you see all these

119  
00:04:59,810 --> 00:05:06,918  
red star four regions that swirl around

120  
00:05:02,538 --> 00:05:09,439  
along the spiral arms these are the

121  
00:05:06,918 --> 00:05:12,918  
places where stars are just forming okay

122  
00:05:09,439 --> 00:05:15,019  
the red is a hydrogen alpha which is a

123  
00:05:12,918 --> 00:05:17,029  
hydrogen gas heated to about three of

124  
00:05:15,019 --> 00:05:18,859  
these star forming regions but you

125  
00:05:17,029 --> 00:05:20,689  
notice how they're smoothly spread out

126  
00:05:18,860 --> 00:05:22,639  
throughout this galaxy and this is what

127  
00:05:20,689 --> 00:05:24,379  
we sort of expect because you know the

128  
00:05:22,639 --> 00:05:25,819  
density waves that produce star

129  
00:05:24,379 --> 00:05:28,819  
formation just you know flow throughout

130  
00:05:25,819 --> 00:05:32,090  
an entire galaxy and you see them well

131  
00:05:28,819 --> 00:05:32,810  
we released an image last month of NGC

132  
00:05:32,089 --> 00:05:37,939  
44

133  
00:05:32,810 --> 00:05:39,680  
and tell me what you don't see here you

134  
00:05:37,939 --> 00:05:42,769  
don't see that same sort of symmetry

135  
00:05:39,680 --> 00:05:44,959  
okay you see that all of the star

136  
00:05:42,769 --> 00:05:47,389  
forming regions are over here on the

137  
00:05:44,959 --> 00:05:49,489  
right side of this galaxy and the left

138  
00:05:47,389 --> 00:05:52,639  
side looks kind of like non strong

139  
00:05:49,490 --> 00:05:54,610  
forming regions okay old stars and a

140  
00:05:52,639 --> 00:05:57,918  
little bit of you know young blue stars

141  
00:05:54,610 --> 00:06:01,218  
so what's going on here what does this

142  
00:05:57,918 --> 00:06:03,649  
indicate anybody have a guess on this

143

00:06:01,218 --> 00:06:06,610  
you've got a disturbance on one side

144  
00:06:03,649 --> 00:06:06,609  
right yeah

145  
00:06:08,949 --> 00:06:13,400  
good resolve of galaxy collision not

146  
00:06:11,120 --> 00:06:16,069  
quite a collision but an interaction

147  
00:06:13,399 --> 00:06:17,508  
okay when you see that gravitate that

148  
00:06:16,069 --> 00:06:19,218  
star formation that means that something

149  
00:06:17,509 --> 00:06:22,009  
funky is happening on that side and that

150  
00:06:19,218 --> 00:06:24,019  
side only and if you take a larger view

151  
00:06:22,009 --> 00:06:27,229  
from a ground-based this is where the

152  
00:06:24,019 --> 00:06:33,439  
Hubble image is within this larger view

153  
00:06:27,228 --> 00:06:35,689  
and this is NGC 4490 and 44 85 as taken

154  
00:06:33,439 --> 00:06:37,848  
by the internet named Jay Schulman five

155  
00:06:35,689 --> 00:06:39,079  
five five I couldn't actually find out

156  
00:06:37,848 --> 00:06:40,009  
what this person's name is I'm assuming

157  
00:06:39,079 --> 00:06:44,198

it's

158

00:06:40,009 --> 00:06:47,330

somebody Sherman and here you see that

159

00:06:44,199 --> 00:06:50,649

4490 which is in the center here has the

160

00:06:47,329 --> 00:06:54,618

title tail stretching back towards 44 85

161

00:06:50,649 --> 00:06:56,180

so as you expected very good intuition

162

00:06:54,619 --> 00:06:58,789

there has been an interaction between

163

00:06:56,180 --> 00:07:00,978

these two galaxies and this star

164

00:06:58,788 --> 00:07:05,509

formation here appears to be the result

165

00:07:00,978 --> 00:07:08,838

of it so that the asymmetry in 44 85 is

166

00:07:05,509 --> 00:07:10,338

that this was a normal galaxy possibly

167

00:07:08,838 --> 00:07:11,959

with starvation ever possible with very

168

00:07:10,338 --> 00:07:13,218

little star formation but at least it

169

00:07:11,959 --> 00:07:16,008

would have been somewhat symmetrical and

170

00:07:13,218 --> 00:07:18,468

that the interaction sweeping past it if

171

00:07:16,009 --> 00:07:20,120

we zoom in on the details of this you

172  
00:07:18,468 --> 00:07:24,019  
can see that there are some very large

173  
00:07:20,120 --> 00:07:25,759  
star forming entities here they're

174  
00:07:24,019 --> 00:07:28,278  
forming thousands upon thousands of

175  
00:07:25,759 --> 00:07:30,710  
stars and this is one thing that this

176  
00:07:28,278 --> 00:07:34,189  
teaches us is that interactions between

177  
00:07:30,709 --> 00:07:36,498  
galaxies create these density ways that

178  
00:07:34,189 --> 00:07:39,259  
flow across galaxies and can produce

179  
00:07:36,499 --> 00:07:41,088  
copious amounts of star formation when

180  
00:07:39,259 --> 00:07:44,270  
you see two galaxies interacting you

181  
00:07:41,088 --> 00:07:48,110  
often see these large waves of star

182  
00:07:44,269 --> 00:07:50,359  
formation and this this image

183  
00:07:48,110 --> 00:07:52,189  
illustrates it here there is no

184  
00:07:50,360 --> 00:07:53,658  
particular science result of this this

185  
00:07:52,189 --> 00:07:56,240  
is one of what we call our pretty

186  
00:07:53,658 --> 00:07:58,879  
picture releases where we have one of

187  
00:07:56,240 --> 00:08:02,028  
our gorgeous images from the archive and

188  
00:07:58,879 --> 00:08:04,550  
release it to the public to show off the

189  
00:08:02,028 --> 00:08:07,249  
beautiful beauty of the universe but you

190  
00:08:04,550 --> 00:08:09,620  
can see in this one in particular how

191  
00:08:07,249 --> 00:08:13,490  
the interactions between galaxies can

192  
00:08:09,620 --> 00:08:18,259  
produce this star formation our second

193  
00:08:13,490 --> 00:08:19,999  
story mind the gap part two all right so

194  
00:08:18,259 --> 00:08:22,519  
let's start with our solar system our

195  
00:08:19,999 --> 00:08:25,729  
solar system we as remarkable because

196  
00:08:22,519 --> 00:08:28,999  
all of the planets are basically in a

197  
00:08:25,728 --> 00:08:31,248  
plane right and that sort of suggests to

198  
00:08:28,999 --> 00:08:34,038  
us that well the planets formed in this

199  
00:08:31,249 --> 00:08:35,959  
disk that's encircling our Sun right

200

00:08:34,038 --> 00:08:37,429  
that seemed very logical and so we

201  
00:08:35,958 --> 00:08:40,759  
looked out into the universe looking for

202  
00:08:37,429 --> 00:08:41,870  
that and we did find disks of material

203  
00:08:40,759 --> 00:08:44,568  
around other stars

204  
00:08:41,870 --> 00:08:47,600  
this one au microscopy over on the right

205  
00:08:44,568 --> 00:08:50,750  
HD 107 146 this you can see an edge-on

206  
00:08:47,600 --> 00:08:53,019  
disc on the left and on the right you

207  
00:08:50,750 --> 00:08:55,480  
can see a face on disk and so we

208  
00:08:53,019 --> 00:08:58,899  
did discover these discs around young

209  
00:08:55,480 --> 00:09:03,220  
stars where stars form and then we got

210  
00:08:58,899 --> 00:09:05,590  
Alma the Atacama Large millimeter or a

211  
00:09:03,220 --> 00:09:07,300  
which is able to look in millimeter

212  
00:09:05,590 --> 00:09:11,080  
wavelengths and see these discs in

213  
00:09:07,299 --> 00:09:14,229  
unprecedented detail and they saw HL

214  
00:09:11,080 --> 00:09:16,840

Tauri seeing this gorgeous disc not just

215

00:09:14,230 --> 00:09:19,750

the disc but also the gaps in the disc

216

00:09:16,840 --> 00:09:22,000

and this tell us is like oh this is a

217

00:09:19,750 --> 00:09:23,830

Holy Grail because this is where we

218

00:09:22,000 --> 00:09:25,990

expect the planets to form in the disk

219

00:09:23,830 --> 00:09:28,180

with these gaps those gaps are going to

220

00:09:25,990 --> 00:09:30,399

be produced by formation of planets

221

00:09:28,179 --> 00:09:33,159

either by the planets themselves sucking

222

00:09:30,399 --> 00:09:35,259

up the material or by residents of

223

00:09:33,159 --> 00:09:39,459

gravitational resonances in it so this

224

00:09:35,259 --> 00:09:41,019

you know just blew us away okay so the

225

00:09:39,460 --> 00:09:45,820

story we're going to tell this week is

226

00:09:41,019 --> 00:09:48,100

about the star pds 70 and this is one of

227

00:09:45,820 --> 00:09:50,500

the early observations of it where you

228

00:09:48,100 --> 00:09:53,649

can see this big whitish blueish thing



229  
00:09:50,500 --> 00:09:54,850  
is a large disc and this black spot in

230  
00:09:53,649 --> 00:09:57,129  
the center is where they're blocking out

231  
00:09:54,850 --> 00:09:58,540  
the light of the star of course and that

232  
00:09:57,129 --> 00:10:00,850  
you can see just around this black spot

233  
00:09:58,539 --> 00:10:02,529  
there's a small little disc in here but

234  
00:10:00,850 --> 00:10:04,960  
in between the outer disk and the inner

235  
00:10:02,529 --> 00:10:07,179  
disk there is what they called in this

236  
00:10:04,960 --> 00:10:08,410  
and this thing a giant gap in the disk

237  
00:10:07,179 --> 00:10:13,089  
all right

238  
00:10:08,409 --> 00:10:15,579  
whereas the outer disk is around 70s

239  
00:10:13,090 --> 00:10:18,399  
atomic units in radius 140 in diameter

240  
00:10:15,580 --> 00:10:22,540  
that's you know a bit twice the distance

241  
00:10:18,399 --> 00:10:26,439  
of Neptune the inner one there seems to

242  
00:10:22,539 --> 00:10:29,379  
be at least a 30 or 40 au gap in there

243  
00:10:26,440 --> 00:10:30,820  
all right and so the question is are we

244  
00:10:29,379 --> 00:10:31,870  
going to find planets in there well they

245  
00:10:30,820 --> 00:10:34,900  
did a little bit of follow-up

246  
00:10:31,870 --> 00:10:37,210  
observations and yes inside this outer

247  
00:10:34,899 --> 00:10:41,620  
disk and outside the inner disk they did

248  
00:10:37,210 --> 00:10:45,370  
find an object and this is Planet pds 70

249  
00:10:41,620 --> 00:10:47,889  
B but this hasn't gotten the Alma

250  
00:10:45,370 --> 00:10:50,049  
treatment yet then it got the Alma

251  
00:10:47,889 --> 00:10:53,529  
treatment and you see all this fuzziness

252  
00:10:50,049 --> 00:10:54,069  
it goes away boom that's Alma for you

253  
00:10:53,529 --> 00:10:57,519  
okay

254  
00:10:54,070 --> 00:11:00,340  
behinds just like boom see that you can

255  
00:10:57,519 --> 00:11:02,620  
see the detail in the Alma observation

256  
00:11:00,340 --> 00:11:03,970  
of the outer disk and if you blow it up

257

00:11:02,620 --> 00:11:06,490  
on the right-hand side you can see also

258  
00:11:03,970 --> 00:11:06,830  
the inner disk you can see the spot

259  
00:11:06,490 --> 00:11:10,070  
where

260  
00:11:06,830 --> 00:11:11,690  
PDS 7tb should should be but it doesn't

261  
00:11:10,070 --> 00:11:15,430  
show up in the Alma thing but you also

262  
00:11:11,690 --> 00:11:17,709  
see this spur here that spur right there

263  
00:11:15,429 --> 00:11:20,659  
indicates that there might be another

264  
00:11:17,708 --> 00:11:24,139  
gravitational presence pulling on that

265  
00:11:20,659 --> 00:11:26,689  
outer disk so what the folks at the

266  
00:11:24,139 --> 00:11:30,078  
European Southern Observatory did was

267  
00:11:26,690 --> 00:11:32,440  
they did a targeted campaign on PDS 70

268  
00:11:30,078 --> 00:11:34,759  
and they had to use incredible

269  
00:11:32,440 --> 00:11:37,459  
sophisticated computer algorithms to

270  
00:11:34,759 --> 00:11:40,490  
block the light of the star and try and

271  
00:11:37,458 --> 00:11:42,799

pull out and enhance the planets that

272

00:11:40,490 --> 00:11:45,620

could be there searching to see the

273

00:11:42,799 --> 00:11:50,088

details of PDS 7tb and if there was

274

00:11:45,620 --> 00:11:54,110

anything else there they succeeded here

275

00:11:50,089 --> 00:11:57,860

is one of the two existing images of a

276

00:11:54,110 --> 00:12:00,589

multi-planet observation two planets

277

00:11:57,860 --> 00:12:03,919

around the star PDS 70 there's only one

278

00:12:00,589 --> 00:12:07,010

other HR 58 at 99 which is a four planet

279

00:12:03,919 --> 00:12:09,409

system this is the second planetary

280

00:12:07,009 --> 00:12:14,958

system where we have to direct images

281

00:12:09,409 --> 00:12:17,059

PDS 7tb PDS 70c to planets around

282

00:12:14,958 --> 00:12:18,799

another star and we can see them both we

283

00:12:17,059 --> 00:12:21,469

can see the light we gave it a pull out

284

00:12:18,799 --> 00:12:23,990

that faint light of those planets around

285

00:12:21,470 --> 00:12:25,850

that star now this is of course

286

00:12:23,990 --> 00:12:27,620  
scientific data it's kind of ratty and

287

00:12:25,850 --> 00:12:30,589  
ugly and what do we do here so

288

00:12:27,620 --> 00:12:34,429  
beautifully we create cool graphics all

289

00:12:30,589 --> 00:12:37,339  
right so this is an artist's rendition

290

00:12:34,429 --> 00:12:39,769  
of the pds 70 system you can see the

291

00:12:37,339 --> 00:12:43,730  
star in the center PDS 70 you can see

292

00:12:39,769 --> 00:12:46,970  
the inner disk here you have a PDS 70 B

293

00:12:43,730 --> 00:12:48,829  
at the top you have PDS 70 C here in the

294

00:12:46,970 --> 00:12:51,290  
foreground and you have material

295

00:12:48,828 --> 00:12:52,879  
streaming onto them why is there

296

00:12:51,289 --> 00:12:56,028  
material streaming onto them because

297

00:12:52,879 --> 00:12:59,509  
this system is only six million years

298

00:12:56,028 --> 00:13:02,778  
old okay these two planets are the

299

00:12:59,509 --> 00:13:05,480  
jupiter-mass range from between 1 and 14

300  
00:13:02,778 --> 00:13:07,039  
Jupiter masses both of them and they

301  
00:13:05,480 --> 00:13:09,620  
would still be forming jupiter-mass

302  
00:13:07,039 --> 00:13:12,019  
planets take about 10 million years to

303  
00:13:09,620 --> 00:13:14,870  
form so material is streaming onto it

304  
00:13:12,019 --> 00:13:18,220  
this is what they believe is happening

305  
00:13:14,870 --> 00:13:21,730  
in pds 70 is that these two planets

306  
00:13:18,220 --> 00:13:24,160  
have cleared out this gap right I showed

307  
00:13:21,730 --> 00:13:26,950  
you that HL Tauri image I said maybe

308  
00:13:24,159 --> 00:13:29,529  
planets are forming in there in PDS 70

309  
00:13:26,950 --> 00:13:34,240  
we know there are planets that have

310  
00:13:29,529 --> 00:13:37,089  
formed inside that gap so I did a news

311  
00:13:34,240 --> 00:13:39,490  
story called mine the gap before but

312  
00:13:37,090 --> 00:13:43,300  
this is mine to gap part two because we

313  
00:13:39,490 --> 00:13:46,629  
have two planets forming inside a gap in

314

00:13:43,299 --> 00:13:49,509  
the PDS 70 system our knowledge of

315  
00:13:46,629 --> 00:13:52,210  
extrasolar planetary systems is truly

316  
00:13:49,509 --> 00:13:53,919  
developing this is a really great time

317  
00:13:52,210 --> 00:13:56,379  
to be studying astronomy because we're

318  
00:13:53,919 --> 00:13:58,029  
learning so much about what solar

319  
00:13:56,379 --> 00:13:59,439  
systems are like elsewhere in the

320  
00:13:58,029 --> 00:14:02,049  
universe kind of fun

321  
00:13:59,440 --> 00:14:09,010  
all right any questions before I move on

322  
00:14:02,049 --> 00:14:10,979  
yeah the tea tour itself one of the

323  
00:14:09,009 --> 00:14:13,809  
things that stops the formation of a

324  
00:14:10,980 --> 00:14:16,810  
giant planet is what's called the T

325  
00:14:13,809 --> 00:14:19,299  
Tauri wind gust of the star and that

326  
00:14:16,809 --> 00:14:22,089  
usually kicks in about 10 to 15 million

327  
00:14:19,299 --> 00:14:26,949  
years after the star has started nuclear

328  
00:14:22,090 --> 00:14:29,019

fusion okay so when PDF 70 undergoes its

329

00:14:26,950 --> 00:14:30,970

T Tauri wind and blows away most of the

330

00:14:29,019 --> 00:14:33,069

light of the low-density material and

331

00:14:30,970 --> 00:14:35,050

system there won't be this material to

332

00:14:33,070 --> 00:14:37,270

fall onto these these planets so they

333

00:14:35,049 --> 00:14:41,229

will stop for me okay which is why

334

00:14:37,269 --> 00:14:43,419

actually we believe giant planets like

335

00:14:41,230 --> 00:14:45,789

Jupiter have to form in ten million

336

00:14:43,419 --> 00:14:47,199

first ten million years because the low

337

00:14:45,789 --> 00:14:49,899

Z&C material that would normally fall

338

00:14:47,200 --> 00:14:57,850

onto them is gone after that one other

339

00:14:49,899 --> 00:14:59,889

question before we go yeah you're

340

00:14:57,850 --> 00:15:03,909

talking from PDS 7tb just a little bit

341

00:14:59,889 --> 00:15:05,049

to lower boat lower than that yeah we

342

00:15:03,909 --> 00:15:07,779

recognize that you're trying to pull



343  
00:15:05,049 --> 00:15:11,349  
signal from a lot of the signal noise

344  
00:15:07,779 --> 00:15:13,449  
suppression and if that were real they

345  
00:15:11,350 --> 00:15:15,399  
would have trumpeted it but obviously

346  
00:15:13,450 --> 00:15:17,020  
the researchers who process this image

347  
00:15:15,399 --> 00:15:18,909  
said no that's that doesn't have enough

348  
00:15:17,019 --> 00:15:21,519  
signal-to-noise ratio to indicate that

349  
00:15:18,909 --> 00:15:23,350  
it's real or they can't follow it you

350  
00:15:21,519 --> 00:15:25,600  
know usually to confirm planets you want

351  
00:15:23,350 --> 00:15:28,690  
to follow them moving around so you take

352  
00:15:25,600 --> 00:15:30,190  
different observations to see their

353  
00:15:28,690 --> 00:15:35,200  
motions

354  
00:15:30,190 --> 00:15:37,090  
by the dessert inspector no not yet

355  
00:15:35,200 --> 00:15:40,840  
this is just the first observations of

356  
00:15:37,090 --> 00:15:43,389  
it will be able be people are trying to

357  
00:15:40,840 --> 00:15:45,399  
try and do spectra of things like this

358  
00:15:43,389 --> 00:15:47,710  
you need a lot more light to be able to

359  
00:15:45,399 --> 00:15:51,100  
get spectro something like this okay

360  
00:15:47,710 --> 00:15:54,900  
all right now our featured speaker

361  
00:15:51,100 --> 00:15:56,740  
tonight dr. Christopher Britt eyes

362  
00:15:54,899 --> 00:15:58,659  
astronomer here in the office of public

363  
00:15:56,740 --> 00:16:01,690  
outreach at the Space Telescope Science

364  
00:15:58,659 --> 00:16:05,620  
Institute he is new to us having joined

365  
00:16:01,690 --> 00:16:07,930  
last August you said yeah so he is still

366  
00:16:05,620 --> 00:16:10,570  
learning the ropes and showing us all

367  
00:16:07,929 --> 00:16:15,489  
the new tricks that he learned he did

368  
00:16:10,570 --> 00:16:17,530  
his PhD at Louisiana Louisiana State or

369  
00:16:15,490 --> 00:16:20,230  
is it Louisiana state that's what I

370  
00:16:17,529 --> 00:16:22,709  
thought okay and then did postdocs at

371

00:16:20,230 --> 00:16:26,379  
Texas Tech and Michigan State University

372  
00:16:22,710 --> 00:16:29,259  
studying old dead stars and non-binary

373  
00:16:26,379 --> 00:16:32,350  
stars and waste stars die and and do all

374  
00:16:29,259 --> 00:16:34,000  
these crazy things sometimes they you

375  
00:16:32,350 --> 00:16:34,960  
know when stars die they become pulsars

376  
00:16:34,000 --> 00:16:37,269  
which is what I'll talk to you about

377  
00:16:34,960 --> 00:16:39,580  
tonight Chris and I've gotten to know

378  
00:16:37,269 --> 00:16:42,610  
each other a little bit because he plays

379  
00:16:39,580 --> 00:16:44,050  
disc golf and I play disc golf I think I

380  
00:16:42,610 --> 00:16:47,230  
play it a little bit more seriously than

381  
00:16:44,049 --> 00:16:51,549  
he does but one other thing in his favor

382  
00:16:47,230 --> 00:16:54,129  
he also brews his own beer so he has

383  
00:16:51,549 --> 00:16:56,139  
disc golf and beer got to be one of my

384  
00:16:54,129 --> 00:16:58,450  
favorite people out there ladies and

385  
00:16:56,139 --> 00:17:28,128

gentlemen let us welcome dr. history

386

00:16:58,450 --> 00:17:54,179

bris three doesn't say all right

387

00:17:28,128 --> 00:17:58,398

that's for sorry I touched I must have

388

00:17:54,179 --> 00:18:00,389

pushed the wrong button save me save me

389

00:17:58,398 --> 00:18:07,079

ladies and gentlemen Thomas is coming

390

00:18:00,388 --> 00:18:08,998

down to save us I played this all I'm

391

00:18:07,079 --> 00:18:10,678

getting old I'm looking down here trying

392

00:18:08,999 --> 00:18:20,690

to see which button says change input

393

00:18:10,679 --> 00:18:23,249

and I couldn't read it he's on three

394

00:18:20,690 --> 00:18:24,250

today I hit one of these other buttons

395

00:18:23,249 --> 00:18:27,328

and makes it go

396

00:18:24,250 --> 00:18:27,328

[Music]

397

00:18:32,759 --> 00:18:36,809

when in doubt turn it off and on again

398

00:18:42,809 --> 00:18:52,929

that's ladies and gentlemen another hand

399

00:18:46,900 --> 00:18:55,300

for Chris with it okay thanks for the

400  
00:18:52,930 --> 00:18:57,850  
introduction and Frank definitely is

401  
00:18:55,299 --> 00:18:59,740  
better at disc-off than I am we played

402  
00:18:57,849 --> 00:19:02,919  
together once and he beat me pretty

403  
00:18:59,740 --> 00:19:05,769  
soundly so yeah I wanted to talk about

404  
00:19:02,920 --> 00:19:07,240  
this kind of puzzle and current

405  
00:19:05,769 --> 00:19:08,769  
astronomy and astrophysics it's

406  
00:19:07,240 --> 00:19:11,380  
something that's not really solved yet

407  
00:19:08,769 --> 00:19:13,750  
in part because it involves just a lot

408  
00:19:11,380 --> 00:19:16,030  
of really cool stuff from all different

409  
00:19:13,750 --> 00:19:17,470  
parts of astronomy and in part because

410  
00:19:16,029 --> 00:19:20,710  
it kind of gives a little bit of a

411  
00:19:17,470 --> 00:19:22,480  
window onto how science has done and how

412  
00:19:20,710 --> 00:19:24,930  
we go about solving these problems when

413  
00:19:22,480 --> 00:19:27,460  
the the answer isn't immediately obvious

414  
00:19:24,930 --> 00:19:30,039  
so I'm going to be talking about kind of

415  
00:19:27,460 --> 00:19:31,600  
extra gamma radiation coming from the

416  
00:19:30,039 --> 00:19:33,759  
center of our own galaxy the Milky Way

417  
00:19:31,599 --> 00:19:36,399  
and when you hear a gamma radiation a

418  
00:19:33,759 --> 00:19:37,960  
lot of you may have read some Avengers

419  
00:19:36,400 --> 00:19:38,590  
in the past and be thinking of the Hulk

420  
00:19:37,960 --> 00:19:40,539  
yeah

421  
00:19:38,589 --> 00:19:43,480  
gamma radiation famously gave the whole

422  
00:19:40,539 --> 00:19:45,609  
kiss powers right so far I haven't known

423  
00:19:43,480 --> 00:19:47,170  
anyone at NASA to turn giant and green

424  
00:19:45,609 --> 00:19:50,469  
and angry but you never know maybe

425  
00:19:47,170 --> 00:19:52,539  
they're keeping it quiet so when I talk

426  
00:19:50,470 --> 00:19:54,339  
about our galaxy in the Milky Way I'm

427  
00:19:52,539 --> 00:19:56,670  
really just talking about the same thing

428

00:19:54,339 --> 00:20:00,039  
you can go out on a dark night and see

429  
00:19:56,670 --> 00:20:02,070  
so if you go out to a dark sky maybe up

430  
00:20:00,039 --> 00:20:04,359  
in the mountains in Western Maryland or

431  
00:20:02,069 --> 00:20:06,909  
wherever you happen to be listening at

432  
00:20:04,359 --> 00:20:09,819  
home driving out away from the city and

433  
00:20:06,910 --> 00:20:12,580  
look up a dark sky you can see the Milky

434  
00:20:09,819 --> 00:20:15,339  
Way with your unaided eye this image in

435  
00:20:12,579 --> 00:20:18,399  
particular was on a timed exposure with

436  
00:20:15,339 --> 00:20:19,990  
a camera but your I can still see even

437  
00:20:18,400 --> 00:20:22,480  
some of these dark clouds and stripes

438  
00:20:19,990 --> 00:20:24,069  
cutting through the dark stars so it's

439  
00:20:22,480 --> 00:20:26,349  
really something to do if you can have

440  
00:20:24,069 --> 00:20:28,720  
the chance to go out to a dark site and

441  
00:20:26,349 --> 00:20:31,659  
look up you should absolutely take the

442  
00:20:28,720 --> 00:20:32,829

time to do it it's well worth it and if

443

00:20:31,660 --> 00:20:36,450

you go and take pictures of the night

444

00:20:32,829 --> 00:20:39,189

sky all over the sky around the earth

445

00:20:36,450 --> 00:20:41,110

the whole sky put together look

446

00:20:39,190 --> 00:20:43,000

something like this so this is like a

447

00:20:41,109 --> 00:20:45,219

globe for the sky it's a global map of

448

00:20:43,000 --> 00:20:45,460

the entire night sky you can see there's

449

00:20:45,220 --> 00:20:48,460

this

450

00:20:45,460 --> 00:20:50,500

plane of dust and stars stretching

451

00:20:48,460 --> 00:20:52,539

across the night sky and that's our

452

00:20:50,500 --> 00:20:55,089

galaxy that's where we live it looks

453

00:20:52,539 --> 00:20:56,559

like a plane like this flatline because

454

00:20:55,089 --> 00:20:58,329

we're inside it we're kind of sitting

455

00:20:56,559 --> 00:21:00,429

out on one of the spiral arms looking at

456

00:20:58,329 --> 00:21:02,259

okay you can see all kinds of other



457  
00:21:00,430 --> 00:21:04,450  
stuff scattered around you can see these

458  
00:21:02,259 --> 00:21:07,029  
kind of fuzz balls down here these are

459  
00:21:04,450 --> 00:21:08,980  
small galaxies orbiting ours called the

460  
00:21:07,029 --> 00:21:11,019  
Magellanic Clouds and if you're in the

461  
00:21:08,980 --> 00:21:12,849  
southern hemisphere ever you can look up

462  
00:21:11,019 --> 00:21:15,759  
in a dark sky and see them with your

463  
00:21:12,849 --> 00:21:17,919  
naked eyes they look like clouds in the

464  
00:21:15,759 --> 00:21:19,450  
sky so they're called the Magellanic

465  
00:21:17,920 --> 00:21:21,610  
Clouds because Magellan was the first

466  
00:21:19,450 --> 00:21:22,990  
European to see them so of course he got

467  
00:21:21,609 --> 00:21:24,250  
the name after him never mind the fact

468  
00:21:22,990 --> 00:21:25,569  
that people have lived in that part of

469  
00:21:24,250 --> 00:21:26,769  
the world from you know thousands and

470  
00:21:25,569 --> 00:21:27,819  
thousands of years and have been seeing

471  
00:21:26,769 --> 00:21:31,509  
them for thousands and thousands of

472  
00:21:27,819 --> 00:21:35,259  
years but if we look at the night sky in

473  
00:21:31,509 --> 00:21:37,599  
other wavelengths not just well I hope

474  
00:21:35,259 --> 00:21:40,420  
that our eyes can see we can see other

475  
00:21:37,599 --> 00:21:42,069  
kinds of things so you may know that

476  
00:21:40,420 --> 00:21:45,370  
white light can be broken down into the

477  
00:21:42,069 --> 00:21:47,559  
different colors blue green and red if

478  
00:21:45,369 --> 00:21:49,659  
you keep going past blue green and red

479  
00:21:47,559 --> 00:21:52,509  
on the other side of red there's a color

480  
00:21:49,660 --> 00:21:53,650  
your eyes can't see called infra red if

481  
00:21:52,509 --> 00:21:55,599  
you look at the night sky in infrared

482  
00:21:53,650 --> 00:21:58,720  
light or something like this you can

483  
00:21:55,599 --> 00:22:01,000  
suddenly see through all of those dust

484  
00:21:58,720 --> 00:22:02,860  
clouds from before so you can see all

485

00:22:01,000 --> 00:22:04,779  
these kind of black dust blocking the

486  
00:22:02,859 --> 00:22:06,459  
light of the stars when we look down an

487  
00:22:04,779 --> 00:22:09,309  
infrared we can finally see the stars

488  
00:22:06,460 --> 00:22:12,160  
underneath this is infrared light that's

489  
00:22:09,309 --> 00:22:14,859  
very close to what our eyes can see it's

490  
00:22:12,160 --> 00:22:16,540  
just a little bit longer wavelength so

491  
00:22:14,859 --> 00:22:18,849  
where our instruments can see it but our

492  
00:22:16,539 --> 00:22:20,619  
eyes can't we can keep going into

493  
00:22:18,849 --> 00:22:23,199  
infrared and go into kind of longer and

494  
00:22:20,619 --> 00:22:24,849  
longer wavelengths and this guy starts

495  
00:22:23,200 --> 00:22:28,269  
to look like this you can see the blue

496  
00:22:24,849 --> 00:22:30,969  
here is the Stars and the green is some

497  
00:22:28,269 --> 00:22:32,889  
of the warm dust in our galaxy but this

498  
00:22:30,970 --> 00:22:36,370  
is still an infrared image it's just a

499  
00:22:32,890 --> 00:22:38,560

little bit further into the infrared if

500

00:22:36,369 --> 00:22:41,469

we keep going to even lower energies of

501

00:22:38,559 --> 00:22:43,029

light even longer wavelengths further

502

00:22:41,470 --> 00:22:45,789

into red we start to crack into

503

00:22:43,029 --> 00:22:49,779

microwave and radio light and that's

504

00:22:45,789 --> 00:22:52,240

what this image shows now radio is very

505

00:22:49,779 --> 00:22:55,839

low energy light and in fact there is

506

00:22:52,240 --> 00:22:58,470

Carl Sagan said in 1980 in the episode

507

00:22:55,839 --> 00:23:00,449

of cosmos that there is more in

508

00:22:58,470 --> 00:23:03,870

in a snowflake falling to the ground

509

00:23:00,450 --> 00:23:06,058

then there is in all of the radio light

510

00:23:03,869 --> 00:23:08,639

that every radio telescope on earth has

511

00:23:06,058 --> 00:23:11,279

ever detected put together now that was

512

00:23:08,640 --> 00:23:13,350

back in 1980 it was a long time ago 40

513

00:23:11,279 --> 00:23:18,058

years gods are pretty good that we're up

514  
00:23:13,349 --> 00:23:19,469  
to about two snowflakes by now so if we

515  
00:23:18,058 --> 00:23:21,178  
keep going the other direction

516  
00:23:19,470 --> 00:23:24,179  
we've gone kind of down in energy if we

517  
00:23:21,179 --> 00:23:26,490  
go up in energy then we can get up to X

518  
00:23:24,179 --> 00:23:28,500  
ray light the kind of light that your

519  
00:23:26,490 --> 00:23:30,659  
doctor will use to look at broken bones

520  
00:23:28,500 --> 00:23:32,400  
inside your body or that your dentist

521  
00:23:30,659 --> 00:23:34,440  
will use to look at your teeth the same

522  
00:23:32,400 --> 00:23:37,140  
kind of light you can see now there's

523  
00:23:34,440 --> 00:23:39,390  
all these little bright sources of they

524  
00:23:37,140 --> 00:23:42,360  
look like just bright stars and these

525  
00:23:39,390 --> 00:23:44,460  
are the kinds of dead stars that I kind

526  
00:23:42,359 --> 00:23:45,629  
of cut my teeth on that I was most

527  
00:23:44,460 --> 00:23:48,179  
interested in when I started in

528  
00:23:45,630 --> 00:23:50,039  
astronomy things like black holes and

529  
00:23:48,179 --> 00:23:53,850  
neutron stars what's left over after a

530  
00:23:50,038 --> 00:23:57,298  
star dies and if we keep going up in

531  
00:23:53,849 --> 00:23:58,949  
energy we get up to gamma ray light so

532  
00:23:57,298 --> 00:24:00,779  
this is a map of all the gamma-ray light

533  
00:23:58,950 --> 00:24:02,970  
in the sky that was put together by the

534  
00:24:00,779 --> 00:24:05,369  
Fermi gamma-ray Observatory which is a

535  
00:24:02,970 --> 00:24:06,808  
NASA instrument that's up now and

536  
00:24:05,369 --> 00:24:10,139  
they've been gathering gamma-ray light

537  
00:24:06,808 --> 00:24:12,168  
since for about 10 years now you can see

538  
00:24:10,140 --> 00:24:15,179  
the same plane of our Milky Way galaxy

539  
00:24:12,169 --> 00:24:18,259  
here you can see some bright individual

540  
00:24:15,179 --> 00:24:20,640  
objects scattered around the sky as well

541  
00:24:18,259 --> 00:24:23,940  
now when I say it's high-energy light

542

00:24:20,640 --> 00:24:27,750  
that doesn't really quite get across how

543  
00:24:23,940 --> 00:24:29,820  
high-energy this light is it's really

544  
00:24:27,750 --> 00:24:32,099  
quite extreme it's so extreme right it

545  
00:24:29,819 --> 00:24:34,408  
gave the Hulk his superpowers right so

546  
00:24:32,099 --> 00:24:37,408  
to try and put this into perspective of

547  
00:24:34,409 --> 00:24:39,090  
how high-energy gamma-ray light is I'm

548  
00:24:37,409 --> 00:24:41,039  
going to compare it to some temperatures

549  
00:24:39,089 --> 00:24:44,339  
okay there's temperatures or something

550  
00:24:41,038 --> 00:24:47,759  
we have a better feel for so if we take

551  
00:24:44,339 --> 00:24:50,069  
something like hot lava say and look at

552  
00:24:47,759 --> 00:24:52,048  
the temperature of hot lava we can

553  
00:24:50,069 --> 00:24:54,149  
associate that temperature with a

554  
00:24:52,048 --> 00:24:55,889  
particular kind of light okay it's

555  
00:24:54,150 --> 00:24:58,259  
glowing after all we can see some light

556  
00:24:55,890 --> 00:25:00,600

coming from it and as we heat it up

557

00:24:58,259 --> 00:25:04,140

it'll glow even more it'll turn than

558

00:25:00,599 --> 00:25:07,079

yellow and then eventually white-hot so

559

00:25:04,140 --> 00:25:10,919

we can associate a temperature to an

560

00:25:07,079 --> 00:25:11,909

energy of light so if we talk about hot

561

00:25:10,919 --> 00:25:13,740

lava

562

00:25:11,910 --> 00:25:16,200

might take a moment just to think about

563

00:25:13,740 --> 00:25:19,529

what kind of light might pair with this

564

00:25:16,200 --> 00:25:21,900

particular temperature okay neither pair

565

00:25:19,529 --> 00:25:24,329

with microwave light visible light or

566

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

x-ray light now obviously there's no

567

00:25:24,329 --> 00:25:26,879

grades or anything and just take a

568

00:25:25,319 --> 00:25:30,298

moment to think about what you might

569

00:25:26,880 --> 00:25:39,750

expect the what type of light to match

570

00:25:30,298 --> 00:25:41,538

to this temperature now I bet a lot of



571  
00:25:39,750 --> 00:25:43,349  
people are probably expecting that it's

572  
00:25:41,538 --> 00:25:45,538  
visible light because we can see it

573  
00:25:43,349 --> 00:25:49,199  
glowing but in fact the light that pairs

574  
00:25:45,538 --> 00:25:52,440  
best with it is infrared so this lava is

575  
00:25:49,200 --> 00:25:54,690  
glowing most brightly and basically

576  
00:25:52,440 --> 00:25:56,340  
what's blue in this image is where most

577  
00:25:54,690 --> 00:25:58,169  
of that light's coming out okay so

578  
00:25:56,339 --> 00:26:00,329  
something even as hot as hot lava is

579  
00:25:58,169 --> 00:26:04,230  
still coming up mostly in infrared

580  
00:26:00,329 --> 00:26:07,230  
wavelengths if we cool down say let's go

581  
00:26:04,230 --> 00:26:09,950  
to a nice beach day kind of a nice day

582  
00:26:07,230 --> 00:26:12,779  
outside pleasant sitting in a hammock

583  
00:26:09,950 --> 00:26:14,819  
breeze coming in we can do the same kind

584  
00:26:12,779 --> 00:26:18,149  
of thought experiment what kind of light

585  
00:26:14,819 --> 00:26:20,879  
pairs with that kind of temperature kind

586  
00:26:18,150 --> 00:26:28,830  
of think about it for a minute make a

587  
00:26:20,880 --> 00:26:30,419  
prediction and it's again infrared light

588  
00:26:28,829 --> 00:26:31,408  
so we're still an infrared this now

589  
00:26:30,419 --> 00:26:34,950  
where we have to move into the green

590  
00:26:31,409 --> 00:26:37,380  
parts that if we keep cooling off let's

591  
00:26:34,950 --> 00:26:40,620  
go somewhere more extreme like the poles

592  
00:26:37,380 --> 00:26:43,110  
of Mars say Mars in the wintertime at

593  
00:26:40,619 --> 00:26:45,389  
the North and South Pole is extremely

594  
00:26:43,109 --> 00:26:47,788  
cold it's so cold it's somewhere between

595  
00:26:45,390 --> 00:26:50,759  
the temperature of dry ice and liquid

596  
00:26:47,788 --> 00:26:52,619  
nitrogen so in fact a lot of that white

597  
00:26:50,759 --> 00:26:55,710  
stuff that you can see on the poles is

598  
00:26:52,619 --> 00:26:57,808  
actually dry ice it's carbon dioxide the

599

00:26:55,710 --> 00:27:00,569  
same gas that you breathe out every time

600  
00:26:57,808 --> 00:27:04,048  
you take a breath frozen solid and it's

601  
00:27:00,569 --> 00:27:06,720  
even colder than that so this is a

602  
00:27:04,048 --> 00:27:08,279  
really quite extreme cold so if we had

603  
00:27:06,720 --> 00:27:12,179  
to think about what kind of light might

604  
00:27:08,279 --> 00:27:14,639  
pair with that temperature might you

605  
00:27:12,179 --> 00:27:19,460  
expect it to be on a microwave radio

606  
00:27:14,640 --> 00:27:19,460  
light infrared light or visible light

607  
00:27:20,329 --> 00:27:25,548  
that's right it's still infrared

608  
00:27:23,750 --> 00:27:27,829  
so we still haven't even gotten down

609  
00:27:25,548 --> 00:27:31,190  
into the into the microwave and radio

610  
00:27:27,829 --> 00:27:33,470  
yet to get down to that kind of energy

611  
00:27:31,190 --> 00:27:36,650  
we have to keep going in temperature

612  
00:27:33,470 --> 00:27:38,360  
down to liquid helium so now at four

613  
00:27:36,650 --> 00:27:41,030

degrees above absolute zero

614

00:27:38,359 --> 00:27:44,269

is the the warmest liquid helium can be

615

00:27:41,029 --> 00:27:45,859

and now we're finally at the level where

616

00:27:44,269 --> 00:27:48,710

we're just starting to crack into

617

00:27:45,859 --> 00:27:51,139

microwave and radio light comparatively

618

00:27:48,710 --> 00:27:54,319

so even this is why we said you know

619

00:27:51,140 --> 00:27:56,150

radio lights so low energy that even a

620

00:27:54,319 --> 00:27:58,548

snowflake falling to earth has more

621

00:27:56,150 --> 00:28:01,788

energy than everything that we've seen

622

00:27:58,548 --> 00:28:05,000

in radio telescopes is because it's just

623

00:28:01,788 --> 00:28:06,919

such a low energy light if we go the

624

00:28:05,000 --> 00:28:09,200

other way and compare it to temperatures

625

00:28:06,919 --> 00:28:11,240

kinda going up we can use this as a

626

00:28:09,200 --> 00:28:12,919

starting point as liquid helium in a lab

627

00:28:11,240 --> 00:28:15,349

and compare it to something like the

628  
00:28:12,919 --> 00:28:17,419  
surface of the Sun all right the surface

629  
00:28:15,349 --> 00:28:20,538  
of the sun's famously a hot place right

630  
00:28:17,419 --> 00:28:22,759  
and that maps I think probably obviously

631  
00:28:20,538 --> 00:28:24,230  
to visible light because that's what our

632  
00:28:22,759 --> 00:28:26,150  
eyes are seeing it's so bright when you

633  
00:28:24,230 --> 00:28:28,819  
look outside the surface of the Sun you

634  
00:28:26,150 --> 00:28:30,440  
don't want to look at it directly but

635  
00:28:28,819 --> 00:28:33,200  
it's mostly emitting its energy at

636  
00:28:30,440 --> 00:28:35,179  
visible light so the temperature of

637  
00:28:33,200 --> 00:28:37,130  
liquid helium compared to the

638  
00:28:35,179 --> 00:28:39,830  
temperature of visible of the surface of

639  
00:28:37,130 --> 00:28:42,400  
the Sun is about the same as the energy

640  
00:28:39,829 --> 00:28:46,720  
gap between microwaves and visible light

641  
00:28:42,400 --> 00:28:49,630  
if we can extend that kind of analogy

642  
00:28:46,720 --> 00:28:52,970  
that's about the same ratio as the

643  
00:28:49,630 --> 00:28:55,400  
surface of the Sun to the corona of the

644  
00:28:52,970 --> 00:28:58,429  
Sun how many people went to the solar

645  
00:28:55,400 --> 00:28:59,780  
eclipse in 2017 and some people in the

646  
00:28:58,429 --> 00:29:02,000  
back did you get to see the corona of

647  
00:28:59,779 --> 00:29:03,109  
the Sun when when you were there yeah

648  
00:29:02,000 --> 00:29:06,740  
great

649  
00:29:03,109 --> 00:29:08,149  
yeah so that's a few million degrees is

650  
00:29:06,740 --> 00:29:09,470  
the surface of the Sun it's about a

651  
00:29:08,150 --> 00:29:12,019  
thousand times hotter than the surface

652  
00:29:09,470 --> 00:29:13,130  
of the Sun the surface of the Sun is

653  
00:29:12,019 --> 00:29:17,150  
about a thousand times hotter than

654  
00:29:13,130 --> 00:29:19,429  
liquid helium so these ratios are hand

655  
00:29:17,150 --> 00:29:21,740  
waving ly roughly equivalent okay so

656

00:29:19,429 --> 00:29:24,409  
let's keep scaling that up let's now

657  
00:29:21,740 --> 00:29:27,169  
compare say if this is now emitting

658  
00:29:24,409 --> 00:29:30,140  
mostly an x-ray light okay go microwave

659  
00:29:27,169 --> 00:29:32,960  
to visible visible to x-ray let's keep

660  
00:29:30,140 --> 00:29:35,809  
scaling that up and now we're comparing

661  
00:29:32,960 --> 00:29:36,940  
microwave to x-ray light liquid helium

662  
00:29:35,808 --> 00:29:41,139  
to the

663  
00:29:36,940 --> 00:29:44,950  
the Sun hey that's about the same ratio

664  
00:29:41,140 --> 00:29:48,070  
as the corona of the Sun to this

665  
00:29:44,950 --> 00:29:49,660  
gamma-ray light so this is so

666  
00:29:48,069 --> 00:29:50,679  
high-energy it's really hard to get a

667  
00:29:49,660 --> 00:29:52,540  
grip on okay

668  
00:29:50,680 --> 00:29:54,400  
but this difference between the x-ray

669  
00:29:52,539 --> 00:29:56,079  
light and these gamma rays that Fermi is

670  
00:29:54,400 --> 00:29:57,580

emitting it's just so extreme it's about

671

00:29:56,079 --> 00:30:02,369

the same as the corona the Sun compared

672

00:29:57,579 --> 00:30:05,919

to liquid helium scaled up again it's a

673

00:30:02,369 --> 00:30:09,759

factor of a million times more energetic

674

00:30:05,920 --> 00:30:14,050

the light coming out yeah which is why I

675

00:30:09,759 --> 00:30:15,549

can give Hulk his superpowers right so

676

00:30:14,049 --> 00:30:17,649

what could possibly make this kind of

677

00:30:15,549 --> 00:30:20,289

light right what could possibly have so

678

00:30:17,650 --> 00:30:24,240

much energy in it this kind of

679

00:30:20,289 --> 00:30:26,859

unfathomably energetic light coming out

680

00:30:24,240 --> 00:30:28,500

generally what's what happens when you

681

00:30:26,859 --> 00:30:32,349

have charged particles like electrons

682

00:30:28,500 --> 00:30:34,329

that are being rapidly accelerated so

683

00:30:32,349 --> 00:30:36,669

some environments that can do that are

684

00:30:34,329 --> 00:30:39,939

things like supernova remnants so this



685  
00:30:36,670 --> 00:30:41,500  
image here is an x-ray image of a

686  
00:30:39,940 --> 00:30:44,680  
supernova called the Crab Nebula

687  
00:30:41,500 --> 00:30:47,410  
supernova remnant and if you look in

688  
00:30:44,680 --> 00:30:49,509  
x-ray light at the crab this is what you

689  
00:30:47,410 --> 00:30:52,300  
see and you can see this motion in it

690  
00:30:49,509 --> 00:30:55,000  
these ripples kind of coming out from

691  
00:30:52,299 --> 00:30:57,250  
the center there and a bright central

692  
00:30:55,000 --> 00:30:58,569  
source in the middle and what's

693  
00:30:57,250 --> 00:31:01,240  
happening is there's a remnant of the

694  
00:30:58,569 --> 00:31:04,539  
old dead star in the center there called

695  
00:31:01,240 --> 00:31:07,120  
it now called a neutron star and it's

696  
00:31:04,539 --> 00:31:09,519  
spinning around it's giving some of its

697  
00:31:07,119 --> 00:31:11,259  
energy to the nebula around it and you

698  
00:31:09,519 --> 00:31:14,500  
can see the motion in that nebula it's

699

00:31:11,259 --> 00:31:16,629  
accelerating these particles as it

700

00:31:14,500 --> 00:31:19,000  
accelerates those particles they can

701

00:31:16,630 --> 00:31:22,630  
flare in this gamma ray light so this is

702

00:31:19,000 --> 00:31:25,450  
a gamma ray movie over here taken with

703

00:31:22,630 --> 00:31:27,760  
Fermi of the crab pulsar and you can see

704

00:31:25,450 --> 00:31:29,710  
when this flare goes off it gets quite

705

00:31:27,759 --> 00:31:31,839  
bright and then fades away again and

706

00:31:29,710 --> 00:31:33,309  
this is happening very close to the

707

00:31:31,839 --> 00:31:35,049  
center of this nebula so something's

708

00:31:33,309 --> 00:31:37,119  
going on very close to the old dead

709

00:31:35,049 --> 00:31:43,389  
remnant of this star that's creating

710

00:31:37,119 --> 00:31:45,639  
this spike in very energetic light so

711

00:31:43,390 --> 00:31:48,280  
when we look at this all-sky map we can

712

00:31:45,640 --> 00:31:49,750  
find remnants of supernovae in it things

713

00:31:48,279 --> 00:31:50,529  
that we know about from other studies

714  
00:31:49,750 --> 00:31:53,829  
where we know

715  
00:31:50,529 --> 00:31:55,539  
other supernovae have gone off so we can

716  
00:31:53,829 --> 00:31:57,970  
see they're mostly in the plane of our

717  
00:31:55,539 --> 00:31:59,109  
galaxy which makes a lot of sense right

718  
00:31:57,970 --> 00:32:01,839  
because that's where most of the stars

719  
00:31:59,109 --> 00:32:04,419  
in our galaxy are so we can find

720  
00:32:01,839 --> 00:32:07,809  
supernova remnants we can also find

721  
00:32:04,420 --> 00:32:11,410  
those old dead remnants of stars the

722  
00:32:07,809 --> 00:32:12,789  
pulsars spinning around and we can see

723  
00:32:11,410 --> 00:32:15,430  
those kind of scattered through our

724  
00:32:12,789 --> 00:32:16,990  
galaxy but mostly in that plane and

725  
00:32:15,430 --> 00:32:18,460  
they're a little bit easier to find up

726  
00:32:16,990 --> 00:32:20,170  
here and down here than they are in the

727  
00:32:18,460 --> 00:32:22,630

middle and I'll talk a little bit about

728

00:32:20,170 --> 00:32:25,150

why that is in a minute we can find some

729

00:32:22,630 --> 00:32:27,850

pulsars we can also find some really

730

00:32:25,150 --> 00:32:30,820

massive black holes in other galaxies

731

00:32:27,849 --> 00:32:33,969

far away now black holes and other

732

00:32:30,819 --> 00:32:36,339

galaxies are greedy they eat all kinds

733

00:32:33,970 --> 00:32:39,009

of gas and dust and they're messy eaters

734

00:32:36,339 --> 00:32:41,439

and some of that gets shot out each end

735

00:32:39,009 --> 00:32:43,509

in these Jets these giant Jets and when

736

00:32:41,440 --> 00:32:45,850

one of those is pointed at us you can

737

00:32:43,509 --> 00:32:48,339

see see it in the gamma-ray see the

738

00:32:45,849 --> 00:32:51,369

gamma-ray light coming in so these are

739

00:32:48,339 --> 00:32:53,230

really massive engines pointing their

740

00:32:51,369 --> 00:32:56,949

jet right at us and it's showing us

741

00:32:53,230 --> 00:33:00,519

their accelerated particles there's also

742  
00:32:56,950 --> 00:33:01,990  
a lot of this fuzz right a lot of that

743  
00:33:00,519 --> 00:33:04,269  
fuzz is what's happening when you have

744  
00:33:01,990 --> 00:33:06,490  
electrons the colliding with the light

745  
00:33:04,269 --> 00:33:09,220  
and just like two billiard balls can

746  
00:33:06,490 --> 00:33:11,109  
collide and give its energy to the other

747  
00:33:09,220 --> 00:33:13,420  
billiard ball that happens with

748  
00:33:11,109 --> 00:33:15,909  
electrons and photons and light light

749  
00:33:13,420 --> 00:33:19,810  
can gain energy from a fast-moving

750  
00:33:15,910 --> 00:33:22,930  
electron so if we take all that stuff we

751  
00:33:19,809 --> 00:33:25,059  
know about and try and take it away from

752  
00:33:22,930 --> 00:33:26,860  
our map of the gamma ray light coming

753  
00:33:25,059 --> 00:33:29,079  
from the galaxy subtract it all off

754  
00:33:26,859 --> 00:33:32,500  
account for all the pulsars all the

755  
00:33:29,079 --> 00:33:36,549  
supernovae that we know about we're left

756  
00:33:32,500 --> 00:33:38,400  
with something extra at the end it's

757  
00:33:36,549 --> 00:33:41,440  
concentrated in the center of our galaxy

758  
00:33:38,400 --> 00:33:45,220  
takes up a couple degrees you know not a

759  
00:33:41,440 --> 00:33:47,680  
big area and but we're not really sure

760  
00:33:45,220 --> 00:33:51,940  
what the cause of it is there's this

761  
00:33:47,680 --> 00:33:53,590  
extra super high-energy radiation coming

762  
00:33:51,940 --> 00:33:56,559  
from the very center of our galaxy and

763  
00:33:53,589 --> 00:34:00,789  
the area around it we don't really know

764  
00:33:56,559 --> 00:34:02,529  
why there are a few ideas one of them

765  
00:34:00,789 --> 00:34:03,500  
relies on the fact that we've now

766  
00:34:02,529 --> 00:34:05,359  
removed

767  
00:34:03,500 --> 00:34:08,269  
all of the known sources of the gamma

768  
00:34:05,359 --> 00:34:10,969  
radiation so what if there's a type of

769  
00:34:08,269 --> 00:34:12,889  
thing that we can't see what else can

770

00:34:10,969 --> 00:34:14,959  
make that kind of light if you remember

771  
00:34:12,889 --> 00:34:17,570  
Einstein's famous equation  $e$  equals  $MC$

772  
00:34:14,960 --> 00:34:18,500  
squared right energy is mass times the

773  
00:34:17,570 --> 00:34:21,679  
speed of light squared

774  
00:34:18,500 --> 00:34:24,139  
something with mass carries energy with

775  
00:34:21,679 --> 00:34:27,429  
it just inherently so if we could

776  
00:34:24,139 --> 00:34:29,389  
liberate some of that mass into photons

777  
00:34:27,429 --> 00:34:30,829  
then we could create some of this

778  
00:34:29,389 --> 00:34:31,539  
gamma-ray light and that can happen with

779  
00:34:30,829 --> 00:34:34,340  
antimatter

780  
00:34:31,539 --> 00:34:36,289  
so if we have particles of antimatter in

781  
00:34:34,340 --> 00:34:39,260  
the galactic center we can annihilate

782  
00:34:36,289 --> 00:34:42,378  
some regular matter and create this

783  
00:34:39,260 --> 00:34:44,570  
high-energy light but we already remove

784  
00:34:42,378 --> 00:34:47,719

the matter we knew about we remove the

785

00:34:44,570 --> 00:34:49,550

stuff we could see so what else is left

786

00:34:47,719 --> 00:34:51,589

well maybe it's stuff we can't see

787

00:34:49,550 --> 00:34:56,300

things like dark matter which kind of by

788

00:34:51,590 --> 00:34:58,160

definition we can't see right now dark

789

00:34:56,300 --> 00:35:00,170

matter sounds like it's kind of a tooth

790

00:34:58,159 --> 00:35:02,230

fairy that people inject into the world

791

00:35:00,170 --> 00:35:05,420

because they can't explain everything

792

00:35:02,230 --> 00:35:08,539

but there are really good reasons to

793

00:35:05,420 --> 00:35:10,088

think that Dark Matter exists and there

794

00:35:08,539 --> 00:35:13,460

have been for some time

795

00:35:10,088 --> 00:35:15,739

it started off through a totally

796

00:35:13,460 --> 00:35:18,019

different approach from just noticing

797

00:35:15,739 --> 00:35:19,399

that orbits don't work the way where

798

00:35:18,019 --> 00:35:21,889

they that we think they should in



799

00:35:19,400 --> 00:35:24,130

galaxies if you look at our solar system

800

00:35:21,889 --> 00:35:26,809

and look at how fast planets move around

801

00:35:24,130 --> 00:35:30,050

stuff close to the Sun moves fast like

802

00:35:26,809 --> 00:35:32,509

mercury right the messenger god mercury

803

00:35:30,050 --> 00:35:34,970

from Roman mythology moves very quickly

804

00:35:32,510 --> 00:35:38,150

the stuff way further out like Neptune

805

00:35:34,969 --> 00:35:40,098

and Pluto moves very slowly but if you

806

00:35:38,150 --> 00:35:43,338

look at galaxies and the velocity of

807

00:35:40,099 --> 00:35:45,170

stars you don't see that kind of fall

808

00:35:43,338 --> 00:35:47,509

off if you move away from the center of

809

00:35:45,170 --> 00:35:51,349

the galaxy the stars don't go any slower

810

00:35:47,510 --> 00:35:54,740

they stay the same speed now that

811

00:35:51,349 --> 00:35:56,539

suggests that there's matter that's

812

00:35:54,739 --> 00:35:59,569

still pulling on the star that we can't

813  
00:35:56,539 --> 00:36:01,099  
see so that's the kind of the origin of

814  
00:35:59,570 --> 00:36:04,130  
dark matter so the structure of our

815  
00:36:01,099 --> 00:36:07,099  
galaxy then is we're living out here on

816  
00:36:04,130 --> 00:36:08,930  
this kind of outer spiral arm and the

817  
00:36:07,099 --> 00:36:12,980  
unfashionable end of the spiral galaxy

818  
00:36:08,929 --> 00:36:14,929  
right it's flat with us in the middle

819  
00:36:12,980 --> 00:36:17,119  
and we can see that on the sky but

820  
00:36:14,929 --> 00:36:19,248  
surrounding us is this

821  
00:36:17,119 --> 00:36:22,460  
a low of dark matter invisible to our

822  
00:36:19,248 --> 00:36:25,818  
eyes and to our instruments but the

823  
00:36:22,460 --> 00:36:27,949  
influence of its gravity is not so the

824  
00:36:25,818 --> 00:36:32,210  
idea that we could maybe detect it

825  
00:36:27,949 --> 00:36:34,058  
directly is pretty tantalizing there are

826  
00:36:32,210 --> 00:36:37,940  
some theories about what dark matter is

827

00:36:34,059 --> 00:36:40,369  
well some of those theories think that

828  
00:36:37,940 --> 00:36:43,009  
dark matter is a type of massive

829  
00:36:40,369 --> 00:36:44,630  
particle that interacts through the weak

830  
00:36:43,009 --> 00:36:45,829  
nuclear force is what it's called so

831  
00:36:44,630 --> 00:36:49,608  
they call it a weakly interacting

832  
00:36:45,829 --> 00:36:51,920  
massive particle or a wimp

833  
00:36:49,608 --> 00:36:54,170  
astronomers really love terrible

834  
00:36:51,920 --> 00:36:57,858  
terrible acronyms and wimps are one of

835  
00:36:54,170 --> 00:37:00,190  
them but some theories of WIPP Dark

836  
00:36:57,858 --> 00:37:02,210  
Matter thinks that they're their own

837  
00:37:00,190 --> 00:37:04,039  
antiparticle so if you have lots of dark

838  
00:37:02,210 --> 00:37:05,539  
matter concentrated you would expect

839  
00:37:04,039 --> 00:37:08,329  
those particles of dark matter to run

840  
00:37:05,539 --> 00:37:11,180  
into each other and when they do create

841  
00:37:08,329 --> 00:37:13,519

gamma ray light because a equals MC

842

00:37:11,179 --> 00:37:16,098  
squared so maybe the reason that we see

843

00:37:13,518 --> 00:37:17,989  
this extra stuff is because that's where

844

00:37:16,099 --> 00:37:19,970  
the dark matter is most concentrated and

845

00:37:17,989 --> 00:37:23,748  
that's where we see the these particle

846

00:37:19,969 --> 00:37:27,828  
annihilations coming from so that's one

847

00:37:23,748 --> 00:37:29,838  
idea there are other ideas that don't

848

00:37:27,829 --> 00:37:31,309  
involve invoking new kinds of matter

849

00:37:29,838 --> 00:37:34,759  
even matter that we have a really good

850

00:37:31,309 --> 00:37:36,739  
reason to think exists okay and that's

851

00:37:34,759 --> 00:37:39,679  
based on the fact that there are analogs

852

00:37:36,739 --> 00:37:42,710  
of this excess in other places and that

853

00:37:39,679 --> 00:37:44,899  
this guy is really crowded if we look at

854

00:37:42,710 --> 00:37:47,028  
the Galactic bulge there are so many

855

00:37:44,900 --> 00:37:49,730  
stars there it's very difficult to tell

856  
00:37:47,028 --> 00:37:51,318  
them apart this is an image that I took

857  
00:37:49,730 --> 00:37:53,358  
as part of my research when I was in

858  
00:37:51,318 --> 00:37:56,058  
grad school of a part of the Galactic

859  
00:37:53,358 --> 00:37:58,578  
bulge all of the white bits in here are

860  
00:37:56,059 --> 00:38:01,460  
stars the black is the gap in between

861  
00:37:58,579 --> 00:38:03,589  
them and this image was taken with a

862  
00:38:01,460 --> 00:38:05,659  
resolution about 70 times better than

863  
00:38:03,588 --> 00:38:08,028  
what your eye can see so this is really

864  
00:38:05,659 --> 00:38:11,960  
a quite a detailed image from the ground

865  
00:38:08,028 --> 00:38:15,588  
and it's just chock full of stars and an

866  
00:38:11,960 --> 00:38:18,650  
instrument like Fermi doesn't have the

867  
00:38:15,588 --> 00:38:21,558  
resolution to tell these stars apart any

868  
00:38:18,650 --> 00:38:23,829  
more than your eye does so maybe there's

869  
00:38:21,559 --> 00:38:25,999  
a population of stuff blending together

870  
00:38:23,829 --> 00:38:28,700  
now just to give you a sense of how

871  
00:38:25,998 --> 00:38:31,608  
crowded this is this whole

872  
00:38:28,699 --> 00:38:34,250  
thing would fit on the size of your

873  
00:38:31,608 --> 00:38:36,199  
pinkie nail held a certain distance away

874  
00:38:34,250 --> 00:38:38,389  
that's how much of this guy it takes up

875  
00:38:36,199 --> 00:38:39,828  
let's see if we can guess how how much

876  
00:38:38,389 --> 00:38:41,179  
how far away you'd have to hold your

877  
00:38:39,829 --> 00:38:44,180  
pinkie nail to take up that amount of

878  
00:38:41,179 --> 00:38:46,309  
this guy think you'd have to hold it in

879  
00:38:44,179 --> 00:38:49,669  
front of your nose kind of out at arm's

880  
00:38:46,309 --> 00:38:51,190  
length about ten feet away or about 50

881  
00:38:49,670 --> 00:38:53,720  
feet away

882  
00:38:51,190 --> 00:39:06,490  
what patch of this guy do you think that

883  
00:38:53,719 --> 00:39:08,569  
fits in it make your final guesses here

884

00:39:06,489 --> 00:39:11,389  
it would have to be about 50 feet away

885  
00:39:08,570 --> 00:39:13,220  
so if you those of you in the back of

886  
00:39:11,389 --> 00:39:17,000  
the room or about 50 feet away from me

887  
00:39:13,219 --> 00:39:20,719  
my pinky nail would contain everything

888  
00:39:17,000 --> 00:39:23,179  
in that image and that's tiled over the

889  
00:39:20,719 --> 00:39:25,279  
center of our galaxy so it's just chock

890  
00:39:23,179 --> 00:39:27,919  
full of stars and some of those stars

891  
00:39:25,280 --> 00:39:32,290  
have died and some of those stars are

892  
00:39:27,920 --> 00:39:35,659  
now pulsars and since Fermi is

893  
00:39:32,289 --> 00:39:38,000  
relatively blurry it's possible that

894  
00:39:35,659 --> 00:39:41,568  
those could blend together into

895  
00:39:38,000 --> 00:39:44,409  
something else so I don't know if

896  
00:39:41,568 --> 00:39:48,588  
anybody recognizes what this is so far

897  
00:39:44,409 --> 00:39:51,469  
no so there's a style of art where you

898  
00:39:48,588 --> 00:39:53,989

draw kind of large colored dots on the

899

00:39:51,469 --> 00:39:57,049

canvas and when you stand far enough

900

00:39:53,989 --> 00:40:00,199

away they blend together into a new

901

00:39:57,050 --> 00:40:02,000

image so here we're standing kind of

902

00:40:00,199 --> 00:40:03,439

close enough to the painting that we

903

00:40:02,000 --> 00:40:05,989

can't tell what it is it's just a bunch

904

00:40:03,440 --> 00:40:09,108

of colored dots as we zoom out and

905

00:40:05,989 --> 00:40:13,309

things blur together a shape starts to

906

00:40:09,108 --> 00:40:18,380

emerge until finally the full piece of

907

00:40:13,309 --> 00:40:20,420

art is revealed so something similar

908

00:40:18,380 --> 00:40:22,519

could be happening with the stars in the

909

00:40:20,420 --> 00:40:24,139

Galactic bulge where individually if you

910

00:40:22,519 --> 00:40:26,108

had the resolution you could pull them

911

00:40:24,139 --> 00:40:29,150

apart into the individual colored dots

912

00:40:26,108 --> 00:40:31,969

but with an instrument that has less



913  
00:40:29,150 --> 00:40:37,309  
resolution like Fermi they blur together

914  
00:40:31,969 --> 00:40:38,989  
into kind of the smooth looking art so

915  
00:40:37,309 --> 00:40:41,049  
could these gamma rays be coming from

916  
00:40:38,989 --> 00:40:42,118  
lots of small things that blend together

917  
00:40:41,050 --> 00:40:45,589  
well

918  
00:40:42,119 --> 00:40:49,349  
we have examples of when this happens

919  
00:40:45,588 --> 00:40:53,219  
this is a star cluster okay called

920  
00:40:49,349 --> 00:40:55,829  
Tarzan five and it's in our Milky Way so

921  
00:40:53,219 --> 00:40:56,699  
called a globular cluster this image was

922  
00:40:55,829 --> 00:40:59,009  
taken with the Hubble Space Telescope

923  
00:40:56,699 --> 00:41:02,248  
and you can see lots of individual stars

924  
00:40:59,009 --> 00:41:06,269  
here right and if we look at that

925  
00:41:02,248 --> 00:41:09,179  
cluster in gamma rays this is what it

926  
00:41:06,268 --> 00:41:13,078  
looks like so you can see that it just

927

00:41:09,179 --> 00:41:15,210

looks like one solid blob okay you can't

928

00:41:13,079 --> 00:41:18,690

tell the individual stars apart anymore

929

00:41:15,210 --> 00:41:20,880

in the gamma ray so maybe whatever is

930

00:41:18,690 --> 00:41:23,068

responsible for those gamma rays in the

931

00:41:20,880 --> 00:41:24,660

cluster which is the same kind of thing

932

00:41:23,068 --> 00:41:27,358

that's responsible for the gamma rays in

933

00:41:24,659 --> 00:41:29,368

the galactic center globular clusters

934

00:41:27,358 --> 00:41:32,690

don't have dark matter

935

00:41:29,369 --> 00:41:35,309

okay we've kind of studied lots of them

936

00:41:32,690 --> 00:41:37,230

measured the velocity of their stars

937

00:41:35,309 --> 00:41:39,329

moving around and they behave like you

938

00:41:37,230 --> 00:41:41,159

would expect them to if all of the mass

939

00:41:39,329 --> 00:41:43,798

is coming from the stars they don't seem

940

00:41:41,159 --> 00:41:45,480

to have any dark matter so if the same

941

00:41:43,798 --> 00:41:47,489  
thing is responsible for the gamma rays

942  
00:41:45,480 --> 00:41:49,289  
in the cluster as in the galactic center

943  
00:41:47,489 --> 00:41:51,139  
then it's not dark matter it's something

944  
00:41:49,289 --> 00:41:53,849  
else

945  
00:41:51,139 --> 00:41:57,058  
there are these objects in these

946  
00:41:53,849 --> 00:41:58,528  
clusters these old dead remnants of

947  
00:41:57,059 --> 00:42:01,230  
stars that can give you high-energy

948  
00:41:58,528 --> 00:42:03,329  
light this is an x-ray image taken of

949  
00:42:01,230 --> 00:42:05,219  
Tarzan 5 and with the Chandra x-ray

950  
00:42:03,329 --> 00:42:07,650  
Observatory and you can see these

951  
00:42:05,219 --> 00:42:11,399  
individual points sitting around in the

952  
00:42:07,650 --> 00:42:13,880  
core of the cluster these are what

953  
00:42:11,400 --> 00:42:16,170  
happens when you have an old dead star

954  
00:42:13,880 --> 00:42:20,880  
feeding on something kind of a zombie

955  
00:42:16,170 --> 00:42:25,499

star right so what happens is as the

956

00:42:20,880 --> 00:42:29,068

star dies what's left is it's shrunken

957

00:42:25,498 --> 00:42:30,659

core okay called a neutron star so to

958

00:42:29,068 --> 00:42:33,568

give you a kind of a quick primer on how

959

00:42:30,659 --> 00:42:35,960

neutron stars how small they are and how

960

00:42:33,568 --> 00:42:38,998

dense they are after they've shrunk down

961

00:42:35,960 --> 00:42:40,528

and we can compare it to something that

962

00:42:38,998 --> 00:42:43,018

maybe most even familiar with the city

963

00:42:40,528 --> 00:42:45,389

of Baltimore okay so if we put a neutron

964

00:42:43,018 --> 00:42:47,699

star down on top of Baltimore see how

965

00:42:45,389 --> 00:42:50,940

big it's gonna be it fits pretty neatly

966

00:42:47,699 --> 00:42:53,608

inside the loop around the city okay

967

00:42:50,940 --> 00:42:55,440

there's somewhere between 10 and 15

968

00:42:53,608 --> 00:42:57,480

kilometers

969

00:42:55,440 --> 00:43:00,480

in radius okay the one I've drawn here

970  
00:42:57,480 --> 00:43:03,869  
is 11 kilometers in radius it's pretty

971  
00:43:00,480 --> 00:43:04,829  
well okay these spin around really

972  
00:43:03,869 --> 00:43:06,720  
rapidly

973  
00:43:04,829 --> 00:43:08,700  
most of them spin around about once a

974  
00:43:06,719 --> 00:43:13,529  
second take about a second to make the

975  
00:43:08,699 --> 00:43:17,639  
entire loop around Baltimore so if you'd

976  
00:43:13,530 --> 00:43:21,180  
also weigh more than the Sun does just

977  
00:43:17,639 --> 00:43:23,279  
for comparison 99.5% of all the mass in

978  
00:43:21,179 --> 00:43:25,288  
the solar system is wrapped up in the

979  
00:43:23,280 --> 00:43:28,170  
Sun and most of what's left is in

980  
00:43:25,289 --> 00:43:29,520  
Jupiter so weighing more than the Sun

981  
00:43:28,170 --> 00:43:32,608  
and fitting into something the size of

982  
00:43:29,519 --> 00:43:36,750  
Baltimore is really quite dense she had

983  
00:43:32,608 --> 00:43:38,009  
to guess a teaspoon of neutron star how

984  
00:43:36,750 --> 00:43:39,630  
much do you think that would weigh if

985  
00:43:38,010 --> 00:43:47,369  
you just dipped a little teaspoon of

986  
00:43:39,630 --> 00:43:50,390  
neutron star out yeah BC yeah 10 million

987  
00:43:47,369 --> 00:43:55,980  
tons from one teaspoon of neutron star

988  
00:43:50,389 --> 00:43:58,288  
are fantastically dense something

989  
00:43:55,980 --> 00:44:00,179  
interesting can happen when you get it

990  
00:43:58,289 --> 00:44:01,680  
close to another star it can start to

991  
00:44:00,179 --> 00:44:04,739  
eat it and that happens a lot in these

992  
00:44:01,679 --> 00:44:07,739  
globular clusters okay deep in the core

993  
00:44:04,739 --> 00:44:12,269  
this is a really dense environment this

994  
00:44:07,739 --> 00:44:14,608  
whole area here is about the size of the

995  
00:44:12,269 --> 00:44:17,429  
distance between the Sun and the nearest

996  
00:44:14,608 --> 00:44:20,308  
star to the Sun so where we are we'd

997  
00:44:17,429 --> 00:44:22,379  
have the Sun and then Alpha Centauri the

998

00:44:20,309 --> 00:44:24,869  
closest star in the same image here we

999  
00:44:22,380 --> 00:44:25,950  
packed hundreds of thousands of stars so

1000  
00:44:24,869 --> 00:44:28,440  
they're so close they can really

1001  
00:44:25,949 --> 00:44:31,078  
interact and have a lot of cool things

1002  
00:44:28,440 --> 00:44:33,720  
going on so this is a simulation of a

1003  
00:44:31,079 --> 00:44:34,950  
way that they can interact there's a

1004  
00:44:33,719 --> 00:44:37,379  
binary up here

1005  
00:44:34,949 --> 00:44:39,210  
two stars orbiting each other ones green

1006  
00:44:37,380 --> 00:44:41,730  
ones blue and there's another one down

1007  
00:44:39,210 --> 00:44:44,699  
here another pair of stars orbiting each

1008  
00:44:41,730 --> 00:44:47,460  
other ones yellow ones red so keep your

1009  
00:44:44,699 --> 00:44:51,328  
eye on the green one and the yellow one

1010  
00:44:47,460 --> 00:44:53,818  
these two pairs of stars are gonna going

1011  
00:44:51,329 --> 00:44:59,160  
to go by each other and watch what

1012  
00:44:53,818 --> 00:45:00,599

happens to now you see how close

1013

00:44:59,159 --> 00:45:06,639

together the green one and the yellow

1014

00:45:00,599 --> 00:45:08,349

and get at the end and how

1015

00:45:06,639 --> 00:45:12,239

fast they end up spiraling around each

1016

00:45:08,349 --> 00:45:16,088

other so when they get so close together

1017

00:45:12,239 --> 00:45:18,369

it becomes important that something else

1018

00:45:16,088 --> 00:45:20,920

happens to stars as they age stars

1019

00:45:18,369 --> 00:45:23,829

expand as they age so once you've gotten

1020

00:45:20,920 --> 00:45:25,480

a neutron star and another star close

1021

00:45:23,829 --> 00:45:28,839

together when that star starts to age

1022

00:45:25,480 --> 00:45:31,298

and get old stars much you know like

1023

00:45:28,838 --> 00:45:34,239

people pass you know I'm starting to get

1024

00:45:31,298 --> 00:45:38,889

there myself have to regulate the intake

1025

00:45:34,239 --> 00:45:40,420

of beer and start to expand and when

1026

00:45:38,889 --> 00:45:44,259

that happens the material at the edge



1027  
00:45:40,420 --> 00:45:46,838  
can start to fall off of the star and

1028  
00:45:44,259 --> 00:45:47,460  
onto the neutron star looks something

1029  
00:45:46,838 --> 00:45:50,679  
like that

1030  
00:45:47,460 --> 00:45:54,880  
okay so here we've got a neutron star

1031  
00:45:50,679 --> 00:45:58,118  
here at the very center and this kind of

1032  
00:45:54,880 --> 00:46:00,818  
starting to age and expand star dumping

1033  
00:45:58,119 --> 00:46:02,170  
the material out onto the neutron star

1034  
00:46:00,818 --> 00:46:05,048  
and when it happens it forms this

1035  
00:46:02,170 --> 00:46:07,630  
whirlpool of material hey have you ever

1036  
00:46:05,048 --> 00:46:09,909  
gone to the zoo or a museum or something

1037  
00:46:07,630 --> 00:46:13,028  
like that and they've got those little

1038  
00:46:09,909 --> 00:46:15,129  
coin drop things that spiral the coin

1039  
00:46:13,028 --> 00:46:16,960  
around into the donation bucket in the

1040  
00:46:15,130 --> 00:46:19,028  
middle it's the same sort of thing

1041  
00:46:16,960 --> 00:46:20,619  
happens you drop the coins and they

1042  
00:46:19,028 --> 00:46:22,389  
spiral around until they finally reach

1043  
00:46:20,619 --> 00:46:26,890  
the center going faster and faster the

1044  
00:46:22,389 --> 00:46:28,838  
closer they get to the center okay all

1045  
00:46:26,889 --> 00:46:30,940  
that stuff moving faster and faster as

1046  
00:46:28,838 --> 00:46:32,528  
it gets to the center when it lands on

1047  
00:46:30,940 --> 00:46:34,298  
the neutron star it's going pretty fast

1048  
00:46:32,528 --> 00:46:38,018  
it's going faster than the neutron star

1049  
00:46:34,298 --> 00:46:43,449  
is spinning and it that spins up the

1050  
00:46:38,018 --> 00:46:45,909  
neutron star so responsible binaries

1051  
00:46:43,449 --> 00:46:47,739  
recycle their old neutron stars and all

1052  
00:46:45,909 --> 00:46:49,409  
that material starts to spin it up

1053  
00:46:47,739 --> 00:46:51,880  
faster and faster and faster

1054  
00:46:49,409 --> 00:46:54,129  
so instead of a neutron star spinning

1055

00:46:51,880 --> 00:46:57,670  
every one second or every two seconds

1056  
00:46:54,130 --> 00:46:59,829  
these will spend hundreds of times every

1057  
00:46:57,670 --> 00:47:01,900  
second so if you could imagine traveling

1058  
00:46:59,829 --> 00:47:04,028  
the outer loop of Baltimore hundreds of

1059  
00:47:01,900 --> 00:47:05,440  
times in one second you'll get the kind

1060  
00:47:04,028 --> 00:47:10,028  
of a feel for how quickly these things

1061  
00:47:05,440 --> 00:47:13,210  
are going okay so what's left at the end

1062  
00:47:10,028 --> 00:47:15,489  
eventually this accretion stops this

1063  
00:47:13,210 --> 00:47:17,440  
robbing of material stops and you're

1064  
00:47:15,489 --> 00:47:20,470  
left with this really fast spinning

1065  
00:47:17,440 --> 00:47:23,980  
neutron star at the end okay

1066  
00:47:20,469 --> 00:47:25,299  
that's spun spinning up so quickly this

1067  
00:47:23,980 --> 00:47:30,068  
is the kind of thing that you can see

1068  
00:47:25,300 --> 00:47:32,800  
now as a pulsar so every time these

1069  
00:47:30,068 --> 00:47:35,199

magnetic poles of the spinning neutron

1070

00:47:32,800 --> 00:47:37,089

star sweep past you you see a bright

1071

00:47:35,199 --> 00:47:40,929

flash of radio light that's what it

1072

00:47:37,088 --> 00:47:44,679

means to be a pulsar a milli second

1073

00:47:40,929 --> 00:47:47,159

pulsar a recycled pulsar is one that has

1074

00:47:44,679 --> 00:47:50,710

been spun up to these fantastic speeds

1075

00:47:47,159 --> 00:47:54,818

and you see a pulse hundreds of times

1076

00:47:50,710 --> 00:47:57,670

every second these are known to be gamma

1077

00:47:54,818 --> 00:47:59,858

ray emitters we can identify them out

1078

00:47:57,670 --> 00:48:03,460

loose in the galaxy we can see that

1079

00:47:59,858 --> 00:48:07,659

they're emitting gamma rays so one

1080

00:48:03,460 --> 00:48:09,789

hypothesis then for the gamma ray excess

1081

00:48:07,659 --> 00:48:11,500

in the center of our galaxy is that

1082

00:48:09,789 --> 00:48:13,179

there's a whole bunch of these really

1083

00:48:11,500 --> 00:48:15,969

rapidly spinning neutron stars hanging

1084  
00:48:13,179 --> 00:48:18,190  
out in the center of the galaxy each of

1085  
00:48:15,969 --> 00:48:21,250  
them emitting gamma rays and blending

1086  
00:48:18,190 --> 00:48:26,108  
together just like a pointillist artwork

1087  
00:48:21,250 --> 00:48:29,050  
okay so we've got these two ideas right

1088  
00:48:26,108 --> 00:48:31,119  
oh yeah sorry so there is a a hang-up

1089  
00:48:29,050 --> 00:48:34,839  
and that we should see some pulsars

1090  
00:48:31,119 --> 00:48:37,300  
right we can see them in the radio why

1091  
00:48:34,838 --> 00:48:39,909  
don't we see them in the center of the

1092  
00:48:37,300 --> 00:48:43,210  
galaxy if they're there why do we miss

1093  
00:48:39,909 --> 00:48:46,239  
them we should actually be able to point

1094  
00:48:43,210 --> 00:48:49,449  
a radio telescope at them right and see

1095  
00:48:46,239 --> 00:48:52,328  
the pulses coming but we don't there are

1096  
00:48:49,449 --> 00:48:55,269  
some reasons that might happen there are

1097  
00:48:52,329 --> 00:48:58,180  
hot electrons or just free electrons in

1098  
00:48:55,269 --> 00:49:00,630  
the galaxies loose and whenever a radio

1099  
00:48:58,179 --> 00:49:04,088  
wave passes by those it slows it down

1100  
00:49:00,630 --> 00:49:06,550  
and when it slows it down it smears the

1101  
00:49:04,088 --> 00:49:09,279  
radio pulse out so whereas the radio

1102  
00:49:06,550 --> 00:49:11,920  
pulse might start out as this really

1103  
00:49:09,280 --> 00:49:14,109  
coherent single thing at different

1104  
00:49:11,920 --> 00:49:16,240  
frequencies the pulse is being delayed

1105  
00:49:14,108 --> 00:49:17,828  
by different amounts so when you look

1106  
00:49:16,239 --> 00:49:20,139  
with the radio telescope instead of

1107  
00:49:17,829 --> 00:49:22,810  
seeing one nice neat pulse you're

1108  
00:49:20,139 --> 00:49:25,980  
getting a smeared out pulse and that

1109  
00:49:22,809 --> 00:49:25,980  
makes them harder to detect

1110  
00:49:28,230 --> 00:49:34,449  
inconveniently this smearing is worse at

1111  
00:49:32,500 --> 00:49:36,130  
the center of the galaxy

1112

00:49:34,449 --> 00:49:38,348  
if you measure how much smearing there

1113  
00:49:36,130 --> 00:49:40,450  
is as a function of the Galactic

1114  
00:49:38,349 --> 00:49:42,250  
latitude and how far away from the plane

1115  
00:49:40,449 --> 00:49:45,039  
you move right in the middle of the

1116  
00:49:42,250 --> 00:49:46,539  
plane it's terrible right now towards

1117  
00:49:45,039 --> 00:49:48,579  
the edges it's fine and you can see the

1118  
00:49:46,539 --> 00:49:49,630  
pulsars no problem looking right towards

1119  
00:49:48,579 --> 00:49:51,010  
the center there's all these free

1120  
00:49:49,630 --> 00:49:54,160  
electrons and the pulses just get

1121  
00:49:51,010 --> 00:49:56,920  
hopelessly smeared that's worst at low

1122  
00:49:54,159 --> 00:49:58,960  
frequency which is a problem because

1123  
00:49:56,920 --> 00:50:00,639  
pulsars are brightest at low frequency

1124  
00:49:58,960 --> 00:50:03,760  
so if you want to find pulsars you want

1125  
00:50:00,639 --> 00:50:05,279  
to go to really low energy radio because

1126  
00:50:03,760 --> 00:50:07,270

that's where they're really bright and

1127

00:50:05,280 --> 00:50:08,890

but that's also where they're smearing

1128

00:50:07,269 --> 00:50:10,659

the most and as you move to where the

1129

00:50:08,889 --> 00:50:13,059

smearing is less severe at high

1130

00:50:10,659 --> 00:50:16,328

frequencies then you're running into

1131

00:50:13,059 --> 00:50:19,838

problems with how bright the Pulsar is

1132

00:50:16,329 --> 00:50:23,890

and it's just hard to see so we've got

1133

00:50:19,838 --> 00:50:26,349

these two scenarios to explain kind of

1134

00:50:23,889 --> 00:50:28,539

this puzzle one is that there are

1135

00:50:26,349 --> 00:50:31,510

particles we can't see dark matter and

1136

00:50:28,539 --> 00:50:34,750

the other is that there are pulsars we

1137

00:50:31,510 --> 00:50:37,680

can't see which one is it is it either

1138

00:50:34,750 --> 00:50:39,489

of them is there some way to find out oh

1139

00:50:37,679 --> 00:50:42,309

there are a couple of different ways you

1140

00:50:39,489 --> 00:50:44,879

could approach it there are groups out



1141  
00:50:42,309 --> 00:50:47,949  
at the Large Hadron Collider in Geneva

1142  
00:50:44,880 --> 00:50:49,539  
in Switzerland looking for these dark

1143  
00:50:47,949 --> 00:50:51,460  
matter particles looking to see if they

1144  
00:50:49,539 --> 00:50:54,190  
can find something that looks like it

1145  
00:50:51,460 --> 00:50:57,670  
would be responsible for this excess of

1146  
00:50:54,190 --> 00:50:58,900  
gamma rays I'm not part of that effort

1147  
00:50:57,670 --> 00:51:03,430  
so I'm not going to talk about it

1148  
00:50:58,900 --> 00:51:06,369  
anymore the other ways we can go about

1149  
00:51:03,429 --> 00:51:08,618  
looking for new pulsars see if we can

1150  
00:51:06,369 --> 00:51:10,480  
find them where it has been difficult to

1151  
00:51:08,619 --> 00:51:11,950  
find them before and we can take

1152  
00:51:10,480 --> 00:51:14,380  
advantage of a couple of things one

1153  
00:51:11,949 --> 00:51:17,828  
pulsars are small all right they fit

1154  
00:51:14,380 --> 00:51:19,420  
inside the loop around Baltimore the

1155  
00:51:17,829 --> 00:51:21,519  
other thing we can take advantage of to

1156  
00:51:19,420 --> 00:51:22,960  
see if we can find them is that they're

1157  
00:51:21,519 --> 00:51:26,559  
bright at low frequencies we know these

1158  
00:51:22,960 --> 00:51:30,068  
two facts about pulsars so what we can

1159  
00:51:26,559 --> 00:51:31,960  
do is go out and look with radio

1160  
00:51:30,068 --> 00:51:34,239  
telescopes and see if we can separate

1161  
00:51:31,960 --> 00:51:35,949  
things that are small and bright at low

1162  
00:51:34,239 --> 00:51:38,108  
frequencies from the rest of the stuff

1163  
00:51:35,949 --> 00:51:40,118  
we can see some of the rest of the stuff

1164  
00:51:38,108 --> 00:51:45,009  
we can see are these massive galaxies

1165  
00:51:40,119 --> 00:51:47,140  
shooting out Jets of particles from a

1166  
00:51:45,010 --> 00:51:48,310  
central source black hole eating

1167  
00:51:47,139 --> 00:51:52,029  
gobbling up

1168  
00:51:48,309 --> 00:51:55,090  
material as rapidly as it can these big

1169

00:51:52,030 --> 00:51:58,180  
jets that are large on the sky they're

1170  
00:51:55,090 --> 00:52:00,970  
not small so we can we can see them they

1171  
00:51:58,179 --> 00:52:02,230  
are much brighter at low frequencies but

1172  
00:52:00,969 --> 00:52:04,389  
they don't fulfill both requirements

1173  
00:52:02,230 --> 00:52:07,300  
right they're bright at low frequencies

1174  
00:52:04,389 --> 00:52:11,589  
but they're not small that central

1175  
00:52:07,300 --> 00:52:13,990  
source is very small but it's not super

1176  
00:52:11,590 --> 00:52:16,600  
bright at low frequencies pulsars are

1177  
00:52:13,989 --> 00:52:19,629  
much brighter relatively so by combining

1178  
00:52:16,599 --> 00:52:23,380  
these two facts we can try and separate

1179  
00:52:19,630 --> 00:52:26,680  
out the pulsars from kind of distant

1180  
00:52:23,380 --> 00:52:30,490  
black holes and other sources that might

1181  
00:52:26,679 --> 00:52:31,839  
cause confusion so we need lots of radio

1182  
00:52:30,489 --> 00:52:37,179  
dishes to make a really high-resolution

1183  
00:52:31,840 --> 00:52:40,570

image to really zoom in on the the small

1184

00:52:37,179 --> 00:52:42,009

small things so this is the the VLA the

1185

00:52:40,570 --> 00:52:43,930

Very Large Array out in Socorro New

1186

00:52:42,010 --> 00:52:46,510

Mexico if anybody's seen the movie

1187

00:52:43,929 --> 00:52:49,480

contact yeah I was in the movie contact

1188

00:52:46,510 --> 00:52:51,370

Jodie Foster was out there on a CB radio

1189

00:52:49,480 --> 00:52:56,949

while she was trying to take radio data

1190

00:52:51,369 --> 00:52:58,900

right not a not a good call yeah so this

1191

00:52:56,949 --> 00:53:00,069

is an aerial photo of the VLA just try

1192

00:52:58,900 --> 00:53:02,619

and give you a sense of how big it is

1193

00:53:00,070 --> 00:53:05,050

you can't really see very well the arms

1194

00:53:02,619 --> 00:53:06,670

here so I'll highlight them this is

1195

00:53:05,050 --> 00:53:08,950

where all the different antennae can go

1196

00:53:06,670 --> 00:53:10,510

they can spread out over ten miles

1197

00:53:08,949 --> 00:53:12,730

across

1198  
00:53:10,510 --> 00:53:17,260  
I think 22 kilometers is the length of

1199  
00:53:12,730 --> 00:53:19,389  
the arms maybe 21 I'm not right so your

1200  
00:53:17,260 --> 00:53:21,160  
size of the telescope basically becomes

1201  
00:53:19,389 --> 00:53:25,299  
the size of these arms when you link

1202  
00:53:21,159 --> 00:53:27,579  
them all up so using data from the VLA I

1203  
00:53:25,300 --> 00:53:29,110  
got to go out which is a lot of fun they

1204  
00:53:27,579 --> 00:53:32,739  
let me climb into one of the dishes for

1205  
00:53:29,110 --> 00:53:36,519  
some reason you get to use some data

1206  
00:53:32,739 --> 00:53:41,169  
there they taught me how to use it to

1207  
00:53:36,519 --> 00:53:43,780  
look for these compact radio sources so

1208  
00:53:41,170 --> 00:53:46,360  
this is just a small section of one of

1209  
00:53:43,780 --> 00:53:50,110  
the images we took with the VLA looking

1210  
00:53:46,360 --> 00:53:51,700  
for small objects that are bright at low

1211  
00:53:50,110 --> 00:53:52,360  
frequency and not very bright at high

1212  
00:53:51,699 --> 00:53:53,859  
frequency

1213  
00:53:52,360 --> 00:53:56,559  
and you can see that there are these

1214  
00:53:53,860 --> 00:53:58,900  
I've circled some very small point like

1215  
00:53:56,559 --> 00:54:01,849  
objects and you can also see here

1216  
00:53:58,900 --> 00:54:05,030  
something extended

1217  
00:54:01,849 --> 00:54:06,980  
clearer on my screen but the this is a

1218  
00:54:05,030 --> 00:54:10,240  
supermassive black hole kind of shooting

1219  
00:54:06,980 --> 00:54:13,000  
out some jets of material out around it

1220  
00:54:10,239 --> 00:54:14,569  
which is kind of cool to find

1221  
00:54:13,000 --> 00:54:16,010  
accidentally right because we're not

1222  
00:54:14,570 --> 00:54:19,370  
really looking for those but it's there

1223  
00:54:16,010 --> 00:54:21,440  
and it's neat the then after we've got

1224  
00:54:19,369 --> 00:54:23,929  
all those point sources of small objects

1225  
00:54:21,440 --> 00:54:25,070  
we can look at how bright they are at

1226

00:54:23,929 --> 00:54:27,469  
low frequencies compared to high

1227  
00:54:25,070 --> 00:54:30,289  
frequencies so stuff further down on

1228  
00:54:27,469 --> 00:54:33,649  
this plot is bright at low frequencies

1229  
00:54:30,289 --> 00:54:35,119  
stuff around zero here is about the same

1230  
00:54:33,650 --> 00:54:37,730  
brightness at high frequencies as to

1231  
00:54:35,119 --> 00:54:40,609  
visit low frequencies we've plotted up

1232  
00:54:37,730 --> 00:54:41,960  
just three different fields of where we

1233  
00:54:40,610 --> 00:54:44,120  
observe three different parts of the

1234  
00:54:41,960 --> 00:54:46,329  
Milky Way and we can see that there are

1235  
00:54:44,119 --> 00:54:48,559  
several sources here that are points and

1236  
00:54:46,329 --> 00:54:50,449  
very bright at low frequencies compared

1237  
00:54:48,559 --> 00:54:52,429  
to high frequencies so we've got all

1238  
00:54:50,449 --> 00:54:56,000  
these candidates now things that look

1239  
00:54:52,429 --> 00:54:58,009  
like pulsars but the smoking gun really

1240  
00:54:56,000 --> 00:55:01,369

is to search these candidates so these

1241  
00:54:58,010 --> 00:55:04,220  
two were bright at low frequencies and

1242  
00:55:01,369 --> 00:55:05,750  
not at high frequencies this one was not

1243  
00:55:04,219 --> 00:55:06,849  
so we throw it out we're not going to

1244  
00:55:05,750 --> 00:55:09,949  
look at it anymore

1245  
00:55:06,849 --> 00:55:12,139  
but we can now go and look at these

1246  
00:55:09,949 --> 00:55:14,509  
objects with something like the Green

1247  
00:55:12,139 --> 00:55:17,690  
Bank Observatory this is out in West

1248  
00:55:14,510 --> 00:55:21,410  
Virginia not too far away from here and

1249  
00:55:17,690 --> 00:55:23,900  
we can point this massive dish at each

1250  
00:55:21,409 --> 00:55:26,539  
of these candidates and look for pulses

1251  
00:55:23,900 --> 00:55:29,329  
you might say well you didn't find

1252  
00:55:26,539 --> 00:55:31,429  
pulses earlier why would you find pulses

1253  
00:55:29,329 --> 00:55:33,739  
now what what's better about having done

1254  
00:55:31,429 --> 00:55:36,079  
this right and the thing is if you look



1255  
00:55:33,739 --> 00:55:39,019  
at where these are on the sky the red

1256  
00:55:36,079 --> 00:55:41,659  
dots here the red circles are where the

1257  
00:55:39,019 --> 00:55:44,360  
pulsar candidates are the blue circles

1258  
00:55:41,659 --> 00:55:47,059  
are the part of the sky that this dish

1259  
00:55:44,360 --> 00:55:49,700  
can see okay and you might notice

1260  
00:55:47,059 --> 00:55:51,619  
there's a lot of the sky here that we

1261  
00:55:49,699 --> 00:55:54,139  
don't have to look at anymore we can

1262  
00:55:51,619 --> 00:55:56,750  
ignore it that means that we don't have

1263  
00:55:54,139 --> 00:55:59,329  
to search for pulsars kind of blindly in

1264  
00:55:56,750 --> 00:56:01,070  
the dark we can direct our search we

1265  
00:55:59,329 --> 00:56:04,279  
don't have to waste the time here and

1266  
00:56:01,070 --> 00:56:06,260  
instead we can put all of that time into

1267  
00:56:04,280 --> 00:56:07,940  
the center or into the onto the Pulsar

1268  
00:56:06,260 --> 00:56:10,070  
candidates trying to build up some

1269  
00:56:07,940 --> 00:56:12,349  
signal right because if you want to find

1270  
00:56:10,070 --> 00:56:15,320  
something real you need enough signals

1271  
00:56:12,349 --> 00:56:15,969  
and noise okay so by focusing our Pulsar

1272  
00:56:15,320 --> 00:56:20,480  
searches

1273  
00:56:15,969 --> 00:56:22,879  
we can find some real pulsars and not

1274  
00:56:20,480 --> 00:56:24,650  
have to hamstring ourselves by searching

1275  
00:56:22,880 --> 00:56:29,030  
where we know pretty well there aren't

1276  
00:56:24,650 --> 00:56:30,200  
any so pretty soon we'll be in a

1277  
00:56:29,030 --> 00:56:31,730  
position where we'll have so many

1278  
00:56:30,199 --> 00:56:33,379  
pulsars we won't know what to do with

1279  
00:56:31,730 --> 00:56:37,369  
them right I won't know what to do with

1280  
00:56:33,380 --> 00:56:42,130  
them all okay so that point will I'll go

1281  
00:56:37,369 --> 00:56:42,130  
ahead and open it up to two questions

1282  
00:56:44,329 --> 00:56:50,559  
[Applause]

1283

00:57:05,949 --> 00:57:09,199

[Music]

1284

00:57:14,230 --> 00:57:23,449

yeah other than just timing the beam can

1285

00:57:21,139 --> 00:57:27,339

they do anything with it like shadow

1286

00:57:23,449 --> 00:57:31,309

other objects or it's a good question

1287

00:57:27,340 --> 00:57:33,050

so in general sometimes it is neat to be

1288

00:57:31,309 --> 00:57:34,670

able to see light being emitted from

1289

00:57:33,050 --> 00:57:36,519

something strongly bounced off another

1290

00:57:34,670 --> 00:57:38,900

object nearby structure and come to you

1291

00:57:36,519 --> 00:57:41,389

and that that kind of thing has been

1292

00:57:38,900 --> 00:57:44,500

done with other sorts of objects I don't

1293

00:57:41,389 --> 00:57:48,079

think it's ever been done with pulsars

1294

00:57:44,500 --> 00:57:50,539

maybe some of the x-ray pulsars some of

1295

00:57:48,079 --> 00:57:53,599

the x-rays could be bounced like that

1296

00:57:50,539 --> 00:57:55,099

I'm not aware of that but it's the kind

1297

00:57:53,599 --> 00:57:56,900

of thing that someone might already have

1298

00:57:55,099 --> 00:58:01,969

done and then now fuss at me for not

1299

00:57:56,900 --> 00:58:05,690

knowing about it but let's see we have a

1300

00:58:01,969 --> 00:58:15,589

question way in the back gonna make you

1301

00:58:05,690 --> 00:58:19,099

gonna make your work grant Oh oh good

1302

00:58:15,590 --> 00:58:24,260

catch alright so I was just wondering if

1303

00:58:19,099 --> 00:58:26,349

I was wondering if that there were what

1304

00:58:24,260 --> 00:58:29,780

I was actually at the Green Bank

1305

00:58:26,349 --> 00:58:33,409

listening to a lecture there

1306

00:58:29,780 --> 00:58:36,470

they talked about a source of radio

1307

00:58:33,409 --> 00:58:39,039

waves that they didn't know so you

1308

00:58:36,469 --> 00:58:42,319

talked about how this could also

1309

00:58:39,039 --> 00:58:44,150

generate waves and lower frequencies so

1310

00:58:42,320 --> 00:58:47,870

I was just wondering if they're sort of

1311

00:58:44,150 --> 00:58:51,289

the same mystery they are called fast

1312  
00:58:47,869 --> 00:58:53,389  
radio bursts ah yeah fast radio bursts

1313  
00:58:51,289 --> 00:58:55,579  
are something a little bit different

1314  
00:58:53,389 --> 00:58:58,309  
though they're also something that is

1315  
00:58:55,579 --> 00:59:01,460  
not really explained and is really

1316  
00:58:58,309 --> 00:59:03,920  
interesting fast radio bursts pop off

1317  
00:59:01,460 --> 00:59:07,699  
kind of all over the sky so here we have

1318  
00:59:03,920 --> 00:59:09,079  
kind of a sky map of just the Milky Way

1319  
00:59:07,699 --> 00:59:11,719  
and everything if we were to draw a

1320  
00:59:09,079 --> 00:59:15,139  
circle around every fast radio bursts

1321  
00:59:11,719 --> 00:59:17,480  
that has been seen we would they kind of

1322  
00:59:15,139 --> 00:59:18,799  
scatter around right they're not coming

1323  
00:59:17,480 --> 00:59:22,639  
from just the the center of the galaxy

1324  
00:59:18,800 --> 00:59:26,030  
here so that's a good it's a good

1325  
00:59:22,639 --> 00:59:28,339  
question and neutron stars probably have

1326  
00:59:26,030 --> 00:59:29,840  
something to do with fast radio bursts

1327  
00:59:28,340 --> 00:59:31,910  
they're probably tied because they're

1328  
00:59:29,840 --> 00:59:34,340  
happening so quickly you need a lot of

1329  
00:59:31,909 --> 00:59:38,049  
energy on a very small scale for those

1330  
00:59:34,340 --> 00:59:40,850  
fast radio bursts so neutron stars and

1331  
00:59:38,050 --> 00:59:45,740  
pulsars more generally yes probably are

1332  
00:59:40,849 --> 00:59:48,139  
tied into that somehow yeah okay we have

1333  
00:59:45,739 --> 00:59:49,669  
a question from online which is

1334  
00:59:48,139 --> 00:59:51,799  
intriguing I haven't thought about this

1335  
00:59:49,670 --> 00:59:55,099  
before can one use pulsars for

1336  
00:59:51,800 --> 00:59:57,470  
gravitational lensing and I'm not sure

1337  
00:59:55,099 --> 01:00:00,380  
because that that strikes two questions

1338  
00:59:57,469 --> 01:00:01,639  
in me the lensing around a pulsar yeah

1339  
01:00:00,380 --> 01:00:04,610  
but you'd have to have a really fine

1340

01:00:01,639 --> 01:00:07,519  
resolution but if you get a pulsar that

1341  
01:00:04,610 --> 01:00:09,530  
gets lens multiple sources then you can

1342  
01:00:07,519 --> 01:00:11,630  
see the timing difference between the

1343  
01:00:09,530 --> 01:00:13,790  
multiple sources and that would be cool

1344  
01:00:11,630 --> 01:00:15,320  
would be really cool yeah so I'm not

1345  
01:00:13,789 --> 01:00:17,809  
aware that that's ever happened but that

1346  
01:00:15,320 --> 01:00:19,940  
that's a good idea yeah yeah there is a

1347  
01:00:17,809 --> 01:00:22,759  
supernova the kind of thing that makes a

1348  
01:00:19,940 --> 01:00:25,429  
pulsar that was lens by a distant galaxy

1349  
01:00:22,760 --> 01:00:28,160  
you could see the supernova arrive at

1350  
01:00:25,429 --> 01:00:29,389  
different times I've gotta explain make

1351  
01:00:28,159 --> 01:00:31,789  
sure everyone knows gravitational

1352  
01:00:29,389 --> 01:00:34,400  
lensing okay you want to take it yeah so

1353  
01:00:31,789 --> 01:00:36,829  
gravitational lensing is just when light

1354  
01:00:34,400 --> 01:00:39,200

gets bent by gravity so if you have a

1355

01:00:36,829 --> 01:00:41,299

massive object like a neutron star or

1356

01:00:39,199 --> 01:00:42,699

another galaxy as the light is passing

1357

01:00:41,300 --> 01:00:45,339

by

1358

01:00:42,699 --> 01:00:46,929

the gravity curves the space around the

1359

01:00:45,338 --> 01:00:49,809

object and that light traveling through

1360

01:00:46,929 --> 01:00:51,578

that curved space gets bent so it just

1361

01:00:49,809 --> 01:00:54,009

acts like a big magnifying glass the

1362

01:00:51,579 --> 01:00:55,329

path of the light gets diverted right

1363

01:00:54,010 --> 01:00:57,250

and the point I was making is that

1364

01:00:55,329 --> 01:00:59,019

sometimes the light comes this way

1365

01:00:57,250 --> 01:01:00,190

around it and sometimes it goes this way

1366

01:00:59,019 --> 01:01:01,900

around it and the time that I would go

1367

01:01:00,190 --> 01:01:04,990

this way and you can actually see three

1368

01:01:01,900 --> 01:01:07,088

different paths to the same object and



1369  
01:01:04,989 --> 01:01:09,309  
so if there's a timing event going on

1370  
01:01:07,088 --> 01:01:10,989  
here it can take different amounts of

1371  
01:01:09,309 --> 01:01:14,019  
time to pass through these three

1372  
01:01:10,989 --> 01:01:15,639  
different curvatures around the object

1373  
01:01:14,019 --> 01:01:17,050  
and then you can tell the timing

1374  
01:01:15,639 --> 01:01:19,750  
difference to measure the gravitational

1375  
01:01:17,050 --> 01:01:20,920  
lensing that's going on yeah as you said

1376  
01:01:19,750 --> 01:01:22,329  
we think we've done it was a supernova

1377  
01:01:20,920 --> 01:01:23,950  
and maybe a couple of one or two other

1378  
01:01:22,329 --> 01:01:25,390  
things yeah but I'm kind of wondering if

1379  
01:01:23,949 --> 01:01:29,739  
there could be like micro lensing of

1380  
01:01:25,389 --> 01:01:32,379  
pulsars or something like that all right

1381  
01:01:29,739 --> 01:01:33,759  
questions from the live audience yes we

1382  
01:01:32,380 --> 01:01:35,410  
do go ahead so you've left us all

1383  
01:01:33,760 --> 01:01:38,349  
hanging because you've gotten only as

1384  
01:01:35,409 --> 01:01:40,509  
far as you've gotten and if you were to

1385  
01:01:38,349 --> 01:01:43,300  
get all the data that you wanted and you

1386  
01:01:40,510 --> 01:01:46,300  
were going towards your Holy Grail what

1387  
01:01:43,300 --> 01:01:47,920  
would you altima know yeah so we

1388  
01:01:46,300 --> 01:01:49,900  
actually have the data from the Green

1389  
01:01:47,920 --> 01:01:54,159  
Bank telescope in hand and we're working

1390  
01:01:49,900 --> 01:01:58,480  
on it now but we don't have the answers

1391  
01:01:54,159 --> 01:02:01,179  
yet we have found enough candidates to

1392  
01:01:58,480 --> 01:02:03,130  
explain the Fermi gamma-ray excess it's

1393  
01:02:01,179 --> 01:02:05,049  
entirely possible that those know that

1394  
01:02:03,130 --> 01:02:06,880  
all those candidates are not pulsars so

1395  
01:02:05,050 --> 01:02:11,109  
it's too early to say that you know it's

1396  
01:02:06,880 --> 01:02:14,440  
done but we have found enough small

1397

01:02:11,108 --> 01:02:16,389  
point-like objects with really steep

1398  
01:02:14,440 --> 01:02:17,920  
radio spectra that are very bright at

1399  
01:02:16,389 --> 01:02:22,239  
low frequencies and not at high

1400  
01:02:17,920 --> 01:02:24,159  
frequencies they don't have like

1401  
01:02:22,239 --> 01:02:25,479  
counterparts and infrared and other type

1402  
01:02:24,159 --> 01:02:25,750  
where you can identify it as something

1403  
01:02:25,480 --> 01:02:28,960  
else

1404  
01:02:25,750 --> 01:02:30,309  
so screening out all the contaminants we

1405  
01:02:28,960 --> 01:02:33,250  
soar left with enough candidates to

1406  
01:02:30,309 --> 01:02:35,679  
explain it it's still premature to say

1407  
01:02:33,250 --> 01:02:39,280  
that it's explained but I think I'm I am

1408  
01:02:35,679 --> 01:02:46,659  
personally optimistic maybe about as far

1409  
01:02:39,280 --> 01:02:48,450  
as I can go yeah question Jocelyn Bell

1410  
01:02:46,659 --> 01:02:52,838  
yes thank you

1411  
01:02:48,449 --> 01:02:54,338

67 was is credited with discovering

1412

01:02:52,838 --> 01:02:56,529

pulsars yes

1413

01:02:54,338 --> 01:02:59,108

how how is it

1414

01:02:56,530 --> 01:03:03,329

I think I had a picture of her Pulsar

1415

01:02:59,108 --> 01:03:07,690

there - yeah there was it how is it that

1416

01:03:03,329 --> 01:03:12,579

somebody they could find did discover

1417

01:03:07,690 --> 01:03:16,838

something new she was did she was denied

1418

01:03:12,579 --> 01:03:18,760

the the Nobel Prize correct yes how does

1419

01:03:16,838 --> 01:03:20,710

how did that happen her she was a grad

1420

01:03:18,760 --> 01:03:23,079

student right was it red student yes I

1421

01:03:20,710 --> 01:03:28,740

mean her PhD adviser got the prize yeah

1422

01:03:23,079 --> 01:03:31,269

how did how did that hat but yeah yeah

1423

01:03:28,739 --> 01:03:33,279

so I actually got to meet Jocelyn Bernal

1424

01:03:31,269 --> 01:03:40,088

when I was at Texas Tech and Jocelyn

1425

01:03:33,280 --> 01:03:46,260

Bell Burnell and she was very easygoing

1426  
01:03:40,088 --> 01:03:48,849  
about it she was not at all bitter or

1427  
01:03:46,260 --> 01:03:50,500  
upset about what had happened even

1428  
01:03:48,849 --> 01:03:57,190  
though I think she might have every

1429  
01:03:50,500 --> 01:03:59,349  
right to be but her attitude was that it

1430  
01:03:57,190 --> 01:04:03,179  
was not traditional for graduate

1431  
01:03:59,349 --> 01:04:04,990  
students to receive the prize I don't

1432  
01:04:03,179 --> 01:04:08,980  
personally I think it would've been fine

1433  
01:04:04,989 --> 01:04:13,118  
to give it to her but she was the one

1434  
01:04:08,980 --> 01:04:14,889  
who first you know identified it her PhD

1435  
01:04:13,119 --> 01:04:17,289  
adviser also did a lot of work on the

1436  
01:04:14,889 --> 01:04:19,469  
object so I'm not trying to say that he

1437  
01:04:17,289 --> 01:04:23,259  
didn't deserve the Nobel Prize as well

1438  
01:04:19,469 --> 01:04:24,399  
but I think it would have been I agree

1439  
01:04:23,260 --> 01:04:27,160  
it would have been good to include her

1440  
01:04:24,400 --> 01:04:37,780  
that I think she personally I would say

1441  
01:04:27,159 --> 01:04:39,519  
that she deserved it but yeah it is if

1442  
01:04:37,780 --> 01:04:41,859  
she made an enormous contribution that

1443  
01:04:39,519 --> 01:04:45,219  
discovery of hers this object in fact of

1444  
01:04:41,858 --> 01:04:49,059  
the regular pulse is arriving every once

1445  
01:04:45,219 --> 01:04:51,338  
a second or so birth the whole new field

1446  
01:04:49,059 --> 01:04:55,328  
of astronomy and it was something that

1447  
01:04:51,338 --> 01:04:58,059  
we didn't write yeah exactly and so it's

1448  
01:04:55,329 --> 01:04:59,710  
it's not every day that someone burst an

1449  
01:04:58,059 --> 01:05:04,509  
entirely new field of study in the

1450  
01:04:59,710 --> 01:05:06,369  
Natural Sciences so yeah I think it

1451  
01:05:04,510 --> 01:05:07,960  
would have you know it merited it

1452  
01:05:06,369 --> 01:05:11,229  
clearly did merit a Nobel Prize because

1453  
01:05:07,960 --> 01:05:15,679  
they awarded one for the discovery

1454

01:05:11,228 --> 01:05:17,179  
yeah I agree with you the online

1455  
01:05:15,679 --> 01:05:19,129  
audience it was referenced that we have

1456  
01:05:17,179 --> 01:05:21,679  
a picture of Jocelyn hanging here at the

1457  
01:05:19,130 --> 01:05:26,930  
Space Telescope Institute yeah all right

1458  
01:05:21,679 --> 01:05:29,298  
other questions months going twice

1459  
01:05:26,929 --> 01:05:33,348  
alright and ireenie arrives right on

1460  
01:05:29,298 --> 01:05:35,688  
time okay ladies and gentlemen that is

1461  
01:05:33,349 --> 01:05:37,548  
Ari Neil and Bradys and she will be

1462  
01:05:35,688 --> 01:05:39,978  
taking people across the street to the

1463  
01:05:37,548 --> 01:05:41,059  
Maryland Space Grant observatory where

1464  
01:05:39,978 --> 01:05:43,098  
would you like to hang out you want to

1465  
01:05:41,059 --> 01:05:45,650  
hang out over here by the door okay so

1466  
01:05:43,099 --> 01:05:46,818  
if you would like to see they'll use the

1467  
01:05:45,650 --> 01:05:50,959  
telescopes across the street

1468  
01:05:46,818 --> 01:05:53,538

please join rainy over here next month

1469

01:05:50,958 --> 01:05:57,259

the art and science of astronomical

1470

01:05:53,539 --> 01:05:58,640

image processing please join us and let

1471

01:05:57,259 --> 01:06:00,409

us give one more big hand for dr.

1472

01:05:58,639 --> 01:06:07,170

Christopher bread

1473

01:06:00,409 --> 01:06:07,170

[Applause]