

1
00:00:02,428 --> 00:00:07,619
and in the backroom grant justice is

2
00:00:05,309 --> 00:00:09,539
taking their their wonderful webcast

3
00:00:07,620 --> 00:00:18,118
feed and streaming it out to YouTube so

4
00:00:09,539 --> 00:00:21,239
give grant a hand alright let's get

5
00:00:18,118 --> 00:00:23,429
started good evening ladies and

6
00:00:21,239 --> 00:00:25,858
gentlemen and welcome to the Space

7
00:00:23,429 --> 00:00:27,329
Telescope public lecture series I'm dr.

8
00:00:25,859 --> 00:00:30,380
Frank summers of the office of public

9
00:00:27,329 --> 00:00:33,509
outreach and when you came in today

10
00:00:30,379 --> 00:00:35,729
there may have been these lithographs on

11
00:00:33,509 --> 00:00:38,128
the tables here and over there

12
00:00:35,729 --> 00:00:43,078
tonight's lithograph is galaxy cluster

13
00:00:38,128 --> 00:00:45,509
Abell 2744 which is a cluster so large

14
00:00:43,079 --> 00:00:47,219
that it produces gravitational lensing

15
00:00:45,509 --> 00:00:49,079
and you want to know what gravitational

16
00:00:47,219 --> 00:00:50,969
lensing is well turnover on the back and

17
00:00:49,079 --> 00:00:52,679
we have a few paragraphs to tell you

18
00:00:50,969 --> 00:00:55,350
about the amazing things that are

19
00:00:52,679 --> 00:00:57,238
happening inside this galaxy cluster if

20
00:00:55,350 --> 00:01:01,340
you did not get one on your way in pick

21
00:00:57,238 --> 00:01:05,489
one up on your way out our talk tonight

22
00:01:01,340 --> 00:01:07,109
gravitational wave astronomy talking

23
00:01:05,489 --> 00:01:10,770
about the some of the discoveries that

24
00:01:07,109 --> 00:01:13,019
won the Nobel Prize last year next month

25
00:01:10,769 --> 00:01:15,658
we will have star formation in Orion

26
00:01:13,019 --> 00:01:20,188
from will Fischer that will be on June

27
00:01:15,659 --> 00:01:22,109
5th and Orion is really one of the

28
00:01:20,188 --> 00:01:24,658
coolest places where we can study star

29

00:01:22,109 --> 00:01:26,310
formation because it's the nearest star

30
00:01:24,659 --> 00:01:29,189
star forming region where we've got the

31
00:01:26,310 --> 00:01:31,740
full range of stars being born from the

32
00:01:29,188 --> 00:01:33,658
smallest to the very largest and so we

33
00:01:31,739 --> 00:01:36,419
it's one of our prototypical star

34
00:01:33,659 --> 00:01:39,509
forming regions so a great place to

35
00:01:36,420 --> 00:01:42,329
learn about a star formation on July 3rd

36
00:01:39,509 --> 00:01:44,609
David Netto from Johns Hopkins we'll be

37
00:01:42,328 --> 00:01:47,188
talking about the Milky Way's bulge from

38
00:01:44,609 --> 00:01:51,539
a hypothesized blob to a remarkably

39
00:01:47,188 --> 00:01:54,688
detailed picture the structure of the

40
00:01:51,540 --> 00:01:57,270
Milky Way has you know evolved over the

41
00:01:54,688 --> 00:01:59,639
years and he'll give us a great history

42
00:01:57,269 --> 00:02:02,849
about its core of the galaxies the Bulge

43
00:01:59,640 --> 00:02:06,060

in August we have our infamous mister

44

00:02:02,849 --> 00:02:08,969

error ms TBA which means I've got a

45

00:02:06,060 --> 00:02:11,098

little work to do this month it's it's

46

00:02:08,969 --> 00:02:13,259

sometimes hard to wrangle speakers for

47

00:02:11,098 --> 00:02:14,619

the summer months but I always do end up

48

00:02:13,259 --> 00:02:16,840

getting

49

00:02:14,620 --> 00:02:19,509

when I do have a speaker you'll find it

50

00:02:16,840 --> 00:02:20,890

on our website if you go to your

51

00:02:19,509 --> 00:02:22,899

favorite search engine and type in

52

00:02:20,889 --> 00:02:23,529

Hubbell public talk sir Space Telescope

53

00:02:22,900 --> 00:02:25,900

public talks

54

00:02:23,530 --> 00:02:27,669

you should find this page which has the

55

00:02:25,900 --> 00:02:29,680

list of the upcoming lectures over on

56

00:02:27,669 --> 00:02:32,199

the right-hand side on the left-hand

57

00:02:29,680 --> 00:02:36,879

side we have the links to our webcasting

58
00:02:32,199 --> 00:02:39,669
both the live and on YouTube we also

59
00:02:36,879 --> 00:02:43,150
have our past lecture our archives which

60
00:02:39,669 --> 00:02:45,699
go back to 2014 on YouTube and all the

61
00:02:43,150 --> 00:02:48,520
way back to 2005 with our STScI

62
00:02:45,699 --> 00:02:51,039
webcasting lots and lots of lectures for

63
00:02:48,520 --> 00:02:53,409
you to watch and you can also subscribe

64
00:02:51,039 --> 00:02:55,060
to our email list and get one or two

65
00:02:53,409 --> 00:02:58,139
emails a month reminding of what's

66
00:02:55,060 --> 00:03:01,239
coming up and when our webcast is posted

67
00:02:58,139 --> 00:03:03,579
the announcements as I said sign up in

68
00:03:01,239 --> 00:03:05,110
the website or if you can't do that you

69
00:03:03,580 --> 00:03:06,969
can write your name write your email

70
00:03:05,110 --> 00:03:08,440
address on a piece of paper and hand it

71
00:03:06,969 --> 00:03:11,770
to me at the end of the lecture and I'll

72
00:03:08,439 --> 00:03:13,329
make sure you are signed up if you have

73
00:03:11,770 --> 00:03:16,810
comments or questions we have an email

74
00:03:13,330 --> 00:03:21,130
setup public lecture at stsci edu where

75
00:03:16,810 --> 00:03:23,620
you can ask questions social media we

76
00:03:21,129 --> 00:03:26,769
have facebook we have Twitter we have

77
00:03:23,620 --> 00:03:29,110
YouTube we have Instagram if you're into

78
00:03:26,769 --> 00:03:31,930
that Hubble and James Webb and Space

79
00:03:29,110 --> 00:03:34,540
Telescope provide feeds social media

80
00:03:31,930 --> 00:03:37,629
feeds for all of you I myself do a

81
00:03:34,539 --> 00:03:40,298
little bit on with Facebook Google+ and

82
00:03:37,629 --> 00:03:41,859
Twitter so if you'd like to find out

83
00:03:40,299 --> 00:03:46,560
more about me you can follow me on

84
00:03:41,860 --> 00:03:50,320
social media the weather is nice tonight

85
00:03:46,560 --> 00:03:52,000
we would be able to go to the telescope

86

00:03:50,319 --> 00:03:55,239
across the street

87
00:03:52,000 --> 00:03:57,849
except Johns Hopkins University

88
00:03:55,240 --> 00:04:01,000
scheduled an event there tonight and

89
00:03:57,849 --> 00:04:02,530
usurped us so I know last few months

90
00:04:01,000 --> 00:04:04,599
it's been bad weather and we haven't

91
00:04:02,530 --> 00:04:06,550
been able to do it this month it's good

92
00:04:04,599 --> 00:04:09,340
weather but I'm sorry there was another

93
00:04:06,550 --> 00:04:10,870
event already scheduled so we will not

94
00:04:09,340 --> 00:04:13,360
be going to the observatory this after

95
00:04:10,870 --> 00:04:16,239
this evening after the talk however as

96
00:04:13,360 --> 00:04:19,840
always you can go to MD dot space grant

97
00:04:16,238 --> 00:04:22,539
o RG you'll find this webpage about

98
00:04:19,839 --> 00:04:24,668
their open houses on Fridays and this

99
00:04:22,540 --> 00:04:27,189
box over here on the right where it says

100
00:04:24,668 --> 00:04:28,209

Observatory status that is where you

101

00:04:27,189 --> 00:04:30,399

will find out whether or not they're

102

00:04:28,209 --> 00:04:33,310

open this Friday night our next Friday

103

00:04:30,399 --> 00:04:35,139

night are every Friday night and you can

104

00:04:33,310 --> 00:04:38,980

check this if you would like to look

105

00:04:35,139 --> 00:04:42,870

through their telescope and now the news

106

00:04:38,980 --> 00:04:47,350

from the universe from May 2018 our

107

00:04:42,870 --> 00:04:50,410

first story tonight Gaia dr2 which

108

00:04:47,350 --> 00:04:54,460

stands for data released to redefining

109

00:04:50,410 --> 00:04:56,380

the Milky Way and I had such a geek out

110

00:04:54,459 --> 00:04:58,359

last week when this data was released I

111

00:04:56,379 --> 00:05:00,370

had to show you some of this stuff so

112

00:04:58,360 --> 00:05:03,580

let's start let's start with stellar

113

00:05:00,370 --> 00:05:05,530

databases okay so this is a photograph

114

00:05:03,579 --> 00:05:08,289

of the night sky showing what

115
00:05:05,529 --> 00:05:10,689
constellation Orion thank you very much

116
00:05:08,290 --> 00:05:13,629
and you can see the stars here of Orion

117
00:05:10,689 --> 00:05:16,060
and the data for these seven main stars

118
00:05:13,629 --> 00:05:18,759
in Orion might look something like this

119
00:05:16,060 --> 00:05:20,800
and so here we have the the names of the

120
00:05:18,759 --> 00:05:22,149
stars on the left the RA in Dec the

121
00:05:20,800 --> 00:05:24,280
right Ascension and declination they're

122
00:05:22,149 --> 00:05:26,589
positioned on the sky you have the

123
00:05:24,279 --> 00:05:28,269
magnitudes which is their brightness we

124
00:05:26,589 --> 00:05:30,549
have the spectral type which helps give

125
00:05:28,269 --> 00:05:32,859
you their color etc and from these

126
00:05:30,550 --> 00:05:35,680
stellar databases we could create a

127
00:05:32,860 --> 00:05:38,740
picture of Orion and so a visualization

128
00:05:35,680 --> 00:05:40,930
of Orion on the on the right coming from

129
00:05:38,740 --> 00:05:42,639
just the data can produce an image like

130
00:05:40,930 --> 00:05:44,650
that compare it comparable to the

131
00:05:42,639 --> 00:05:47,289
picture and so that image on the right

132
00:05:44,649 --> 00:05:49,539
is only from the data all right and so

133
00:05:47,290 --> 00:05:52,660
the data that goes into that picture

134
00:05:49,540 --> 00:05:54,970
comes from the Hipparcos catalog which

135
00:05:52,660 --> 00:05:57,160
has a hundred and eighteen thousand

136
00:05:54,970 --> 00:06:00,160
stars and it's got the positions on the

137
00:05:57,160 --> 00:06:02,140
sky and it's got the spectral types and

138
00:06:00,160 --> 00:06:04,330
the magnitudes and the parallax and 3d

139
00:06:02,139 --> 00:06:05,310
distances allowing us to visualize the

140
00:06:04,329 --> 00:06:08,490
universe

141
00:06:05,310 --> 00:06:11,610
but Hipparcos flew as a mint a space

142
00:06:08,490 --> 00:06:15,650
mission that flew between 1989 and 1993

143

00:06:11,610 --> 00:06:19,169
and the data set came out in 1997

144
00:06:15,649 --> 00:06:20,099
twenty-one years ago what have we been

145
00:06:19,168 --> 00:06:23,699
doing in the meantime

146
00:06:20,100 --> 00:06:25,439
well the Hipparchus catalog covers just

147
00:06:23,699 --> 00:06:27,269
a small part of our galaxy a hundred

148
00:06:25,439 --> 00:06:30,089
thousand stars sounds like a lot but

149
00:06:27,269 --> 00:06:33,000
when you compare it to our galaxy this

150
00:06:30,089 --> 00:06:34,529
is a visualization of our galaxy an

151
00:06:33,000 --> 00:06:39,480
artist's depiction of our galaxy and

152
00:06:34,529 --> 00:06:41,759
this white spot here that is the extent

153
00:06:39,480 --> 00:06:44,100
of the Hipparcos catalog okay it's

154
00:06:41,759 --> 00:06:45,539
actually 20 times the Hipparcos kettle

155
00:06:44,100 --> 00:06:48,120
because it's really the Tycho catalog

156
00:06:45,540 --> 00:06:50,490
from which type Argos is a subset okay

157
00:06:48,120 --> 00:06:52,709

so it's like if our galaxy is a pizza

158

00:06:50,490 --> 00:06:54,150

it's the size of a sausage a little

159

00:06:52,709 --> 00:06:56,969

sausage piece on our pit on our pizza

160

00:06:54,149 --> 00:07:00,539

okay and that was the state of the art

161

00:06:56,970 --> 00:07:03,900

for the last 20 years until last

162

00:07:00,540 --> 00:07:07,110

Thursday all right they've been doing

163

00:07:03,899 --> 00:07:09,689

the Gaia mission and the Gaia mission is

164

00:07:07,110 --> 00:07:12,900

designed to take up our coast and really

165

00:07:09,689 --> 00:07:15,750

do it well okay and go full-bore with it

166

00:07:12,899 --> 00:07:22,799

okay on Thursday of last week

167

00:07:15,750 --> 00:07:25,560

Gaia released 1.7 billion stars not a

168

00:07:22,800 --> 00:07:30,110

hundred thousand of Hipparcos not the 2

169

00:07:25,560 --> 00:07:35,100

million of Tycho 1.7 billion and this is

170

00:07:30,110 --> 00:07:39,030

not an image this is a data plot from

171

00:07:35,100 --> 00:07:42,539

Gaia this is plotting the color and

172
00:07:39,029 --> 00:07:47,009
brightness of all 1.7 billion stars

173
00:07:42,538 --> 00:07:50,099
across the entire night sky it is so

174
00:07:47,009 --> 00:07:52,500
remarkably detailed it looks like a

175
00:07:50,100 --> 00:07:54,810
photograph but it's not it's a

176
00:07:52,500 --> 00:07:57,389
visualization of a data table think of

177
00:07:54,810 --> 00:07:59,430
an Excel data table with 1.7 billion

178
00:07:57,389 --> 00:08:00,659
entries and you're plotting each one of

179
00:07:59,430 --> 00:08:04,379
those points and combining them all

180
00:08:00,660 --> 00:08:07,320
together that's the picture you get yeah

181
00:08:04,379 --> 00:08:10,110
this is why I was geeking out last week

182
00:08:07,319 --> 00:08:12,029
it's not amazing and let me show you

183
00:08:10,110 --> 00:08:14,370
some of the details because if we zoom

184
00:08:12,029 --> 00:08:16,408
into the center all right you can now

185
00:08:14,370 --> 00:08:17,899
start to see the pixelization of the

186
00:08:16,408 --> 00:08:20,629
other thing and what we

187
00:08:17,899 --> 00:08:24,079
plotting here as all of those stars and

188
00:08:20,629 --> 00:08:26,689
it looks like we've got gas clouds dark

189
00:08:24,079 --> 00:08:29,990
dust clouds in there right there's no

190
00:08:26,689 --> 00:08:32,899
dust clouds in this database what you're

191
00:08:29,990 --> 00:08:34,610
seeing here is the absence of stars now

192
00:08:32,899 --> 00:08:36,918
it's of course due to dust clouds that

193
00:08:34,610 --> 00:08:38,839
are actually out there but we're not

194
00:08:36,918 --> 00:08:40,610
plotting the dust clouds we're pas and

195
00:08:38,839 --> 00:08:42,380
only the stars and you're seeing the

196
00:08:40,610 --> 00:08:45,289
absence of the stars in those regions

197
00:08:42,379 --> 00:08:48,740
where there are dust clouds this

198
00:08:45,289 --> 00:08:51,708
database is so remarkably detailed that

199
00:08:48,740 --> 00:08:54,950
it gets pictures of the Large Magellanic

200

00:08:51,708 --> 00:08:57,500
and small Magellanic Clouds that are

201
00:08:54,950 --> 00:08:59,870
almost 200,000 light years away these

202
00:08:57,500 --> 00:09:02,809
are satellite galaxies of the Milky Way

203
00:08:59,870 --> 00:09:05,269
and you get these remarkably detailed

204
00:09:02,809 --> 00:09:08,509
images of them what look like images

205
00:09:05,269 --> 00:09:11,088
when you plot up the data oh and by the

206
00:09:08,509 --> 00:09:12,528
way this white spot down here that looks

207
00:09:11,089 --> 00:09:16,250
like it's in the small Magellanic Cloud

208
00:09:12,528 --> 00:09:19,278
it's not it's in our galaxy this is the

209
00:09:16,250 --> 00:09:23,778
globular star cluster 47 Tucanae so

210
00:09:19,278 --> 00:09:26,679
you've got 1.7 billion stars in this

211
00:09:23,778 --> 00:09:29,208
database and from it you know just the

212
00:09:26,679 --> 00:09:32,659
brightness in color you get in a

213
00:09:29,208 --> 00:09:34,909
remarkably detailed image but it's got a

214
00:09:32,659 --> 00:09:37,909

lot more because they measured these

215

00:09:34,909 --> 00:09:40,458

stars over and over again to get their

216

00:09:37,909 --> 00:09:44,230

motion on the sky their motion relative

217

00:09:40,458 --> 00:09:47,299

to the Sun and so measuring all those

218

00:09:44,230 --> 00:09:49,759

velocities relative to the Sun we can

219

00:09:47,299 --> 00:09:51,319

measure the motion of our galaxy so this

220

00:09:49,759 --> 00:09:52,819

is the plane of our galaxy here our

221

00:09:51,320 --> 00:09:56,270

planet our galaxy is shaped like a

222

00:09:52,820 --> 00:09:58,820

pancake and that pancake is rotating so

223

00:09:56,269 --> 00:10:00,799

when we look at their velocities and we

224

00:09:58,820 --> 00:10:04,760

measure the Doppler shift we get an

225

00:10:00,799 --> 00:10:07,250

image like this so here the blue is

226

00:10:04,759 --> 00:10:08,929

coming towards us and the red is going

227

00:10:07,250 --> 00:10:11,089

away from us all right

228

00:10:08,929 --> 00:10:13,609

so this is the radial velocity map these

229
00:10:11,089 --> 00:10:18,080
are motions on the sky relative to the

230
00:10:13,610 --> 00:10:20,300
Sun and so inside this circle here in

231
00:10:18,080 --> 00:10:22,310
the central region those are the stars

232
00:10:20,299 --> 00:10:24,769
that are closer to the center of the

233
00:10:22,309 --> 00:10:26,899
galaxy and they're rotating faster than

234
00:10:24,769 --> 00:10:28,338
the Sun so the ones on the right hand

235
00:10:26,899 --> 00:10:29,840
side that blue blob there that's

236
00:10:28,339 --> 00:10:31,580
approaching the Sun

237
00:10:29,840 --> 00:10:33,639
and the red stuff on the left-hand side

238
00:10:31,580 --> 00:10:37,250
that's going away from the Sun

239
00:10:33,639 --> 00:10:39,319
alternatively the outside part beyond

240
00:10:37,250 --> 00:10:41,809
this outside the circle are stars that

241
00:10:39,320 --> 00:10:44,030
are outside the galaxy and the Sun is

242
00:10:41,809 --> 00:10:46,369
moving faster than them so the Sun is

243
00:10:44,029 --> 00:10:48,799
moving away from this red blob over here

244
00:10:46,370 --> 00:10:52,429
on the right and towards this blue blob

245
00:10:48,799 --> 00:10:55,039
over here on the left we are seeing the

246
00:10:52,429 --> 00:10:58,309
rotation of our galaxy in detail as

247
00:10:55,039 --> 00:11:00,589
we've never seen it before okay I mean

248
00:10:58,309 --> 00:11:02,239
if I showed you the plots of what we

249
00:11:00,590 --> 00:11:03,950
used to know about this is there really

250
00:11:02,240 --> 00:11:06,980
patchy and just you know they sort of

251
00:11:03,950 --> 00:11:09,890
get the idea would you this this this

252
00:11:06,980 --> 00:11:11,090
this cause a astronomer a friend of mine

253
00:11:09,889 --> 00:11:14,360
when I showed it to her this afternoon

254
00:11:11,090 --> 00:11:16,490
she just went oh she just started go

255
00:11:14,360 --> 00:11:18,620
mind you started racing about all the

256
00:11:16,490 --> 00:11:21,470
various things they could do if you

257

00:11:18,620 --> 00:11:24,649
looked up the guy the Twitter hashtag a

258
00:11:21,470 --> 00:11:26,990
guy a dr - last Thursday and Friday

259
00:11:24,649 --> 00:11:29,299
you saw a ton of astronomers just

260
00:11:26,990 --> 00:11:31,730
geeking out and trying to you know get

261
00:11:29,299 --> 00:11:33,549
an initial looks of this data set and

262
00:11:31,730 --> 00:11:35,960
trying to find all sorts of cool things

263
00:11:33,549 --> 00:11:40,099
there's gonna be so much discovered from

264
00:11:35,960 --> 00:11:43,160
this that the the discoveries have just

265
00:11:40,100 --> 00:11:44,810
begun and in particular take a look on

266
00:11:43,159 --> 00:11:46,549
this red blob over here on the left in

267
00:11:44,809 --> 00:11:48,319
the center what are these blue blobs

268
00:11:46,549 --> 00:11:50,419
here what are the things on the left

269
00:11:48,320 --> 00:11:52,640
side that should be going away from us

270
00:11:50,419 --> 00:11:54,759
look like they're approaching us what

271
00:11:52,639 --> 00:11:57,289

are the details they're some of the

272

00:11:54,759 --> 00:11:59,929

obvious things to look at and of course

273

00:11:57,289 --> 00:12:02,269

there's a tremendous number of more much

274

00:11:59,929 --> 00:12:05,899

more detailed questions so guy is going

275

00:12:02,269 --> 00:12:10,309

to provide an amazing number of

276

00:12:05,899 --> 00:12:12,009

discoveries and it expands the 3d

277

00:12:10,309 --> 00:12:15,979

distances that we know of in our galaxy

278

00:12:12,009 --> 00:12:18,259

we go from that sausage on the pizza to

279

00:12:15,980 --> 00:12:22,250

a pepperoni a really large pepperoni on

280

00:12:18,259 --> 00:12:24,080

our pizza okay that here on the right

281

00:12:22,250 --> 00:12:27,379

hand side that's plots plot on the right

282

00:12:24,080 --> 00:12:30,230

hand side of Gaia dr2 that is 1.7

283

00:12:27,379 --> 00:12:33,379

billion stars the extent of 1.7 billion

284

00:12:30,230 --> 00:12:35,600

stars and when you look at that you can

285

00:12:33,379 --> 00:12:37,939

start to believe that oh my gosh yeah I

286
00:12:35,600 --> 00:12:40,310
guess the galaxy really does contain a

287
00:12:37,940 --> 00:12:43,100
hundred billion stars if that's all

288
00:12:40,309 --> 00:12:45,949
that's covered by two billion all right

289
00:12:43,100 --> 00:12:47,570
and so more will coming and hopefully in

290
00:12:45,950 --> 00:12:49,070
about a year from now well I'll be able

291
00:12:47,570 --> 00:12:51,410
to have a speaker in to give a talk on

292
00:12:49,070 --> 00:12:55,400
all the amazing discoveries from Gaia

293
00:12:51,409 --> 00:13:00,049
and it's data released to our second

294
00:12:55,399 --> 00:13:04,340
story tonight 28 years of Hubble Hubble

295
00:13:00,049 --> 00:13:06,289
launched on April 24 1990 and every

296
00:13:04,340 --> 00:13:08,750
April we and the office of public

297
00:13:06,289 --> 00:13:10,819
outreach have this huge pressure pushing

298
00:13:08,750 --> 00:13:12,830
down on us come up with a really cool

299
00:13:10,820 --> 00:13:15,650
image to celebrate Hubble's 28th

300
00:13:12,830 --> 00:13:18,200
Hubble's anniversary this year so the

301
00:13:15,649 --> 00:13:20,709
image processors put their thinking caps

302
00:13:18,200 --> 00:13:23,629
on and this year they decided to go with

303
00:13:20,710 --> 00:13:24,860
the Lagoon Nebula okay now this is not a

304
00:13:23,629 --> 00:13:28,189
Hubble image this is a ground-based

305
00:13:24,860 --> 00:13:29,960
image right and actually the Lagoon

306
00:13:28,190 --> 00:13:33,140
Nebula is so large that Hubble can't

307
00:13:29,960 --> 00:13:35,600
really cover this without many many many

308
00:13:33,139 --> 00:13:37,370
pointings so the Hubble images that you

309
00:13:35,600 --> 00:13:39,610
can I'm going to show you is just this

310
00:13:37,370 --> 00:13:41,539
region in the heart of the Lagoon Nebula

311
00:13:39,610 --> 00:13:43,580
because you've got all this beautiful

312
00:13:41,539 --> 00:13:45,620
red gas out here that's sort of been

313
00:13:43,580 --> 00:13:47,360
blown out and that's ionized but where

314

00:13:45,620 --> 00:13:48,950
the star formation is still taking place

315
00:13:47,360 --> 00:13:50,779
is right here in the heart of loon get

316
00:13:48,950 --> 00:13:53,030
Lagoon Nebula and when you look at that

317
00:13:50,779 --> 00:13:56,049
with Hubble resolution using specific

318
00:13:53,029 --> 00:13:59,449
filters to pull out the elements you get

319
00:13:56,049 --> 00:14:02,419
that all right

320
00:13:59,450 --> 00:14:04,550
this side of the room say ooh and this

321
00:14:02,419 --> 00:14:06,029
side of the room say ah ready and hold

322
00:14:04,549 --> 00:14:07,319
on

323
00:14:06,029 --> 00:14:11,278
[Music]

324
00:14:07,320 --> 00:14:13,110
thank you let me zoom in and show you

325
00:14:11,278 --> 00:14:15,629
some of the cool details all right so

326
00:14:13,110 --> 00:14:18,180
right in this central region here we

327
00:14:15,629 --> 00:14:20,639
zoom in you can see that there's a

328
00:14:18,179 --> 00:14:23,189

massive star there it's sort of hidden

329

00:14:20,639 --> 00:14:25,528

behind this curtain of dark gas okay

330

00:14:23,190 --> 00:14:27,209

this is an oast star this is a really

331

00:14:25,528 --> 00:14:29,879

massive star and they tell me it's only

332

00:14:27,208 --> 00:14:32,309

1 million years old it's just been born

333

00:14:29,879 --> 00:14:34,769

yeah 1 million years is not old for a

334

00:14:32,309 --> 00:14:37,500

star ok and you can see how it's

335

00:14:34,769 --> 00:14:40,318

illuminating all that gas in behind that

336

00:14:37,500 --> 00:14:41,909

dark that dark cloud and it's also

337

00:14:40,318 --> 00:14:43,500

producing things like there's this bow

338

00:14:41,909 --> 00:14:45,659

shock down here over on the left where

339

00:14:43,500 --> 00:14:47,250

the wind from That star is pushing back

340

00:14:45,659 --> 00:14:49,469

the gas around it you've got these

341

00:14:47,250 --> 00:14:52,049

pillars etc and there's an incredible

342

00:14:49,470 --> 00:14:53,870

energy not only in the radiation but

343
00:14:52,049 --> 00:14:56,159
also in the wind coming from That star

344
00:14:53,870 --> 00:14:58,799
we've got a lot of other cool things

345
00:14:56,159 --> 00:15:00,809
like on the left here we've got some

346
00:14:58,799 --> 00:15:02,639
ionization fronts there's some stars

347
00:15:00,809 --> 00:15:04,888
that are just off the image of the

348
00:15:02,639 --> 00:15:06,509
Hubble and they're their Energy's coming

349
00:15:04,889 --> 00:15:08,669
down and creating these ionization

350
00:15:06,509 --> 00:15:10,860
fronts here on the left and also this

351
00:15:08,669 --> 00:15:12,899
gorgeous ionization front over here on

352
00:15:10,860 --> 00:15:14,730
the right lower right where you can see

353
00:15:12,899 --> 00:15:17,370
that the energy the ultraviolet

354
00:15:14,730 --> 00:15:20,310
radiation is heating that gas causing it

355
00:15:17,370 --> 00:15:22,709
to ionize go from neutral gas to ionized

356
00:15:20,309 --> 00:15:25,078
gas and then we got these tiny little

357
00:15:22,708 --> 00:15:27,838
pillars in the upper right there where

358
00:15:25,078 --> 00:15:29,429
the gas is being eaten away and all your

359
00:15:27,839 --> 00:15:32,040
left these small little blobs that have

360
00:15:29,429 --> 00:15:34,138
been ionized Weatherhead have little

361
00:15:32,039 --> 00:15:37,110
ionization fronts on top of the pillars

362
00:15:34,139 --> 00:15:40,220
as everything else gets stripped away so

363
00:15:37,110 --> 00:15:42,600
this is the visible light image but

364
00:15:40,220 --> 00:15:44,879
Hubble of course has really good

365
00:15:42,600 --> 00:15:49,470
infrared sensitivities since servicing

366
00:15:44,879 --> 00:15:53,328
mission 4 and visible light we also took

367
00:15:49,470 --> 00:15:56,189
an infrared that looks like that Oh

368
00:15:53,328 --> 00:16:03,169
quite different hey let's go back

369
00:15:56,188 --> 00:16:07,409
visible light infrared visible infrared

370
00:16:03,169 --> 00:16:09,778
look at all the stars alright the longer

371

00:16:07,409 --> 00:16:11,759
wavelengths of infrared passes through

372
00:16:09,778 --> 00:16:14,938
that gas and you can see all the stars

373
00:16:11,759 --> 00:16:16,740
behind it the Lagoon Nebula is toward

374
00:16:14,938 --> 00:16:18,750
the galactic center so it's a very dense

375
00:16:16,740 --> 00:16:20,129
star field that you're only not yet

376
00:16:18,750 --> 00:16:20,610
you're not seeing in visible light

377
00:16:20,129 --> 00:16:23,220
because

378
00:16:20,610 --> 00:16:25,169
of course the gas is blocking it and

379
00:16:23,220 --> 00:16:27,360
when you see the dense gas here in this

380
00:16:25,169 --> 00:16:29,189
visible light all right in here let me

381
00:16:27,360 --> 00:16:31,200
go back and you can see how how dense

382
00:16:29,190 --> 00:16:33,360
the gas appears in the invisible light

383
00:16:31,200 --> 00:16:35,910
right all this central gas looks like

384
00:16:33,360 --> 00:16:38,070
it's really dense but infrared shows you

385
00:16:35,909 --> 00:16:39,929

that most of it's not that dense and

386

00:16:38,070 --> 00:16:42,510

that the infrared light can pass through

387

00:16:39,929 --> 00:16:43,859

it but some part pockets are really

388

00:16:42,509 --> 00:16:46,319

dense because when they're dark and

389

00:16:43,860 --> 00:16:49,440

infrared they're really dense pockets of

390

00:16:46,320 --> 00:16:51,750

gas and so by using both visible and

391

00:16:49,440 --> 00:16:55,800

infrared we gain different pictures of

392

00:16:51,750 --> 00:16:59,009

this of these regions so we put together

393

00:16:55,799 --> 00:17:00,539

a visualization of it and when we were

394

00:16:59,009 --> 00:17:02,399

discussing it we said oh we got all

395

00:17:00,539 --> 00:17:04,289

these all these structures that are

396

00:17:02,399 --> 00:17:05,880

coming from the ionization and from the

397

00:17:04,289 --> 00:17:08,308

winds and we said oh you know what this

398

00:17:05,880 --> 00:17:10,980

was like it's like a sculpture garden of

399

00:17:08,308 --> 00:17:13,789

gas and dust and that's what we called

400
00:17:10,980 --> 00:17:13,789
our visualization

401
00:17:18,809 --> 00:17:22,629
[Music]

402
00:17:42,240 --> 00:17:49,230
and that was a 2d zoom and now we give

403
00:17:46,200 --> 00:17:52,380
you a bit of a 3d feel as we do some

404
00:17:49,230 --> 00:17:55,159
pants across these different sculptures

405
00:17:52,380 --> 00:17:55,159
in the nebula

406
00:17:55,619 --> 00:17:58,799
[Music]

407
00:18:02,200 --> 00:18:15,068
[Music]

408
00:18:42,880 --> 00:18:46,449
[Music]

409
00:18:52,799 --> 00:19:01,710
[Music]

410
00:19:09,200 --> 00:19:13,068
[Music]

411
00:19:13,200 --> 00:19:19,950
and that's how we wish to be a happy

412
00:19:17,170 --> 00:19:24,879
28th anniversary

413
00:19:19,950 --> 00:19:27,759
[Applause]

414
00:19:24,878 --> 00:19:31,728
all right our featured speaker tonight

415
00:19:27,759 --> 00:19:33,889
is dr. Andy whom I met at

416
00:19:31,729 --> 00:19:36,679
Berkeley while he was doing a Hubble

417
00:19:33,888 --> 00:19:40,908
fellowship at Berkeley and I was doing

418
00:19:36,679 --> 00:19:42,979
my PhD work there and he's always been

419
00:19:40,909 --> 00:19:45,259
known as a very jovial and very friendly

420
00:19:42,979 --> 00:19:46,129
guy and I'm so glad that we have him

421
00:19:45,259 --> 00:19:48,499
here today

422
00:19:46,128 --> 00:19:51,168
he did his undergraduate work at Harvard

423
00:19:48,499 --> 00:19:53,959
then spent some time at Cambridge in

424
00:19:51,169 --> 00:19:56,989
England for a bit before doing his PhD

425
00:19:53,959 --> 00:19:59,028
at Princeton he then came to Berkeley

426
00:19:56,989 --> 00:20:00,858
and did his Hubble fellowship there and

427
00:19:59,028 --> 00:20:04,368
let's see you they went to the Carnegie

428

00:20:00,858 --> 00:20:06,108
Institute in Washington before coming

429
00:20:04,368 --> 00:20:10,689
here to the Space Telescope Science

430
00:20:06,108 --> 00:20:12,798
Institute where he's been how many years

431
00:20:10,690 --> 00:20:17,419
20 years cuz you're a little bit longer

432
00:20:12,798 --> 00:20:20,588
than me I've only been here 17 years not

433
00:20:17,419 --> 00:20:24,229
very long by space telescope standards

434
00:20:20,588 --> 00:20:27,499
his functional job but his astronomy

435
00:20:24,229 --> 00:20:31,788
work has been in pulsars and in

436
00:20:27,499 --> 00:20:34,338
supernovae and gamma ray bursts yes very

437
00:20:31,788 --> 00:20:36,200
gamma ray bursts and he'll talk to you

438
00:20:34,338 --> 00:20:38,690
tonight about gravitational wave

439
00:20:36,200 --> 00:20:40,578
astronomy oh I should also mention that

440
00:20:38,690 --> 00:20:42,950
his functional job here is in this

441
00:20:40,578 --> 00:20:45,338
science mission office helping to run

442
00:20:42,950 --> 00:20:49,910

the science program within this building

443

00:20:45,338 --> 00:20:58,679

ladies and gentlemen dr. Andy Fraser

444

00:20:49,910 --> 00:20:58,680

[Applause]

445

00:21:05,059 --> 00:21:11,369

here we go okay excuse me I'm getting

446

00:21:09,420 --> 00:21:22,430

over a cold as many people are these

447

00:21:11,369 --> 00:21:25,679

days so there we go okay

448

00:21:22,430 --> 00:21:28,860

all right so welcome tonight I'll be

449

00:21:25,680 --> 00:21:33,240

speaking about the very beginning of

450

00:21:28,859 --> 00:21:37,500

gravitational wave astronomy in the last

451

00:21:33,240 --> 00:21:40,259

two years we have opened up the universe

452

00:21:37,500 --> 00:21:42,769

in an entirely new way we have detected

453

00:21:40,259 --> 00:21:45,569

gravitational waves from black holes

454

00:21:42,769 --> 00:21:48,509

binaries and these the black holes in

455

00:21:45,569 --> 00:21:50,369

these binaries are from our stellar mass

456

00:21:48,509 --> 00:21:52,529

they know that there are huge black

457
00:21:50,369 --> 00:21:54,750
holes in the center of galaxies but

458
00:21:52,529 --> 00:21:56,789
these black holes are bigger than any

459
00:21:54,750 --> 00:22:00,420
one balco's that we knew existed around

460
00:21:56,789 --> 00:22:02,399
stars that existed from stars we've seen

461
00:22:00,420 --> 00:22:05,160
many of them are we've seen black holes

462
00:22:02,400 --> 00:22:06,990
merge into a seat black holes come

463
00:22:05,160 --> 00:22:11,340
together and merge into a single black

464
00:22:06,990 --> 00:22:15,230
hole right and you'll see that today and

465
00:22:11,339 --> 00:22:18,209
we've located a neutron star binary

466
00:22:15,230 --> 00:22:22,849
which emitted gravitational waves giving

467
00:22:18,210 --> 00:22:24,809
its position in its distance and we saw

468
00:22:22,849 --> 00:22:28,099
electromagnet alight that we're seeing

469
00:22:24,809 --> 00:22:33,119
we saw light from it gamma rays radio

470
00:22:28,099 --> 00:22:36,179
optical infrared and we saw what we saw

471
00:22:33,119 --> 00:22:39,089
the radioactive decay of material flung

472
00:22:36,180 --> 00:22:42,810
out from these neutron stars and we

473
00:22:39,089 --> 00:22:44,730
believe that this material is the basis

474
00:22:42,809 --> 00:22:47,179
of most of the healthy elements in the

475
00:22:44,730 --> 00:22:50,250
galaxies in the universe that is

476
00:22:47,180 --> 00:22:52,710
supernovae produce oxygen carbon

477
00:22:50,250 --> 00:22:55,259
hydrogen and things like that also winds

478
00:22:52,710 --> 00:23:01,160
off star witness off stars do that too

479
00:22:55,259 --> 00:23:03,720
but but to get things like gold lead

480
00:23:01,160 --> 00:23:05,519
uranium was very hard from supernovae

481
00:23:03,720 --> 00:23:07,759
people didn't know how to do it we think

482
00:23:05,519 --> 00:23:10,519
that they come from merging neutron

483
00:23:07,759 --> 00:23:12,379
stars now so that wedding ring on your

484
00:23:10,519 --> 00:23:13,940
finger if you have one that came out of

485

00:23:12,380 --> 00:23:20,630
a neutral that came from a neutron star

486
00:23:13,940 --> 00:23:23,000
we think okay so in this talk I'm gonna

487
00:23:20,630 --> 00:23:25,730
start off with a bit of background on

488
00:23:23,000 --> 00:23:28,309
what gravitational waves are and how we

489
00:23:25,730 --> 00:23:30,769
detect them right and because that's

490
00:23:28,309 --> 00:23:32,480
that's how we did all of this science so

491
00:23:30,769 --> 00:23:34,940
what was the basis of all this science

492
00:23:32,480 --> 00:23:36,470
and then I'm gonna talk about again some

493
00:23:34,940 --> 00:23:38,720
of that astrophysics that I just gave

494
00:23:36,470 --> 00:23:40,610
you a broad overview of and then I'll

495
00:23:38,720 --> 00:23:42,730
talk a bit about what we might expect in

496
00:23:40,609 --> 00:23:42,729
the future

497
00:23:43,990 --> 00:23:50,240
so Einstein had so many great insights

498
00:23:47,750 --> 00:23:52,279
that it's hard to keep track but the one

499
00:23:50,240 --> 00:23:53,539

that's going to be most relevant tonight

500

00:23:52,279 --> 00:23:56,839

though there's another one that will be

501

00:23:53,539 --> 00:23:58,819

later is from how he's the basis of

502

00:23:56,839 --> 00:24:02,779

what we call general relativity his

503

00:23:58,819 --> 00:24:05,299

theory of general relativity and one of

504

00:24:02,779 --> 00:24:07,399

the insights in the formation of that

505

00:24:05,299 --> 00:24:11,119

theory was to realize that he could

506

00:24:07,400 --> 00:24:14,780

explain many of the ideas that he had by

507

00:24:11,119 --> 00:24:18,919

conceptualizing gravity as a change in

508

00:24:14,779 --> 00:24:21,529

the geometry of the universe so that if

509

00:24:18,920 --> 00:24:23,450

you imagine that this is the this is the

510

00:24:21,529 --> 00:24:25,369

Sun and this is the earth now why does

511

00:24:23,450 --> 00:24:27,980

the earth go in a circle around the Sun

512

00:24:25,369 --> 00:24:29,659

well the earth in nine science idea

513

00:24:27,980 --> 00:24:32,089

wants to follow go in a straight path

514
00:24:29,660 --> 00:24:34,130
but it's anything in free it's in free

515
00:24:32,089 --> 00:24:36,559
fall around the Sun so it should just go

516
00:24:34,130 --> 00:24:37,730
in a straight path should it doesn't

517
00:24:36,559 --> 00:24:39,259
feel it doesn't feel that it's

518
00:24:37,730 --> 00:24:41,809
accelerated it thinks it's going

519
00:24:39,259 --> 00:24:44,509
straight but what Einstein realized is

520
00:24:41,809 --> 00:24:46,700
well if a curved space-time right then a

521
00:24:44,509 --> 00:24:48,799
straight path is just like just like a

522
00:24:46,700 --> 00:24:50,539
great circle if I walk straight out of

523
00:24:48,799 --> 00:24:52,369
this room and keep going and then swim a

524
00:24:50,539 --> 00:24:54,619
bit and then walk a bit in this will bit

525
00:24:52,369 --> 00:24:56,359
I'll end up right back where I started

526
00:24:54,619 --> 00:24:57,949
right yeah all the while I'm thinking

527
00:24:56,359 --> 00:24:59,569
I'm going a straight line but in fact

528
00:24:57,950 --> 00:25:03,140
I'm doing a curve all around the earth

529
00:24:59,569 --> 00:25:05,779
right and in the same way in the in this

530
00:25:03,140 --> 00:25:08,540
conceptualization the earth is going on

531
00:25:05,779 --> 00:25:15,349
a curve is going straight around the

532
00:25:08,539 --> 00:25:17,389
Great Circle around the Sun and so that

533
00:25:15,349 --> 00:25:19,609
he's bending so basically gravity is

534
00:25:17,390 --> 00:25:21,080
bending space-time it's bending the

535
00:25:19,609 --> 00:25:24,169
shape of space in the way

536
00:25:21,079 --> 00:25:28,009
that gravity feels with our bodies feel

537
00:25:24,170 --> 00:25:29,990
it right now he also realized that just

538
00:25:28,009 --> 00:25:31,009
like in electromagnetism or very similar

539
00:25:29,990 --> 00:25:33,049
to an electromagnetism

540
00:25:31,009 --> 00:25:34,039
if you accelerate an electron or a

541
00:25:33,049 --> 00:25:37,009
charged particle

542

00:25:34,039 --> 00:25:39,559
you'll radiate he realized that the

543
00:25:37,009 --> 00:25:43,269
motion that accelerating chart that mass

544
00:25:39,559 --> 00:25:46,549
can also produce gravitational radiation

545
00:25:43,269 --> 00:25:49,400
so here's a picture of that so you can

546
00:25:46,549 --> 00:25:51,769
imagine tear a - object - - but we'll

547
00:25:49,400 --> 00:25:55,759
find out their black holes modeled black

548
00:25:51,769 --> 00:25:58,129
holes right and they're in a binary now

549
00:25:55,759 --> 00:26:00,170
what they're doing is radiating these

550
00:25:58,130 --> 00:26:02,180
are gravitational waves out going out

551
00:26:00,170 --> 00:26:04,009
and the gravitational waves actually are

552
00:26:02,180 --> 00:26:06,500
changing the shape of space-time because

553
00:26:04,009 --> 00:26:08,960
they're energy and the energy deforms

554
00:26:06,500 --> 00:26:11,720
just like mass gravity and then they're

555
00:26:08,960 --> 00:26:18,650
they've merged and the gravity waves

556
00:26:11,720 --> 00:26:20,539

stop coming out note also that when you

557

00:26:18,650 --> 00:26:23,900

emit gravity waves you're emitting

558

00:26:20,539 --> 00:26:26,480

energy so the binary is losing energy so

559

00:26:23,900 --> 00:26:29,330

the two stars fall in towards each other

560

00:26:26,480 --> 00:26:30,860

as they lose that energy and they put

561

00:26:29,329 --> 00:26:32,119

out more energy they fall further in

562

00:26:30,859 --> 00:26:33,889

towards each other they put a more

563

00:26:32,119 --> 00:26:37,069

ungettable further and eventually they

564

00:26:33,890 --> 00:26:40,070

merge right so gravity waves can

565

00:26:37,069 --> 00:26:42,649

actually actually causes binaries to

566

00:26:40,069 --> 00:26:44,450

merge now if they're very far apart and

567

00:26:42,650 --> 00:26:46,460

moving slowly it could take much longer

568

00:26:44,450 --> 00:26:48,980

than the age of the universe but many

569

00:26:46,460 --> 00:26:51,049

objects are tight are massive enough and

570

00:26:48,980 --> 00:26:53,450

at fast enough orbits that the radio a

571
00:26:51,049 --> 00:26:59,419
didn't radiate away their energy and Oh

572
00:26:53,450 --> 00:27:01,850
in that we can hope to see it so what

573
00:26:59,420 --> 00:27:03,620
what what a black hole merger look like

574
00:27:01,849 --> 00:27:06,980
right so this is if we were actually

575
00:27:03,619 --> 00:27:12,229
looking at it with a telescope by tube

576
00:27:06,980 --> 00:27:15,349
massive black holes now what weird it's

577
00:27:12,230 --> 00:27:19,519
let's see show me there no it's not sure

578
00:27:15,349 --> 00:27:24,169
it's not there it is if I click it okay

579
00:27:19,519 --> 00:27:27,049
it worked like that okay go to the next

580
00:27:24,170 --> 00:27:33,629
one hmm it's works differently on this

581
00:27:27,049 --> 00:27:37,359
than it does on a desktop so

582
00:27:33,628 --> 00:27:39,368
you're seeing here the they grab it the

583
00:27:37,359 --> 00:27:42,939
two black holes go around this is the

584
00:27:39,368 --> 00:27:44,589
gravitational lensing that we just Frank

585
00:27:42,940 --> 00:27:47,019
spoke about earlier these are the black

586
00:27:44,589 --> 00:27:48,939
holes changing the light changing the

587
00:27:47,019 --> 00:27:51,509
shape of the objects behind them because

588
00:27:48,940 --> 00:27:54,489
they're lane creating a distorted lens

589
00:27:51,509 --> 00:27:56,889
and then of it here they are basically

590
00:27:54,489 --> 00:27:58,929
coming together into one final black

591
00:27:56,888 --> 00:28:02,099
hole it sends out some gravitational

592
00:27:58,929 --> 00:28:05,739
waves here it ended a changes shape

593
00:28:02,099 --> 00:28:08,439
there's a point does its final dance and

594
00:28:05,739 --> 00:28:10,899
that is the what you would see if you

595
00:28:08,440 --> 00:28:13,600
could actually take a Hubble image of a

596
00:28:10,898 --> 00:28:17,319
gret of a merging black hole the problem

597
00:28:13,599 --> 00:28:21,219
is this is this image is about a

598
00:28:17,319 --> 00:28:23,470
millionth the size of a Hubble pixel so

599

00:28:21,220 --> 00:28:25,329
it's gonna be hard for us to get that

600
00:28:23,470 --> 00:28:26,618
image right that that is sort of a

601
00:28:25,329 --> 00:28:28,898
visualization that they did out of

602
00:28:26,618 --> 00:28:30,069
Caltech but so you really gotta break

603
00:28:28,898 --> 00:28:33,308
that if you want to see this we can have

604
00:28:30,069 --> 00:28:34,778
to see it some other way now there is a

605
00:28:33,308 --> 00:28:37,418
project going on right now

606
00:28:34,778 --> 00:28:40,569
to image the black hole at the center of

607
00:28:37,419 --> 00:28:42,220
our galaxy and it's a huge project using

608
00:28:40,569 --> 00:28:44,138
radio telescopes all across

609
00:28:42,220 --> 00:28:46,298
millimeter-wave tells us all across the

610
00:28:44,138 --> 00:28:48,699
earth and they're going to try to create

611
00:28:46,298 --> 00:28:50,288
a picture basically making the earth

612
00:28:48,700 --> 00:28:53,409
this antenna the size of the earth

613
00:28:50,288 --> 00:28:54,669

trying to get that picture and they're

614

00:28:53,409 --> 00:28:56,259
still working on it it's a very hard

615

00:28:54,669 --> 00:28:57,940
project but we may get it and they may

616

00:28:56,259 --> 00:29:00,548
be able to resolve the black hole at the

617

00:28:57,940 --> 00:29:02,558
center of the galaxy but these to do

618

00:29:00,548 --> 00:29:04,868
that that's just a very that's our

619

00:29:02,558 --> 00:29:06,908
closest large black hole right to do

620

00:29:04,868 --> 00:29:11,769
that in another galaxy is way beyond our

621

00:29:06,909 --> 00:29:12,820
means right now so I'm gonna suggest we

622

00:29:11,769 --> 00:29:15,608
do something crazy

623

00:29:12,819 --> 00:29:19,239
let's try neutron stars instead now but

624

00:29:15,608 --> 00:29:22,148
they're not much bigger in fact this is

625

00:29:19,239 --> 00:29:23,980
a this was put together by colleagues at

626

00:29:22,148 --> 00:29:27,189
Northwestern University who had a

627

00:29:23,980 --> 00:29:31,690
conference and this is a neutron star

628
00:29:27,190 --> 00:29:34,058
over Chicago that's the size the neutron

629
00:29:31,690 --> 00:29:38,859
star is about I don't know what 10 miles

630
00:29:34,058 --> 00:29:41,230
across or so and so they're not very big

631
00:29:38,858 --> 00:29:44,408
but they're made of matter

632
00:29:41,230 --> 00:29:47,019
black holes are dark right neutron stars

633
00:29:44,409 --> 00:29:49,390
are matter still

634
00:29:47,019 --> 00:29:51,849
the way you Foreman so when the earth

635
00:29:49,390 --> 00:29:53,860
when the Sun runs out of fuel it's going

636
00:29:51,849 --> 00:29:58,869
to collapse down to what's called the

637
00:29:53,859 --> 00:30:00,969
white dwarf which is a star that is

638
00:29:58,869 --> 00:30:02,678
basically just atoms packed together as

639
00:30:00,970 --> 00:30:03,610
tight as you can get them and what

640
00:30:02,679 --> 00:30:06,429
supports them

641
00:30:03,609 --> 00:30:07,990
is the fact that electrons are called

642
00:30:06,429 --> 00:30:10,269
Fermi their type of particles called

643
00:30:07,990 --> 00:30:10,778
fermions and fermions to be back

644
00:30:10,269 --> 00:30:12,970
together

645
00:30:10,778 --> 00:30:14,769
they're very anti-social there is no

646
00:30:12,970 --> 00:30:16,839
type of particle called bosons it spins

647
00:30:14,769 --> 00:30:19,690
but spins they are bosons love to be

648
00:30:16,839 --> 00:30:21,759
together fermions hate it and you just

649
00:30:19,690 --> 00:30:23,649
basically you can push and push and push

650
00:30:21,759 --> 00:30:25,148
and they won't go any further but

651
00:30:23,648 --> 00:30:26,469
eventually if you push hard enough you

652
00:30:25,148 --> 00:30:29,619
put enough matter onto that white dwarf

653
00:30:26,470 --> 00:30:30,009
it says okay well I just can't take this

654
00:30:29,619 --> 00:30:33,038
anymore

655
00:30:30,009 --> 00:30:35,230
I'm going into the nucleus and the white

656

00:30:33,038 --> 00:30:37,990
the electron goes into the nucleus it

657
00:30:35,230 --> 00:30:39,909
combines with a proton and the charge of

658
00:30:37,990 --> 00:30:42,940
the proton the electric cancel and they

659
00:30:39,909 --> 00:30:44,679
produce a neutron and so the star turn

660
00:30:42,940 --> 00:30:46,778
all those electrons get captured by all

661
00:30:44,679 --> 00:30:48,909
the protons and what is left is a star

662
00:30:46,778 --> 00:30:51,190
that's just full of neutrons basically

663
00:30:48,909 --> 00:30:54,760
just a neutron matter and that's what we

664
00:30:51,190 --> 00:30:57,519
call a neutron star and neutrons are

665
00:30:54,759 --> 00:30:59,648
also fermions so again it takes a lot a

666
00:30:57,519 --> 00:31:00,908
lot of matter to make them do anything

667
00:30:59,648 --> 00:31:02,678
else but eventually if you put even more

668
00:31:00,909 --> 00:31:07,179
matter onto neutron star it will

669
00:31:02,679 --> 00:31:09,519
collapse down to a black hole and so if

670
00:31:07,179 --> 00:31:12,130

you merge two neutron stars you will

671
00:31:09,519 --> 00:31:14,319
often have enough matter we think that

672
00:31:12,130 --> 00:31:19,870
they will leave behind a black hole

673
00:31:14,319 --> 00:31:23,288
we'll be seeing that there so neutron

674
00:31:19,869 --> 00:31:28,089
stars are also the basis of what go

675
00:31:23,288 --> 00:31:30,690
pulsars pulsars are these magnetized

676
00:31:28,089 --> 00:31:35,199
neutron stars which are spinning and

677
00:31:30,690 --> 00:31:38,620
they basically produce a basically here

678
00:31:35,200 --> 00:31:41,679
this becomes like a lighthouse and that

679
00:31:38,619 --> 00:31:44,379
swings around and if it happens to point

680
00:31:41,679 --> 00:31:46,450
at your direction a life left you see it

681
00:31:44,380 --> 00:31:48,370
flash go off and then it swings away and

682
00:31:46,450 --> 00:31:50,080
it goes off it goes off and then you

683
00:31:48,369 --> 00:31:51,609
turn points at you and it's bright and

684
00:31:50,079 --> 00:31:54,158
then it goes away from most of the time

685
00:31:51,609 --> 00:31:57,308
in it's dark and so you can use that as

686
00:31:54,159 --> 00:31:59,350
a clock you can say okay I can watch and

687
00:31:57,308 --> 00:32:00,359
it's very regular cuz it's a massive

688
00:31:59,349 --> 00:32:02,038
object spinning

689
00:32:00,359 --> 00:32:06,000
so you can say okay no that neutron

690
00:32:02,038 --> 00:32:08,158
stars spin say 30 times second right so

691
00:32:06,000 --> 00:32:10,288
then I can just count those times it's

692
00:32:08,159 --> 00:32:12,600
spinning I can count the clicks as it

693
00:32:10,288 --> 00:32:14,460
goes by now if it's coming toward if

694
00:32:12,599 --> 00:32:16,139
it's a binary sometimes they'll be

695
00:32:14,460 --> 00:32:17,069
coming towards me is sometimes they'll

696
00:32:16,140 --> 00:32:19,259
be coming away from me

697
00:32:17,069 --> 00:32:24,450
and it'll have a Doppler shift so was it

698
00:32:19,259 --> 00:32:25,740
coming away from if you turn it this out

699
00:32:24,450 --> 00:32:26,880
we're gonna be turning something other

700
00:32:25,740 --> 00:32:31,259
things that the sound later and it'll

701
00:32:26,880 --> 00:32:33,059
sound much better than me and and so

702
00:32:31,259 --> 00:32:34,619
they you can use that as a clock so you

703
00:32:33,058 --> 00:32:36,509
can say okay I know whether I can follow

704
00:32:34,619 --> 00:32:44,209
that neutron star in its orbit

705
00:32:36,509 --> 00:32:49,558
okay so what happens in the 1970s was

706
00:32:44,210 --> 00:32:54,630
this pulsar 1913 +16 was discovered and

707
00:32:49,558 --> 00:32:57,359
this pulsar M is in an orbit with

708
00:32:54,630 --> 00:32:59,399
another neutron star the other neutron

709
00:32:57,359 --> 00:33:01,189
star is not a pulsar as far as we know

710
00:32:59,398 --> 00:33:07,408
if it is it's not pointing towards us

711
00:33:01,190 --> 00:33:10,429
but we can measure its orbit and its

712
00:33:07,409 --> 00:33:13,440
orbit is changing it's actually getting

713

00:33:10,429 --> 00:33:18,480
faster and that's what this curve is

714
00:33:13,440 --> 00:33:21,120
showing you here the orbit shrinks by

715
00:33:18,480 --> 00:33:23,220
about seven meters a year so that's the

716
00:33:21,119 --> 00:33:25,648
amazing thing about this this pulsar

717
00:33:23,220 --> 00:33:30,389
it's a very regular clock so you can do

718
00:33:25,648 --> 00:33:33,239
incredibly precise measurements and it

719
00:33:30,388 --> 00:33:34,888
radiates about 2% of it of the solar

720
00:33:33,240 --> 00:33:36,808
luminosity about about 2% of the energy

721
00:33:34,888 --> 00:33:38,788
of the Sun is what it's radiating so

722
00:33:36,808 --> 00:33:39,960
it's losing energy and that's causing

723
00:33:38,788 --> 00:33:42,690
this orbit to decay

724
00:33:39,960 --> 00:33:44,819
right now our solar system doesn't

725
00:33:42,690 --> 00:33:46,950
radiate much energy the solar system

726
00:33:44,819 --> 00:33:49,548
radiates about 5,000 watts in

727
00:33:46,950 --> 00:33:51,990

gravitational energy so less than a

728

00:33:49,548 --> 00:33:56,548

hefty air-conditioner on a summers day

729

00:33:51,990 --> 00:33:57,538

right but but it so that's not you're

730

00:33:56,548 --> 00:33:58,980

not gonna get much energy out of the

731

00:33:57,538 --> 00:34:00,388

solar system that way but you'll see

732

00:33:58,980 --> 00:34:04,769

that some things give out a lot of

733

00:34:00,388 --> 00:34:08,848

gravitational wave energy and this will

734

00:34:04,769 --> 00:34:10,588

merge in about 300 million years now

735

00:34:08,849 --> 00:34:12,269

this this was discovered by hosts and

736

00:34:10,588 --> 00:34:14,610

Taylor Russ Holson Joe tiller Joe tiller

737

00:34:12,269 --> 00:34:19,349

was my adviser at Princeton

738

00:34:14,610 --> 00:34:22,919

and I'm he actually offered they got the

739

00:34:19,349 --> 00:34:24,569

Nobel Prize for this in 1993 Russ host

740

00:34:22,918 --> 00:34:27,210

was his grad student at the University

741

00:34:24,570 --> 00:34:28,710

of Massachusetts and Joe is then at

742
00:34:27,210 --> 00:34:32,929
University of Massachusetts and then at

743
00:34:28,710 --> 00:34:32,929
the time and then moved to Princeton and

744
00:34:33,050 --> 00:34:40,050
Princeton figured this was coming I

745
00:34:35,099 --> 00:34:42,929
think he had some trouble with the

746
00:34:40,050 --> 00:34:45,289
Pulsar company though while I was there

747
00:34:42,929 --> 00:34:50,148
they sent him a cease and desist letter

748
00:34:45,289 --> 00:34:55,199
they said the Pulsar name is trademarked

749
00:34:50,148 --> 00:34:56,039
and so you cannot use it well we know

750
00:34:55,199 --> 00:35:01,529
how that turned out

751
00:34:56,039 --> 00:35:03,389
but so we still use it and I but the

752
00:35:01,530 --> 00:35:06,560
post our company that I think that

753
00:35:03,389 --> 00:35:10,650
watches are still around so all right

754
00:35:06,559 --> 00:35:13,230
and and they got the this prize for

755
00:35:10,650 --> 00:35:15,420
discard it was for discovering this

756
00:35:13,230 --> 00:35:17,570
pulsar mainly and which could give

757
00:35:15,420 --> 00:35:20,880
insight into gravitation gravitation

758
00:35:17,570 --> 00:35:23,550
which it did it that was indirect so

759
00:35:20,880 --> 00:35:24,960
what you're seeing there right what

760
00:35:23,550 --> 00:35:28,289
you're seeing there is the loss of

761
00:35:24,960 --> 00:35:31,380
energy due to gravitational waves this

762
00:35:28,289 --> 00:35:35,279
was proof in it Matt that line there is

763
00:35:31,380 --> 00:35:38,970
in Stein's prediction and the dots are

764
00:35:35,280 --> 00:35:40,530
the data right so it's incredibly good

765
00:35:38,969 --> 00:35:44,608
agreement between what Einstein

766
00:35:40,530 --> 00:35:46,440
predicted and what we observe and you

767
00:35:44,608 --> 00:35:48,090
can you there are so many so much

768
00:35:46,440 --> 00:35:49,590
information from this that you can solve

769
00:35:48,090 --> 00:35:52,230
for all the parameters there's no

770

00:35:49,590 --> 00:35:54,180
assumptions in this and you tie it you

771
00:35:52,230 --> 00:35:57,630
saw for the entire system and you get

772
00:35:54,179 --> 00:36:00,179
that agreement is astonishing so this

773
00:35:57,630 --> 00:36:03,450
was a remarkable can con formation of

774
00:36:00,179 --> 00:36:05,099
general relativity but it wasn't the

775
00:36:03,449 --> 00:36:06,929
direct detection it was an indirect

776
00:36:05,099 --> 00:36:08,279
detection of gravitational waves so

777
00:36:06,929 --> 00:36:12,239
there was still another Nobel Prize out

778
00:36:08,280 --> 00:36:14,010
there to give you gotten so how do you

779
00:36:12,239 --> 00:36:15,419
what how would you what does it mean to

780
00:36:14,010 --> 00:36:17,220
detect a gravitational wave what is a

781
00:36:15,420 --> 00:36:18,900
gravitational wave so I've told you it's

782
00:36:17,219 --> 00:36:23,969
energy but what does it do when it goes

783
00:36:18,900 --> 00:36:26,940
by it does this it distorts space and

784
00:36:23,969 --> 00:36:30,329

time and that it does it in a funny way

785

00:36:26,940 --> 00:36:32,329

so that if I were being a graduation we

786

00:36:30,329 --> 00:36:35,608

was coming this way right I would be

787

00:36:32,329 --> 00:36:38,099

stretched this way and we brought me a

788

00:36:35,608 --> 00:36:39,869

thinner this way and then I would be

789

00:36:38,099 --> 00:36:42,358

pushed down like this way and made

790

00:36:39,869 --> 00:36:44,450

broader this way simultaneously right so

791

00:36:42,358 --> 00:36:47,909

it's a simultaneous stretch and pull

792

00:36:44,449 --> 00:36:50,519

that goes on and in fact this is just

793

00:36:47,909 --> 00:36:52,469

one there's another mode that's it 45

794

00:36:50,519 --> 00:36:54,949

degrees like this but I'm not gonna try

795

00:36:52,469 --> 00:36:58,679

to do that mode I'll kill myself but

796

00:36:54,949 --> 00:37:02,689

okay so and then here in the blue I've

797

00:36:58,679 --> 00:37:02,690

got a version that shows it as a slinky

798

00:37:02,840 --> 00:37:07,920

right so that's what a gravitational

799

00:37:05,280 --> 00:37:12,450
wave does it stretches and pull it

800

00:37:07,920 --> 00:37:14,400
stretches and compresses space-time but

801

00:37:12,449 --> 00:37:14,969
gravity is weak what I mean by gravity

802

00:37:14,400 --> 00:37:16,619
is weak

803

00:37:14,969 --> 00:37:18,419
well you're every time you will get a

804

00:37:16,619 --> 00:37:20,940
refrigerator magnet you're seeing their

805

00:37:18,420 --> 00:37:23,099
gravity is weak right you have the whole

806

00:37:20,940 --> 00:37:25,139
earth trying to pull down that little

807

00:37:23,099 --> 00:37:27,659
tiny magnet and what little buddy Magnus

808

00:37:25,139 --> 00:37:30,269
next to a refrigerator right and it's

809

00:37:27,659 --> 00:37:32,519
it's resisting the pull of the whole of

810

00:37:30,269 --> 00:37:34,409
the earth that's what we mean by gravity

811

00:37:32,519 --> 00:37:37,050
is weak compared to electromagnetism

812

00:37:34,409 --> 00:37:38,819
right it takes a lot of a lot of matter

813
00:37:37,050 --> 00:37:40,769
to have this sort of force that

814
00:37:38,820 --> 00:37:48,150
electromagnetism does with just a few

815
00:37:40,769 --> 00:37:49,650
particles and so if we ask what is the

816
00:37:48,150 --> 00:37:51,059
brightest source we would expect to see

817
00:37:49,650 --> 00:37:53,010
about once per year right

818
00:37:51,059 --> 00:37:54,299
the longer you wait the brighter some

819
00:37:53,010 --> 00:37:56,070
source is going to be because something

820
00:37:54,300 --> 00:37:57,840
will happen closer right but you say

821
00:37:56,070 --> 00:38:00,420
well we sort of good we had to do

822
00:37:57,840 --> 00:38:02,940
predictions of how bright will things

823
00:38:00,420 --> 00:38:04,889
typically be and we had estimates that

824
00:38:02,940 --> 00:38:09,329
were between you know order to a third

825
00:38:04,889 --> 00:38:10,980
order of a factor of 100 really and we

826
00:38:09,329 --> 00:38:13,019
could guess about how it you would need

827

00:38:10,980 --> 00:38:16,019
and we figure we'll probably about one

828
00:38:13,019 --> 00:38:18,449
part in 10 to the 21 that's 1,000

829
00:38:16,019 --> 00:38:20,730
billion billions it's a tiny little bit

830
00:38:18,449 --> 00:38:22,649
but what does that mean what do we mean

831
00:38:20,730 --> 00:38:27,510
you know how much means that first of

832
00:38:22,650 --> 00:38:29,789
all you're not going to feel it but if

833
00:38:27,510 --> 00:38:31,740
you were build I say I built a detector

834
00:38:29,789 --> 00:38:33,329
that just say is four kilometers long

835
00:38:31,739 --> 00:38:34,019
that's what these are the laser

836
00:38:33,329 --> 00:38:36,779
interferometer gravitational-wave

837
00:38:34,019 --> 00:38:38,099
Observatory LIGO there are two of them

838
00:38:36,780 --> 00:38:40,920
because you

839
00:38:38,099 --> 00:38:43,259
at least two because well it helps you

840
00:38:40,920 --> 00:38:44,960
localize them but also you want to be

841
00:38:43,260 --> 00:38:47,430

sure that you see something it's real

842

00:38:44,960 --> 00:38:50,220

right so that was one of the reasons the

843

00:38:47,429 --> 00:38:52,289

bill - and they're well separated so if

844

00:38:50,219 --> 00:38:53,699

a truck goes by Livingston Louisiana

845

00:38:52,289 --> 00:38:57,150

you don't feel it in Hanford Washington

846

00:38:53,699 --> 00:39:00,809

right and there are four kilometres long

847

00:38:57,150 --> 00:39:03,269

here all right now and the waves will

848

00:39:00,809 --> 00:39:05,969

come by and it'll one way a wave will

849

00:39:03,269 --> 00:39:07,980

stretch this arm while it shrinks this

850

00:39:05,969 --> 00:39:11,459

arm and then it'll stretch this arm

851

00:39:07,980 --> 00:39:13,590

while it shrinks the arm okay and that's

852

00:39:11,460 --> 00:39:16,980

why you build it in this sort of right

853

00:39:13,590 --> 00:39:19,289

angle configuration but if you've got

854

00:39:16,980 --> 00:39:21,389

something four kilometers long or about

855

00:39:19,289 --> 00:39:24,719

two and a half miles long

856
00:39:21,389 --> 00:39:27,750
what does ten that size ten to the minus

857
00:39:24,719 --> 00:39:35,339
twenty-one mean in practice well this is

858
00:39:27,750 --> 00:39:37,170
a hydrogen atom that we're now going in

859
00:39:35,340 --> 00:39:43,650
to see the scale of what you have to

860
00:39:37,170 --> 00:39:45,840
measure that's a proton you have to

861
00:39:43,650 --> 00:39:48,450
measure a tiny fraction of the size of

862
00:39:45,840 --> 00:39:52,470
the proton that's what one of these

863
00:39:48,449 --> 00:39:54,809
waves going by will cause this this arm

864
00:39:52,469 --> 00:39:56,909
to shrink by and expand by so it's

865
00:39:54,809 --> 00:39:59,519
incredibly provides it's so precise that

866
00:39:56,909 --> 00:40:01,109
you think these people are crazy right

867
00:39:59,519 --> 00:40:01,949
there's no way and many people thought

868
00:40:01,110 --> 00:40:04,019
that for a long time hey these people

869
00:40:01,949 --> 00:40:06,419
crazy we'll give them the money yeah

870
00:40:04,019 --> 00:40:10,019
well you know we'll shut up but they're

871
00:40:06,420 --> 00:40:12,090
crazy and to believe that you could do

872
00:40:10,019 --> 00:40:16,980
this right well they've done it it's

873
00:40:12,090 --> 00:40:19,260
amazing and so I'm gonna give you the

874
00:40:16,980 --> 00:40:22,740
video here short little video which

875
00:40:19,260 --> 00:40:24,720
where it introduces ray weiss who is the

876
00:40:22,739 --> 00:40:26,339
person who had the idea basically the

877
00:40:24,719 --> 00:40:28,379
person with the idea of using an

878
00:40:26,340 --> 00:40:31,320
interferometer which is it'll explain

879
00:40:28,380 --> 00:40:33,809
here that the use of white light to

880
00:40:31,320 --> 00:40:39,900
measure the distances and to get this

881
00:40:33,809 --> 00:40:40,320
very very precise measurement oh do we

882
00:40:39,900 --> 00:40:42,300
have

883
00:40:40,320 --> 00:40:44,550
oh wait I don't we check that we check

884

00:40:42,300 --> 00:40:48,500
the sound hopefully we have sound we

885
00:40:44,550 --> 00:40:48,500
have sound well check we'll find out

886
00:40:48,780 --> 00:41:03,690
no we only have sawn from here am I

887
00:40:52,650 --> 00:41:07,280
gonna have to do this I can come I'll

888
00:41:03,690 --> 00:41:07,280
change come I'll come change your city

889
00:41:15,829 --> 00:41:20,670
to leisure the stretching and squeezing

890
00:41:18,440 --> 00:41:24,329
return to a device called an

891
00:41:20,670 --> 00:41:26,909
interferometer a laser beam is split and

892
00:41:24,329 --> 00:41:30,719
sent down a pair of long perpendicular

893
00:41:26,909 --> 00:41:33,049
tubes each precisely the same length the

894
00:41:30,719 --> 00:41:36,329
two beams bounce off mirrors and

895
00:41:33,050 --> 00:41:38,730
recombine back at the base the light

896
00:41:36,329 --> 00:41:47,190
waves come back lined up in such a way

897
00:41:38,730 --> 00:41:49,860
that they cancel each other out gets

898
00:41:47,190 --> 00:41:52,619

detected at the photo detector but when

899

00:41:49,860 --> 00:41:55,050

a gravity wave comes along it distorts

900

00:41:52,619 --> 00:41:57,659

space and changes the distance between

901

00:41:55,050 --> 00:42:00,000

the mirrors one arm becomes a little

902

00:41:57,659 --> 00:42:03,599

longer the other a little shorter an

903

00:42:00,000 --> 00:42:05,519

instant later they switch this back and

904

00:42:03,599 --> 00:42:07,860

forth stretching and squeezing happens

905

00:42:05,519 --> 00:42:11,159

over and over until the wave is passed

906

00:42:07,860 --> 00:42:12,990

as the distances change so does the

907

00:42:11,159 --> 00:42:15,779

alignment between the peaks and valleys

908

00:42:12,989 --> 00:42:17,789

of the two returning light waves and the

909

00:42:15,780 --> 00:42:19,560

light waves no longer cancel each other

910

00:42:17,789 --> 00:42:22,469

out when added together in the

911

00:42:19,559 --> 00:42:24,809

recombined beam now some light does

912

00:42:22,469 --> 00:42:27,299

reach the detector with an intensity

913
00:42:24,809 --> 00:42:30,059
that varies as the distance between the

914
00:42:27,300 --> 00:42:33,630
mirrors varies measure that intensity

915
00:42:30,059 --> 00:42:36,210
and you're measuring gravity waves the

916
00:42:33,630 --> 00:42:38,250
light takes longer time in here and it

917
00:42:36,210 --> 00:42:40,230
did in this arm now it takes a shorter

918
00:42:38,250 --> 00:42:47,730
time and these things don't cancel so

919
00:42:40,230 --> 00:42:49,019
beautifully anymore and as remarkable is

920
00:42:47,730 --> 00:42:51,269
that say you're measuring a tiny

921
00:42:49,019 --> 00:42:52,530
fraction of the wavelength of light but

922
00:42:51,269 --> 00:42:54,269
you have to align these things

923
00:42:52,530 --> 00:42:57,780
incredibly precisely and there's another

924
00:42:54,269 --> 00:42:59,940
trick that they do which isn't talked

925
00:42:57,780 --> 00:43:01,269
about a lot but they they actually put

926
00:42:59,940 --> 00:43:03,369
another mirror in here

927
00:43:01,269 --> 00:43:06,099
and so the light goes back and forth

928
00:43:03,369 --> 00:43:07,869
about a hundred times but it doesn't

929
00:43:06,099 --> 00:43:09,969
about a hundred round trips in there so

930
00:43:07,869 --> 00:43:11,679
rather than being four kilometres these

931
00:43:09,969 --> 00:43:13,959
are basically more like four hundred

932
00:43:11,679 --> 00:43:16,659
kilometers as a result so you get that

933
00:43:13,960 --> 00:43:19,179
extra factor of a hundred so that helps

934
00:43:16,659 --> 00:43:20,619
a tremendous amount right now they have

935
00:43:19,179 --> 00:43:22,929
a number of tricks in here that are

936
00:43:20,619 --> 00:43:25,900
simply amazing that allow that basically

937
00:43:22,929 --> 00:43:29,169
turns this 20 watt laser into 100

938
00:43:25,900 --> 00:43:30,789
kilowatts here so they it's you took

939
00:43:29,170 --> 00:43:34,750
many years of research and development

940
00:43:30,789 --> 00:43:37,480
and from many brilliant people but it is

941

00:43:34,750 --> 00:43:39,250
produced a remarkable device right that

942
00:43:37,480 --> 00:43:45,610
can measure these incredibly small

943
00:43:39,250 --> 00:43:48,280
changes in distance now we can use we

944
00:43:45,610 --> 00:43:51,730
can use general relativity to predict

945
00:43:48,280 --> 00:43:54,400
what we should see if two things were if

946
00:43:51,730 --> 00:43:56,800
you had a binary merge in the wave came

947
00:43:54,400 --> 00:43:59,650
passed by us what would it look like in

948
00:43:56,800 --> 00:44:01,750
this detector right and what you see

949
00:43:59,650 --> 00:44:04,090
you'll see and you get something like

950
00:44:01,750 --> 00:44:06,280
these Wiggles here and that's it you're

951
00:44:04,090 --> 00:44:08,980
the wave passing and what happens here

952
00:44:06,280 --> 00:44:11,080
is it the it's going it's relatively

953
00:44:08,980 --> 00:44:13,900
slowly they get closer together it

954
00:44:11,079 --> 00:44:16,539
speeds up goes very very fast then they

955
00:44:13,900 --> 00:44:19,300

combine and then they're gonna spin down

956

00:44:16,539 --> 00:44:21,460

you get a little shaking of the object

957

00:44:19,300 --> 00:44:23,500

it's right as it settles down here this

958

00:44:21,460 --> 00:44:24,730

is very hard to measure because it's

959

00:44:23,500 --> 00:44:28,420

weak but we have a little bit of

960

00:44:24,730 --> 00:44:29,860

indication and here you can see that

961

00:44:28,420 --> 00:44:31,930

these are two black holes that were

962

00:44:29,860 --> 00:44:33,789

actually seen you can see that there in

963

00:44:31,929 --> 00:44:36,690

the end just before they merge they're

964

00:44:33,789 --> 00:44:40,179

moving at almost the speed of light

965

00:44:36,690 --> 00:44:42,940

incredibly incredibly violent process

966

00:44:40,179 --> 00:44:47,289

going on here right two black holes in a

967

00:44:42,940 --> 00:44:48,519

binary coming together now what they do

968

00:44:47,289 --> 00:44:50,170

is they look at I'll show you in a

969

00:44:48,519 --> 00:44:52,150

minute what the waveform looks what they

970
00:44:50,170 --> 00:44:55,210
actually look at what they do is they

971
00:44:52,150 --> 00:44:56,349
try they take gr and they may take all

972
00:44:55,210 --> 00:44:57,909
these different predictions like what

973
00:44:56,349 --> 00:45:00,699
could all the binary orbits look like

974
00:44:57,909 --> 00:45:03,879
and then they try and fit them to the

975
00:45:00,699 --> 00:45:06,129
data right and when you do that when you

976
00:45:03,880 --> 00:45:07,990
find when you finally get a good fit you

977
00:45:06,130 --> 00:45:10,119
get if you have a say very good

978
00:45:07,989 --> 00:45:12,609
signal-to-noise you learn everything

979
00:45:10,119 --> 00:45:15,009
about these objects it's amazing

980
00:45:12,610 --> 00:45:17,890
you get their mass you get

981
00:45:15,010 --> 00:45:20,110
of the two objects you get how circular

982
00:45:17,889 --> 00:45:23,469
there were how little the orbit is you

983
00:45:20,110 --> 00:45:26,079
get if they're spinning or not you get

984
00:45:23,469 --> 00:45:28,569
how that orbit is oriented with respect

985
00:45:26,079 --> 00:45:30,909
to Earth right is it tilted this way is

986
00:45:28,570 --> 00:45:32,350
that you're looking at edge on and you

987
00:45:30,909 --> 00:45:34,449
get the distant you even get the

988
00:45:32,349 --> 00:45:36,190
distance because if you've got all of

989
00:45:34,449 --> 00:45:38,409
these other things you can predict how

990
00:45:36,190 --> 00:45:40,090
bright it should be and then you look at

991
00:45:38,409 --> 00:45:41,679
how bright it was at earth and you say

992
00:45:40,090 --> 00:45:43,300
well the only way it could be that you

993
00:45:41,679 --> 00:45:45,969
know I know how bright it's like if I

994
00:45:43,300 --> 00:45:47,620
held up a flashlight and you know how

995
00:45:45,969 --> 00:45:49,750
bright that flashlight is you could

996
00:45:47,619 --> 00:45:51,699
guesstimate how far away I am by how

997
00:45:49,750 --> 00:45:54,570
bright the flashlight look to you you

998

00:45:51,699 --> 00:45:56,919
can do the same thing with this binary

999
00:45:54,570 --> 00:45:59,350
so you can get everything about the

1000
00:45:56,920 --> 00:46:01,300
binary for in principle if you have

1001
00:45:59,349 --> 00:46:03,789
really good signal-to-noise so that's

1002
00:46:01,300 --> 00:46:08,350
it's incredible system that incredible

1003
00:46:03,789 --> 00:46:09,340
theory and incredible system of course

1004
00:46:08,349 --> 00:46:11,559
so we don't have infinite

1005
00:46:09,340 --> 00:46:13,210
signal-to-noise so you can't you can do

1006
00:46:11,559 --> 00:46:16,690
well but you can't do perfectly but I'll

1007
00:46:13,210 --> 00:46:22,210
show you that later okay this is what

1008
00:46:16,690 --> 00:46:24,130
the first detection looked like so what

1009
00:46:22,210 --> 00:46:28,000
you see here the best fit is that the

1010
00:46:24,130 --> 00:46:29,800
best fit is that is that predicted line

1011
00:46:28,000 --> 00:46:33,760
right is the weather called predicted

1012
00:46:29,800 --> 00:46:35,620

and the the heavier line is the data and

1013

00:46:33,760 --> 00:46:37,810

there are two different right this is

1014

00:46:35,619 --> 00:46:40,000

Hanford in Washington this is the

1015

00:46:37,809 --> 00:46:42,519

Livingston in Louisiana and here they've

1016

00:46:40,000 --> 00:46:44,800

been aligned because of course depending

1017

00:46:42,519 --> 00:46:47,349

on the direction of the direction of the

1018

00:46:44,800 --> 00:46:48,880

light wave the gravity wave it takes

1019

00:46:47,349 --> 00:46:54,429

about a tenth of a second for it to get

1020

00:46:48,880 --> 00:46:56,019

from Louisiana to Washington there's

1021

00:46:54,429 --> 00:46:57,519

another way to look at it and to say

1022

00:46:56,019 --> 00:46:59,250

okay you big you've heard of sonogram

1023

00:46:57,519 --> 00:47:02,230

that's right what you can plot here is

1024

00:46:59,250 --> 00:47:05,139

the frequency of these Wiggles versus

1025

00:47:02,230 --> 00:47:08,079

time you can see that it goes up with

1026

00:47:05,139 --> 00:47:10,480

time it starts low and goes high I'm

1027
00:47:08,079 --> 00:47:13,569
going to play that this one for you now

1028
00:47:10,480 --> 00:47:16,889
it's very brief so you'll have to we

1029
00:47:13,570 --> 00:47:16,890
also have to do this

1030
00:47:20,190 --> 00:47:23,320
[Music]

1031
00:47:29,159 --> 00:47:35,739
not too impressive we've got a more

1032
00:47:31,630 --> 00:47:37,960
impressive little funny later yeah

1033
00:47:35,739 --> 00:47:46,989
that's the properties black holes it

1034
00:47:37,960 --> 00:47:52,990
does pick like that no fun at all of

1035
00:47:46,989 --> 00:47:54,729
course I couldn't get the okay that's

1036
00:47:52,989 --> 00:48:00,909
what that's the sound of two black holes

1037
00:47:54,730 --> 00:48:03,278
merging sounds like there's a pair of

1038
00:48:00,909 --> 00:48:08,440
chipmunks but it's actually two black

1039
00:48:03,278 --> 00:48:09,670
holes merging okay yeah it's more

1040
00:48:08,440 --> 00:48:14,970
conceptually it's more impressive

1041
00:48:09,670 --> 00:48:18,670
somehow alright

1042
00:48:14,969 --> 00:48:20,889
so undetected it was the merger we know

1043
00:48:18,670 --> 00:48:23,619
it's two black holes from the masses and

1044
00:48:20,889 --> 00:48:26,650
their sizes the black holes weighed

1045
00:48:23,619 --> 00:48:28,329
individually made 36 to 20 x times there

1046
00:48:26,650 --> 00:48:30,940
so they were both about 30 times more

1047
00:48:28,329 --> 00:48:33,130
massive than the Sun this is huge the

1048
00:48:30,940 --> 00:48:35,259
biggest ones we've seen you know

1049
00:48:33,130 --> 00:48:36,880
binaries we look at star other stars and

1050
00:48:35,259 --> 00:48:39,579
ask their own orbits around black holes

1051
00:48:36,880 --> 00:48:43,059
it's been about 15-20 solar masses maybe

1052
00:48:39,579 --> 00:48:44,650
10 is usually very high and so these

1053
00:48:43,059 --> 00:48:46,059
these are incredibly high in fact some

1054
00:48:44,650 --> 00:48:47,829
people have suggested that maybe these

1055

00:48:46,059 --> 00:48:50,500
are primordial maybe they didn't come

1056
00:48:47,829 --> 00:48:51,579
from stellar evolution we don't know we

1057
00:48:50,500 --> 00:48:54,009
think that they can probably come from

1058
00:48:51,579 --> 00:48:55,660
stellar evolution but it's up in the air

1059
00:48:54,009 --> 00:48:57,699
where exactly because we're finding a

1060
00:48:55,659 --> 00:49:01,808
lot of these and it isn't completely

1061
00:48:57,699 --> 00:49:03,909
settled why we're finding so many they

1062
00:49:01,809 --> 00:49:06,970
they came together and formed a new

1063
00:49:03,909 --> 00:49:12,058
black hole of 62 solar masses now 36

1064
00:49:06,969 --> 00:49:14,919
plus 29 is less is greater than 62 right

1065
00:49:12,059 --> 00:49:18,039
three solar masses of energy were

1066
00:49:14,920 --> 00:49:20,019
radiated as gravitational waves that is

1067
00:49:18,039 --> 00:49:22,000
more energy that came out of all the

1068
00:49:20,018 --> 00:49:23,379
stars in the visible universe in the

1069
00:49:22,000 --> 00:49:25,929

same amount of time came and

1070

00:49:23,380 --> 00:49:29,259

gravitational waves now you didn't have

1071

00:49:25,929 --> 00:49:33,338

to duck because gravity is weak but even

1072

00:49:29,259 --> 00:49:35,349

so right the merger happen it was far

1073

00:49:33,338 --> 00:49:37,420

away so it happened 1.2 billion

1074

00:49:35,349 --> 00:49:39,340

light-years away and so one point

1075

00:49:37,420 --> 00:49:42,789

jillion gear is billion years before

1076

00:49:39,340 --> 00:49:45,730

did it so it's a ways but if

1077

00:49:42,789 --> 00:49:49,090

gravitational light gravitational waves

1078

00:49:45,730 --> 00:49:50,920

were light it would have looked that you

1079

00:49:49,090 --> 00:49:53,079

would have seen a star as bright as the

1080

00:49:50,920 --> 00:49:55,030

full moon right if you could have your

1081

00:49:53,079 --> 00:49:56,559

eyes could focus gravitational waves and

1082

00:49:55,030 --> 00:49:59,110

detect them the way you detect light

1083

00:49:56,559 --> 00:50:01,179

then on that night if you looked up you

1084
00:49:59,110 --> 00:50:02,769
would have seen a star for a brief

1085
00:50:01,179 --> 00:50:05,079
amount of time that was as bright as the

1086
00:50:02,769 --> 00:50:06,309
full moon in fact there's a there was a

1087
00:50:05,079 --> 00:50:07,989
full moon last night it's still pretty

1088
00:50:06,309 --> 00:50:10,059
full tonight when you go out we're gonna

1089
00:50:07,989 --> 00:50:11,799
go back and think about well that was a

1090
00:50:10,059 --> 00:50:13,750
that's how bright that gravitational

1091
00:50:11,800 --> 00:50:16,990
wave those gravitational waves were from

1092
00:50:13,750 --> 00:50:21,550
a pair of neutron stars that were 1.2

1093
00:50:16,989 --> 00:50:24,609
billion light years away it's amazing

1094
00:50:21,550 --> 00:50:26,800
now we've now over the past two years

1095
00:50:24,610 --> 00:50:29,740
they found a bunch of these there are

1096
00:50:26,800 --> 00:50:31,360
actually 4 pairs that are well

1097
00:50:29,739 --> 00:50:34,029
identified and there's a fifth one that

1098
00:50:31,360 --> 00:50:35,740
is just right at the level of detection

1099
00:50:34,030 --> 00:50:38,200
so they're not a hundred percent sure

1100
00:50:35,739 --> 00:50:44,439
they really detected it but four or five

1101
00:50:38,199 --> 00:50:47,019
and that I'll show you now is the black

1102
00:50:44,440 --> 00:50:48,849
holes that we knew about from X from

1103
00:50:47,019 --> 00:50:51,639
studies of our galaxy and nearby

1104
00:50:48,849 --> 00:50:53,259
galaxies and their masses nearly all of

1105
00:50:51,639 --> 00:50:53,849
these are more massive than the ones we

1106
00:50:53,260 --> 00:50:58,690
know about

1107
00:50:53,849 --> 00:51:01,480
now the more massive something is the

1108
00:50:58,690 --> 00:51:03,550
further the bigger a strain it produces

1109
00:51:01,480 --> 00:51:07,210
when it moves right the bigger Mort

1110
00:51:03,550 --> 00:51:09,940
radiates and so if it's twice as big it

1111
00:51:07,210 --> 00:51:11,679
produces twice as much strain strain is

1112

00:51:09,940 --> 00:51:13,929
linear with distance so you can see it

1113
00:51:11,679 --> 00:51:16,000
twice as far away it's not like if I

1114
00:51:13,929 --> 00:51:17,500
know with energy if I asked how much was

1115
00:51:16,000 --> 00:51:20,349
in the waves it goes down as the square

1116
00:51:17,500 --> 00:51:22,269
of the distance but the strain that goes

1117
00:51:20,349 --> 00:51:24,309
down as distance so we gain here

1118
00:51:22,269 --> 00:51:26,980
tremendously compared to measuring the

1119
00:51:24,309 --> 00:51:28,239
energy so that if things are if we

1120
00:51:26,980 --> 00:51:30,579
improve if something is twice as

1121
00:51:28,239 --> 00:51:32,859
energetic if it's twice as massive we

1122
00:51:30,579 --> 00:51:35,500
can see twice as far away that means we

1123
00:51:32,860 --> 00:51:38,079
can search a volume that's two cubes or

1124
00:51:35,500 --> 00:51:39,730
eight times larger right so that you

1125
00:51:38,079 --> 00:51:41,559
have a with a more massive object you

1126
00:51:39,730 --> 00:51:43,780

have a much larger search volume and

1127

00:51:41,559 --> 00:51:45,190

that's probably part of this but we

1128

00:51:43,780 --> 00:51:46,780

don't know if it's there's a lot of

1129

00:51:45,190 --> 00:51:48,220

debate about whether it's all of it and

1130

00:51:46,780 --> 00:51:50,080

whether we need something else besides

1131

00:51:48,219 --> 00:51:51,849

just el revolution and a big search

1132

00:51:50,079 --> 00:51:56,289

volume

1133

00:51:51,849 --> 00:51:57,880

and here's where a twice again this was

1134

00:51:56,289 --> 00:52:00,340

Nobel Prize number two for general

1135

00:51:57,880 --> 00:52:02,590

relativity there was no Vern Stein did

1136

00:52:00,340 --> 00:52:04,420

not get a prize for Jeff not even

1137

00:52:02,590 --> 00:52:06,519

special relativity yeah they didn't like

1138

00:52:04,420 --> 00:52:09,579

relativity they called yeah it was too

1139

00:52:06,519 --> 00:52:12,210

Jewish for them they said it was called

1140

00:52:09,579 --> 00:52:18,610

Jewish science by a lot of the the the

1141
00:52:12,210 --> 00:52:22,199
the Germans at the time and so but but

1142
00:52:18,610 --> 00:52:25,660
um but it's everyone science now and it

1143
00:52:22,199 --> 00:52:27,009
and it so now it's gotten it's finally

1144
00:52:25,659 --> 00:52:30,809
gotten its second Nobel Prize for the

1145
00:52:27,010 --> 00:52:33,790
actual detection of gravitational waves

1146
00:52:30,809 --> 00:52:35,860
now Europe wanted adjoining the fun and

1147
00:52:33,789 --> 00:52:38,829
so they built their own detector and

1148
00:52:35,860 --> 00:52:42,099
they they got it turned on in this last

1149
00:52:38,829 --> 00:52:44,619
year and there was the LAT the most

1150
00:52:42,099 --> 00:52:46,539
reasons of the black hole mergers that I

1151
00:52:44,619 --> 00:52:48,969
mentioned there was this one it's not

1152
00:52:46,539 --> 00:52:50,980
quite as sensitive yet as the two ones

1153
00:52:48,969 --> 00:52:53,500
in the US and this one isn't the

1154
00:52:50,980 --> 00:52:55,659
sensitive living isn't this one um they

1155
00:52:53,500 --> 00:52:57,730
up they tried to upgrade them the two

1156
00:52:55,659 --> 00:52:59,289
years ago didn't go so well so they

1157
00:52:57,730 --> 00:53:03,630
brought it back and Hanford never quite

1158
00:52:59,289 --> 00:53:06,340
got back recovered from its upgrade but

1159
00:53:03,630 --> 00:53:08,590
so they're trying to upgrade again you

1160
00:53:06,340 --> 00:53:10,420
know what they need to do to get these

1161
00:53:08,590 --> 00:53:12,039
things stored it's just unbelievably if

1162
00:53:10,420 --> 00:53:13,869
you've seen you saw just a tiny fraction

1163
00:53:12,039 --> 00:53:16,179
of what they need to do right that they

1164
00:53:13,869 --> 00:53:17,559
need to completely isolate them from all

1165
00:53:16,179 --> 00:53:20,409
the size of noise everything it's

1166
00:53:17,559 --> 00:53:22,000
incredibly difficult so I'm just hoping

1167
00:53:20,409 --> 00:53:23,139
that they'll come back and better you

1168
00:53:22,000 --> 00:53:25,119
know much better she they really get

1169

00:53:23,139 --> 00:53:27,759
that factor of two that they're planning

1170
00:53:25,119 --> 00:53:30,639
for the next year we'll see but but

1171
00:53:27,760 --> 00:53:35,290
nonetheless have that third point is

1172
00:53:30,639 --> 00:53:37,539
very because if you want to know where

1173
00:53:35,289 --> 00:53:38,679
they are on the sky it helps

1174
00:53:37,539 --> 00:53:42,579
tremendously

1175
00:53:38,679 --> 00:53:44,019
see these big ellipses big of errors

1176
00:53:42,579 --> 00:53:45,429
circles it's not really a circle it's

1177
00:53:44,019 --> 00:53:46,719
because we usually use from ever to

1178
00:53:45,429 --> 00:53:49,419
circle this is an error ellipse or a

1179
00:53:46,719 --> 00:53:51,159
narrow blob right and there's a blob on

1180
00:53:49,420 --> 00:53:52,269
each side of each hemisphere because you

1181
00:53:51,159 --> 00:53:53,859
couldn't even tell which way it was

1182
00:53:52,269 --> 00:53:55,269
coming from there were two different

1183
00:53:53,860 --> 00:53:56,920

directions with they're just two

1184

00:53:55,269 --> 00:53:58,480

directors there were two different

1185

00:53:56,920 --> 00:54:00,760

directions that it could have been

1186

00:53:58,480 --> 00:54:03,250

coming from with the third detector

1187

00:54:00,760 --> 00:54:05,660

that's no longer possible so these two

1188

00:54:03,250 --> 00:54:08,478

objects

1189

00:54:05,659 --> 00:54:10,489

the European Virgo in place and so we

1190

00:54:08,478 --> 00:54:13,518

could you get a much smaller error

1191

00:54:10,489 --> 00:54:15,829

region and you can tell which hemisphere

1192

00:54:13,518 --> 00:54:17,748

it's in which helps a lot but it the

1193

00:54:15,829 --> 00:54:19,670

fact that it's much smaller it's crucial

1194

00:54:17,748 --> 00:54:22,608

because we'd like to go and search them

1195

00:54:19,670 --> 00:54:25,430

with optical instruments and as you

1196

00:54:22,608 --> 00:54:27,409

heard Frank point get out you the Hubble

1197

00:54:25,429 --> 00:54:29,659

has a very small field of view now there

1198
00:54:27,409 --> 00:54:31,399
are there are optical telescopes with

1199
00:54:29,659 --> 00:54:34,129
larger fields of view than Hubble but

1200
00:54:31,400 --> 00:54:35,690
they're still not you know large they're

1201
00:54:34,130 --> 00:54:38,088
not anything compared to the size of the

1202
00:54:35,690 --> 00:54:43,190
sky so you really need a good position

1203
00:54:38,088 --> 00:54:45,318
and this has helped tremendously now we

1204
00:54:43,190 --> 00:54:47,269
always thought that we would see we knew

1205
00:54:45,318 --> 00:54:48,708
about the host Taylor pulsar so he

1206
00:54:47,268 --> 00:54:51,078
thought we always like we're going to

1207
00:54:48,708 --> 00:54:53,929
see his neutron star is merging and for

1208
00:54:51,079 --> 00:54:56,239
a while we just got black holes but last

1209
00:54:53,929 --> 00:54:59,199
late last year three days after that

1210
00:54:56,239 --> 00:55:01,639
last black hole that the Europeans saw a

1211
00:54:59,199 --> 00:55:05,858
pair of neutron stars merging was

1212
00:55:01,639 --> 00:55:05,858
detected that's what you're seeing here

1213
00:55:06,789 --> 00:55:10,699
they had masses about one and a half and

1214
00:55:09,498 --> 00:55:12,738
one and a quarter of solar masses

1215
00:55:10,699 --> 00:55:15,949
neutron stars are typically about the

1216
00:55:12,739 --> 00:55:17,778
solar about the mass of the Sun from a

1217
00:55:15,949 --> 00:55:21,650
little bit less to about two times this

1218
00:55:17,778 --> 00:55:23,509
mass of the Sun the objects are

1219
00:55:21,650 --> 00:55:28,309
extremely compact and leave a single

1220
00:55:23,509 --> 00:55:30,079
massive remnant and again they oh now

1221
00:55:28,309 --> 00:55:31,759
they again they only lose two point five

1222
00:55:30,079 --> 00:55:33,650
percent of solar mass to grab so they

1223
00:55:31,759 --> 00:55:35,150
lose very little compared to what you

1224
00:55:33,650 --> 00:55:37,400
saw for the black holes because the

1225
00:55:35,150 --> 00:55:38,838
neutron stars are not radiating nearly

1226

00:55:37,400 --> 00:55:42,469
as powerfully because they're not moving

1227
00:55:38,838 --> 00:55:45,048
as fast when they come together or not

1228
00:55:42,469 --> 00:55:47,659
and they're not as massive now NASA's

1229
00:55:45,048 --> 00:55:49,759
Fermi Sally is a gamma-ray satellite and

1230
00:55:47,659 --> 00:55:52,578
Europe's integral satellite detected a

1231
00:55:49,759 --> 00:55:56,179
gamma-ray burst 1.7 seconds after the

1232
00:55:52,579 --> 00:55:57,499
merger now you would think the

1233
00:55:56,179 --> 00:55:59,838
gravitational wave should arrive at the

1234
00:55:57,498 --> 00:56:00,708
same time as light that's the prediction

1235
00:55:59,838 --> 00:56:02,630
no this is so pretty

1236
00:56:00,708 --> 00:56:04,608
darkness is so amazingly good because

1237
00:56:02,630 --> 00:56:07,789
that came from a hundred and twenty

1238
00:56:04,608 --> 00:56:10,818
million light years away so that's one

1239
00:56:07,789 --> 00:56:12,380
part in 10 to the 15 that was all so

1240
00:56:10,818 --> 00:56:14,239

it's still very very good and we think

1241
00:56:12,380 --> 00:56:15,920
in fact that it probably takes some time

1242
00:56:14,239 --> 00:56:17,909
to create the gram of the gamma-ray

1243
00:56:15,920 --> 00:56:19,769
bursts you probably have to spin up

1244
00:56:17,909 --> 00:56:21,088
magnetic field if the breakout of the

1245
00:56:19,769 --> 00:56:23,818
neutrons are so we could well be that

1246
00:56:21,088 --> 00:56:25,889
all that 1.7 seconds is creating the

1247
00:56:23,818 --> 00:56:28,259
gamma-ray burst right and so they do

1248
00:56:25,889 --> 00:56:29,608
exactly travel at the same speed but

1249
00:56:28,260 --> 00:56:31,140
that would be the prediction of the

1250
00:56:29,608 --> 00:56:33,058
theory of relativity that they should

1251
00:56:31,139 --> 00:56:36,889
travel exactly the same speed and still

1252
00:56:33,059 --> 00:56:39,720
one part in 10 to the 15 is pretty good

1253
00:56:36,889 --> 00:56:42,929
but we finally got a neutron star merger

1254
00:56:39,719 --> 00:56:45,929
now this is very Oh and Virgo you see it

1255
00:56:42,929 --> 00:56:48,239
didn't see it at all well this was

1256
00:56:45,929 --> 00:56:50,848
important because it's the dog that

1257
00:56:48,239 --> 00:56:53,699
didn't bark because they knew from the

1258
00:56:50,849 --> 00:56:56,099
previous detection how how sensitive

1259
00:56:53,699 --> 00:56:57,719
Virgo was and so they knew that and most

1260
00:56:56,099 --> 00:57:00,000
of the sky Virgo should have seen it

1261
00:56:57,719 --> 00:57:01,649
and so there was only part of the sky

1262
00:57:00,000 --> 00:57:03,269
where Virgo wouldn't see it and they

1263
00:57:01,650 --> 00:57:05,190
could restrict it to put that part of

1264
00:57:03,269 --> 00:57:09,329
the sky so in fact the non detection by

1265
00:57:05,190 --> 00:57:11,190
Virgo was very helpful we'll get to that

1266
00:57:09,329 --> 00:57:16,318
in a minute now what happens when two

1267
00:57:11,190 --> 00:57:18,269
neutron stars merge this is that here's

1268
00:57:16,318 --> 00:57:22,558
the here actually you're seeing the

1269
00:57:18,269 --> 00:57:24,690
matter of the two neutron stars and some

1270
00:57:22,559 --> 00:57:27,809
of the matter is being just thrown off

1271
00:57:24,690 --> 00:57:32,068
into space okay probably a few percent

1272
00:57:27,809 --> 00:57:35,160
of the material of the stars gets thrown

1273
00:57:32,068 --> 00:57:37,769
off during this merger now this is very

1274
00:57:35,159 --> 00:57:39,269
important because this material is again

1275
00:57:37,769 --> 00:57:41,190
I told you earlier we think that this

1276
00:57:39,269 --> 00:57:43,920
this matter is highly radioactive it

1277
00:57:41,190 --> 00:57:45,389
comes off as just pure neutrons and so

1278
00:57:43,920 --> 00:57:46,950
it starts as very heavy elements I'll

1279
00:57:45,389 --> 00:57:49,710
show you that in a minute and so it

1280
00:57:46,949 --> 00:57:54,389
basically comes out and populates the

1281
00:57:49,710 --> 00:57:58,010
universe with heavy elements now it also

1282
00:57:54,389 --> 00:58:01,710
radiates in the optical and the infrared

1283

00:57:58,010 --> 00:58:02,549
now right oh I thought I took that out

1284
00:58:01,710 --> 00:58:03,869
but okay

1285
00:58:02,548 --> 00:58:05,608
doesn't matter it'll show you this in a

1286
00:58:03,869 --> 00:58:12,440
minute so there we have the matter

1287
00:58:05,608 --> 00:58:15,150
emerging now here is a view

1288
00:58:12,440 --> 00:58:16,950
electromagnetic view of the they totally

1289
00:58:15,150 --> 00:58:18,720
this is this is showing sort of the hot

1290
00:58:16,949 --> 00:58:22,348
spots on the neutron stars sort of an

1291
00:58:18,719 --> 00:58:24,929
x-ray view of it now this is produced by

1292
00:58:22,349 --> 00:58:27,298
NASA and it was for the Swift satellite

1293
00:58:24,929 --> 00:58:30,608
which is a gamma ray satellite and they

1294
00:58:27,298 --> 00:58:32,710
wanted to show you saw that that be

1295
00:58:30,608 --> 00:58:34,179
coming out of it there has long been a

1296
00:58:32,710 --> 00:58:35,679
theory that the something we called

1297
00:58:34,179 --> 00:58:37,690

gamma-ray bursts the she would called

1298

00:58:35,679 --> 00:58:39,219

especially the short camera burst may

1299

00:58:37,690 --> 00:58:41,700

come from the merger of two neutron

1300

00:58:39,219 --> 00:58:44,078

stars we've never been able there's no

1301

00:58:41,699 --> 00:58:46,028

absolute proof of that yet but

1302

00:58:44,079 --> 00:58:48,579

everything we've seen is consistent with

1303

00:58:46,028 --> 00:58:50,108

that hypothesis we know that another

1304

00:58:48,579 --> 00:58:51,489

type of gamma-ray bursts called the long

1305

00:58:50,108 --> 00:58:53,409

game reverse they not last much longer

1306

00:58:51,489 --> 00:58:55,720

we know that those come from the deaths

1307

00:58:53,409 --> 00:58:57,998

of very massive stars but this other

1308

00:58:55,719 --> 00:59:00,009

type this sort of much short mass short

1309

00:58:57,998 --> 00:59:01,268

gamma-ray bursts lasts much less lasts

1310

00:59:00,009 --> 00:59:02,889

about a second where the own lasts

1311

00:59:01,268 --> 00:59:03,998

typically tens hundreds of thousand

1312
00:59:02,889 --> 00:59:05,980
seconds um

1313
00:59:03,998 --> 00:59:07,899
this the short ones we thought come from

1314
00:59:05,980 --> 00:59:09,730
the mergers of neutron stars or perhaps

1315
00:59:07,900 --> 00:59:11,528
neutron stars and black holes but never

1316
00:59:09,730 --> 00:59:14,440
able to prove it but where they are

1317
00:59:11,528 --> 00:59:16,449
where we find them all seems to indicate

1318
00:59:14,440 --> 00:59:19,358
that they probably come from your return

1319
00:59:16,449 --> 00:59:20,980
star mergers and Mario Livio who maybe

1320
00:59:19,358 --> 00:59:24,219
you have seen many of us seen used to

1321
00:59:20,980 --> 00:59:27,400
say if the merger of neutron stars

1322
00:59:24,219 --> 00:59:30,368
doesn't produce a gamma-ray burst what

1323
00:59:27,400 --> 00:59:34,048
does it do so that was someone that was

1324
00:59:30,369 --> 00:59:34,048
one of the stronger arguments but

1325
00:59:34,289 --> 00:59:40,389
so but so but now we may have evidence

1326
00:59:38,230 --> 00:59:42,730
that it says because it was on camera

1327
00:59:40,389 --> 00:59:45,429
but the camera verse was very faint so

1328
00:59:42,730 --> 00:59:47,349
it wasn't that that that beam was not

1329
00:59:45,429 --> 00:59:48,819
put if it did produce a true gamma-ray

1330
00:59:47,349 --> 00:59:54,070
burst that beam was not pointing at us

1331
00:59:48,820 --> 00:59:57,880
we were seeing it from a side okay

1332
00:59:54,070 --> 00:59:59,559
now this is so this here we see it sort

1333
00:59:57,880 --> 01:00:03,130
of an this is this is produced by Hubble

1334
00:59:59,559 --> 01:00:04,509
by our own outreach office and because

1335
01:00:03,130 --> 01:00:06,519
we observed this I'll show you later

1336
01:00:04,510 --> 01:00:08,290
admit we observe this with Hubble so

1337
01:00:06,519 --> 01:00:10,210
here's the neutron stars merging then

1338
01:00:08,289 --> 01:00:13,329
they come together they throw out matter

1339
01:00:10,210 --> 01:00:15,220
now this matter is hot and it if you

1340

01:00:13,329 --> 01:00:17,349
look at how much energy it radiates it's

1341
01:00:15,219 --> 01:00:22,088
about a thousand times as much as a nova

1342
01:00:17,349 --> 01:00:25,180
which is a type of a dwarf star that

1343
01:00:22,088 --> 01:00:26,889
burps has a small nuclear explosion

1344
01:00:25,179 --> 01:00:28,598
occasionally and that's called ANOVA and

1345
01:00:26,889 --> 01:00:30,129
there's supernova is a really big Nova

1346
01:00:28,599 --> 01:00:31,869
right but it's actually an explosion of

1347
01:00:30,130 --> 01:00:33,640
a real true explosion of a star and

1348
01:00:31,869 --> 01:00:36,070
these Nova's tend to be sort of surface

1349
01:00:33,639 --> 01:00:37,809
burps surface thermal nuclear reactions

1350
01:00:36,070 --> 01:00:40,420
and this is about a thousand times

1351
01:00:37,809 --> 01:00:43,750
brighter so it's been dubbed the term

1352
01:00:40,420 --> 01:00:46,358
most people use as a killer nova now on

1353
01:00:43,750 --> 01:00:49,659
top of that you'll get the gamma-ray

1354
01:00:46,358 --> 01:00:51,818

burst we think may or may not well go

1355

01:00:49,659 --> 01:00:55,799

into that in a bit and then around that

1356

01:00:51,818 --> 01:01:00,068

you'll get we think a jet quite possibly

1357

01:00:55,800 --> 01:01:03,310

a wind a very strong wind coming out

1358

01:01:00,068 --> 01:01:06,269

near the axis very hot blue winds and

1359

01:01:03,309 --> 01:01:08,409

around it you'll have this red material

1360

01:01:06,269 --> 01:01:10,509

explained away it's this the red the

1361

01:01:08,409 --> 01:01:16,690

neutron star mature why that's red in a

1362

01:01:10,510 --> 01:01:19,690

minute oh right but before that let's

1363

01:01:16,690 --> 01:01:20,950

see NASA just couldn't resist so you had

1364

01:01:19,690 --> 01:01:22,480

to show you the feature the

1365

01:01:20,949 --> 01:01:23,500

feature-length film that was I would

1366

01:01:22,480 --> 01:01:25,088

feature like this but it's

1367

01:01:23,500 --> 01:01:28,559

feature-length productions but feature

1368

01:01:25,088 --> 01:01:28,559

production scale whoo

1369
01:01:39,760 --> 01:01:54,160
[Music]

1370
01:01:51,199 --> 01:01:57,259
[Applause]

1371
01:01:54,159 --> 01:01:57,259
[Music]

1372
01:01:59,059 --> 01:02:12,779
let's go back a bit I'm gonna go do this

1373
01:02:05,369 --> 01:02:14,338
again a little less sound so the here we

1374
01:02:12,780 --> 01:02:15,780
have the gamma-ray burst we here we have

1375
01:02:14,338 --> 01:02:20,578
the two neutron stars merging putting

1376
01:02:15,780 --> 01:02:22,920
out gravitational waves now they produce

1377
01:02:20,579 --> 01:02:24,690
a gamma-ray burst is the idea now you

1378
01:02:22,920 --> 01:02:27,329
have this hot wind coming out and the

1379
01:02:24,690 --> 01:02:30,179
killer Nova in the center coming out now

1380
01:02:27,329 --> 01:02:33,119
here you see these jets later on

1381
01:02:30,179 --> 01:02:35,608
expanding very large this may be crucial

1382
01:02:33,119 --> 01:02:40,050
to what we've seen but you will see in a

1383
01:02:35,608 --> 01:02:42,328
bit so first we had to go find the thing

1384
01:02:40,050 --> 01:02:43,560
right and some of the I was involved in

1385
01:02:42,329 --> 01:02:45,720
the elbow space followed by the

1386
01:02:43,559 --> 01:02:47,250
telescope follow-ups but few people here

1387
01:02:45,719 --> 01:02:50,159
were actually involved in searching that

1388
01:02:47,250 --> 01:02:52,108
very day right and what a number of

1389
01:02:50,159 --> 01:02:54,809
groups did was they said okay well

1390
01:02:52,108 --> 01:02:56,279
here's the here here's what they this is

1391
01:02:54,809 --> 01:02:58,230
the region that the gamma-ray burst

1392
01:02:56,280 --> 01:02:59,910
could have been in here's the region

1393
01:02:58,230 --> 01:03:01,440
that LIGO could have seen it and then

1394
01:02:59,909 --> 01:03:03,328
there's the region that Virgo could have

1395
01:03:01,440 --> 01:03:05,608
been LIGO could have seen it in so it's

1396
01:03:03,329 --> 01:03:08,130
that but there's that's how Virgo helped

1397

01:03:05,608 --> 01:03:10,170
right and then you look on the sky in

1398
01:03:08,130 --> 01:03:13,140
that region and what the smart groups

1399
01:03:10,170 --> 01:03:14,789
did is they said there probably went off

1400
01:03:13,139 --> 01:03:16,650
you know galaxies probably know how

1401
01:03:14,789 --> 01:03:18,259
about how far away it is cuz again they

1402
01:03:16,650 --> 01:03:20,369
could tell us right away that it's about

1403
01:03:18,260 --> 01:03:23,250
120 million light years they got it

1404
01:03:20,369 --> 01:03:25,200
right on the nose and they and so you

1405
01:03:23,250 --> 01:03:27,929
could look for galaxies in that region

1406
01:03:25,199 --> 01:03:29,489
that were about that distance away and

1407
01:03:27,929 --> 01:03:31,108
you could start with the big ones and

1408
01:03:29,489 --> 01:03:33,929
work down to the small ones and it

1409
01:03:31,108 --> 01:03:38,900
wasn't a big one and that's it right

1410
01:03:33,929 --> 01:03:38,899
there that dot an extra dot right there

1411
01:03:39,409 --> 01:03:44,159

now lots and lots of tellus this was one

1412

01:03:42,690 --> 01:03:46,650
of the biggest observing campaigns in

1413

01:03:44,159 --> 01:03:50,460
the history of astronomy look I went too

1414

01:03:46,650 --> 01:03:52,829
far yeah this was a we had a dozen two

1415

01:03:50,460 --> 01:03:54,889
dozen observatories on the ground the

1416

01:03:52,829 --> 01:03:57,480
three gravitationally observatories and

1417

01:03:54,889 --> 01:03:59,279
seven space telescopes observe this

1418

01:03:57,480 --> 01:04:00,539
thing because it was a big event there

1419

01:03:59,280 --> 01:04:03,800
were about a thousand astronomers

1420

01:04:00,539 --> 01:04:05,360
involved in all of the observations what

1421

01:04:03,800 --> 01:04:07,370
action of the Totalus astronomical

1422

01:04:05,360 --> 01:04:09,800
community was involved in some way or

1423

01:04:07,369 --> 01:04:11,989
another most most of them were just like

1424

01:04:09,800 --> 01:04:13,160
I I work at an observatory put my name

1425

01:04:11,989 --> 01:04:15,439
on the day and probably put my name on

1426
01:04:13,159 --> 01:04:17,420
but and in the LIGO group itself is

1427
01:04:15,440 --> 01:04:19,670
around a thousand people it's huge takes

1428
01:04:17,420 --> 01:04:21,559
a true I mean it's a it's like a high

1429
01:04:19,670 --> 01:04:23,599
energy physics experiments incredibly

1430
01:04:21,559 --> 01:04:25,820
involved credibly difficult to build in

1431
01:04:23,599 --> 01:04:29,599
fact I didn't I should have gone we'll

1432
01:04:25,820 --> 01:04:31,460
get there in a minute but like I did

1433
01:04:29,599 --> 01:04:32,960
show them and I didn't go over what each

1434
01:04:31,460 --> 01:04:35,420
of the contributions of the three

1435
01:04:32,960 --> 01:04:44,860
discoverers were maybe three Nobel lists

1436
01:04:35,420 --> 01:04:47,690
were in this case so there was a second

1437
01:04:44,860 --> 01:04:49,970
there ago so I mentioned it was like

1438
01:04:47,690 --> 01:04:51,740
high energy physics experiment Barry

1439
01:04:49,969 --> 01:04:53,659
bearish comes out of the high energy

1440
01:04:51,739 --> 01:04:55,209
physics community and his contribution

1441
01:04:53,659 --> 01:04:57,859
was basically to make the thing work

1442
01:04:55,210 --> 01:05:01,610
he came and became the director and

1443
01:04:57,860 --> 01:05:03,829
really brought it together and Ray Weiss

1444
01:05:01,610 --> 01:05:06,019
as you heard conceptualize the thing way

1445
01:05:03,829 --> 01:05:08,509
back at the very beginning and Kip

1446
01:05:06,019 --> 01:05:10,039
Thorne is a theorist who really was

1447
01:05:08,510 --> 01:05:12,140
behind much of the theoretical

1448
01:05:10,039 --> 01:05:14,409
understanding of what you would see and

1449
01:05:12,139 --> 01:05:17,089
how you would predict what you would see

1450
01:05:14,409 --> 01:05:19,250
and so there's a result and there was

1451
01:05:17,090 --> 01:05:23,120
also ronald ruber who who were totally

1452
01:05:19,250 --> 01:05:25,969
passed away but before the this happened

1453
01:05:23,119 --> 01:05:27,829
but um he the nobel prize can only give

1454

01:05:25,969 --> 01:05:29,239
nobody said is having it over I still

1455
01:05:27,829 --> 01:05:32,449
set up today you can only go to three

1456
01:05:29,239 --> 01:05:34,569
people so and yeah I don't know what

1457
01:05:32,449 --> 01:05:38,689
happened that he was still alive but

1458
01:05:34,570 --> 01:05:41,510
knowing yeah that's a prop that trying

1459
01:05:38,690 --> 01:05:43,820
changing that but they never have okay

1460
01:05:41,510 --> 01:05:47,570
so then it was again it was observed by

1461
01:05:43,820 --> 01:05:49,670
in fact six independent teams discovered

1462
01:05:47,570 --> 01:05:51,350
it the object almost simultaneously I

1463
01:05:49,670 --> 01:05:53,630
showed you the first one but within an

1464
01:05:51,349 --> 01:05:55,699
hour or so lots of other teams found it

1465
01:05:53,630 --> 01:05:57,590
too and it was observed from the gamma

1466
01:05:55,699 --> 01:05:59,389
ray to the radio again one of the

1467
01:05:57,590 --> 01:06:01,039
largest observing campaigns in history

1468
01:05:59,389 --> 01:06:02,809

and this just shows you all the

1469

01:06:01,039 --> 01:06:04,159
different to weighed bands it was

1470

01:06:02,809 --> 01:06:07,929
absorbed in at all different discovery

1471

01:06:04,159 --> 01:06:07,929
image shows it's amazing

1472

01:06:10,449 --> 01:06:19,809
Oh baby there we go there we go all

1473

01:06:16,300 --> 01:06:22,720
right so this is the Hubble image of

1474

01:06:19,809 --> 01:06:26,380
that galaxy and there is this source

1475

01:06:22,719 --> 01:06:28,419
right there on this now it's the host is

1476

01:06:26,380 --> 01:06:30,338
a massive elliptical it's named over

1477

01:06:28,420 --> 01:06:32,108
it's an it's it well it's got a catalog

1478

01:06:30,338 --> 01:06:34,539
it's in a catalog it's large it's well

1479

01:06:32,108 --> 01:06:36,400
was known before was studied before fact

1480

01:06:34,539 --> 01:06:38,529
there was a Hubble image of it taken

1481

01:06:36,400 --> 01:06:40,900
before the this object went off this

1482

01:06:38,530 --> 01:06:43,060
explosion happened actually only several

1483
01:06:40,900 --> 01:06:43,630
months before this explosion happened by

1484
01:06:43,059 --> 01:06:45,670
chance

1485
01:06:43,630 --> 01:06:48,400
item and it's about 120 million light

1486
01:06:45,670 --> 01:06:49,869
years away as I said it but what the

1487
01:06:48,400 --> 01:06:54,070
explosion was actually relatively far

1488
01:06:49,869 --> 01:06:56,980
out on the galaxies and elliptical

1489
01:06:54,070 --> 01:06:58,720
galaxies tend to have lots of groups of

1490
01:06:56,980 --> 01:07:01,329
stars we call globular clusters very

1491
01:06:58,719 --> 01:07:02,588
dense concentrations of stars and we

1492
01:07:01,329 --> 01:07:04,570
think that those are actually very good

1493
01:07:02,588 --> 01:07:06,489
places to form neutron star bind to form

1494
01:07:04,570 --> 01:07:10,030
binaries and massive binaries and

1495
01:07:06,489 --> 01:07:12,069
probably neutron star binaries but then

1496
01:07:10,030 --> 01:07:13,930
we see lots of posts are binaries and

1497
01:07:12,070 --> 01:07:17,079
pulsars in our globular clusters in our

1498
01:07:13,929 --> 01:07:19,088
galaxy but as best as we can tell this

1499
01:07:17,079 --> 01:07:21,010
is not on top of one of those globular

1500
01:07:19,088 --> 01:07:22,659
clusters it just seems to be out in the

1501
01:07:21,010 --> 01:07:25,810
field of the galaxy as best as we can

1502
01:07:22,659 --> 01:07:27,460
tell right now we're not down to the we

1503
01:07:25,809 --> 01:07:31,088
haven't gone down as deep as you could

1504
01:07:27,460 --> 01:07:32,470
possibly go to see the very faintest

1505
01:07:31,088 --> 01:07:34,960
globular clusters because there's still

1506
01:07:32,469 --> 01:07:36,279
light from the source there eventually

1507
01:07:34,960 --> 01:07:38,199
we'll be able to get a very deep image

1508
01:07:36,280 --> 01:07:40,089
and tell but you can go most of the way

1509
01:07:38,199 --> 01:07:41,139
down to how faint and probably classical

1510
01:07:40,088 --> 01:07:44,949
every cluster would be and there's

1511

01:07:41,139 --> 01:07:47,828
nothing there now at this started out as

1512
01:07:44,949 --> 01:07:51,250
I mentioned predictably be blue and in

1513
01:07:47,829 --> 01:08:00,039
fact that's what it was and then it very

1514
01:07:51,250 --> 01:08:02,260
slowly turns reddish and the object

1515
01:08:00,039 --> 01:08:04,480
became fainter but not red or after a

1516
01:08:02,260 --> 01:08:06,099
few days and mostly what's really

1517
01:08:04,480 --> 01:08:09,219
remarkable is that most of this behavior

1518
01:08:06,099 --> 01:08:12,220
was predicted before the event Dan

1519
01:08:09,219 --> 01:08:14,980
kaizen a while back predicted that these

1520
01:08:12,219 --> 01:08:16,838
objects will be very red for reasons

1521
01:08:14,980 --> 01:08:19,779
that I'll get into a minute and Mark

1522
01:08:16,838 --> 01:08:23,048
Metzger has predicted that blue central

1523
01:08:19,779 --> 01:08:24,100
core well it's really quite remarkable

1524
01:08:23,048 --> 01:08:27,909
how

1525
01:08:24,100 --> 01:08:28,930

well we had the theory down before it

1526

01:08:27,909 --> 01:08:30,729
actually no no there were other

1527

01:08:28,930 --> 01:08:31,990
competing theories right so you could

1528

01:08:30,729 --> 01:08:34,750
say okay well you could have picked your

1529

01:08:31,989 --> 01:08:37,358
theory but the this was these were the

1530

01:08:34,750 --> 01:08:40,050
most likely candidates and they turned

1531

01:08:37,359 --> 01:08:40,050
out to be correct

1532

01:08:40,199 --> 01:08:47,108
now you'll remember that I mentioned to

1533

01:08:43,960 --> 01:08:48,520
you that when you take when you took

1534

01:08:47,109 --> 01:08:50,350
this white dwarf and you put more mass

1535

01:08:48,520 --> 01:08:52,630
on to it you forced the electric by the

1536

01:08:50,350 --> 01:08:55,000
pressure force the electrons into the

1537

01:08:52,630 --> 01:08:57,130
nuclei and turn the protons into

1538

01:08:55,000 --> 01:08:58,720
neutrons right as the electron canceled

1539

01:08:57,130 --> 01:09:01,539
the charge of the proton and they form a

1540
01:08:58,720 --> 01:09:03,699
neutron well if this materials thrown

1541
01:09:01,539 --> 01:09:07,300
off it does I'm free the pressures off

1542
01:09:03,699 --> 01:09:10,599
and the electrons pop at and so it

1543
01:09:07,300 --> 01:09:18,070
undergoes a radioactive decay and here's

1544
01:09:10,600 --> 01:09:20,140
a little okay and so over here is a

1545
01:09:18,069 --> 01:09:22,479
little plot showing you the creation of

1546
01:09:20,140 --> 01:09:25,090
elements as you draw as the material

1547
01:09:22,479 --> 01:09:27,909
comes off the neutron star and it just

1548
01:09:25,090 --> 01:09:30,640
starts off very very radioactive and

1549
01:09:27,909 --> 01:09:31,630
very Neutron rich and slowly moves over

1550
01:09:30,640 --> 01:09:34,359
well that's what slowly this is only a

1551
01:09:31,630 --> 01:09:35,920
few seconds in real time turns into

1552
01:09:34,359 --> 01:09:38,109
something very close to the periodic

1553
01:09:35,920 --> 01:09:41,020
table now there'll be lots of

1554
01:09:38,109 --> 01:09:43,180
radioactive elements that we that died

1555
01:09:41,020 --> 01:09:47,920
the break that go decayed before we see

1556
01:09:43,180 --> 01:09:51,010
them now on earth but if you look at the

1557
01:09:47,920 --> 01:09:53,079
the element that the periodic table you

1558
01:09:51,010 --> 01:09:57,989
can ask where do the elements come from

1559
01:09:53,079 --> 01:10:01,569
and we think that the blue star the blue

1560
01:09:57,989 --> 01:10:07,659
shaded ones here come from exploding

1561
01:10:01,569 --> 01:10:09,340
stars by and large the the big these red

1562
01:10:07,659 --> 01:10:12,309
here is largely left over from the Big

1563
01:10:09,340 --> 01:10:16,810
Bang there's a bit of cosmic ray fission

1564
01:10:12,310 --> 01:10:19,090
and then in the bit of the dark brown is

1565
01:10:16,810 --> 01:10:21,460
sort of planetary nebula dying low mass

1566
01:10:19,090 --> 01:10:23,920
stars but all of this yellow we think

1567
01:10:21,460 --> 01:10:27,939
now is probably merging neutron stars

1568

01:10:23,920 --> 01:10:31,149
all of these elements here and when you

1569
01:10:27,939 --> 01:10:33,729
look at a normal supernova it's it's

1570
01:10:31,149 --> 01:10:36,039
spectrum say that is dominated by the

1571
01:10:33,729 --> 01:10:37,808
iron elements iron cook so it you've

1572
01:10:36,039 --> 01:10:39,939
reduced nickel in that radioactive

1573
01:10:37,809 --> 01:10:44,469
into cobalt and that the Kaizen to the

1574
01:10:39,939 --> 01:10:46,089
iron that lasts now and that produces a

1575
01:10:44,469 --> 01:10:51,239
lot of the energy in a supernova

1576
01:10:46,090 --> 01:10:53,559
that's a k now these elements here are

1577
01:10:51,238 --> 01:10:55,598
transparent in the optical but they

1578
01:10:53,559 --> 01:10:57,760
block the ultraviolet so when you look

1579
01:10:55,599 --> 01:10:59,559
at a regular supernova it's bright in

1580
01:10:57,760 --> 01:11:02,079
the optical but it falls off very

1581
01:10:59,559 --> 01:11:03,219
quickly in the ultraviolet you see very

1582
01:11:02,078 --> 01:11:04,960

little light of it from the ultra bio

1583

01:11:03,219 --> 01:11:06,460
because these elements absorb in the

1584

01:11:04,960 --> 01:11:12,460
ultraviolet but they let light through

1585

01:11:06,460 --> 01:11:14,020
in the optical now these elements down

1586

01:11:12,460 --> 01:11:18,849
here the lanthanides and the actinides

1587

01:11:14,020 --> 01:11:21,429
they absorb in the optical but they let

1588

01:11:18,849 --> 01:11:23,650
light through in the infrared and this

1589

01:11:21,429 --> 01:11:25,149
was what Dan Kazan's group realized so

1590

01:11:23,649 --> 01:11:27,279
he said you better produce all of these

1591

01:11:25,149 --> 01:11:28,658
things you won't see it in the optical

1592

01:11:27,279 --> 01:11:29,710
very well you won't see those elements

1593

01:11:28,658 --> 01:11:31,179
in the optical area well because they're

1594

01:11:29,710 --> 01:11:34,569
gonna block all the light you'll see

1595

01:11:31,179 --> 01:11:38,230
them in the infrared and that is what we

1596

01:11:34,569 --> 01:11:42,219
see this is an HST spectrum of the Killa

1597
01:11:38,229 --> 01:11:45,968
nova and that bump there was predicted

1598
01:11:42,219 --> 01:11:48,010
that's the lanthanides if you have a lot

1599
01:11:45,969 --> 01:11:50,198
of land that lanthanide group you'll get

1600
01:11:48,010 --> 01:11:53,619
something like that now in fact the

1601
01:11:50,198 --> 01:11:55,149
actual pasady Xand electron maybe the

1602
01:11:53,618 --> 01:11:56,738
states of the lanthanides are not

1603
01:11:55,149 --> 01:11:58,960
well-known because it could take a lot

1604
01:11:56,738 --> 01:12:00,759
of a it's gonna take a lot more work in

1605
01:11:58,960 --> 01:12:03,069
the lab to really sort that out but it's

1606
01:12:00,760 --> 01:12:05,170
approximately known and then something

1607
01:12:03,069 --> 01:12:07,509
very close to this was predicted right

1608
01:12:05,170 --> 01:12:09,069
exactly how much and it was a little bit

1609
01:12:07,510 --> 01:12:11,349
different cuz so how much do you produce

1610
01:12:09,069 --> 01:12:13,389
exactly how does it come out you know

1611
01:12:11,349 --> 01:12:15,610
what is the geometry but it's very very

1612
01:12:13,389 --> 01:12:17,920
close to what we saw so this is really

1613
01:12:15,609 --> 01:12:19,899
an incredible agreement this this peak

1614
01:12:17,920 --> 01:12:21,250
was very clearly predicted and that was

1615
01:12:19,899 --> 01:12:24,729
the major thing in a spectrum that was

1616
01:12:21,250 --> 01:12:27,010
there so we really think we understand

1617
01:12:24,729 --> 01:12:29,408
the basic mechanics of what's going on

1618
01:12:27,010 --> 01:12:31,480
and we think that this is probably where

1619
01:12:29,408 --> 01:12:33,549
the mote where most of the heavy

1620
01:12:31,479 --> 01:12:35,738
elements of the universe come from now

1621
01:12:33,550 --> 01:12:37,000
of course it depends on what we've seen

1622
01:12:35,738 --> 01:12:38,799
one of these things or sort of

1623
01:12:37,000 --> 01:12:40,599
guesstimating the rate but it's sort of

1624
01:12:38,800 --> 01:12:43,869
comparable to the rate that we expected

1625

01:12:40,599 --> 01:12:45,190
from neutrons from pulsars if you made a

1626
01:12:43,868 --> 01:12:47,979
couple of assumptions about how many

1627
01:12:45,189 --> 01:12:49,658
posters assume come together so it all

1628
01:12:47,979 --> 01:12:51,599
sorts of agree and so we think that

1629
01:12:49,658 --> 01:12:53,609
we've got that

1630
01:12:51,600 --> 01:12:56,430
there there are some mysteries still

1631
01:12:53,609 --> 01:13:00,449
remaining the about this object this is

1632
01:12:56,430 --> 01:13:02,100
the like curve of the of the optic and

1633
01:13:00,449 --> 01:13:04,199
the optical and the infrared the

1634
01:13:02,100 --> 01:13:06,000
infrared did the braid in green here and

1635
01:13:04,199 --> 01:13:08,149
the blue and the orange are sort of

1636
01:13:06,000 --> 01:13:10,920
optical not the best color choice and

1637
01:13:08,149 --> 01:13:12,629
they went down over about ten days they

1638
01:13:10,920 --> 01:13:15,090
just dropped off a cliff right Gwen

1639
01:13:12,630 --> 01:13:15,720

found very quickly but then we looked at

1640

01:13:15,090 --> 01:13:17,340

it again

1641

01:13:15,720 --> 01:13:20,490

about a hundred days and it was still

1642

01:13:17,340 --> 01:13:21,869

there with home now why did we look at

1643

01:13:20,489 --> 01:13:24,149

it again in a hundred days it was

1644

01:13:21,869 --> 01:13:29,189

because other people had been looking at

1645

01:13:24,149 --> 01:13:31,679

it in the optical sorry in the x-ray and

1646

01:13:29,189 --> 01:13:34,979

the gamma ray and so the x-ray and the

1647

01:13:31,680 --> 01:13:38,340

radio this is the radio and this is the

1648

01:13:34,979 --> 01:13:41,489

x-ray and they took they did not turn on

1649

01:13:38,340 --> 01:13:43,199

until ten days and then they got

1650

01:13:41,489 --> 01:13:48,869

brighter for a while now they looks like

1651

01:13:43,199 --> 01:13:51,000

they may have plateaued maybe not so

1652

01:13:48,869 --> 01:13:54,239

what we think there are two

1653

01:13:51,000 --> 01:13:55,949

possibilities we think one is that we're

1654
01:13:54,239 --> 01:13:58,170
seeing that Chet wasn't pointing to us

1655
01:13:55,949 --> 01:14:00,210
but now it's sort of opening up or we're

1656
01:13:58,170 --> 01:14:02,460
actually it's we're and we're seeing it

1657
01:14:00,210 --> 01:14:05,189
get opened up as we get with time

1658
01:14:02,460 --> 01:14:07,500
basically which we is a prediction that

1659
01:14:05,189 --> 01:14:09,479
gamma a gamma ray bursts will do as they

1660
01:14:07,500 --> 01:14:12,750
slow down they beam to a larger area and

1661
01:14:09,479 --> 01:14:14,969
if this jet has a certain is not just a

1662
01:14:12,750 --> 01:14:16,649
perfect wall but has shaped like

1663
01:14:14,970 --> 01:14:17,970
brighter here and then it dies off to

1664
01:14:16,649 --> 01:14:21,539
the edge it would do this sort of thing

1665
01:14:17,970 --> 01:14:23,699
another possibility is that the jet

1666
01:14:21,539 --> 01:14:25,859
never the the gamma ray bursts never got

1667
01:14:23,699 --> 01:14:28,260
out and bruised a very hot bubble and

1668
01:14:25,859 --> 01:14:30,659
that as that bubble starts out small

1669
01:14:28,260 --> 01:14:32,190
it's not so bright but as it expands

1670
01:14:30,659 --> 01:14:34,289
this hot bubble has more surface area

1671
01:14:32,189 --> 01:14:35,579
and so it's brighter this is what

1672
01:14:34,289 --> 01:14:37,380
basically what happens in the early

1673
01:14:35,579 --> 01:14:39,869
stages of a supernova - they get

1674
01:14:37,380 --> 01:14:44,340
brighter as they expand now so that may

1675
01:14:39,869 --> 01:14:47,279
be what's going on here I think there

1676
01:14:44,340 --> 01:14:49,230
can because of short gamma-ray bursts we

1677
01:14:47,279 --> 01:14:51,059
think that they're probably related to

1678
01:14:49,229 --> 01:14:52,889
short gamma-ray bursts and therefore

1679
01:14:51,060 --> 01:14:56,010
they're by the numbers we've seen there

1680
01:14:52,890 --> 01:14:58,440
can't be too many that you would miss as

1681
01:14:56,010 --> 01:14:59,820
short as gamma-ray bursts because they

1682

01:14:58,439 --> 01:15:02,250
otherwise the rates wouldn't work out

1683
01:14:59,819 --> 01:15:04,019
between the mergers and this and their

1684
01:15:02,250 --> 01:15:05,140
short gamma-ray bursts but it's possible

1685
01:15:04,020 --> 01:15:06,640
that in fact this doesn't have

1686
01:15:05,140 --> 01:15:08,530
hammering burst at all but that the

1687
01:15:06,640 --> 01:15:10,350
gamma ray burst got smothered right

1688
01:15:08,529 --> 01:15:13,809
never quite got out and produced a big

1689
01:15:10,350 --> 01:15:15,039
expanding cocoon of hot material but we

1690
01:15:13,810 --> 01:15:16,420
should there's a good chance we'll be

1691
01:15:15,039 --> 01:15:20,229
able to tell by the shape of the light

1692
01:15:16,420 --> 01:15:22,750
curve later on it may fall off faster if

1693
01:15:20,229 --> 01:15:24,039
it we probably will fall off faster it's

1694
01:15:22,750 --> 01:15:26,680
a gamma-ray burst all this depends on

1695
01:15:24,039 --> 01:15:28,019
the shape of the Jets and it's now this

1696
01:15:26,680 --> 01:15:30,579

gets us the complicated stuff

1697

01:15:28,020 --> 01:15:32,860

astrophysics was sort of there's a

1698

01:15:30,579 --> 01:15:34,800

famous astrophysicist really sort of the

1699

01:15:32,859 --> 01:15:37,329

best at physics is slash-and-burn

1700

01:15:34,800 --> 01:15:39,310

because you can't do real experiments so

1701

01:15:37,329 --> 01:15:41,769

you go and get the you get it's easy to

1702

01:15:39,310 --> 01:15:43,870

get the basic idea it's very hard to get

1703

01:15:41,770 --> 01:15:44,830

the details so we've got to sort out the

1704

01:15:43,869 --> 01:15:46,840

detail here right

1705

01:15:44,829 --> 01:15:49,029

we know it's merging neutron stars we

1706

01:15:46,840 --> 01:15:50,650

know we got lots of material for now

1707

01:15:49,029 --> 01:15:52,509

we've got electromagnetic processes

1708

01:15:50,649 --> 01:15:53,679

going on exactly how it's working is

1709

01:15:52,510 --> 01:15:55,720

gonna take a lot of work because we

1710

01:15:53,680 --> 01:15:57,310

can't do we can't just go and take too

1711
01:15:55,720 --> 01:16:00,760
much neutron stars and merge them in the

1712
01:15:57,310 --> 01:16:04,120
lab and figure and see what happens yeah

1713
01:16:00,760 --> 01:16:05,739
but it's just not part of the budget but

1714
01:16:04,119 --> 01:16:07,930
again we may know by the end of the year

1715
01:16:05,739 --> 01:16:09,880
because of what's going on and again

1716
01:16:07,930 --> 01:16:12,280
we'll probably have because the weight

1717
01:16:09,880 --> 01:16:15,369
falls and again in a couple of years we

1718
01:16:12,279 --> 01:16:17,949
may have them anymore okay so here's

1719
01:16:15,369 --> 01:16:20,769
what here are that the blue here again

1720
01:16:17,949 --> 01:16:23,859
are the the black holes that have been

1721
01:16:20,770 --> 01:16:25,950
seen by LIGO here are the black holes we

1722
01:16:23,859 --> 01:16:29,979
saw before like Oh known as a pattern

1723
01:16:25,949 --> 01:16:31,539
yeah and then here are the neutron stars

1724
01:16:29,979 --> 01:16:33,909
that we've seen before these two neutron

1725
01:16:31,539 --> 01:16:35,350
stars are right in the right in the same

1726
01:16:33,909 --> 01:16:37,630
mass range as all the other neutron

1727
01:16:35,350 --> 01:16:40,000
stars this is probably they don't show

1728
01:16:37,630 --> 01:16:41,500
errors this this has an error bar that

1729
01:16:40,000 --> 01:16:43,689
could get it down to about two solar

1730
01:16:41,500 --> 01:16:45,550
masses we think about somewhere around

1731
01:16:43,689 --> 01:16:46,989
twice as massive of the Sun a little

1732
01:16:45,550 --> 01:16:48,760
maybe a little more than that is where

1733
01:16:46,989 --> 01:16:50,349
neutron stars collapse down to black

1734
01:16:48,760 --> 01:16:51,640
holes we don't know for sure maybe we'll

1735
01:16:50,350 --> 01:16:54,430
learn as a result of this sort of work

1736
01:16:51,640 --> 01:16:55,630
these two objects form did merge to

1737
01:16:54,430 --> 01:16:57,820
something of more like three solar

1738
01:16:55,630 --> 01:17:00,069
masses so we think they probably merged

1739

01:16:57,819 --> 01:17:01,329
into a black hole how quickly that black

1740
01:17:00,069 --> 01:17:02,710
hole formed though is really is an

1741
01:17:01,329 --> 01:17:04,840
important question which we don't have

1742
01:17:02,710 --> 01:17:07,029
answered fully yet we don't and the

1743
01:17:04,840 --> 01:17:09,760
gravitational waves we detector we have

1744
01:17:07,029 --> 01:17:14,609
isn't sensitive in the high frequencies

1745
01:17:09,760 --> 01:17:14,610
we need to really to really get to that

1746
01:17:17,930 --> 01:17:35,170
so wait you knew let me go back if I can

1747
01:17:23,630 --> 01:17:35,170
get it to itch blade which I put it yeah

1748
01:17:35,409 --> 01:17:50,510
should've been let me see if we get it

1749
01:17:37,819 --> 01:17:51,979
to go there it is oh you're not seeing

1750
01:17:50,510 --> 01:17:59,739
it now because it for something because

1751
01:17:51,979 --> 01:18:02,089
I switched the mode No oh that's a shame

1752
01:17:59,739 --> 01:18:04,099
it takes about 30 seconds though it's

1753
01:18:02,090 --> 01:18:06,529

the sound of the neutron stars emerging

1754

01:18:04,100 --> 01:18:07,910

and it worked on any trend it may have

1755

01:18:06,529 --> 01:18:13,909

gotten lost in the trends for to this

1756

01:18:07,909 --> 01:18:19,340

machine from the desktop it's a pretty

1757

01:18:13,909 --> 01:18:21,199

actually pretty good indie there you go

1758

01:18:19,340 --> 01:18:23,000

and it takes about that's about the 30

1759

01:18:21,199 --> 01:18:25,159

seconds so they know earlier for some

1760

01:18:23,000 --> 01:18:30,710

reason or we missed it am I talking and

1761

01:18:25,159 --> 01:18:37,849

it was very loud was it because you see

1762

01:18:30,710 --> 01:18:40,730

this the recording that they got is

1763

01:18:37,850 --> 01:18:44,230

about 30 seconds long and so it takes a

1764

01:18:40,729 --> 01:18:44,229

minute for takes half of there

1765

01:18:53,050 --> 01:19:04,310

these new front stars you know they just

1766

01:18:55,279 --> 01:19:06,289

don't go off in you walk and it was it

1767

01:19:04,310 --> 01:19:08,449

was very soft and much lower before that

1768
01:19:06,289 --> 01:19:10,519
but we just hard to here with this set

1769
01:19:08,448 --> 01:19:13,549
up it starts at very low and but it

1770
01:19:10,520 --> 01:19:15,230
starts out sort of off the reason this

1771
01:19:13,550 --> 01:19:17,779
is longer is really because it's better

1772
01:19:15,229 --> 01:19:21,829
suited to the frequency band that the

1773
01:19:17,779 --> 01:19:24,529
LIGO detectors can detect the there's

1774
01:19:21,829 --> 01:19:27,529
too much bass really in the in the black

1775
01:19:24,529 --> 01:19:30,019
holes for Lego and and unfortunately if

1776
01:19:27,529 --> 01:19:33,079
this had more treble it could get it

1777
01:19:30,020 --> 01:19:34,639
could get the the actual spin down and

1778
01:19:33,079 --> 01:19:35,658
merger of the two neutron star so you

1779
01:19:34,639 --> 01:19:37,609
could really see get it form a black

1780
01:19:35,658 --> 01:19:39,589
hole and what is sort of the equation of

1781
01:19:37,609 --> 01:19:41,689
state of the neutron stars that is how

1782
01:19:39,590 --> 01:19:43,369
big are they that was something we

1783
01:19:41,689 --> 01:19:47,138
really like to know I don't think LIGO

1784
01:19:43,369 --> 01:19:47,139
would that may take the next generation

1785
01:20:07,800 --> 01:20:16,449
okay so now there's another thing that

1786
01:20:13,238 --> 01:20:18,968
these neutron stars might do and that's

1787
01:20:16,448 --> 01:20:21,069
helped us with cosmology one of the

1788
01:20:18,969 --> 01:20:23,980
really important questions in cosmology

1789
01:20:21,069 --> 01:20:25,359
which turned out we knew it for a while

1790
01:20:23,979 --> 01:20:28,419
you may have heard about this big

1791
01:20:25,359 --> 01:20:30,609
argument between Sandage and huh is a no

1792
01:20:28,420 --> 01:20:32,260
this is what what is the Hubble constant

1793
01:20:30,609 --> 01:20:35,289
which is how fast is the universe

1794
01:20:32,260 --> 01:20:36,520
expanding locally we know it's expanding

1795
01:20:35,289 --> 01:20:38,769
we know the acceleration of the universe

1796

01:20:36,520 --> 01:20:40,989
is actually expanding with time but the

1797
01:20:38,770 --> 01:20:43,300
actual velocity locally how fast is it

1798
01:20:40,988 --> 01:20:47,198
expanding locally is an important issue

1799
01:20:43,300 --> 01:20:50,110
and it turns out that if you look at the

1800
01:20:47,198 --> 01:20:54,939
people looking at the Cosmic Microwave

1801
01:20:50,109 --> 01:20:56,619
Background using satellites to measure

1802
01:20:54,939 --> 01:20:58,719
the Cosmic Microwave you know the most

1803
01:20:56,619 --> 01:20:59,829
plunk the plunk telescope the European

1804
01:20:58,719 --> 01:21:00,908
Bank telescope did a very accurate

1805
01:20:59,829 --> 01:21:03,670
measure to the Cosmic Microwave

1806
01:21:00,908 --> 01:21:05,289
Background and they have to solve many

1807
01:21:03,670 --> 01:21:09,250
things simultaneously but when they do

1808
01:21:05,289 --> 01:21:11,289
that they get a number of about 67 now

1809
01:21:09,250 --> 01:21:13,119
when kilometers per second per

1810
01:21:11,289 --> 01:21:15,369

megaparsec and mayor barzmann it's like

1811
01:21:13,119 --> 01:21:16,059
three light-years so if you're three

1812
01:21:15,369 --> 01:21:19,029
light-years away

1813
01:21:16,060 --> 01:21:21,280
you're receding from me at about 70

1814
01:21:19,029 --> 01:21:23,649
kilometers per second double that we're

1815
01:21:21,279 --> 01:21:25,840
good so six six light-years you tend to

1816
01:21:23,649 --> 01:21:29,888
go away to hunt at 140 kilometers per

1817
01:21:25,840 --> 01:21:32,440
second on and on and on now the number

1818
01:21:29,889 --> 01:21:34,750
that Adam riess here many maybe you've

1819
01:21:32,439 --> 01:21:36,460
heard was speak before he's been

1820
01:21:34,750 --> 01:21:38,079
measuring and he won the Nobel Prize for

1821
01:21:36,460 --> 01:21:40,060
the expansion of the universe I was on

1822
01:21:38,079 --> 01:21:41,500
the other team so Laura Motors team but

1823
01:21:40,060 --> 01:21:48,310
had I'm still a nice guy

1824
01:21:41,500 --> 01:21:50,679
and and and and and the but the number

1825
01:21:48,310 --> 01:21:55,750
that you get that Adam has gotten is

1826
01:21:50,679 --> 01:21:58,630
more like 73 now that's but that's just

1827
01:21:55,750 --> 01:22:00,488
at this 3.8 Sigma say the term that the

1828
01:21:58,630 --> 01:22:03,940
three Sigma is sort of like where you

1829
01:22:00,488 --> 01:22:06,099
start getting this looks bad right now

1830
01:22:03,939 --> 01:22:08,500
if I it really true the three Sigma

1831
01:22:06,100 --> 01:22:10,150
should be if you're broke justit istic

1832
01:22:08,500 --> 01:22:12,520
Scouse IAM statistic three sigma b

1833
01:22:10,149 --> 01:22:14,920
that's definite the world is not things

1834
01:22:12,520 --> 01:22:17,489
go wrong so really five Sigma is like

1835
01:22:14,920 --> 01:22:20,038
beyond any doubt in this in there

1836
01:22:17,488 --> 01:22:22,408
life but three sigma three-point ageism

1837
01:22:20,038 --> 01:22:24,179
is getting pretty serious so and it

1838
01:22:22,408 --> 01:22:26,879
turns out that it looks like multiple

1839
01:22:24,179 --> 01:22:29,190
experiments when you so it looks like

1840
01:22:26,880 --> 01:22:30,900
you cosmic microwave ink master when

1841
01:22:29,189 --> 01:22:31,948
you're measuring the universe very far

1842
01:22:30,899 --> 01:22:34,109
away you get a slightly different answer

1843
01:22:31,948 --> 01:22:36,748
than when you're measuring closer in so

1844
01:22:34,109 --> 01:22:38,639
it may mean there's something wrong with

1845
01:22:36,748 --> 01:22:39,929
the model that we're using it could be

1846
01:22:38,639 --> 01:22:42,420
something as simple as that it was a

1847
01:22:39,929 --> 01:22:44,699
particle that used to exist

1848
01:22:42,420 --> 01:22:46,139
that's a K did maybe a hundred thousand

1849
01:22:44,698 --> 01:22:48,029
years in the image of the universe and

1850
01:22:46,139 --> 01:22:49,739
it's no longer around a massive particle

1851
01:22:48,029 --> 01:22:51,679
we don't really know it could be

1852
01:22:49,738 --> 01:22:54,919
something more interesting it could be

1853

01:22:51,679 --> 01:22:58,679
just that you really need five sigma but

1854
01:22:54,920 --> 01:23:01,170
so but this the interesting thing is

1855
01:22:58,679 --> 01:23:04,469
that as I mentioned to you that you can

1856
01:23:01,170 --> 01:23:06,389
tell by measuring the gravity wave here

1857
01:23:04,469 --> 01:23:08,609
and how strong it is you can get an

1858
01:23:06,389 --> 01:23:12,179
estimate of how far away the object was

1859
01:23:08,609 --> 01:23:15,299
and this is from that single object this

1860
01:23:12,179 --> 01:23:19,050
bar here and this is the that that line

1861
01:23:15,300 --> 01:23:21,630
is the is the Planck measurement and

1862
01:23:19,050 --> 01:23:24,449
this yellow bar here is Adams

1863
01:23:21,630 --> 01:23:26,309
measurement and you can see that this is

1864
01:23:24,448 --> 01:23:28,678
only one object they Adam has you know

1865
01:23:26,309 --> 01:23:30,869
dozens in here and so if you could get

1866
01:23:28,679 --> 01:23:32,639
many more and if you can get the

1867
01:23:30,868 --> 01:23:34,469

systematic errors down on these there

1868

01:23:32,639 --> 01:23:35,969

are some errors to worry about and so

1869

01:23:34,469 --> 01:23:37,618

it's just starting now but you might

1870

01:23:35,969 --> 01:23:41,189

have a completely independent measure

1871

01:23:37,618 --> 01:23:42,868

and with the the local observations that

1872

01:23:41,189 --> 01:23:45,118

the type atom does you have to sort of

1873

01:23:42,868 --> 01:23:46,679

use a distance ladder use a couple of

1874

01:23:45,118 --> 01:23:48,839

different objects to really build out

1875

01:23:46,679 --> 01:23:50,998

how far your things are this this is a

1876

01:23:48,840 --> 01:23:54,300

direct physical measurement of the

1877

01:23:50,998 --> 01:23:56,399

distance so it's it's potentially very

1878

01:23:54,300 --> 01:23:58,619

powerful but there it's not it's tricky

1879

01:23:56,399 --> 01:23:59,998

to do so well we'll see but it's

1880

01:23:58,618 --> 01:24:01,828

possible this will give us another way

1881

01:23:59,998 --> 01:24:05,550

to really get at this physics this

1882
01:24:01,828 --> 01:24:08,279
cosmology and and or the term that's

1883
01:24:05,550 --> 01:24:10,139
been used right to my far that's just

1884
01:24:08,279 --> 01:24:15,448
sort of cute they're called because of

1885
01:24:10,139 --> 01:24:19,109
that okay so coordination is like not my

1886
01:24:15,448 --> 01:24:21,118
greatest ability all right so um these

1887
01:24:19,109 --> 01:24:24,658
the standard sirens this chirp it's

1888
01:24:21,118 --> 01:24:26,399
called also closer chirp is right so

1889
01:24:24,658 --> 01:24:28,228
there's a standard sirens as the term

1890
01:24:26,399 --> 01:24:29,460
that's being used because you can tell

1891
01:24:28,229 --> 01:24:30,420
how far right the stand you get

1892
01:24:29,460 --> 01:24:31,948
standardized on you

1893
01:24:30,420 --> 01:24:37,350
how far away they are and that would be

1894
01:24:31,948 --> 01:24:40,589
the idea so LIGO and Virgo are being

1895
01:24:37,350 --> 01:24:42,239
upgraded LIGO will return in 2019 it's

1896
01:24:40,590 --> 01:24:44,219
expected to be 2 or 3 times more

1897
01:24:42,238 --> 01:24:46,319
sensitive now as I mentioned you already

1898
01:24:44,219 --> 01:24:48,869
the strain if things are twice as far

1899
01:24:46,319 --> 01:24:50,969
away they're half as powerful so that if

1900
01:24:48,869 --> 01:24:53,130
you can go if you have something that's

1901
01:24:50,969 --> 01:24:55,890
two or three times more can measure

1902
01:24:53,130 --> 01:24:58,560
strain that's two or three times smaller

1903
01:24:55,890 --> 01:25:00,960
you can search a volume that's two cubed

1904
01:24:58,560 --> 01:25:03,330
or three cubed larger radius turns into

1905
01:25:00,960 --> 01:25:06,539
you cube the radius to get the volume

1906
01:25:03,329 --> 01:25:09,529
and so you get the volume goes up by a

1907
01:25:06,539 --> 01:25:13,319
factor of eight to maybe thirty so

1908
01:25:09,529 --> 01:25:15,448
instead of one neutron star merging

1909
01:25:13,319 --> 01:25:17,250
neutron star per year and a few black

1910

01:25:15,448 --> 01:25:20,069
holes merging per year we could be

1911
01:25:17,250 --> 01:25:23,609
seeing one neutron star merger per month

1912
01:25:20,069 --> 01:25:32,609
and maybe one black hole merger per week

1913
01:25:23,609 --> 01:25:34,738
right so it could be rather busy now

1914
01:25:32,609 --> 01:25:41,189
what what's going to be coming in the in

1915
01:25:34,738 --> 01:25:44,729
the far future in the 2030s a this is a

1916
01:25:41,189 --> 01:25:47,460
plan this is called Lisa it's three

1917
01:25:44,729 --> 01:25:50,359
satellites forming any durometer in

1918
01:25:47,460 --> 01:25:54,689
space with arms that are about a million

1919
01:25:50,359 --> 01:25:56,159
million year of ly miles long and they

1920
01:25:54,689 --> 01:26:02,819
said a trailing orbit behind the Earth

1921
01:25:56,159 --> 01:26:04,889
and be able to take merging black holes

1922
01:26:02,819 --> 01:26:08,090
in distant galaxies as well as white

1923
01:26:04,890 --> 01:26:11,730
dwarf binaries verging in our galaxy and

1924
01:26:08,090 --> 01:26:13,949

now this may also look crazy but there

1925

01:26:11,729 --> 01:26:15,359

was it was a satellite the Europeans

1926

01:26:13,948 --> 01:26:18,599

with some American help send up was go

1927

01:26:15,359 --> 01:26:20,939

to Lisa Pathfinder which tested the

1928

01:26:18,600 --> 01:26:22,770

sensitivity of the detector there and

1929

01:26:20,939 --> 01:26:26,639

how quiet they could make the whole

1930

01:26:22,770 --> 01:26:28,560

system and it affair exceeded how the

1931

01:26:26,640 --> 01:26:31,020

goal of what they wanted for the

1932

01:26:28,560 --> 01:26:32,940

Pathfinder it in fact exceeded it met

1933

01:26:31,020 --> 01:26:37,080

and even exceeded what they needed for

1934

01:26:32,939 --> 01:26:39,119

Lisa itself in this first try so this

1935

01:26:37,079 --> 01:26:40,859

looks really doable if that's an

1936

01:26:39,119 --> 01:26:42,929

incredible achievement that in this

1937

01:26:40,859 --> 01:26:44,259

first try right they found that they

1938

01:26:42,929 --> 01:26:45,639

were doing better than he wanted to do

1939
01:26:44,260 --> 01:26:48,909
in the thing that they're gonna do 10

1940
01:26:45,639 --> 01:26:51,309
years from now so we maintain somewhere

1941
01:26:48,908 --> 01:26:53,138
in the 20 late 2020s 20 30 we may

1942
01:26:51,309 --> 01:26:55,900
actually have that thing flying in space

1943
01:26:53,139 --> 01:26:58,900
I don't know where it went

1944
01:26:55,899 --> 01:27:04,538
but when it went flying into space okay

1945
01:26:58,899 --> 01:27:07,598
now so there you have there's like oh

1946
01:27:04,538 --> 01:27:10,238
and they 10 and then you have this is

1947
01:27:07,599 --> 01:27:12,219
Lisa is here can get these things now

1948
01:27:10,238 --> 01:27:15,308
you can do other things to look for

1949
01:27:12,219 --> 01:27:19,739
gravitational waves pulsars again clocks

1950
01:27:15,309 --> 01:27:23,079
and they're all over the sky and so if a

1951
01:27:19,738 --> 01:27:26,109
big of a long wave comes and passes by

1952
01:27:23,078 --> 01:27:28,268
right all it'll affect all of the

1953
01:27:26,109 --> 01:27:29,380
objects in one way one way and the other

1954
01:27:28,269 --> 01:27:31,989
way the other way right so it's

1955
01:27:29,380 --> 01:27:33,969
stretching it's making the space so for

1956
01:27:31,988 --> 01:27:36,189
example the pulsars in this direction

1957
01:27:33,969 --> 01:27:37,989
would look further away and the pulsars

1958
01:27:36,189 --> 01:27:40,210
in that direction look closer to us and

1959
01:27:37,988 --> 01:27:44,799
then change right it would change the

1960
01:27:40,210 --> 01:27:48,599
other way so you could potentially use

1961
01:27:44,800 --> 01:27:51,579
this to look for very low-frequency

1962
01:27:48,599 --> 01:27:53,529
gravitational waves very so what sort of

1963
01:27:51,578 --> 01:27:56,139
things with like over time spans of

1964
01:27:53,529 --> 01:27:58,448
years that as they pass the earth and

1965
01:27:56,139 --> 01:28:01,630
those would be found by those can be

1966
01:27:58,448 --> 01:28:04,598
produced both by binary black holes in

1967

01:28:01,630 --> 01:28:06,099
galactic nuclei as they're merging not

1968
01:28:04,599 --> 01:28:09,369
quite at the end but is there close to

1969
01:28:06,099 --> 01:28:11,739
merging and and then it also it is a lot

1970
01:28:09,368 --> 01:28:14,078
of this prediction that the early

1971
01:28:11,738 --> 01:28:16,328
universe would have radiated the black

1972
01:28:14,078 --> 01:28:18,099
the the actual big bang would have

1973
01:28:16,328 --> 01:28:20,799
radiated gravitational waves

1974
01:28:18,099 --> 01:28:22,840
it's basically Hawking radiation from

1975
01:28:20,800 --> 01:28:25,480
the from the horizon Inventor isin of

1976
01:28:22,840 --> 01:28:27,670
the universe so you want to blow your

1977
01:28:25,479 --> 01:28:29,948
mind you can just think about that it's

1978
01:28:27,670 --> 01:28:32,260
in fact for a while there was this there

1979
01:28:29,948 --> 01:28:33,368
was a observation called the bicep may

1980
01:28:32,260 --> 01:28:36,059
some of you may have heard of this there

1981
01:28:33,368 --> 01:28:38,408

was a there was a pro observation of the

1982

01:28:36,059 --> 01:28:39,880

Cosmic Microwave Background from sent

1983

01:28:38,408 --> 01:28:41,399

Antarctica and they thought they had

1984

01:28:39,880 --> 01:28:43,480

found this they thought they had found

1985

01:28:41,399 --> 01:28:45,518

evidence in the Cosmic Microwave

1986

01:28:43,479 --> 01:28:46,988

Background of just that radiation and

1987

01:28:45,519 --> 01:28:50,260

that would have been like for Nobel

1988

01:28:46,988 --> 01:28:53,609

Prizes wrapped in one and it turned out

1989

01:28:50,260 --> 01:28:53,610

in the end it was dust in our galaxy

1990

01:28:54,868 --> 01:29:00,279

dusts you know I just you know it's just

1991

01:28:57,698 --> 01:29:02,049

a pain there are people who are

1992

01:29:00,279 --> 01:29:03,309

astronomers who they get all upset when

1993

01:29:02,050 --> 01:29:04,659

it we've let I say that sort of thing

1994

01:29:03,310 --> 01:29:07,510

but there cuz they're astronomers who

1995

01:29:04,658 --> 01:29:15,029

like study dust I just you know just

1996
01:29:07,510 --> 01:29:15,030
give me a clean galaxy but alright

1997
01:29:15,719 --> 01:29:21,010
alright they I love that effect no

1998
01:29:18,670 --> 01:29:23,139
matter what you say it's got it you know

1999
01:29:21,010 --> 01:29:25,119
you're right it's important all right so

2000
01:29:23,139 --> 01:29:26,980
so the detection of gravitational waves

2001
01:29:25,118 --> 01:29:29,198
has given us new insights into stellar

2002
01:29:26,979 --> 01:29:31,118
astrophysics and we Martin confirmation

2003
01:29:29,198 --> 01:29:35,769
of general relativity and may give us a

2004
01:29:31,118 --> 01:29:38,259
new test of the cosmological model yeah

2005
01:29:35,770 --> 01:29:40,750
we have seen massive black holes in

2006
01:29:38,260 --> 01:29:42,400
abundance that we did not expect right

2007
01:29:40,750 --> 01:29:44,618
and that's gonna tell us a lot probably

2008
01:29:42,399 --> 01:29:46,479
about how the for probably about stellar

2009
01:29:44,618 --> 01:29:50,259
evolution maybe about primordial black

2010
01:29:46,479 --> 01:29:52,299
holes we have seen a neutron star killer

2011
01:29:50,260 --> 01:29:54,250
merger prusik elenova confirm the

2012
01:29:52,300 --> 01:29:56,500
suggestion that the majority of Hell in

2013
01:29:54,250 --> 01:29:59,439
the elements in the universe are formed

2014
01:29:56,500 --> 01:30:02,020
by neutron star mergers we're not sure

2015
01:29:59,439 --> 01:30:03,428
if we've seen a GRB associated with this

2016
01:30:02,020 --> 01:30:06,130
neutron star merger we but we should

2017
01:30:03,429 --> 01:30:08,109
know soon and there are gonna be if LIGO

2018
01:30:06,130 --> 01:30:10,750
this upgrade succeeds doesn't go

2019
01:30:08,109 --> 01:30:13,448
backwards but goes forward we should

2020
01:30:10,750 --> 01:30:17,170
have lots more to test right and some of

2021
01:30:13,448 --> 01:30:19,238
those should be pointed at us so that

2022
01:30:17,170 --> 01:30:22,239
will help the statistics alone will help

2023
01:30:19,238 --> 01:30:23,379
us there and so again the prospects for

2024

01:30:22,238 --> 01:30:25,509
the future of gravitational wave

2025
01:30:23,380 --> 01:30:27,109
astronomy look very good indeed so thank

2026
01:30:25,510 --> 01:30:36,550
you very much

2027
01:30:27,109 --> 01:30:39,918
[Applause]

2028
01:30:36,550 --> 01:30:42,199
okay so we have hit our sort of neutral

2029
01:30:39,918 --> 01:30:45,260
limit of 9:30 so if you need to leave

2030
01:30:42,198 --> 01:30:48,078
please get up and leave them we went on

2031
01:30:45,260 --> 01:30:50,570
for a while for those who want to stay

2032
01:30:48,078 --> 01:30:51,889
and ask some questions um we have a few

2033
01:30:50,569 --> 01:30:57,549
questions I'm going to start without a

2034
01:30:51,889 --> 01:30:57,550
question from online so

2035
01:31:03,618 --> 01:31:08,509
so Brenda asks if there were two black

2036
01:31:06,710 --> 01:31:11,000
holes in the center of our galaxy that

2037
01:31:08,510 --> 01:31:13,610
merged and emitted gravitational waves

2038
01:31:11,000 --> 01:31:22,250

what if any effect would this have on

2039

01:31:13,609 --> 01:31:24,769

earth so I don't know it hurt I don't

2040

01:31:22,250 --> 01:31:26,868

think you would notice um but because

2041

01:31:24,770 --> 01:31:30,770

we're small and so the stretch is very

2042

01:31:26,868 --> 01:31:34,250

tiny but why would the gravitational

2043

01:31:30,770 --> 01:31:36,679

wave detectors have a field day yet so I

2044

01:31:34,250 --> 01:31:38,510

don't I haven't done the culture I don't

2045

01:31:36,679 --> 01:31:41,529

think seismologists would didn't know it

2046

01:31:38,510 --> 01:31:43,969

do you have a question no she she wants

2047

01:31:41,529 --> 01:31:47,198

just in case you guys need a refresher

2048

01:31:43,969 --> 01:31:49,939

for this Nancy brought up this book and

2049

01:31:47,198 --> 01:31:54,738

it's called general relativity for

2050

01:31:49,939 --> 01:31:56,899

babies in which the one of the last

2051

01:31:54,738 --> 01:32:02,799

parts of it is about gravitational waves

2052

01:31:56,899 --> 01:32:02,799

okay sharing that with us

2053
01:32:06,079 --> 01:32:47,449
[Applause]

2054
01:32:08,210 --> 01:32:49,130
that is other questions we have that

2055
01:32:47,449 --> 01:32:53,869
gravitational waves are actually a

2056
01:32:49,130 --> 01:32:57,020
superposition of okay I'm trying to

2057
01:32:53,869 --> 01:32:58,099
repeat that for the online audience then

2058
01:32:57,020 --> 01:32:59,600
you talked about the compression and

2059
01:32:58,100 --> 01:33:03,260
rarefaction of the wave it's that

2060
01:32:59,600 --> 01:33:05,750
indicate of the wave is polarized and if

2061
01:33:03,260 --> 01:33:07,760
so does that mean that the waves are

2062
01:33:05,750 --> 01:33:10,488
super positions of polarization States

2063
01:33:07,760 --> 01:33:12,079
yes so the average wave you see is the

2064
01:33:10,488 --> 01:33:14,269
superposition of polarization States

2065
01:33:12,079 --> 01:33:17,719
this is one polarization you stretch

2066
01:33:14,270 --> 01:33:20,870
like this in a this then 90 degrees away

2067
01:33:17,719 --> 01:33:23,600
now hopefully if this works yeah you can

2068
01:33:20,869 --> 01:33:25,819
rotate by 45 degrees and then the

2069
01:33:23,600 --> 01:33:27,950
stretching 45 degrees in the expansion

2070
01:33:25,819 --> 01:33:30,229
45 degrees that's the other polarization

2071
01:33:27,949 --> 01:33:31,819
if that's the way gravitational waves

2072
01:33:30,229 --> 01:33:33,439
work they're not quite like the dipoles

2073
01:33:31,819 --> 01:33:35,210
of electromagnetism that you think of

2074
01:33:33,439 --> 01:33:37,879
where it's typically like a vector one

2075
01:33:35,210 --> 01:33:41,289
direction and then it's the 90 degrees

2076
01:33:37,880 --> 01:33:43,010
here you've got basically it's this is a

2077
01:33:41,289 --> 01:33:46,100
electromagnet is called dipole radiation

2078
01:33:43,010 --> 01:33:49,039
it's along basically along a line this

2079
01:33:46,100 --> 01:33:51,380
is a quadrupole it's basically a sort of

2080
01:33:49,039 --> 01:33:55,909
elliptical shape right a two-dimensional

2081

01:33:51,380 --> 01:33:57,739
shape that radiates and and so you get

2082
01:33:55,909 --> 01:33:59,779
that the polarization is actually just

2083
01:33:57,738 --> 01:34:01,909
the stretching and compression being

2084
01:33:59,779 --> 01:34:03,319
rotated by 45 degrees and the

2085
01:34:01,909 --> 01:34:05,000
polarization is important in

2086
01:34:03,319 --> 01:34:07,909
understanding the orientation of the

2087
01:34:05,000 --> 01:34:09,979
object from you that come right and so

2088
01:34:07,909 --> 01:34:11,359
so when you measure these gravitational

2089
01:34:09,979 --> 01:34:13,879
waves trying to measure the polarization

2090
01:34:11,359 --> 01:34:18,369
is important if you want to solve for

2091
01:34:13,880 --> 01:34:18,369
all of these parameters of the orbit

2092
01:34:19,539 --> 01:34:44,960
no no these are in generality these are

2093
01:34:23,300 --> 01:34:47,690
the two modes okay down here no let me

2094
01:34:44,960 --> 01:34:49,399
so in a supernova the neutrinos are part

2095
01:34:47,689 --> 01:34:51,979

of the thing that blows the star apart

2096

01:34:49,399 --> 01:34:54,739
is there a similar release here it

2097

01:34:51,979 --> 01:34:56,750
probably was but our neutrino detectors

2098

01:34:54,739 --> 01:34:59,119
aren't sensitive enough to detect it so

2099

01:34:56,750 --> 01:35:01,970
the neutrino detectors can detect things

2100

01:34:59,119 --> 01:35:04,039
in our in our galaxy and in the local

2101

01:35:01,970 --> 01:35:05,990
with the nearby galaxies these the

2102

01:35:04,039 --> 01:35:08,029
things we're seeing here are too distant

2103

01:35:05,989 --> 01:35:09,949
we think for the neutrino detectors but

2104

01:35:08,029 --> 01:35:12,829
it's an important question you ask in

2105

01:35:09,949 --> 01:35:14,750
the way that so gravity this is called

2106

01:35:12,829 --> 01:35:17,029
multi in the astronomy communities it's

2107

01:35:14,750 --> 01:35:18,829
called multi messenger astrophysics in a

2108

01:35:17,029 --> 01:35:21,699
sense that you're using different types

2109

01:35:18,829 --> 01:35:23,630
of particles or form right so

2110
01:35:21,699 --> 01:35:26,090
electromagnetic radiation is one

2111
01:35:23,630 --> 01:35:28,250
messenger gravity is another message

2112
01:35:26,090 --> 01:35:29,840
messenger neutrinos are another type of

2113
01:35:28,250 --> 01:35:31,579
completely different type of messenger

2114
01:35:29,840 --> 01:35:33,289
and so if you had something close enough

2115
01:35:31,579 --> 01:35:36,229
or we had much more sensitive neutrino

2116
01:35:33,289 --> 01:35:37,850
detectors you could get that yeah I mean

2117
01:35:36,229 --> 01:35:42,039
we talked about gravitational wave

2118
01:35:37,850 --> 01:35:46,460
astronomy neutrino astronomy is also a

2119
01:35:42,039 --> 01:35:48,229
very infancy type development and you

2120
01:35:46,460 --> 01:35:53,270
know there are talks of being able to

2121
01:35:48,229 --> 01:35:55,849
see neutrinos from or in early cosmology

2122
01:35:53,270 --> 01:35:58,430
right well such so I mean there's

2123
01:35:55,850 --> 01:36:01,539
there's possibilities of other non

2124
01:35:58,430 --> 01:36:04,090
optical yeah oh yeah especially from a

2125
01:36:01,539 --> 01:36:07,340
supernova going off in the local group

2126
01:36:04,090 --> 01:36:10,010
in fact it right so neutrinos were

2127
01:36:07,340 --> 01:36:12,980
detected from nineteen supernova 1987a

2128
01:36:10,010 --> 01:36:15,260
right right and so a handful but they

2129
01:36:12,979 --> 01:36:17,029
were detected and so but that was a very

2130
01:36:15,260 --> 01:36:21,340
closed galaxy right and so that's the

2131
01:36:17,029 --> 01:36:21,340
problem question over here

2132
01:36:32,770 --> 01:36:37,990
not really no and it's not quite

2133
01:36:35,800 --> 01:36:39,369
analogous and in some ways I was

2134
01:36:37,989 --> 01:36:41,380
thinking about this earlier I think that

2135
01:36:39,369 --> 01:36:42,789
part of it is also that in fact what

2136
01:36:41,380 --> 01:36:45,130
we've learned from quantum mechanics is

2137
01:36:42,789 --> 01:36:48,850
that the way to think of it isn't really

2138

01:36:45,130 --> 01:36:51,609
has it's to think the elect the the

2139
01:36:48,850 --> 01:36:53,289
Elektra E&M modes the E&B modes are

2140
01:36:51,609 --> 01:36:55,539
actually different derivatives of a

2141
01:36:53,289 --> 01:36:58,779
thing we call of a potential away call

2142
01:36:55,539 --> 01:37:00,310
vector potential and the quantity it's

2143
01:36:58,779 --> 01:37:01,869
only quantum mechanically people thought

2144
01:37:00,310 --> 01:37:02,680
that was just a mathematic for a long

2145
01:37:01,869 --> 01:37:04,689
time people thought that was just a

2146
01:37:02,680 --> 01:37:06,520
mathematical creation but there's some

2147
01:37:04,689 --> 01:37:08,409
cosmic account to quantum mechanical

2148
01:37:06,520 --> 01:37:09,460
tests where there's no electric field or

2149
01:37:08,409 --> 01:37:11,590
magnetic field but there's just this

2150
01:37:09,460 --> 01:37:13,750
potential and it affects the way grab

2151
01:37:11,590 --> 01:37:17,260
onto mechanical particles propagate so

2152
01:37:13,750 --> 01:37:20,199

that in some sense maybe the real real

2153

01:37:17,260 --> 01:37:22,150

deal and right rather than the E and the

2154

01:37:20,199 --> 01:37:25,779

B and so that in some ways it's more

2155

01:37:22,149 --> 01:37:27,339

known is that way yeah but there's no

2156

01:37:25,779 --> 01:37:29,949

real comfort there is no real difference

2157

01:37:27,340 --> 01:37:31,810

it's just the different polarization all

2158

01:37:29,949 --> 01:37:42,609

right two more questions here and then

2159

01:37:31,810 --> 01:37:47,740

the over there yeah directionality that

2160

01:37:42,609 --> 01:37:55,750

seems like it's not it's clear it's

2161

01:37:47,739 --> 01:37:58,269

clear reason so you have to use timing

2162

01:37:55,750 --> 01:38:00,729

basically that's right so you the major

2163

01:37:58,270 --> 01:38:02,560

thing is that you say okay the grave

2164

01:38:00,729 --> 01:38:05,259

came you know hit me here and then he

2165

01:38:02,560 --> 01:38:07,150

hit me here and then I know so that if

2166

01:38:05,260 --> 01:38:08,980

it hit here first then it had to be sort

2167
01:38:07,149 --> 01:38:10,779
of you just draw circles right where

2168
01:38:08,979 --> 01:38:14,259
where is that where is it going to be

2169
01:38:10,779 --> 01:38:16,149
that much closer right and and that

2170
01:38:14,260 --> 01:38:17,650
third object gives you it so that's why

2171
01:38:16,149 --> 01:38:19,420
the position it's so it's like if you do

2172
01:38:17,649 --> 01:38:20,829
reckoning right if you drew if I tell

2173
01:38:19,420 --> 01:38:23,230
you the distance of something is from

2174
01:38:20,829 --> 01:38:25,059
two objects you'll get two points right

2175
01:38:23,229 --> 01:38:26,379
so solutions you draw two circles and

2176
01:38:25,060 --> 01:38:30,280
these are sexually two circles is

2177
01:38:26,380 --> 01:38:31,840
usually two points right and and the but

2178
01:38:30,279 --> 01:38:34,210
you put if I give you a third point and

2179
01:38:31,840 --> 01:38:35,739
it tell you that you get one one

2180
01:38:34,210 --> 01:38:39,039
distance and the same thing happens here

2181
01:38:35,739 --> 01:38:40,599
right and wasn't it sort of like a

2182
01:38:39,039 --> 01:38:41,939
confirmation that gravitational waves

2183
01:38:40,600 --> 01:38:44,650
travel at the speed of light by the

2184
01:38:41,939 --> 01:38:46,479
timing between Hanford and Livingston no

2185
01:38:44,649 --> 01:38:48,639
well yeah I guess the better the better

2186
01:38:46,479 --> 01:38:51,549
one was the 1.7 seconds of the gamma

2187
01:38:48,640 --> 01:38:54,480
rays and the gamma rays coming only 1.7

2188
01:38:51,550 --> 01:38:56,170
seconds after the arrival of the

2189
01:38:54,479 --> 01:38:58,419
gravitational waves there's much more

2190
01:38:56,170 --> 01:39:00,369
precise and proportionally right but

2191
01:38:58,420 --> 01:39:08,109
fortunately are there I and Peter you

2192
01:39:00,369 --> 01:39:09,369
get the last question any chance the

2193
01:39:08,109 --> 01:39:12,250
gravitational waves could be a useful

2194
01:39:09,369 --> 01:39:15,099
source of energy so as you saw you mean

2195

01:39:12,250 --> 01:39:16,989
well so you know this is not really I

2196
01:39:15,100 --> 01:39:18,670
mean because just like the moonlight

2197
01:39:16,989 --> 01:39:19,960
wouldn't be of useful source of a bright

2198
01:39:18,670 --> 01:39:21,279
the brother full moon isn't a useful

2199
01:39:19,960 --> 01:39:23,920
source of energies like that sort sort

2200
01:39:21,279 --> 01:39:26,319
of talking about but even so harvesting

2201
01:39:23,920 --> 01:39:27,760
that energy is not easy right I was

2202
01:39:26,319 --> 01:39:29,729
saying well if you could you know focus

2203
01:39:27,760 --> 01:39:31,449
if the way you could focus

2204
01:39:29,729 --> 01:39:32,589
electromagnetism we look at they would

2205
01:39:31,449 --> 01:39:34,059
look like a point source as bright as

2206
01:39:32,590 --> 01:39:38,409
the full moon but focusing in

2207
01:39:34,060 --> 01:39:39,730
gravitational ways not easy so yeah so

2208
01:39:38,409 --> 01:39:41,769
there's a lot of energy at the source

2209
01:39:39,729 --> 01:39:45,219

but we'd rather keep it over at the

2210

01:39:41,770 --> 01:39:48,070
source than get to close space honey

2211

01:39:45,220 --> 01:39:50,680
turns out that space if you do the

2212

01:39:48,069 --> 01:39:52,059
calculation of like space time there's a

2213

01:39:50,680 --> 01:39:53,950
lot of energy but space time doesn't

2214

01:39:52,060 --> 01:39:56,710
move very much and you can say well how

2215

01:39:53,949 --> 01:39:58,389
how stiff is space-time and its tenth

2216

01:39:56,710 --> 01:40:01,109
but it's about 10 to the 20 times

2217

01:39:58,390 --> 01:40:04,990
stiffer than steel okay yeah it's like

2218

01:40:01,109 --> 01:40:07,659
it's like it's like a billion billion

2219

01:40:04,989 --> 01:40:08,829
million or something million a thousand

2220

01:40:07,659 --> 01:40:11,979
yeah all right

2221

01:40:08,829 --> 01:40:15,550
so space-time is very are very very

2222

01:40:11,979 --> 01:40:19,809
stiff only translates a little bit of

2223

01:40:15,550 --> 01:40:22,600
the energy all right so next month we

2224
01:40:19,810 --> 01:40:23,800
have star formation in Orion and June I

2225
01:40:22,600 --> 01:40:26,710
think it's third or something like that

2226
01:40:23,800 --> 01:40:28,690
it's on the calendar hope to see you all

2227
01:40:26,710 --> 01:40:30,970
there you have now just been

2228
01:40:28,689 --> 01:40:32,409
indoctrinating the brand-new great brave

2229
01:40:30,970 --> 01:40:35,140
new world of gravitational wave

2230
01:40:32,409 --> 01:40:35,659
astronomy let's give dr. Richter one

2231
01:40:35,140 --> 01:40:44,489
more hand

2232
01:40:35,659 --> 01:40:44,488
[Applause]