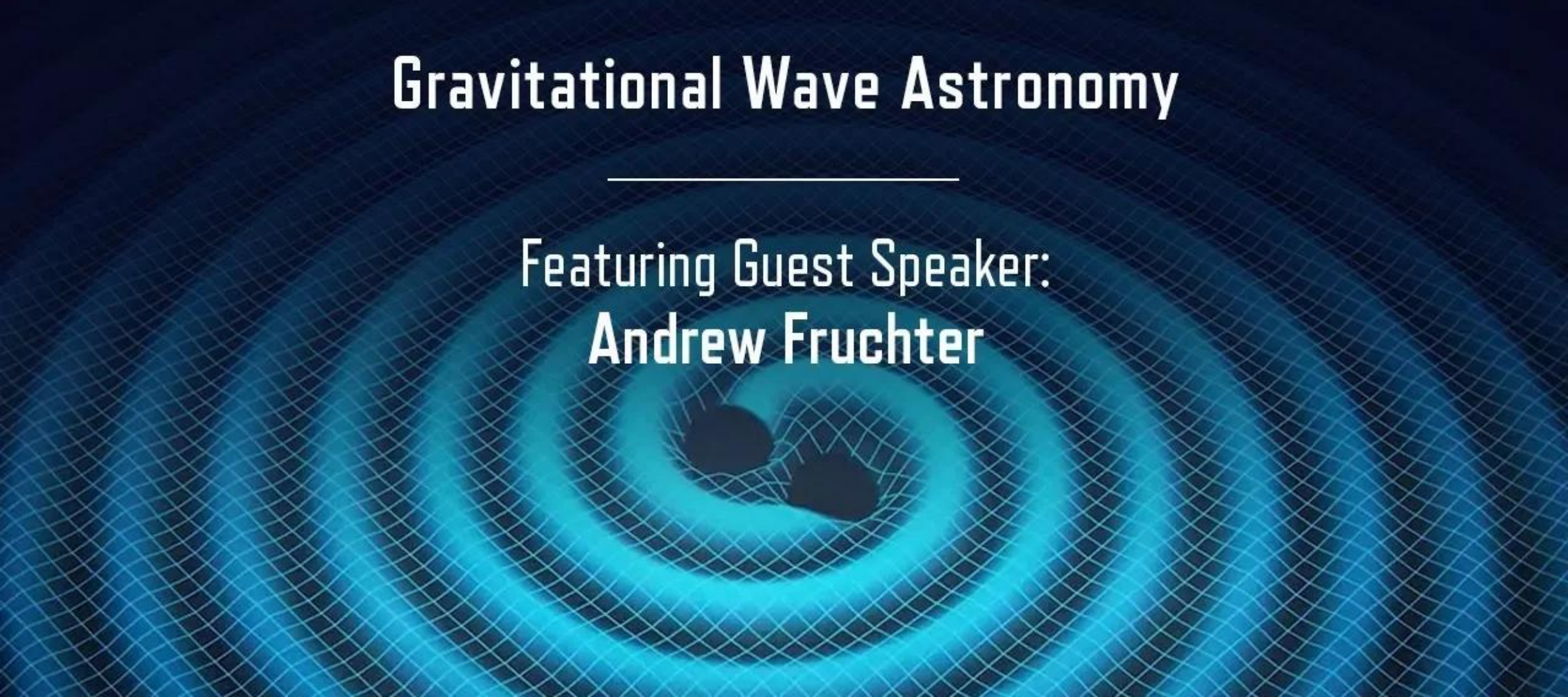
PUBLIC LECTURE SERIES

Gravitational Wave Astronomy

Featuring Guest Speaker:

Andrew Fruchter



1
00:00:07,610 --> 00:00:05,300
and in the backroom grant justice is

2
00:00:09,530 --> 00:00:07,620
taking their their wonderful webcast

3
00:00:18,109 --> 00:00:09,540
feed and streaming it out to YouTube so

4
00:00:21,230 --> 00:00:18,119
give grant a hand alright let's get

5
00:00:23,420 --> 00:00:21,240
started good evening ladies and

6
00:00:25,849 --> 00:00:23,430
gentlemen and welcome to the Space

7
00:00:27,320 --> 00:00:25,859
Telescope public lecture series I'm dr.

8
00:00:30,370 --> 00:00:27,330
Frank summers of the office of public

9
00:00:33,500 --> 00:00:30,380
outreach and when you came in today

10
00:00:35,720 --> 00:00:33,510
there may have been these lithographs on

11
00:00:38,119 --> 00:00:35,730
the tables here and over there

12
00:00:43,069 --> 00:00:38,129
tonight's lithograph is galaxy cluster

13
00:00:45,500 --> 00:00:43,079

Abell 2744 which is a cluster so large

14
00:00:47,209 --> 00:00:45,510
that it produces gravitational lensing

15
00:00:49,069 --> 00:00:47,219
and you want to know what gravitational

16
00:00:50,959 --> 00:00:49,079
lensing is well turnover on the back and

17
00:00:52,670 --> 00:00:50,969
we have a few paragraphs to tell you

18
00:00:55,340 --> 00:00:52,680
about the amazing things that are

19
00:00:57,229 --> 00:00:55,350
happening inside this galaxy cluster if

20
00:01:01,330 --> 00:00:57,239
you did not get one on your way in pick

21
00:01:05,479 --> 00:01:01,340
one up on your way out our talk tonight

22
00:01:07,100 --> 00:01:05,489
gravitational wave astronomy talking

23
00:01:10,760 --> 00:01:07,110
about the some of the discoveries that

24
00:01:13,010 --> 00:01:10,770
won the Nobel Prize last year next month

25
00:01:15,649 --> 00:01:13,020
we will have star formation in Orion

26
00:01:20,179 --> 00:01:15,659
from will Fischer that will be on June

27
00:01:22,100 --> 00:01:20,189
5th and Orion is really one of the

28
00:01:24,649 --> 00:01:22,110
coolest places where we can study star

29
00:01:26,300 --> 00:01:24,659
formation because it's the nearest star

30
00:01:29,179 --> 00:01:26,310
star forming region where we've got the

31
00:01:31,730 --> 00:01:29,189
full range of stars being born from the

32
00:01:33,649 --> 00:01:31,740
smallest to the very largest and so we

33
00:01:36,410 --> 00:01:33,659
it's one of our prototypical star

34
00:01:39,499 --> 00:01:36,420
forming regions so a great place to

35
00:01:42,319 --> 00:01:39,509
learn about a star formation on July 3rd

36
00:01:44,600 --> 00:01:42,329
David Netto from Johns Hopkins we'll be

37
00:01:47,179 --> 00:01:44,610
talking about the Milky Way's bulge from

38
00:01:51,530 --> 00:01:47,189

a hypothesized blob to a remarkably

39
00:01:54,679 --> 00:01:51,540
detailed picture the structure of the

40
00:01:57,260 --> 00:01:54,689
Milky Way has you know evolved over the

41
00:01:59,630 --> 00:01:57,270
years and he'll give us a great history

42
00:02:02,840 --> 00:01:59,640
about its core of the galaxies the Bulge

43
00:02:06,050 --> 00:02:02,850
in August we have our infamous mister

44
00:02:08,960 --> 00:02:06,060
error ms TBA which means I've got a

45
00:02:11,089 --> 00:02:08,970
little work to do this month it's it's

46
00:02:13,250 --> 00:02:11,099
sometimes hard to wrangle speakers for

47
00:02:14,610 --> 00:02:13,260
the summer months but I always do end up

48
00:02:16,830 --> 00:02:14,620
getting

49
00:02:19,500 --> 00:02:16,840
when I do have a speaker you'll find it

50
00:02:20,880 --> 00:02:19,510
on our website if you go to your

51
00:02:22,890 --> 00:02:20,890
favorite search engine and type in

52
00:02:23,520 --> 00:02:22,900
Hubbell public talk sir Space Telescope

53
00:02:25,890 --> 00:02:23,530
public talks

54
00:02:27,660 --> 00:02:25,900
you should find this page which has the

55
00:02:29,670 --> 00:02:27,670
list of the upcoming lectures over on

56
00:02:32,190 --> 00:02:29,680
the right-hand side on the left-hand

57
00:02:36,870 --> 00:02:32,200
side we have the links to our webcasting

58
00:02:39,660 --> 00:02:36,880
both the live and on YouTube we also

59
00:02:43,140 --> 00:02:39,670
have our past lecture our archives which

60
00:02:45,690 --> 00:02:43,150
go back to 2014 on YouTube and all the

61
00:02:48,510 --> 00:02:45,700
way back to 2005 with our STScI

62
00:02:51,030 --> 00:02:48,520
webcasting lots and lots of lectures for

63
00:02:53,400 --> 00:02:51,040

you to watch and you can also subscribe

64
00:02:55,050 --> 00:02:53,410
to our email list and get one or two

65
00:02:58,130 --> 00:02:55,060
emails a month reminding of what's

66
00:03:01,229 --> 00:02:58,140
coming up and when our webcast is posted

67
00:03:03,570 --> 00:03:01,239
the announcements as I said sign up in

68
00:03:05,100 --> 00:03:03,580
the website or if you can't do that you

69
00:03:06,960 --> 00:03:05,110
can write your name write your email

70
00:03:08,430 --> 00:03:06,970
address on a piece of paper and hand it

71
00:03:11,760 --> 00:03:08,440
to me at the end of the lecture and I'll

72
00:03:13,320 --> 00:03:11,770
make sure you are signed up if you have

73
00:03:16,800 --> 00:03:13,330
comments or questions we have an email

74
00:03:21,120 --> 00:03:16,810
setup public lecture at stsci edu where

75
00:03:23,610 --> 00:03:21,130
you can ask questions social media we

76
00:03:26,759 --> 00:03:23,620
have facebook we have Twitter we have

77
00:03:29,100 --> 00:03:26,769
YouTube we have Instagram if you're into

78
00:03:31,920 --> 00:03:29,110
that Hubble and James Webb and Space

79
00:03:34,530 --> 00:03:31,930
Telescope provide feeds social media

80
00:03:37,620 --> 00:03:34,540
feeds for all of you I myself do a

81
00:03:40,289 --> 00:03:37,630
little bit on with Facebook Google+ and

82
00:03:41,850 --> 00:03:40,299
Twitter so if you'd like to find out

83
00:03:46,550 --> 00:03:41,860
more about me you can follow me on

84
00:03:50,310 --> 00:03:46,560
social media the weather is nice tonight

85
00:03:51,990 --> 00:03:50,320
we would be able to go to the telescope

86
00:03:55,230 --> 00:03:52,000
across the street

87
00:03:57,840 --> 00:03:55,240
except Johns Hopkins University

88
00:04:00,990 --> 00:03:57,850

scheduled an event there tonight and

89
00:04:02,520 --> 00:04:01,000
usurped us so I know last few months

90
00:04:04,590 --> 00:04:02,530
it's been bad weather and we haven't

91
00:04:06,540 --> 00:04:04,600
been able to do it this month it's good

92
00:04:09,330 --> 00:04:06,550
weather but I'm sorry there was another

93
00:04:10,860 --> 00:04:09,340
event already scheduled so we will not

94
00:04:13,350 --> 00:04:10,870
be going to the observatory this after

95
00:04:16,229 --> 00:04:13,360
this evening after the talk however as

96
00:04:19,830 --> 00:04:16,239
always you can go to MD dot space grant

97
00:04:22,530 --> 00:04:19,840
o RG you'll find this webpage about

98
00:04:24,659 --> 00:04:22,540
their open houses on Fridays and this

99
00:04:27,180 --> 00:04:24,669
box over here on the right where it says

100
00:04:28,200 --> 00:04:27,190
Observatory status that is where you

101
00:04:30,390 --> 00:04:28,210
will find out whether or not they're

102
00:04:33,300 --> 00:04:30,400
open this Friday night our next Friday

103
00:04:35,130 --> 00:04:33,310
night are every Friday night and you can

104
00:04:38,970 --> 00:04:35,140
check this if you would like to look

105
00:04:42,860 --> 00:04:38,980
through their telescope and now the news

106
00:04:47,340 --> 00:04:42,870
from the universe from May 2018 our

107
00:04:50,400 --> 00:04:47,350
first story tonight Gaia dr2 which

108
00:04:54,450 --> 00:04:50,410
stands for data released to redefining

109
00:04:56,370 --> 00:04:54,460
the Milky Way and I had such a geek out

110
00:04:58,350 --> 00:04:56,380
last week when this data was released I

111
00:05:00,360 --> 00:04:58,360
had to show you some of this stuff so

112
00:05:03,570 --> 00:05:00,370
let's start let's start with stellar

113
00:05:05,520 --> 00:05:03,580

databases okay so this is a photograph

114
00:05:08,280 --> 00:05:05,530
of the night sky showing what

115
00:05:10,680 --> 00:05:08,290
constellation Orion thank you very much

116
00:05:13,620 --> 00:05:10,690
and you can see the stars here of Orion

117
00:05:16,050 --> 00:05:13,630
and the data for these seven main stars

118
00:05:18,750 --> 00:05:16,060
in Orion might look something like this

119
00:05:20,790 --> 00:05:18,760
and so here we have the the names of the

120
00:05:22,140 --> 00:05:20,800
stars on the left the RA in Dec the

121
00:05:24,270 --> 00:05:22,150
right Ascension and declination they're

122
00:05:26,580 --> 00:05:24,280
positioned on the sky you have the

123
00:05:28,260 --> 00:05:26,590
magnitudes which is their brightness we

124
00:05:30,540 --> 00:05:28,270
have the spectral type which helps give

125
00:05:32,850 --> 00:05:30,550
you their color etc and from these

126
00:05:35,670 --> 00:05:32,860
stellar databases we could create a

127
00:05:38,730 --> 00:05:35,680
picture of Orion and so a visualization

128
00:05:40,920 --> 00:05:38,740
of Orion on the on the right coming from

129
00:05:42,630 --> 00:05:40,930
just the data can produce an image like

130
00:05:44,640 --> 00:05:42,640
that compare it comparable to the

131
00:05:47,280 --> 00:05:44,650
picture and so that image on the right

132
00:05:49,530 --> 00:05:47,290
is only from the data all right and so

133
00:05:52,650 --> 00:05:49,540
the data that goes into that picture

134
00:05:54,960 --> 00:05:52,660
comes from the Hipparcos catalog which

135
00:05:57,150 --> 00:05:54,970
has a hundred and eighteen thousand

136
00:06:00,150 --> 00:05:57,160
stars and it's got the positions on the

137
00:06:02,130 --> 00:06:00,160
sky and it's got the spectral types and

138
00:06:04,320 --> 00:06:02,140

the magnitudes and the parallax and 3d

139
00:06:05,300 --> 00:06:04,330
distances allowing us to visualize the

140
00:06:08,480 --> 00:06:05,310
universe

141
00:06:11,600 --> 00:06:08,490
but Hipparcos flew as a mint a space

142
00:06:15,640 --> 00:06:11,610
mission that flew between 1989 and 1993

143
00:06:19,159 --> 00:06:15,650
and the data set came out in 1997

144
00:06:20,090 --> 00:06:19,169
twenty-one years ago what have we been

145
00:06:23,690 --> 00:06:20,100
doing in the meantime

146
00:06:25,430 --> 00:06:23,700
well the Hipparchus catalog covers just

147
00:06:27,260 --> 00:06:25,440
a small part of our galaxy a hundred

148
00:06:30,080 --> 00:06:27,270
thousand stars sounds like a lot but

149
00:06:32,990 --> 00:06:30,090
when you compare it to our galaxy this

150
00:06:34,520 --> 00:06:33,000
is a visualization of our galaxy an

151
00:06:39,470 --> 00:06:34,530
artist's depiction of our galaxy and

152
00:06:41,750 --> 00:06:39,480
this white spot here that is the extent

153
00:06:44,090 --> 00:06:41,760
of the Hipparcos catalog okay it's

154
00:06:45,530 --> 00:06:44,100
actually 20 times the Hipparcos kettle

155
00:06:48,110 --> 00:06:45,540
because it's really the Tyco catalog

156
00:06:50,480 --> 00:06:48,120
from which type Argos is a subset okay

157
00:06:52,700 --> 00:06:50,490
so it's like if our galaxy is a pizza

158
00:06:54,140 --> 00:06:52,710
it's the size of a sausage a little

159
00:06:56,960 --> 00:06:54,150
sausage piece on our pit on our pizza

160
00:07:00,530 --> 00:06:56,970
okay and that was the state of the art

161
00:07:03,890 --> 00:07:00,540
for the last 20 years until last

162
00:07:07,100 --> 00:07:03,900
Thursday all right they've been doing

163
00:07:09,680 --> 00:07:07,110

the Gaia mission and the Gaia mission is

164
00:07:12,890 --> 00:07:09,690
designed to take up our coast and really

165
00:07:15,740 --> 00:07:12,900
do it well okay and go full-bore with it

166
00:07:22,790 --> 00:07:15,750
okay on Thursday of last week

167
00:07:25,550 --> 00:07:22,800
Gaia released 1.7 billion stars not a

168
00:07:30,100 --> 00:07:25,560
hundred thousand of Hipparcos not the 2

169
00:07:35,090 --> 00:07:30,110
million of Tycho 1.7 billion and this is

170
00:07:39,020 --> 00:07:35,100
not an image this is a data plot from

171
00:07:42,529 --> 00:07:39,030
Gaia this is plotting the color and

172
00:07:47,000 --> 00:07:42,539
brightness of all 1.7 billion stars

173
00:07:50,090 --> 00:07:47,010
across the entire night sky it is so

174
00:07:52,490 --> 00:07:50,100
remarkably detailed it looks like a

175
00:07:54,800 --> 00:07:52,500
photograph but it's not it's a

176
00:07:57,380 --> 00:07:54,810
visualization of a data table think of

177
00:07:59,420 --> 00:07:57,390
an Excel data table with 1.7 billion

178
00:08:00,650 --> 00:07:59,430
entries and you're plotting each one of

179
00:08:04,370 --> 00:08:00,660
those points and combining them all

180
00:08:07,310 --> 00:08:04,380
together that's the picture you get yeah

181
00:08:10,100 --> 00:08:07,320
this is why I was geeking out last week

182
00:08:12,020 --> 00:08:10,110
it's not amazing and let me show you

183
00:08:14,360 --> 00:08:12,030
some of the details because if we zoom

184
00:08:16,399 --> 00:08:14,370
into the center all right you can now

185
00:08:17,890 --> 00:08:16,409
start to see the pixelization of the

186
00:08:20,620 --> 00:08:17,900
other thing and what we

187
00:08:24,070 --> 00:08:20,630
plotting here as all of those stars and

188
00:08:26,680 --> 00:08:24,080

it looks like we've got gas clouds dark

189
00:08:29,980 --> 00:08:26,690
dust clouds in there right there's no

190
00:08:32,890 --> 00:08:29,990
dust clouds in this database what you're

191
00:08:34,600 --> 00:08:32,900
seeing here is the absence of stars now

192
00:08:36,909 --> 00:08:34,610
it's of course due to dust clouds that

193
00:08:38,829 --> 00:08:36,919
are actually out there but we're not

194
00:08:40,600 --> 00:08:38,839
plotting the dust clouds we're pas and

195
00:08:42,370 --> 00:08:40,610
only the stars and you're seeing the

196
00:08:45,280 --> 00:08:42,380
absence of the stars in those regions

197
00:08:48,730 --> 00:08:45,290
where there are dust clouds this

198
00:08:51,699 --> 00:08:48,740
database is so remarkably detailed that

199
00:08:54,940 --> 00:08:51,709
it gets pictures of the Large Magellanic

200
00:08:57,490 --> 00:08:54,950
and small Magellanic Clouds that are

201
00:08:59,860 --> 00:08:57,500
almost 200,000 light years away these

202
00:09:02,800 --> 00:08:59,870
are satellite galaxies of the Milky Way

203
00:09:05,260 --> 00:09:02,810
and you get these remarkably detailed

204
00:09:08,500 --> 00:09:05,270
images of them what look like images

205
00:09:11,079 --> 00:09:08,510
when you plot up the data oh and by the

206
00:09:12,519 --> 00:09:11,089
way this white spot down here that looks

207
00:09:16,240 --> 00:09:12,529
like it's in the small Magellanic Cloud

208
00:09:19,269 --> 00:09:16,250
it's not it's in our galaxy this is the

209
00:09:23,769 --> 00:09:19,279
globular star cluster 47 Tucanae so

210
00:09:26,670 --> 00:09:23,779
you've got 1.7 billion stars in this

211
00:09:29,199 --> 00:09:26,680
database and from it you know just the

212
00:09:32,650 --> 00:09:29,209
brightness in color you get in a

213
00:09:34,900 --> 00:09:32,660

remarkably detailed image but it's got a

214
00:09:37,900 --> 00:09:34,910
lot more because they measured these

215
00:09:40,449 --> 00:09:37,910
stars over and over again to get their

216
00:09:44,220 --> 00:09:40,459
motion on the sky their motion relative

217
00:09:47,290 --> 00:09:44,230
to the Sun and so measuring all those

218
00:09:49,750 --> 00:09:47,300
velocities relative to the Sun we can

219
00:09:51,310 --> 00:09:49,760
measure the motion of our galaxy so this

220
00:09:52,810 --> 00:09:51,320
is the plane of our galaxy here our

221
00:09:56,260 --> 00:09:52,820
planet our galaxy is shaped like a

222
00:09:58,810 --> 00:09:56,270
pancake and that pancake is rotating so

223
00:10:00,790 --> 00:09:58,820
when we look at their velocities and we

224
00:10:04,750 --> 00:10:00,800
measure the Doppler shift we get an

225
00:10:07,240 --> 00:10:04,760
image like this so here the blue is

226
00:10:08,920 --> 00:10:07,250
coming towards us and the red is going

227
00:10:11,079 --> 00:10:08,930
away from us all right

228
00:10:13,600 --> 00:10:11,089
so this is the radial velocity map these

229
00:10:18,070 --> 00:10:13,610
are motions on the sky relative to the

230
00:10:20,290 --> 00:10:18,080
Sun and so inside this circle here in

231
00:10:22,300 --> 00:10:20,300
the central region those are the stars

232
00:10:24,760 --> 00:10:22,310
that are closer to the center of the

233
00:10:26,890 --> 00:10:24,770
galaxy and they're rotating faster than

234
00:10:28,329 --> 00:10:26,900
the Sun so the ones on the right hand

235
00:10:29,830 --> 00:10:28,339
side that blue blob there that's

236
00:10:31,570 --> 00:10:29,840
approaching the Sun

237
00:10:33,630 --> 00:10:31,580
and the red stuff on the left-hand side

238
00:10:37,240 --> 00:10:33,640

that's going away from the Sun

239
00:10:39,310 --> 00:10:37,250
alternatively the outside part beyond

240
00:10:41,800 --> 00:10:39,320
this outside the circle are stars that

241
00:10:44,020 --> 00:10:41,810
are outside the galaxy and the Sun is

242
00:10:46,360 --> 00:10:44,030
moving faster than them so the Sun is

243
00:10:48,790 --> 00:10:46,370
moving away from this red blob over here

244
00:10:52,420 --> 00:10:48,800
on the right and towards this blue blob

245
00:10:55,030 --> 00:10:52,430
over here on the left we are seeing the

246
00:10:58,300 --> 00:10:55,040
rotation of our galaxy in detail as

247
00:11:00,580 --> 00:10:58,310
we've never seen it before okay I mean

248
00:11:02,230 --> 00:11:00,590
if I showed you the plots of what we

249
00:11:03,940 --> 00:11:02,240
used to know about this is there really

250
00:11:06,970 --> 00:11:03,950
patchy and just you know they sort of

251
00:11:09,880 --> 00:11:06,980
get the idea would you this this this

252
00:11:11,080 --> 00:11:09,890
this cause a astronomer a friend of mine

253
00:11:14,350 --> 00:11:11,090
when I showed it to her this afternoon

254
00:11:16,480 --> 00:11:14,360
she just went oh she just started go

255
00:11:18,610 --> 00:11:16,490
mind you started racing about all the

256
00:11:21,460 --> 00:11:18,620
various things they could do if you

257
00:11:24,640 --> 00:11:21,470
looked up the guy the Twitter hashtag a

258
00:11:26,980 --> 00:11:24,650
guy a dr - last Thursday and Friday

259
00:11:29,290 --> 00:11:26,990
you saw a ton of astronomers just

260
00:11:31,720 --> 00:11:29,300
geeking out and trying to you know get

261
00:11:33,540 --> 00:11:31,730
an initial looks of this data set and

262
00:11:35,950 --> 00:11:33,550
trying to find all sorts of cool things

263
00:11:40,090 --> 00:11:35,960

there's gonna be so much discovered from

264
00:11:43,150 --> 00:11:40,100
this that the the discoveries have just

265
00:11:44,800 --> 00:11:43,160
begun and in particular take a look on

266
00:11:46,540 --> 00:11:44,810
this red blob over here on the left in

267
00:11:48,310 --> 00:11:46,550
the center what are these blue blobs

268
00:11:50,410 --> 00:11:48,320
here what are the things on the left

269
00:11:52,630 --> 00:11:50,420
side that should be going away from us

270
00:11:54,750 --> 00:11:52,640
look like they're approaching us what

271
00:11:57,280 --> 00:11:54,760
are the details they're some of the

272
00:11:59,920 --> 00:11:57,290
obvious things to look at and of course

273
00:12:02,260 --> 00:11:59,930
there's a tremendous number of more much

274
00:12:05,890 --> 00:12:02,270
more detailed questions so guy is going

275
00:12:10,300 --> 00:12:05,900
to provide an amazing number of

276
00:12:12,000 --> 00:12:10,310
discoveries and it expands the 3d

277
00:12:15,970 --> 00:12:12,010
distances that we know of in our galaxy

278
00:12:18,250 --> 00:12:15,980
we go from that sausage on the pizza to

279
00:12:22,240 --> 00:12:18,260
a pepperoni a really large pepperoni on

280
00:12:24,070 --> 00:12:22,250
our pizza okay that here on the right

281
00:12:27,370 --> 00:12:24,080
hand side that's plots plot on the right

282
00:12:30,220 --> 00:12:27,380
hand side of Gaia dr2 that is 1.7

283
00:12:33,370 --> 00:12:30,230
billion stars the extent of 1.7 billion

284
00:12:35,590 --> 00:12:33,380
stars and when you look at that you can

285
00:12:37,930 --> 00:12:35,600
start to believe that oh my gosh yeah I

286
00:12:40,300 --> 00:12:37,940
guess the galaxy really does contain a

287
00:12:43,090 --> 00:12:40,310
hundred billion stars if that's all

288
00:12:45,940 --> 00:12:43,100

that's covered by two billion all right

289
00:12:47,560 --> 00:12:45,950
and so more will coming and hopefully in

290
00:12:49,060 --> 00:12:47,570
about a year from now well I'll be able

291
00:12:51,400 --> 00:12:49,070
to have a speaker in to give a talk on

292
00:12:55,390 --> 00:12:51,410
all the amazing discoveries from Gaia

293
00:13:00,040 --> 00:12:55,400
and it's data released to our second

294
00:13:04,330 --> 00:13:00,050
story tonight 28 years of Hubble Hubble

295
00:13:06,280 --> 00:13:04,340
launched on April 24 1990 and every

296
00:13:08,740 --> 00:13:06,290
April we and the office of public

297
00:13:10,810 --> 00:13:08,750
outreach have this huge pressure pushing

298
00:13:12,820 --> 00:13:10,820
down on us come up with a really cool

299
00:13:15,640 --> 00:13:12,830
image to celebrate Hubble's 28th

300
00:13:18,190 --> 00:13:15,650
Hubble's anniversary this year so the

301
00:13:20,700 --> 00:13:18,200
image processors put their thinking caps

302
00:13:23,620 --> 00:13:20,710
on and this year they decided to go with

303
00:13:24,850 --> 00:13:23,630
the Lagoon Nebula okay now this is not a

304
00:13:28,180 --> 00:13:24,860
Hubble image this is a ground-based

305
00:13:29,950 --> 00:13:28,190
image right and actually the Lagoon

306
00:13:33,130 --> 00:13:29,960
Nebula is so large that Hubble can't

307
00:13:35,590 --> 00:13:33,140
really cover this without many many many

308
00:13:37,360 --> 00:13:35,600
pointings so the Hubble images that you

309
00:13:39,600 --> 00:13:37,370
can I'm going to show you is just this

310
00:13:41,530 --> 00:13:39,610
region in the heart of the Lagoon Nebula

311
00:13:43,570 --> 00:13:41,540
because you've got all this beautiful

312
00:13:45,610 --> 00:13:43,580
red gas out here that's sort of been

313
00:13:47,350 --> 00:13:45,620

blown out and that's ionized but where

314
00:13:48,940 --> 00:13:47,360
the star formation is still taking place

315
00:13:50,770 --> 00:13:48,950
is right here in the heart of loon get

316
00:13:53,020 --> 00:13:50,780
Lagoon Nebula and when you look at that

317
00:13:56,040 --> 00:13:53,030
with Hubble resolution using specific

318
00:13:59,440 --> 00:13:56,050
filters to pull out the elements you get

319
00:14:02,410 --> 00:13:59,450
that all right

320
00:14:04,540 --> 00:14:02,420
this side of the room say ooh and this

321
00:14:06,020 --> 00:14:04,550
side of the room say ah ready and hold

322
00:14:07,310 --> 00:14:06,030
on

323
00:14:11,269 --> 00:14:07,320
[Music]

324
00:14:13,100 --> 00:14:11,279
thank you let me zoom in and show you

325
00:14:15,620 --> 00:14:13,110
some of the cool details all right so

326
00:14:18,170 --> 00:14:15,630
right in this central region here we

327
00:14:20,629 --> 00:14:18,180
zoom in you can see that there's a

328
00:14:23,180 --> 00:14:20,639
massive star there it's sort of hidden

329
00:14:25,519 --> 00:14:23,190
behind this curtain of dark gas okay

330
00:14:27,199 --> 00:14:25,529
this is an oast star this is a really

331
00:14:29,870 --> 00:14:27,209
massive star and they tell me it's only

332
00:14:32,300 --> 00:14:29,880
1 million years old it's just been born

333
00:14:34,759 --> 00:14:32,310
yeah 1 million years is not old for a

334
00:14:37,490 --> 00:14:34,769
star ok and you can see how it's

335
00:14:40,309 --> 00:14:37,500
illuminating all that gas in behind that

336
00:14:41,900 --> 00:14:40,319
dark that dark cloud and it's also

337
00:14:43,490 --> 00:14:41,910
producing things like there's this bow

338
00:14:45,650 --> 00:14:43,500

shock down here over on the left where

339
00:14:47,240 --> 00:14:45,660
the wind from That star is pushing back

340
00:14:49,460 --> 00:14:47,250
the gas around it you've got these

341
00:14:52,040 --> 00:14:49,470
pillars etc and there's an incredible

342
00:14:53,860 --> 00:14:52,050
energy not only in the radiation but

343
00:14:56,150 --> 00:14:53,870
also in the wind coming from That star

344
00:14:58,790 --> 00:14:56,160
we've got a lot of other cool things

345
00:15:00,800 --> 00:14:58,800
like on the left here we've got some

346
00:15:02,629 --> 00:15:00,810
ionization fronts there's some stars

347
00:15:04,879 --> 00:15:02,639
that are just off the image of the

348
00:15:06,499 --> 00:15:04,889
Hubble and they're their Energy's coming

349
00:15:08,660 --> 00:15:06,509
down and creating these ionization

350
00:15:10,850 --> 00:15:08,670
fronts here on the left and also this

351
00:15:12,889 --> 00:15:10,860
gorgeous ionization front over here on

352
00:15:14,720 --> 00:15:12,899
the right lower right where you can see

353
00:15:17,360 --> 00:15:14,730
that the energy the ultraviolet

354
00:15:20,300 --> 00:15:17,370
radiation is heating that gas causing it

355
00:15:22,699 --> 00:15:20,310
to ionize go from neutral gas to ionized

356
00:15:25,069 --> 00:15:22,709
gas and then we got these tiny little

357
00:15:27,829 --> 00:15:25,079
pillars in the upper right there where

358
00:15:29,420 --> 00:15:27,839
the gas is being eaten away and all your

359
00:15:32,030 --> 00:15:29,430
left these small little blobs that have

360
00:15:34,129 --> 00:15:32,040
been ionized Weatherhead have little

361
00:15:37,100 --> 00:15:34,139
ionization fronts on top of the pillars

362
00:15:40,210 --> 00:15:37,110
as everything else gets stripped away so

363
00:15:42,590 --> 00:15:40,220

this is the visible light image but

364
00:15:44,870 --> 00:15:42,600
Hubble of course has really good

365
00:15:49,460 --> 00:15:44,880
infrared sensitivities since servicing

366
00:15:53,319 --> 00:15:49,470
mission 4 and visible light we also took

367
00:15:56,179 --> 00:15:53,329
an infrared that looks like that Oh

368
00:16:03,160 --> 00:15:56,189
quite different hey let's go back

369
00:16:07,400 --> 00:16:03,170
visible light infrared visible infrared

370
00:16:09,769 --> 00:16:07,410
look at all the stars alright the longer

371
00:16:11,749 --> 00:16:09,779
wavelengths of infrared passes through

372
00:16:14,929 --> 00:16:11,759
that gas and you can see all the stars

373
00:16:16,730 --> 00:16:14,939
behind it the Lagoon Nebula is toward

374
00:16:18,740 --> 00:16:16,740
the galactic center so it's a very dense

375
00:16:20,120 --> 00:16:18,750
star field that you're only not yet

376
00:16:20,600 --> 00:16:20,130
you're not seeing in visible light

377
00:16:23,210 --> 00:16:20,610
because

378
00:16:25,160 --> 00:16:23,220
of course the gas is blocking it and

379
00:16:27,350 --> 00:16:25,170
when you see the dense gas here in this

380
00:16:29,180 --> 00:16:27,360
visible light all right in here let me

381
00:16:31,190 --> 00:16:29,190
go back and you can see how how dense

382
00:16:33,350 --> 00:16:31,200
the gas appears in the invisible light

383
00:16:35,900 --> 00:16:33,360
right all this central gas looks like

384
00:16:38,060 --> 00:16:35,910
it's really dense but infrared shows you

385
00:16:39,920 --> 00:16:38,070
that most of it's not that dense and

386
00:16:42,500 --> 00:16:39,930
that the infrared light can pass through

387
00:16:43,850 --> 00:16:42,510
it but some part pockets are really

388
00:16:46,310 --> 00:16:43,860

dense because when they're dark and

389
00:16:49,430 --> 00:16:46,320
infrared they're really dense pockets of

390
00:16:51,740 --> 00:16:49,440
gas and so by using both visible and

391
00:16:55,790 --> 00:16:51,750
infrared we gain different pictures of

392
00:16:59,000 --> 00:16:55,800
this of these regions so we put together

393
00:17:00,530 --> 00:16:59,010
a visualization of it and when we were

394
00:17:02,389 --> 00:17:00,540
discussing it we said oh we got all

395
00:17:04,280 --> 00:17:02,399
these all these structures that are

396
00:17:05,870 --> 00:17:04,290
coming from the ionization and from the

397
00:17:08,299 --> 00:17:05,880
winds and we said oh you know what this

398
00:17:10,970 --> 00:17:08,309
was like it's like a sculpture garden of

399
00:17:18,800 --> 00:17:10,980
gas and dust and that's what we called

400
00:17:18,810 --> 00:17:42,230
[Music]

401
00:17:49,220 --> 00:17:46,190
and that was a 2d zoom and now we give

402
00:17:52,370 --> 00:17:49,230
you a bit of a 3d feel as we do some

403
00:17:55,610 --> 00:17:52,380
pants across these different sculptures

404
00:19:13,190 --> 00:18:02,190
[Music]

405
00:19:19,940 --> 00:19:17,160
and that's how we wish tobol a happy

406
00:19:24,869 --> 00:19:19,950
28th anniversary

407
00:19:27,749 --> 00:19:24,879
[Applause]

408
00:19:31,719 --> 00:19:27,759
all right our featured speaker tonight

409
00:19:33,879 --> 00:19:31,729
is dr. Andy whom I met at

410
00:19:36,669 --> 00:19:33,889
Berkeley while he was doing a Hubble

411
00:19:40,899 --> 00:19:36,679
fellowship at Berkeley and I was doing

412
00:19:42,969 --> 00:19:40,909
my PhD work there and he's always been

413
00:19:45,249 --> 00:19:42,979

known as a very jovial and very friendly

414
00:19:46,119 --> 00:19:45,259
guy and I'm so glad that we have him

415
00:19:48,489 --> 00:19:46,129
here today

416
00:19:51,159 --> 00:19:48,499
he did his undergraduate work at Harvard

417
00:19:53,949 --> 00:19:51,169
then spent some time at Cambridge in

418
00:19:56,979 --> 00:19:53,959
England for a bit before doing his PhD

419
00:19:59,019 --> 00:19:56,989
at Princeton he then came to Berkeley

420
00:20:00,849 --> 00:19:59,029
and did his Hubble fellowship there and

421
00:20:04,359 --> 00:20:00,859
let's see you they went to the Carnegie

422
00:20:06,099 --> 00:20:04,369
Institute in Washington before coming

423
00:20:10,680 --> 00:20:06,109
here to the Space Telescope Science

424
00:20:12,789 --> 00:20:10,690
Institute where he's been how many years

425
00:20:17,409 --> 00:20:12,799
20 years cuz you're a little bit longer

426
00:20:20,579 --> 00:20:17,419
than me I've only been here 17 years not

427
00:20:24,219 --> 00:20:20,589
very long by space telescope standards

428
00:20:27,489 --> 00:20:24,229
his functional job but his astronomy

429
00:20:31,779 --> 00:20:27,499
work has been in pulsars and in

430
00:20:34,329 --> 00:20:31,789
supernovae and gamma ray bursts yes very

431
00:20:36,190 --> 00:20:34,339
gamma ray bursts and he'll talk to you

432
00:20:38,680 --> 00:20:36,200
tonight about gravitational wave

433
00:20:40,569 --> 00:20:38,690
astronomy oh I should also mention that

434
00:20:42,940 --> 00:20:40,579
his functional job here is in this

435
00:20:45,329 --> 00:20:42,950
science mission office helping to run

436
00:20:49,900 --> 00:20:45,339
the science program within this building

437
00:21:05,050 --> 00:20:49,910
ladies and gentlemen dr. Andy Fraser

438
00:21:11,360 --> 00:21:09,410

here we go okay excuse me I'm getting

439
00:21:22,420 --> 00:21:11,370
over a cold as many people are these

440
00:21:25,670 --> 00:21:22,430
days so there we go okay

441
00:21:28,850 --> 00:21:25,680
all right so welcome tonight I'll be

442
00:21:33,230 --> 00:21:28,860
speaking about the very beginning of

443
00:21:37,490 --> 00:21:33,240
gravitational wave astronomy in the last

444
00:21:40,250 --> 00:21:37,500
two years we have opened up the universe

445
00:21:42,760 --> 00:21:40,260
in an entirely new way we have detected

446
00:21:45,560 --> 00:21:42,770
gravitational waves from black holes

447
00:21:48,500 --> 00:21:45,570
binaries and these the black holes in

448
00:21:50,360 --> 00:21:48,510
these binaries are from our stellar mass

449
00:21:52,520 --> 00:21:50,370
they know that there are huge black

450
00:21:54,740 --> 00:21:52,530
holes in the center of galaxies but

451
00:21:56,780 --> 00:21:54,750
these black holes are bigger than any

452
00:22:00,410 --> 00:21:56,790
one balco's that we knew existed around

453
00:22:02,390 --> 00:22:00,420
stars that existed from stars we've seen

454
00:22:05,150 --> 00:22:02,400
many of them are we've seen black holes

455
00:22:06,980 --> 00:22:05,160
merge into a seat black holes come

456
00:22:11,330 --> 00:22:06,990
together and merge into a single black

457
00:22:15,220 --> 00:22:11,340
hole right and you'll see that today and

458
00:22:18,200 --> 00:22:15,230
we've located a neutron star binary

459
00:22:22,840 --> 00:22:18,210
which emitted gravitational waves giving

460
00:22:24,800 --> 00:22:22,850
its position in its distance and we saw

461
00:22:28,090 --> 00:22:24,810
electromagnet alight that we're seeing

462
00:22:33,110 --> 00:22:28,100
we saw light from it gamma rays radio

463
00:22:36,170 --> 00:22:33,120

optical infrared and we saw what we saw

464
00:22:39,080 --> 00:22:36,180
the radioactive decay of material flung

465
00:22:42,800 --> 00:22:39,090
out from these neutron stars and we

466
00:22:44,720 --> 00:22:42,810
believe that this material is the basis

467
00:22:47,170 --> 00:22:44,730
of most of the healthy elements in the

468
00:22:50,240 --> 00:22:47,180
galaxies in the universe that is

469
00:22:52,700 --> 00:22:50,250
supernovae produce oxygen carbon

470
00:22:55,250 --> 00:22:52,710
hydrogen and things like that also winds

471
00:23:01,150 --> 00:22:55,260
off star witness off stars do that too

472
00:23:03,710 --> 00:23:01,160
but but to get things like gold lead

473
00:23:05,510 --> 00:23:03,720
uranium was very hard from supernovae

474
00:23:07,750 --> 00:23:05,520
people didn't know how to do it we think

475
00:23:10,510 --> 00:23:07,760
that they come from merging neutron

476
00:23:12,370 --> 00:23:10,520
stars now so that wedding ring on your

477
00:23:13,930 --> 00:23:12,380
finger if you have one that came out of

478
00:23:20,620 --> 00:23:13,940
a neutral that came from a neutron star

479
00:23:22,990 --> 00:23:20,630
we think okay so in this talk I'm gonna

480
00:23:25,720 --> 00:23:23,000
start off with a bit of background on

481
00:23:28,300 --> 00:23:25,730
what gravitational waves are and how we

482
00:23:30,760 --> 00:23:28,310
detect them right and because that's

483
00:23:32,470 --> 00:23:30,770
that's how we did all of this science so

484
00:23:34,930 --> 00:23:32,480
what was the basis of all this science

485
00:23:36,460 --> 00:23:34,940
and then I'm gonna talk about again some

486
00:23:38,710 --> 00:23:36,470
of that astrophysics that I just gave

487
00:23:40,600 --> 00:23:38,720
you a broad overview of and then I'll

488
00:23:43,980 --> 00:23:40,610

talk a bit about what we might expect in

489
00:23:50,230 --> 00:23:47,740
so Einstein had so many great insights

490
00:23:52,270 --> 00:23:50,240
that it's hard to keep track but the one

491
00:23:53,530 --> 00:23:52,280
that's going to be most relevant tonight

492
00:23:56,830 --> 00:23:53,540
though there's another one that will be

493
00:23:58,810 --> 00:23:56,840
later is is from how he's the basis of

494
00:24:02,770 --> 00:23:58,820
what we call general relativity his

495
00:24:05,290 --> 00:24:02,780
theory of general relativity and one of

496
00:24:07,390 --> 00:24:05,300
the insights in the formation of that

497
00:24:11,110 --> 00:24:07,400
theory was to realize that he could

498
00:24:14,770 --> 00:24:11,120
explain many of the ideas that he had by

499
00:24:18,910 --> 00:24:14,780
conceptualizing gravity as a change in

500
00:24:21,520 --> 00:24:18,920
the geometry of the universe so that if

501
00:24:23,440 --> 00:24:21,530
you imagine that this is the this is the

502
00:24:25,360 --> 00:24:23,450
Sun and this is the earth now why does

503
00:24:27,970 --> 00:24:25,370
the earth go in a circle around the Sun

504
00:24:29,650 --> 00:24:27,980
well the earth in nine science idea

505
00:24:32,080 --> 00:24:29,660
wants to follow go in a straight path

506
00:24:34,120 --> 00:24:32,090
but it's anything in free it's in free

507
00:24:36,550 --> 00:24:34,130
fall around the Sun so it should just go

508
00:24:37,720 --> 00:24:36,560
in a straight path should it doesn't

509
00:24:39,250 --> 00:24:37,730
feel it doesn't feel that it's

510
00:24:41,800 --> 00:24:39,260
accelerated it thinks it's going

511
00:24:44,500 --> 00:24:41,810
straight but what Einstein realized is

512
00:24:46,690 --> 00:24:44,510
well if a curved space-time right then a

513
00:24:48,790 --> 00:24:46,700

straight path is just like just like a

514
00:24:50,530 --> 00:24:48,800
great circle if I walk straight out of

515
00:24:52,360 --> 00:24:50,540
this room and keep going and then swim a

516
00:24:54,610 --> 00:24:52,370
bit and then walk a bit in this will bit

517
00:24:56,350 --> 00:24:54,620
I'll end up right back where I started

518
00:24:57,940 --> 00:24:56,360
right yeah all the while I'm thinking

519
00:24:59,560 --> 00:24:57,950
I'm going a straight line but in fact

520
00:25:03,130 --> 00:24:59,570
I'm doing a curve all around the earth

521
00:25:05,770 --> 00:25:03,140
right and in the same way in the in this

522
00:25:08,530 --> 00:25:05,780
conceptualization the earth is going on

523
00:25:15,340 --> 00:25:08,540
a curve is going straight around the

524
00:25:17,380 --> 00:25:15,350
Great Circle around the Sun and so that

525
00:25:19,600 --> 00:25:17,390
he's bending so basically gravity is

526
00:25:21,070 --> 00:25:19,610
bending space-time it's bending the

527
00:25:24,160 --> 00:25:21,080
shape of space in the way

528
00:25:28,000 --> 00:25:24,170
that gravity feels with our bodies feel

529
00:25:29,980 --> 00:25:28,010
it right now he also realized that just

530
00:25:31,000 --> 00:25:29,990
like in electromagnetism or very similar

531
00:25:33,040 --> 00:25:31,010
to an electromagnetism

532
00:25:34,030 --> 00:25:33,050
if you accelerate an electron or a

533
00:25:37,000 --> 00:25:34,040
charged particle

534
00:25:39,550 --> 00:25:37,010
you'll radiate he realized that the

535
00:25:43,260 --> 00:25:39,560
motion that accelerating chart that mass

536
00:25:46,540 --> 00:25:43,270
can also produce gravitational radiation

537
00:25:49,390 --> 00:25:46,550
so here's a picture of that so you can

538
00:25:51,760 --> 00:25:49,400

imagine tear a - object - - but we'll

539
00:25:55,750 --> 00:25:51,770
find out their black holes modeled black

540
00:25:58,120 --> 00:25:55,760
holes right and they're in a binary now

541
00:26:00,160 --> 00:25:58,130
what they're doing is radiating these

542
00:26:02,170 --> 00:26:00,170
are gravitational waves out going out

543
00:26:04,000 --> 00:26:02,180
and the gravitational waves actually are

544
00:26:06,490 --> 00:26:04,010
changing the shape of space-time because

545
00:26:08,950 --> 00:26:06,500
they're energy and the energy deforms

546
00:26:11,710 --> 00:26:08,960
just like mass gravity and then they're

547
00:26:18,640 --> 00:26:11,720
they've merged and the gravity waves

548
00:26:20,530 --> 00:26:18,650
stop coming out note also that when you

549
00:26:23,890 --> 00:26:20,540
emit gravity waves you're emitting

550
00:26:26,470 --> 00:26:23,900
energy so the binary is losing energy so

551
00:26:29,320 --> 00:26:26,480
the two stars fall in towards each other

552
00:26:30,850 --> 00:26:29,330
as they lose that energy and they put

553
00:26:32,110 --> 00:26:30,860
out more energy they fall further in

554
00:26:33,880 --> 00:26:32,120
towards each other they put a more

555
00:26:37,060 --> 00:26:33,890
ungettable further and eventually they

556
00:26:40,060 --> 00:26:37,070
merge right so gravity waves can

557
00:26:42,640 --> 00:26:40,070
actually actually causes binaries to

558
00:26:44,440 --> 00:26:42,650
merge now if they're very far apart and

559
00:26:46,450 --> 00:26:44,450
moving slowly it could take much longer

560
00:26:48,970 --> 00:26:46,460
than the age of the universe but many

561
00:26:51,040 --> 00:26:48,980
objects are tight are massive enough and

562
00:26:53,440 --> 00:26:51,050
at fast enough orbits that the radio a

563
00:26:59,410 --> 00:26:53,450

didn't radiate away their energy and Oh

564
00:27:01,840 --> 00:26:59,420
in that we can hope to see it so what

565
00:27:03,610 --> 00:27:01,850
what what a black hole merger look like

566
00:27:06,970 --> 00:27:03,620
right so this is if we were actually

567
00:27:12,220 --> 00:27:06,980
looking at it with a telescope by tube

568
00:27:15,340 --> 00:27:12,230
massive black holes now what weird it's

569
00:27:19,510 --> 00:27:15,350
let's see show me there no it's not sure

570
00:27:24,160 --> 00:27:19,520
it's not there it is if I click it okay

571
00:27:27,040 --> 00:27:24,170
it worked like that okay go to the next

572
00:27:33,619 --> 00:27:27,050
one hmm it's works differently on this

573
00:27:37,350 --> 00:27:33,629
than it does on a desktop so

574
00:27:39,359 --> 00:27:37,360
you're seeing here the they grab it the

575
00:27:42,930 --> 00:27:39,369
two black holes go around this is the

576
00:27:44,580 --> 00:27:42,940
gravitational lensing that we just Frank

577
00:27:47,009 --> 00:27:44,590
spoke about earlier these are the black

578
00:27:48,930 --> 00:27:47,019
holes changing the light changing the

579
00:27:51,499 --> 00:27:48,940
shape of the objects behind them because

580
00:27:54,479 --> 00:27:51,509
they're lane creating a distorted lens

581
00:27:56,879 --> 00:27:54,489
and then of it here they are basically

582
00:27:58,919 --> 00:27:56,889
coming together into one final black

583
00:28:02,090 --> 00:27:58,929
hole it sends out some gravitational

584
00:28:05,729 --> 00:28:02,100
waves here it ended a changes shape

585
00:28:08,430 --> 00:28:05,739
there's a point does its final dance and

586
00:28:10,889 --> 00:28:08,440
that is the what you would see if you

587
00:28:13,590 --> 00:28:10,899
could actually take a Hubble image of a

588
00:28:17,310 --> 00:28:13,600

gret of a merging black hole the problem

589
00:28:21,210 --> 00:28:17,320
is this is this image is about a

590
00:28:23,460 --> 00:28:21,220
millionth the size of a Hubble pixel so

591
00:28:25,320 --> 00:28:23,470
it's gonna be hard for us to get that

592
00:28:26,609 --> 00:28:25,330
image right that that is sort of a

593
00:28:28,889 --> 00:28:26,619
visualization that they did out of

594
00:28:30,060 --> 00:28:28,899
Caltech but so you really gotta break

595
00:28:33,299 --> 00:28:30,070
that if you want to see this we can have

596
00:28:34,769 --> 00:28:33,309
to see it some other way now there is a

597
00:28:37,409 --> 00:28:34,779
project going on right now

598
00:28:40,560 --> 00:28:37,419
to image the black hole at the center of

599
00:28:42,210 --> 00:28:40,570
our galaxy and it's a huge project using

600
00:28:44,129 --> 00:28:42,220
radio telescopes all across

601
00:28:46,289 --> 00:28:44,139
millimeter-wave tells us all across the

602
00:28:48,690 --> 00:28:46,299
earth and they're going to try to create

603
00:28:50,279 --> 00:28:48,700
a picture basically making the earth

604
00:28:53,399 --> 00:28:50,289
this antenna the size of the earth

605
00:28:54,659 --> 00:28:53,409
trying to get that picture and they're

606
00:28:56,249 --> 00:28:54,669
still working on it it's a very hard

607
00:28:57,930 --> 00:28:56,259
project but we may get it and they may

608
00:29:00,539 --> 00:28:57,940
be able to resolve the black hole at the

609
00:29:02,549 --> 00:29:00,549
center of the galaxy but these to do

610
00:29:04,859 --> 00:29:02,559
that that's just a very that's our

611
00:29:06,899 --> 00:29:04,869
closest large black hole right to do

612
00:29:11,759 --> 00:29:06,909
that in another galaxy is way beyond our

613
00:29:12,810 --> 00:29:11,769

means right now so I'm gonna suggest we

614
00:29:15,599 --> 00:29:12,820
do something crazy

615
00:29:19,229 --> 00:29:15,609
let's try neutron stars instead now but

616
00:29:22,139 --> 00:29:19,239
they're not much bigger in fact this is

617
00:29:23,970 --> 00:29:22,149
a this was put together by colleagues at

618
00:29:27,180 --> 00:29:23,980
Northwestern University who had a

619
00:29:31,680 --> 00:29:27,190
conference and this is a neutron star

620
00:29:34,049 --> 00:29:31,690
over Chicago that's the size the neutron

621
00:29:38,849 --> 00:29:34,059
star is about I don't know what 10 miles

622
00:29:41,220 --> 00:29:38,859
across or so and so they're not very big

623
00:29:44,399 --> 00:29:41,230
but they're made of matter

624
00:29:47,010 --> 00:29:44,409
black holes are dark right neutron stars

625
00:29:49,380 --> 00:29:47,020
are matter still

626
00:29:51,840 --> 00:29:49,390
the way you Foreman so when the earth

627
00:29:53,850 --> 00:29:51,850
when the Sun runs out of fuel it's going

628
00:29:58,860 --> 00:29:53,860
to collapse down to what's called the

629
00:30:00,960 --> 00:29:58,870
white dwarf which is a star that is

630
00:30:02,669 --> 00:30:00,970
basically just atoms packed together as

631
00:30:03,600 --> 00:30:02,679
tight as you can get them and what

632
00:30:06,419 --> 00:30:03,610
supports them

633
00:30:07,980 --> 00:30:06,429
is the fact that electrons are called

634
00:30:10,260 --> 00:30:07,990
Fermi their type of particles called

635
00:30:10,769 --> 00:30:10,270
fermions and fermions to be back

636
00:30:12,960 --> 00:30:10,779
together

637
00:30:14,760 --> 00:30:12,970
they're very anti-social there is no

638
00:30:16,830 --> 00:30:14,770

type of particle called bosons it spins

639
00:30:19,680 --> 00:30:16,840
but spins they are bosons love to be

640
00:30:21,750 --> 00:30:19,690
together fermions hate it and you just

641
00:30:23,639 --> 00:30:21,760
basically you can push and push and push

642
00:30:25,139 --> 00:30:23,649
and they won't go any further but

643
00:30:26,460 --> 00:30:25,149
eventually if you push hard enough you

644
00:30:29,610 --> 00:30:26,470
put enough matter onto that white dwarf

645
00:30:30,000 --> 00:30:29,620
it says okay well I just can't take this

646
00:30:33,029 --> 00:30:30,010
anymore

647
00:30:35,220 --> 00:30:33,039
I'm going into the nucleus and the white

648
00:30:37,980 --> 00:30:35,230
the electron goes into the nucleus it

649
00:30:39,899 --> 00:30:37,990
combines with a proton and the charge of

650
00:30:42,930 --> 00:30:39,909
the proton the electric cancel and they

651
00:30:44,669 --> 00:30:42,940
produce a neutron and so the star turn

652
00:30:46,769 --> 00:30:44,679
all those electrons get captured by all

653
00:30:48,899 --> 00:30:46,779
the protons and what is left is a star

654
00:30:51,180 --> 00:30:48,909
that's just full of neutrons basically

655
00:30:54,750 --> 00:30:51,190
just a neutron matter and that's what we

656
00:30:57,510 --> 00:30:54,760
call a neutron star and neutrons are

657
00:30:59,639 --> 00:30:57,520
also fermions so again it takes a lot a

658
00:31:00,899 --> 00:30:59,649
lot of matter to make them do anything

659
00:31:02,669 --> 00:31:00,909
else but eventually if you put even more

660
00:31:07,169 --> 00:31:02,679
matter onto neutron star it will

661
00:31:09,510 --> 00:31:07,179
collapse down to a black hole and so if

662
00:31:12,120 --> 00:31:09,520
you merge two neutron stars you will

663
00:31:14,310 --> 00:31:12,130

often have enough matter we think that

664
00:31:19,860 --> 00:31:14,320
they will leave behind a black hole

665
00:31:23,279 --> 00:31:19,870
we'll be seeing that there so neutron

666
00:31:28,080 --> 00:31:23,289
stars are also the basis of what go

667
00:31:30,680 --> 00:31:28,090
pulsars pulsars are these magnetized

668
00:31:35,190 --> 00:31:30,690
neutron stars which are spinning and

669
00:31:38,610 --> 00:31:35,200
they basically produce a basically here

670
00:31:41,669 --> 00:31:38,620
this becomes like a lighthouse and that

671
00:31:44,370 --> 00:31:41,679
swings around and if it happens to point

672
00:31:46,440 --> 00:31:44,380
at your direction a life left you see it

673
00:31:48,360 --> 00:31:46,450
flash go off and then it swings away and

674
00:31:50,070 --> 00:31:48,370
it goes off it goes off and then you

675
00:31:51,600 --> 00:31:50,080
turn points at you and it's bright and

676
00:31:54,149 --> 00:31:51,610
then it goes away from most of the time

677
00:31:57,299 --> 00:31:54,159
in it's dark and so you can use that as

678
00:31:59,340 --> 00:31:57,309
a clock you can say okay I can watch and

679
00:32:00,350 --> 00:31:59,350
it's very regular cuz it's a massive

680
00:32:02,029 --> 00:32:00,360
object spinning

681
00:32:05,990 --> 00:32:02,039
so you can say okay no that neutron

682
00:32:08,149 --> 00:32:06,000
stars spin say 30 times second right so

683
00:32:10,279 --> 00:32:08,159
then I can just count those times it's

684
00:32:12,590 --> 00:32:10,289
spinning I can count the clicks as it

685
00:32:14,450 --> 00:32:12,600
goes by now if it's coming toward if

686
00:32:16,130 --> 00:32:14,460
it's a binary sometimes they'll be

687
00:32:17,060 --> 00:32:16,140
coming towards me is sometimes they'll

688
00:32:19,250 --> 00:32:17,070

be coming away from me

689
00:32:24,440 --> 00:32:19,260
and it'll have a Doppler shift so was it

690
00:32:25,730 --> 00:32:24,450
coming away from if you turn it this out

691
00:32:26,870 --> 00:32:25,740
we're gonna be turning something other

692
00:32:31,250 --> 00:32:26,880
things that the sound later and it'll

693
00:32:33,049 --> 00:32:31,260
sound much better than me and and so

694
00:32:34,610 --> 00:32:33,059
they you can use that as a clock so you

695
00:32:36,500 --> 00:32:34,620
can say okay I know whether I can follow

696
00:32:44,200 --> 00:32:36,510
that neutron star in its orbit

697
00:32:49,549 --> 00:32:44,210
okay so what happens in the 1970s was

698
00:32:54,620 --> 00:32:49,559
this pulsar 1913 +16 was discovered and

699
00:32:57,350 --> 00:32:54,630
this pulsar M is in an orbit with

700
00:32:59,389 --> 00:32:57,360
another neutron star the other neutron

701
00:33:01,180 --> 00:32:59,399
star is not a pulsar as far as we know

702
00:33:07,399 --> 00:33:01,190
if it is it's not pointing towards us

703
00:33:10,419 --> 00:33:07,409
but we can measure its orbit and its

704
00:33:13,430 --> 00:33:10,429
orbit is changing it's actually getting

705
00:33:18,470 --> 00:33:13,440
faster and that's what this curve is

706
00:33:21,110 --> 00:33:18,480
showing you here the orbit shrinks by

707
00:33:23,210 --> 00:33:21,120
about seven meters a year so that's the

708
00:33:25,639 --> 00:33:23,220
amazing thing about this this pulsar

709
00:33:30,379 --> 00:33:25,649
it's a very regular clock so you can do

710
00:33:33,230 --> 00:33:30,389
incredibly precise measurements and it

711
00:33:34,879 --> 00:33:33,240
radiates about 2% of it of the solar

712
00:33:36,799 --> 00:33:34,889
luminosity about about 2% of the energy

713
00:33:38,779 --> 00:33:36,809

of the Sun is what it's radiating so

714
00:33:39,950 --> 00:33:38,789
it's losing energy and that's causing

715
00:33:42,680 --> 00:33:39,960
this orbit to decay

716
00:33:44,810 --> 00:33:42,690
right now our solar system doesn't

717
00:33:46,940 --> 00:33:44,820
radiate much energy the solar system

718
00:33:49,539 --> 00:33:46,950
radiates about 5,000 watts in

719
00:33:51,980 --> 00:33:49,549
gravitational energy so less than a

720
00:33:56,539 --> 00:33:51,990
hefty air-conditioner on a summers day

721
00:33:57,529 --> 00:33:56,549
right but but it so that's not you're

722
00:33:58,970 --> 00:33:57,539
not gonna get much energy out of the

723
00:34:00,379 --> 00:33:58,980
solar system that way but you'll see

724
00:34:04,759 --> 00:34:00,389
that some things give out a lot of

725
00:34:08,839 --> 00:34:04,769
gravitational wave energy and this will

726
00:34:10,579 --> 00:34:08,849
merge in about 300 million years now

727
00:34:12,260 --> 00:34:10,589
this this was discovered by hosts and

728
00:34:14,600 --> 00:34:12,270
Taylor Russ Holson Joe tiller Joe tiller

729
00:34:19,340 --> 00:34:14,610
was my adviser at Princeton

730
00:34:22,909 --> 00:34:19,350
and I'm he actually offered they got the

731
00:34:24,560 --> 00:34:22,919
Nobel Prize for this in 1993 Russ host

732
00:34:27,200 --> 00:34:24,570
was his grad student at the University

733
00:34:28,700 --> 00:34:27,210
of Massachusetts and Joe is then at

734
00:34:33,040 --> 00:34:28,710
University of Massachusetts and then at

735
00:34:40,040 --> 00:34:35,090
Princeton figured this was coming I

736
00:34:42,919 --> 00:34:40,050
think he had some trouble with the

737
00:34:45,280 --> 00:34:42,929
Pulsar company though while I was there

738
00:34:50,139 --> 00:34:45,290

they sent him a cease and desist letter

739
00:34:55,190 --> 00:34:50,149
they said the Pulsar name is trademarked

740
00:34:56,030 --> 00:34:55,200
and so you cannot use it well we know

741
00:35:01,520 --> 00:34:56,040
how that turned out

742
00:35:03,380 --> 00:35:01,530
but so we still use it and I but the

743
00:35:06,550 --> 00:35:03,390
post our company that I think that

744
00:35:10,640 --> 00:35:06,560
watches are still around so all right

745
00:35:13,220 --> 00:35:10,650
and and they got the this prize for

746
00:35:15,410 --> 00:35:13,230
discard it was for discovering this

747
00:35:17,560 --> 00:35:15,420
pulsar mainly and which could give

748
00:35:20,870 --> 00:35:17,570
insight into gravitation gravitation

749
00:35:23,540 --> 00:35:20,880
which it did it that was indirect so

750
00:35:24,950 --> 00:35:23,550
what you're seeing there right what

751
00:35:28,280 --> 00:35:24,960
you're seeing there is the loss of

752
00:35:31,370 --> 00:35:28,290
energy due to gravitational waves this

753
00:35:35,270 --> 00:35:31,380
was proof in it Matt that line there is

754
00:35:38,960 --> 00:35:35,280
in Stein's prediction and the dots are

755
00:35:40,520 --> 00:35:38,970
the data right so it's incredibly good

756
00:35:44,599 --> 00:35:40,530
agreement between what Einstein

757
00:35:46,430 --> 00:35:44,609
predicted and what we observe and you

758
00:35:48,080 --> 00:35:46,440
can you there are so many so much

759
00:35:49,580 --> 00:35:48,090
information from this that you can solve

760
00:35:52,220 --> 00:35:49,590
for all the parameters there's no

761
00:35:54,170 --> 00:35:52,230
assumptions in this and you tie it you

762
00:35:57,620 --> 00:35:54,180
saw for the entire system and you get

763
00:36:00,170 --> 00:35:57,630

that agreement is astonishing so this

764
00:36:03,440 --> 00:36:00,180
was a remarkable can con formation of

765
00:36:05,090 --> 00:36:03,450
general relativity but it wasn't the

766
00:36:06,920 --> 00:36:05,100
direct detection it was an indirect

767
00:36:08,270 --> 00:36:06,930
detection of gravitational waves so

768
00:36:12,230 --> 00:36:08,280
there was still another Nobel Prize out

769
00:36:14,000 --> 00:36:12,240
there to give you gotten so how do you

770
00:36:15,410 --> 00:36:14,010
what how would you what does it mean to

771
00:36:17,210 --> 00:36:15,420
detect a gravitational wave what is a

772
00:36:18,890 --> 00:36:17,220
gravitational wave so I've told you it's

773
00:36:23,960 --> 00:36:18,900
energy but what does it do when it goes

774
00:36:26,930 --> 00:36:23,970
by it does this it distorts space and

775
00:36:30,320 --> 00:36:26,940
time and that it does it in a funny way

776
00:36:32,320 --> 00:36:30,330
so that if I were being a graduation we

777
00:36:35,599 --> 00:36:32,330
was coming this way right I would be

778
00:36:38,090 --> 00:36:35,609
stretched this way and we brought me a

779
00:36:39,859 --> 00:36:38,100
thinner this way and then I would be

780
00:36:42,349 --> 00:36:39,869
pushed down like this way and made

781
00:36:44,440 --> 00:36:42,359
broader this way simultaneously right so

782
00:36:47,900 --> 00:36:44,450
it's a simultaneous stretch and pull

783
00:36:50,510 --> 00:36:47,910
that goes on and in fact this is just

784
00:36:52,460 --> 00:36:50,520
one there's another mode that's it 45

785
00:36:54,940 --> 00:36:52,470
degrees like this but I'm not gonna try

786
00:36:58,670 --> 00:36:54,950
to do that mode I'll kill myself but

787
00:37:02,830 --> 00:36:58,680
okay so and then here in the blue I've

788
00:37:07,910 --> 00:37:05,270

right so that's what a gravitational

789
00:37:12,440 --> 00:37:07,920
wave does it stretches and pull it

790
00:37:14,390 --> 00:37:12,450
stretches and compresses space-time but

791
00:37:14,960 --> 00:37:14,400
gravity is weak what I mean by gravity

792
00:37:16,609 --> 00:37:14,970
is weak

793
00:37:18,410 --> 00:37:16,619
well you're every time you will get a

794
00:37:20,930 --> 00:37:18,420
refrigerator magnet you're seeing their

795
00:37:23,090 --> 00:37:20,940
gravity is weak right you have the whole

796
00:37:25,130 --> 00:37:23,100
earth trying to pull down that little

797
00:37:27,650 --> 00:37:25,140
tiny magnet and what little buddy Magnus

798
00:37:30,260 --> 00:37:27,660
next to a refrigerator right and it's

799
00:37:32,510 --> 00:37:30,270
it's resisting the pull of the whole of

800
00:37:34,400 --> 00:37:32,520
the earth that's what we mean by gravity

801
00:37:37,040 --> 00:37:34,410
is weak compared to electromagnetism

802
00:37:38,810 --> 00:37:37,050
right it takes a lot of a lot of matter

803
00:37:40,760 --> 00:37:38,820
to have this sort of force that

804
00:37:48,140 --> 00:37:40,770
electromagnetism does with just a few

805
00:37:49,640 --> 00:37:48,150
particles and so if we ask what is the

806
00:37:51,050 --> 00:37:49,650
brightest source we would expect to see

807
00:37:53,000 --> 00:37:51,060
about once per year right

808
00:37:54,290 --> 00:37:53,010
the longer you wait the brighter some

809
00:37:56,060 --> 00:37:54,300
source is going to be because something

810
00:37:57,830 --> 00:37:56,070
will happen closer right but you say

811
00:38:00,410 --> 00:37:57,840
well we sort of good we had to do

812
00:38:02,930 --> 00:38:00,420
predictions of how bright will things

813
00:38:04,880 --> 00:38:02,940

typically be and we had estimates that

814
00:38:09,320 --> 00:38:04,890
were between you know order to a third

815
00:38:10,970 --> 00:38:09,330
order of a factor of 100 really and we

816
00:38:13,010 --> 00:38:10,980
could guess about how it you would need

817
00:38:16,010 --> 00:38:13,020
and we figure we'll probably about one

818
00:38:18,440 --> 00:38:16,020
part in 10 to the 21 that's 1,000

819
00:38:20,720 --> 00:38:18,450
billion billions it's a tiny little bit

820
00:38:22,640 --> 00:38:20,730
but what does that mean what do we mean

821
00:38:27,500 --> 00:38:22,650
you know how much means that first of

822
00:38:29,780 --> 00:38:27,510
all you're not going to feel it but if

823
00:38:31,730 --> 00:38:29,790
you were build I say I built a detector

824
00:38:33,320 --> 00:38:31,740
that just say is four kilometers long

825
00:38:34,010 --> 00:38:33,330
that's what these are the laser

826
00:38:36,770 --> 00:38:34,020
interferometer gravitational-wave

827
00:38:38,090 --> 00:38:36,780
Observatory LIGO there are two of them

828
00:38:40,910 --> 00:38:38,100
because you

829
00:38:43,250 --> 00:38:40,920
at least two because well it helps you

830
00:38:44,950 --> 00:38:43,260
localize them but also you want to be

831
00:38:47,420 --> 00:38:44,960
sure that you see something it's real

832
00:38:50,210 --> 00:38:47,430
right so that was one of the reasons the

833
00:38:52,280 --> 00:38:50,220
bill - and they're well separated so if

834
00:38:53,690 --> 00:38:52,290
a truck goes by Livingston Louisiana

835
00:38:57,140 --> 00:38:53,700
you don't feel it in Hanford Washington

836
00:39:00,800 --> 00:38:57,150
right and there are four kilometres long

837
00:39:03,260 --> 00:39:00,810
here all right now and the waves will

838
00:39:05,960 --> 00:39:03,270

come by and it'll one way a wave will

839
00:39:07,970 --> 00:39:05,970
stretch this arm while it shrinks this

840
00:39:11,450 --> 00:39:07,980
arm and then it'll stretch this arm

841
00:39:13,580 --> 00:39:11,460
while it shrinks the arm okay and that's

842
00:39:16,970 --> 00:39:13,590
why you build it in this sort of right

843
00:39:19,280 --> 00:39:16,980
angle configuration but if you've got

844
00:39:21,380 --> 00:39:19,290
something four kilometers long or about

845
00:39:24,710 --> 00:39:21,390
two and a half miles long

846
00:39:27,740 --> 00:39:24,720
what does ten that size ten to the minus

847
00:39:35,330 --> 00:39:27,750
twenty-one mean in practice well this is

848
00:39:37,160 --> 00:39:35,340
a hydrogen atom that we're now going in

849
00:39:43,640 --> 00:39:37,170
to see the scale of what you have to

850
00:39:45,830 --> 00:39:43,650
measure that's a proton you have to

851
00:39:48,440 --> 00:39:45,840
measure a tiny fraction of the size of

852
00:39:52,460 --> 00:39:48,450
the proton that's what one of these

853
00:39:54,800 --> 00:39:52,470
waves going by will cause this this arm

854
00:39:56,900 --> 00:39:54,810
to shrink by and expand by so it's

855
00:39:59,510 --> 00:39:56,910
incredibly provides it's so precise that

856
00:40:01,100 --> 00:39:59,520
you think these people are crazy right

857
00:40:01,940 --> 00:40:01,110
there's no way and many people thought

858
00:40:04,010 --> 00:40:01,950
that for a long time hey these people

859
00:40:06,410 --> 00:40:04,020
crazy we'll give them the money yeah

860
00:40:10,010 --> 00:40:06,420
well you know we'll shut up but they're

861
00:40:12,080 --> 00:40:10,020
crazy and to believe that you could do

862
00:40:16,970 --> 00:40:12,090
this right well they've done it it's

863
00:40:19,250 --> 00:40:16,980

amazing and so I'm gonna give you the

864
00:40:22,730 --> 00:40:19,260
video here short little video which

865
00:40:24,710 --> 00:40:22,740
where it introduces ray weiss who is the

866
00:40:26,330 --> 00:40:24,720
person who had the idea basically the

867
00:40:28,370 --> 00:40:26,340
person with the idea of using an

868
00:40:31,310 --> 00:40:28,380
interferometer which is it'll explain

869
00:40:33,800 --> 00:40:31,320
here that the use of white light to

870
00:40:39,890 --> 00:40:33,810
measure the distances and to get this

871
00:40:40,310 --> 00:40:39,900
very very precise measurement oh do we

872
00:40:42,290 --> 00:40:40,320
have

873
00:40:44,540 --> 00:40:42,300
oh wait I don't we check that we check

874
00:40:48,770 --> 00:40:44,550
the sound hopefully we have sound we

875
00:41:03,680 --> 00:40:52,640
no we only have sawn from here am I

876
00:41:15,820 --> 00:41:03,690
gonna have to do this I can come I'll

877
00:41:20,660 --> 00:41:18,430
to leisure the stretching and squeezing

878
00:41:24,320 --> 00:41:20,670
return to a device called an

879
00:41:26,900 --> 00:41:24,330
interferometer a laser beam is split and

880
00:41:30,710 --> 00:41:26,910
sent down a pair of long perpendicular

881
00:41:33,040 --> 00:41:30,720
tubes each precisely the same length the

882
00:41:36,320 --> 00:41:33,050
two beams bounce off mirrors and

883
00:41:38,720 --> 00:41:36,330
recombine back at the base the light

884
00:41:47,180 --> 00:41:38,730
waves come back lined up in such a way

885
00:41:49,850 --> 00:41:47,190
that they cancel each other out gets

886
00:41:52,610 --> 00:41:49,860
detected at the photo detector but when

887
00:41:55,040 --> 00:41:52,620
a gravity wave comes along it distorts

888
00:41:57,650 --> 00:41:55,050

space and changes the distance between

889
00:41:59,990 --> 00:41:57,660
the mirrors one arm becomes a little

890
00:42:03,590 --> 00:42:00,000
longer the other a little shorter an

891
00:42:05,510 --> 00:42:03,600
instant later they switch this back and

892
00:42:07,850 --> 00:42:05,520
forth stretching and squeezing happens

893
00:42:11,150 --> 00:42:07,860
over and over until the wave is passed

894
00:42:12,980 --> 00:42:11,160
as the distances change so does the

895
00:42:15,770 --> 00:42:12,990
alignment between the peaks and valleys

896
00:42:17,780 --> 00:42:15,780
of the two returning light waves and the

897
00:42:19,550 --> 00:42:17,790
light waves no longer cancel each other

898
00:42:22,460 --> 00:42:19,560
out when added together in the

899
00:42:24,800 --> 00:42:22,470
recombined beam now some light does

900
00:42:27,290 --> 00:42:24,810
reach the detector with an intensity

901
00:42:30,050 --> 00:42:27,300
that varies as the distance between the

902
00:42:33,620 --> 00:42:30,060
mirrors varies measure that intensity

903
00:42:36,200 --> 00:42:33,630
and you're measuring gravity waves the

904
00:42:38,240 --> 00:42:36,210
light takes longer time in here and it

905
00:42:40,220 --> 00:42:38,250
did in this arm now it takes a shorter

906
00:42:47,720 --> 00:42:40,230
time and these things don't cancel so

907
00:42:49,010 --> 00:42:47,730
beautifully anymore and as remarkable is

908
00:42:51,260 --> 00:42:49,020
that say you're measuring a tiny

909
00:42:52,520 --> 00:42:51,270
fraction of the wavelength of light but

910
00:42:54,260 --> 00:42:52,530
you have to align these things

911
00:42:57,770 --> 00:42:54,270
incredibly precisely and there's another

912
00:42:59,930 --> 00:42:57,780
trick that they do which isn't talked

913
00:43:01,260 --> 00:42:59,940

about a lot but they they actually put

914
00:43:03,360 --> 00:43:01,270
another mirror in here

915
00:43:06,090 --> 00:43:03,370
and so the light goes back and forth

916
00:43:07,860 --> 00:43:06,100
about a hundred times but it doesn't

917
00:43:09,960 --> 00:43:07,870
about a hundred round trips in there so

918
00:43:11,670 --> 00:43:09,970
rather than being four kilometres these

919
00:43:13,950 --> 00:43:11,680
are basically more like four hundred

920
00:43:16,650 --> 00:43:13,960
kilometers as a result so you get that

921
00:43:19,170 --> 00:43:16,660
extra factor of a hundred so that helps

922
00:43:20,610 --> 00:43:19,180
a tremendous amount right now they have

923
00:43:22,920 --> 00:43:20,620
a number of tricks in here that are

924
00:43:25,890 --> 00:43:22,930
simply amazing that allow that basically

925
00:43:29,160 --> 00:43:25,900
turns this 20 watt laser into 100

926
00:43:30,780 --> 00:43:29,170
kilowatts here so they it's you took

927
00:43:34,740 --> 00:43:30,790
many years of research and development

928
00:43:37,470 --> 00:43:34,750
and from many brilliant people but it is

929
00:43:39,240 --> 00:43:37,480
produced a remarkable device right that

930
00:43:45,600 --> 00:43:39,250
can measure these incredibly small

931
00:43:48,270 --> 00:43:45,610
changes in distance now we can use we

932
00:43:51,720 --> 00:43:48,280
can use general relativity to predict

933
00:43:54,390 --> 00:43:51,730
what we should see if two things were if

934
00:43:56,790 --> 00:43:54,400
you had a binary merge in the wave came

935
00:43:59,640 --> 00:43:56,800
passed by us what would it look like in

936
00:44:01,740 --> 00:43:59,650
this detector right and what you see

937
00:44:04,080 --> 00:44:01,750
you'll see and you get something like

938
00:44:06,270 --> 00:44:04,090

these Wiggles here and that's it you're

939
00:44:08,970 --> 00:44:06,280
the wave passing and what happens here

940
00:44:11,070 --> 00:44:08,980
is it the it's going it's relatively

941
00:44:13,890 --> 00:44:11,080
slowly they get closer together it

942
00:44:16,530 --> 00:44:13,900
speeds up goes very very fast then they

943
00:44:19,290 --> 00:44:16,540
combine and then they're gonna spin down

944
00:44:21,450 --> 00:44:19,300
you get a little shaking of the object

945
00:44:23,490 --> 00:44:21,460
it's right as it settles down here this

946
00:44:24,720 --> 00:44:23,500
is very hard to measure because it's

947
00:44:28,410 --> 00:44:24,730
weak but we have a little bit of

948
00:44:29,850 --> 00:44:28,420
indication and here you can see that

949
00:44:31,920 --> 00:44:29,860
these are two black holes that were

950
00:44:33,780 --> 00:44:31,930
actually seen you can see that there in

951
00:44:36,680 --> 00:44:33,790
the end just before they merge they're

952
00:44:40,170 --> 00:44:36,690
moving at almost the speed of light

953
00:44:42,930 --> 00:44:40,180
incredibly incredibly violent process

954
00:44:47,280 --> 00:44:42,940
going on here right two black holes in a

955
00:44:48,510 --> 00:44:47,290
binary coming together now what they do

956
00:44:50,160 --> 00:44:48,520
is they look at I'll show you in a

957
00:44:52,140 --> 00:44:50,170
minute what the waveform looks what they

958
00:44:55,200 --> 00:44:52,150
actually look at what they do is they

959
00:44:56,340 --> 00:44:55,210
try they take gr and they may take all

960
00:44:57,900 --> 00:44:56,350
these different predictions like what

961
00:45:00,690 --> 00:44:57,910
could all the binary orbits look like

962
00:45:03,870 --> 00:45:00,700
and then they try and fit them to the

963
00:45:06,120 --> 00:45:03,880

data right and when you do that when you

964
00:45:07,980 --> 00:45:06,130
find when you finally get a good fit you

965
00:45:10,110 --> 00:45:07,990
get if you have a say very good

966
00:45:12,600 --> 00:45:10,120
signal-to-noise you learn everything

967
00:45:15,000 --> 00:45:12,610
about these objects it's amazing

968
00:45:17,880 --> 00:45:15,010
you get their mass you get

969
00:45:20,100 --> 00:45:17,890
of the two objects you get how circular

970
00:45:23,460 --> 00:45:20,110
there were how little the orbit is you

971
00:45:26,070 --> 00:45:23,470
get if they're spinning or not you get

972
00:45:28,560 --> 00:45:26,080
how that orbit is oriented with respect

973
00:45:30,900 --> 00:45:28,570
to Earth right is it tilted this way is

974
00:45:32,340 --> 00:45:30,910
that you're looking at edge on and you

975
00:45:34,440 --> 00:45:32,350
get the distant you even get the

976
00:45:36,180 --> 00:45:34,450
distance because if you've got all of

977
00:45:38,400 --> 00:45:36,190
these other things you can predict how

978
00:45:40,080 --> 00:45:38,410
bright it should be and then you look at

979
00:45:41,670 --> 00:45:40,090
how bright it was at earth and you say

980
00:45:43,290 --> 00:45:41,680
well the only way it could be that you

981
00:45:45,960 --> 00:45:43,300
know I know how bright it's like if I

982
00:45:47,610 --> 00:45:45,970
held up a flashlight and you know how

983
00:45:49,740 --> 00:45:47,620
bright that flashlight is you could

984
00:45:51,690 --> 00:45:49,750
guesstimate how far away I am by how

985
00:45:54,560 --> 00:45:51,700
bright the flashlight look to you you

986
00:45:56,910 --> 00:45:54,570
can do the same thing with this binary

987
00:45:59,340 --> 00:45:56,920
so you can get everything about the

988
00:46:01,290 --> 00:45:59,350

binary for in principle if you have

989
00:46:03,780 --> 00:46:01,300
really good signal-to-noise so that's

990
00:46:08,340 --> 00:46:03,790
it's incredible system that incredible

991
00:46:09,330 --> 00:46:08,350
theory and incredible system of course

992
00:46:11,550 --> 00:46:09,340
so we don't have infinite

993
00:46:13,200 --> 00:46:11,560
signal-to-noise so you can't you can do

994
00:46:16,680 --> 00:46:13,210
well but you can't do perfectly but I'll

995
00:46:22,200 --> 00:46:16,690
show you that later okay this is what

996
00:46:24,120 --> 00:46:22,210
the first detection looked like so what

997
00:46:27,990 --> 00:46:24,130
you see here the best fit is that the

998
00:46:29,790 --> 00:46:28,000
best fit is that is that predicted line

999
00:46:33,750 --> 00:46:29,800
right is the weather called predicted

1000
00:46:35,610 --> 00:46:33,760
and the the heavier line is the data and

1001
00:46:37,800 --> 00:46:35,620
there are two different right this is

1002
00:46:39,990 --> 00:46:37,810
Hanford in Washington this is the

1003
00:46:42,510 --> 00:46:40,000
Livingston in Louisiana and here they've

1004
00:46:44,790 --> 00:46:42,520
been aligned because of course depending

1005
00:46:47,340 --> 00:46:44,800
on the direction of the direction of the

1006
00:46:48,870 --> 00:46:47,350
light wave the gravity wave it takes

1007
00:46:54,420 --> 00:46:48,880
about a tenth of a second for it to get

1008
00:46:56,010 --> 00:46:54,430
from Louisiana to Washington there's

1009
00:46:57,510 --> 00:46:56,020
another way to look at it and to say

1010
00:46:59,240 --> 00:46:57,520
okay you big you've heard of sonogram

1011
00:47:02,220 --> 00:46:59,250
that's right what you can plot here is

1012
00:47:05,130 --> 00:47:02,230
the frequency of these Wiggles versus

1013
00:47:08,070 --> 00:47:05,140

time you can see that it goes up with

1014
00:47:10,470 --> 00:47:08,080
time it starts low and goes high I'm

1015
00:47:13,560 --> 00:47:10,480
going to play that this one for you now

1016
00:47:20,180 --> 00:47:13,570
it's very brief so you'll have to we

1017
00:47:20,190 --> 00:47:29,150
[Music]

1018
00:47:35,730 --> 00:47:31,620
not too impressive we've got a more

1019
00:47:37,950 --> 00:47:35,740
impressive little funny later yeah

1020
00:47:46,980 --> 00:47:37,960
that's the properties black holes it

1021
00:47:52,980 --> 00:47:46,990
does pick like that no fun at all of

1022
00:47:54,720 --> 00:47:52,990
course I couldn't get the okay that's

1023
00:48:00,900 --> 00:47:54,730
what that's the sound of two black holes

1024
00:48:03,269 --> 00:48:00,910
merging sounds like there's a pair of

1025
00:48:08,430 --> 00:48:03,279
chipmunks but it's actually two black

1026
00:48:09,660 --> 00:48:08,440
holes merging okay yeah it's more

1027
00:48:14,960 --> 00:48:09,670
conceptually it's more impressive

1028
00:48:18,660 --> 00:48:14,970
somehow alright

1029
00:48:20,880 --> 00:48:18,670
so undetected it was the merger we know

1030
00:48:23,609 --> 00:48:20,890
it's two black holes from the masses and

1031
00:48:26,640 --> 00:48:23,619
their sizes the black holes weighed

1032
00:48:28,319 --> 00:48:26,650
individually made 36 to 20 x times there

1033
00:48:30,930 --> 00:48:28,329
so they were both about 30 times more

1034
00:48:33,120 --> 00:48:30,940
massive than the Sun this is huge the

1035
00:48:35,249 --> 00:48:33,130
biggest ones we've seen you know

1036
00:48:36,870 --> 00:48:35,259
binaries we look at star other stars and

1037
00:48:39,569 --> 00:48:36,880
ask their own orbits around black holes

1038
00:48:43,049 --> 00:48:39,579

it's been about 15-20 solar masses maybe

1039
00:48:44,640 --> 00:48:43,059
10 is usually very high and so these

1040
00:48:46,049 --> 00:48:44,650
these are incredibly high in fact some

1041
00:48:47,819 --> 00:48:46,059
people have suggested that maybe these

1042
00:48:50,490 --> 00:48:47,829
are primordial maybe they didn't come

1043
00:48:51,569 --> 00:48:50,500
from stellar evolution we don't know we

1044
00:48:53,999 --> 00:48:51,579
think that they can probably come from

1045
00:48:55,650 --> 00:48:54,009
stellar evolution but it's up in the air

1046
00:48:57,690 --> 00:48:55,660
where exactly because we're finding a

1047
00:49:01,799 --> 00:48:57,700
lot of these and it isn't completely

1048
00:49:03,900 --> 00:49:01,809
settled why we're finding so many they

1049
00:49:06,960 --> 00:49:03,910
they came together and formed a new

1050
00:49:12,049 --> 00:49:06,970
black hole of 62 solar masses now 36

1051
00:49:14,910 --> 00:49:12,059
plus 29 is less is greater than 62 right

1052
00:49:18,029 --> 00:49:14,920
three solar masses of energy were

1053
00:49:20,009 --> 00:49:18,039
radiated as gravitational waves that is

1054
00:49:21,990 --> 00:49:20,019
more energy that came out of all the

1055
00:49:23,370 --> 00:49:22,000
stars in the visible universe in the

1056
00:49:25,920 --> 00:49:23,380
same amount of time came and

1057
00:49:29,249 --> 00:49:25,930
gravitational waves now you didn't have

1058
00:49:33,329 --> 00:49:29,259
to duck because gravity is weak but even

1059
00:49:35,339 --> 00:49:33,339
so right the merger happen it was far

1060
00:49:37,410 --> 00:49:35,349
away so it happened 1.2 billion

1061
00:49:39,330 --> 00:49:37,420
light-years away and so one point

1062
00:49:42,780 --> 00:49:39,340
jillion gear is billion years before

1063
00:49:45,720 --> 00:49:42,790

did it so it's a ways but if

1064
00:49:49,080 --> 00:49:45,730
gravitational light gravitational waves

1065
00:49:50,910 --> 00:49:49,090
were light it would have looked that you

1066
00:49:53,070 --> 00:49:50,920
would have seen a star as bright as the

1067
00:49:55,020 --> 00:49:53,080
full moon right if you could have your

1068
00:49:56,550 --> 00:49:55,030
eyes could focus gravitational waves and

1069
00:49:59,100 --> 00:49:56,560
detect them the way you detect light

1070
00:50:01,170 --> 00:49:59,110
then on that night if you looked up you

1071
00:50:02,760 --> 00:50:01,180
would have seen a star for a brief

1072
00:50:05,070 --> 00:50:02,770
amount of time that was as bright as the

1073
00:50:06,300 --> 00:50:05,080
full moon in fact there's a there was a

1074
00:50:07,980 --> 00:50:06,310
full moon last night it's still pretty

1075
00:50:10,050 --> 00:50:07,990
full tonight when you go out we're gonna

1076
00:50:11,790 --> 00:50:10,060
go back and think about well that was a

1077
00:50:13,740 --> 00:50:11,800
that's how bright that gravitational

1078
00:50:16,980 --> 00:50:13,750
wave those gravitational waves were from

1079
00:50:21,540 --> 00:50:16,990
a pair of neutron stars that were 1.2

1080
00:50:24,600 --> 00:50:21,550
billion light years away it's amazing

1081
00:50:26,790 --> 00:50:24,610
now we've now over the past two years

1082
00:50:29,730 --> 00:50:26,800
they found a bunch of these there are

1083
00:50:31,350 --> 00:50:29,740
actually 4 pairs that are well

1084
00:50:34,020 --> 00:50:31,360
identified and there's a fifth one that

1085
00:50:35,730 --> 00:50:34,030
is just right at the level of detection

1086
00:50:38,190 --> 00:50:35,740
so they're not a hundred percent sure

1087
00:50:44,430 --> 00:50:38,200
they really detected it but four or five

1088
00:50:47,010 --> 00:50:44,440

and that I'll show you now is the black

1089
00:50:48,840 --> 00:50:47,020
holes that we knew about from X from

1090
00:50:51,630 --> 00:50:48,850
studies of our galaxy and nearby

1091
00:50:53,250 --> 00:50:51,640
galaxies and their masses nearly all of

1092
00:50:53,840 --> 00:50:53,260
these are more massive than the ones we

1093
00:50:58,680 --> 00:50:53,850
know about

1094
00:51:01,470 --> 00:50:58,690
now the more massive something is the

1095
00:51:03,540 --> 00:51:01,480
further the bigger a strain it produces

1096
00:51:07,200 --> 00:51:03,550
when it moves right the bigger Mort

1097
00:51:09,930 --> 00:51:07,210
radiates and so if it's twice as big it

1098
00:51:11,670 --> 00:51:09,940
produces twice as much strain strain is

1099
00:51:13,920 --> 00:51:11,680
linear with distance so you can see it

1100
00:51:15,990 --> 00:51:13,930
twice as far away it's not like if I

1101
00:51:17,490 --> 00:51:16,000
know with energy if I asked how much was

1102
00:51:20,340 --> 00:51:17,500
in the waves it goes down as the square

1103
00:51:22,260 --> 00:51:20,350
of the distance but the strain that goes

1104
00:51:24,300 --> 00:51:22,270
down as distance so we gain here

1105
00:51:26,970 --> 00:51:24,310
tremendously compared to measuring the

1106
00:51:28,230 --> 00:51:26,980
energy so that if things are if we

1107
00:51:30,570 --> 00:51:28,240
improve if something is twice as

1108
00:51:32,850 --> 00:51:30,580
energetic if it's twice as massive we

1109
00:51:35,490 --> 00:51:32,860
can see twice as far away that means we

1110
00:51:38,070 --> 00:51:35,500
can search a volume that's two cubes or

1111
00:51:39,720 --> 00:51:38,080
eight times larger right so that you

1112
00:51:41,550 --> 00:51:39,730
have a with a more massive object you

1113
00:51:43,770 --> 00:51:41,560

have a much larger search volume and

1114
00:51:45,180 --> 00:51:43,780
that's probably part of this but we

1115
00:51:46,770 --> 00:51:45,190
don't know if it's there's a lot of

1116
00:51:48,210 --> 00:51:46,780
debate about whether it's all of it and

1117
00:51:50,070 --> 00:51:48,220
whether we need something else besides

1118
00:51:51,840 --> 00:51:50,080
just el revolution and a big search

1119
00:51:56,280 --> 00:51:51,850
volume

1120
00:51:57,870 --> 00:51:56,290
and here's where a twice again this was

1121
00:52:00,330 --> 00:51:57,880
Nobel Prize number two for general

1122
00:52:02,580 --> 00:52:00,340
relativity there was no Vern Stein did

1123
00:52:04,410 --> 00:52:02,590
not get a prize for Jeff not even

1124
00:52:06,510 --> 00:52:04,420
special relativity yeah they didn't like

1125
00:52:09,570 --> 00:52:06,520
relativity they called yeah it was too

1126
00:52:12,200 --> 00:52:09,580
Jewish for them they said it was called

1127
00:52:18,600 --> 00:52:12,210
Jewish science by a lot of the the the

1128
00:52:22,190 --> 00:52:18,610
the Germans at the time and so but but

1129
00:52:25,650 --> 00:52:22,200
um but it's everyone science now and it

1130
00:52:27,000 --> 00:52:25,660
and it so now it's gotten it's finally

1131
00:52:30,800 --> 00:52:27,010
gotten its second Nobel Prize for the

1132
00:52:33,780 --> 00:52:30,810
actual detection of gravitational waves

1133
00:52:35,850 --> 00:52:33,790
now Europe wanted adjoining the fun and

1134
00:52:38,820 --> 00:52:35,860
so they built their own detector and

1135
00:52:42,090 --> 00:52:38,830
they they got it turned on in this last

1136
00:52:44,610 --> 00:52:42,100
year and there was the LAT the most

1137
00:52:46,530 --> 00:52:44,620
reasons of the black hole mergers that I

1138
00:52:48,960 --> 00:52:46,540

mentioned there was this one it's not

1139
00:52:50,970 --> 00:52:48,970
quite as sensitive yet as the two ones

1140
00:52:53,490 --> 00:52:50,980
in the US and this one isn't the

1141
00:52:55,650 --> 00:52:53,500
sensitive living isn't this one um they

1142
00:52:57,720 --> 00:52:55,660
up they tried to upgrade them the two

1143
00:52:59,280 --> 00:52:57,730
years ago didn't go so well so they

1144
00:53:03,620 --> 00:52:59,290
brought it back and Hanford never quite

1145
00:53:06,330 --> 00:53:03,630
got back recovered from its upgrade but

1146
00:53:08,580 --> 00:53:06,340
so they're trying to upgrade again you

1147
00:53:10,410 --> 00:53:08,590
know what they need to do to get these

1148
00:53:12,030 --> 00:53:10,420
things stored it's just unbelievably if

1149
00:53:13,860 --> 00:53:12,040
you've seen you saw just a tiny fraction

1150
00:53:16,170 --> 00:53:13,870
of what they need to do right that they

1151
00:53:17,550 --> 00:53:16,180
need to completely isolate them from all

1152
00:53:20,400 --> 00:53:17,560
the size of noise everything it's

1153
00:53:21,990 --> 00:53:20,410
incredibly difficult so I'm just hoping

1154
00:53:23,130 --> 00:53:22,000
that they'll come back and better you

1155
00:53:25,110 --> 00:53:23,140
know much better she they really get

1156
00:53:27,750 --> 00:53:25,120
that factor of two that they're planning

1157
00:53:30,630 --> 00:53:27,760
for the next year we'll see but but

1158
00:53:35,280 --> 00:53:30,640
nonetheless have that third point is

1159
00:53:37,530 --> 00:53:35,290
very because if you want to know where

1160
00:53:38,670 --> 00:53:37,540
they are on the sky it helps

1161
00:53:42,570 --> 00:53:38,680
tremendously

1162
00:53:44,010 --> 00:53:42,580
see these big ellipses big of errors

1163
00:53:45,420 --> 00:53:44,020

circles it's not really a circle it's

1164
00:53:46,710 --> 00:53:45,430
because we usually use from ever to

1165
00:53:49,410 --> 00:53:46,720
circle this is an error ellipse or a

1166
00:53:51,150 --> 00:53:49,420
narrow blob right and there's a blob on

1167
00:53:52,260 --> 00:53:51,160
each side of each hemisphere because you

1168
00:53:53,850 --> 00:53:52,270
couldn't even tell which way it was

1169
00:53:55,260 --> 00:53:53,860
coming from there were two different

1170
00:53:56,910 --> 00:53:55,270
directions with they're just two

1171
00:53:58,470 --> 00:53:56,920
directors there were two different

1172
00:54:00,750 --> 00:53:58,480
directions that it could have been

1173
00:54:03,240 --> 00:54:00,760
coming from with the third detector

1174
00:54:05,650 --> 00:54:03,250
that's no longer possible so these two

1175
00:54:08,469 --> 00:54:05,660
objects

1176
00:54:10,479 --> 00:54:08,479
the European Virgo in place and so we

1177
00:54:13,509 --> 00:54:10,489
could you get a much smaller error

1178
00:54:15,819 --> 00:54:13,519
region and you can tell which hemisphere

1179
00:54:17,739 --> 00:54:15,829
it's in which helps a lot but it the

1180
00:54:19,660 --> 00:54:17,749
fact that it's much smaller it's crucial

1181
00:54:22,599 --> 00:54:19,670
because we'd like to go and search them

1182
00:54:25,420 --> 00:54:22,609
with optical instruments and as you

1183
00:54:27,400 --> 00:54:25,430
heard Frank point get out you the Hubble

1184
00:54:29,650 --> 00:54:27,410
has a very small field of view now there

1185
00:54:31,390 --> 00:54:29,660
are there are optical telescopes with

1186
00:54:34,120 --> 00:54:31,400
larger fields of view than Hubble but

1187
00:54:35,680 --> 00:54:34,130
they're still not you know large they're

1188
00:54:38,079 --> 00:54:35,690

not anything compared to the size of the

1189
00:54:43,180 --> 00:54:38,089
sky so you really need a good position

1190
00:54:45,309 --> 00:54:43,190
and this has helped tremendously now we

1191
00:54:47,259 --> 00:54:45,319
always thought that we would see we knew

1192
00:54:48,699 --> 00:54:47,269
about the host Taylor pulsar so he

1193
00:54:51,069 --> 00:54:48,709
thought we always like we're going to

1194
00:54:53,920 --> 00:54:51,079
see his neutron star is merging and for

1195
00:54:56,229 --> 00:54:53,930
a while we just got black holes but last

1196
00:54:59,190 --> 00:54:56,239
late last year three days after that

1197
00:55:01,630 --> 00:54:59,200
last black hole that the Europeans saw a

1198
00:55:06,779 --> 00:55:01,640
pair of neutron stars merging was

1199
00:55:10,689 --> 00:55:09,489
they had masses about one and a half and

1200
00:55:12,729 --> 00:55:10,699
one and a quarter of solar masses

1201
00:55:15,939 --> 00:55:12,739
neutron stars are typically about the

1202
00:55:17,769 --> 00:55:15,949
solar about the mass of the Sun from a

1203
00:55:21,640 --> 00:55:17,779
little bit less to about two times this

1204
00:55:23,499 --> 00:55:21,650
mass of the Sun the objects are

1205
00:55:28,299 --> 00:55:23,509
extremely compact and leave a single

1206
00:55:30,069 --> 00:55:28,309
massive remnant and again they oh now

1207
00:55:31,749 --> 00:55:30,079
they again they only lose two point five

1208
00:55:33,640 --> 00:55:31,759
percent of solar mass to grab so they

1209
00:55:35,140 --> 00:55:33,650
lose very little compared to what you

1210
00:55:37,390 --> 00:55:35,150
saw for the black holes because the

1211
00:55:38,829 --> 00:55:37,400
neutron stars are not radiating nearly

1212
00:55:42,459 --> 00:55:38,839
as powerfully because they're not moving

1213
00:55:45,039 --> 00:55:42,469

as fast when they come together or not

1214
00:55:47,650 --> 00:55:45,049
and they're not as massive now NASA's

1215
00:55:49,749 --> 00:55:47,660
Fermi Sally is a gamma-ray satellite and

1216
00:55:52,569 --> 00:55:49,759
Europe's integral satellite detected a

1217
00:55:56,170 --> 00:55:52,579
gamma-ray burst 1.7 seconds after the

1218
00:55:57,489 --> 00:55:56,180
merger now you would think the

1219
00:55:59,829 --> 00:55:57,499
gravitational wave should arrive at the

1220
00:56:00,699 --> 00:55:59,839
same time as light that's the prediction

1221
00:56:02,620 --> 00:56:00,709
no this is so pretty

1222
00:56:04,599 --> 00:56:02,630
darkness is so amazingly good because

1223
00:56:07,779 --> 00:56:04,609
that came from a hundred and twenty

1224
00:56:10,809 --> 00:56:07,789
million light years away so that's one

1225
00:56:12,370 --> 00:56:10,819
part in 10 to the 15 that was all so

1226
00:56:14,229 --> 00:56:12,380
it's still very very good and we think

1227
00:56:15,910 --> 00:56:14,239
in fact that it probably takes some time

1228
00:56:17,900 --> 00:56:15,920
to create the gram of the gamma-ray

1229
00:56:19,760 --> 00:56:17,910
bursts you probably have to spin up

1230
00:56:21,079 --> 00:56:19,770
magnetic field if the breakout of the

1231
00:56:23,809 --> 00:56:21,089
neutrons are so we could well be that

1232
00:56:25,880 --> 00:56:23,819
all that 1.7 seconds is creating the

1233
00:56:28,250 --> 00:56:25,890
gamma-ray burst right and so they do

1234
00:56:29,599 --> 00:56:28,260
exactly travel at the same speed but

1235
00:56:31,130 --> 00:56:29,609
that would be the prediction of the

1236
00:56:33,049 --> 00:56:31,140
theory of relativity that they should

1237
00:56:36,880 --> 00:56:33,059
travel exactly the same speed and still

1238
00:56:39,710 --> 00:56:36,890

one part in 10 to the 15 is pretty good

1239
00:56:42,920 --> 00:56:39,720
but we finally got a neutron star merger

1240
00:56:45,920 --> 00:56:42,930
now this is very Oh and Virgo you see it

1241
00:56:48,230 --> 00:56:45,930
didn't see it at all well this was

1242
00:56:50,839 --> 00:56:48,240
important because it's the dog that

1243
00:56:53,690 --> 00:56:50,849
didn't bark because they knew from the

1244
00:56:56,089 --> 00:56:53,700
previous detection how how sensitive

1245
00:56:57,710 --> 00:56:56,099
Virgo was and so they knew that and most

1246
00:56:59,990 --> 00:56:57,720
of the sky Virgo should have seen it

1247
00:57:01,640 --> 00:57:00,000
and so there was only part of the sky

1248
00:57:03,260 --> 00:57:01,650
where Virgo wouldn't see it and they

1249
00:57:05,180 --> 00:57:03,270
could restrict it to put that part of

1250
00:57:09,319 --> 00:57:05,190
the sky so in fact the non detection by

1251
00:57:11,180 --> 00:57:09,329
Virgo was very helpful we'll get to that

1252
00:57:16,309 --> 00:57:11,190
in a minute now what happens when two

1253
00:57:18,260 --> 00:57:16,319
neutron stars merge this is that here's

1254
00:57:22,549 --> 00:57:18,270
the here actually you're seeing the

1255
00:57:24,680 --> 00:57:22,559
matter of the two neutron stars and some

1256
00:57:27,799 --> 00:57:24,690
of the matter is being just thrown off

1257
00:57:32,059 --> 00:57:27,809
into space okay probably a few percent

1258
00:57:35,150 --> 00:57:32,069
of the material of the stars gets thrown

1259
00:57:37,760 --> 00:57:35,160
off during this merger now this is very

1260
00:57:39,260 --> 00:57:37,770
important because this material is again

1261
00:57:41,180 --> 00:57:39,270
I told you earlier we think that this

1262
00:57:43,910 --> 00:57:41,190
this mature is highly radioactive it

1263
00:57:45,380 --> 00:57:43,920

comes off as just pure neutrons and so

1264
00:57:46,940 --> 00:57:45,390
it starts as very heavy elements I'll

1265
00:57:49,700 --> 00:57:46,950
show you that in a minute and so it

1266
00:57:54,380 --> 00:57:49,710
basically comes out and populates the

1267
00:57:58,000 --> 00:57:54,390
universe with heavy elements now it also

1268
00:58:01,700 --> 00:57:58,010
radiates in the optical and the infrared

1269
00:58:02,539 --> 00:58:01,710
now right oh I thought I took that out

1270
00:58:03,859 --> 00:58:02,549
but okay

1271
00:58:05,599 --> 00:58:03,869
doesn't matter it'll show you this in a

1272
00:58:12,430 --> 00:58:05,609
minute so there we have the matter

1273
00:58:15,140 --> 00:58:12,440
emerging now here is a view

1274
00:58:16,940 --> 00:58:15,150
electromagnetic view of the they totally

1275
00:58:18,710 --> 00:58:16,950
this is this is showing sort of the hot

1276
00:58:22,339 --> 00:58:18,720
spots on the neutron stars sort of an

1277
00:58:24,920 --> 00:58:22,349
x-ray view of it now this is produced by

1278
00:58:27,289 --> 00:58:24,930
NASA and it was for the Swift satellite

1279
00:58:30,599 --> 00:58:27,299
which is a gamma ray satellite and they

1280
00:58:32,700 --> 00:58:30,609
wanted to show you saw that that be

1281
00:58:34,170 --> 00:58:32,710
coming out of it there has long been a

1282
00:58:35,670 --> 00:58:34,180
theory that the something we called

1283
00:58:37,680 --> 00:58:35,680
gamma-ray bursts the she would called

1284
00:58:39,210 --> 00:58:37,690
especially the short camera burst may

1285
00:58:41,690 --> 00:58:39,220
come from the merger of two neutron

1286
00:58:44,069 --> 00:58:41,700
stars we've never been able there's no

1287
00:58:46,019 --> 00:58:44,079
absolute proof of that yet but

1288
00:58:48,569 --> 00:58:46,029

everything we've seen is consistent with

1289
00:58:50,099 --> 00:58:48,579
that hypothesis we know that another

1290
00:58:51,479 --> 00:58:50,109
type of gamma-ray bursts called the long

1291
00:58:53,400 --> 00:58:51,489
game reverse they not last much longer

1292
00:58:55,710 --> 00:58:53,410
we know that those come from the deaths

1293
00:58:57,989 --> 00:58:55,720
of very massive stars but this other

1294
00:58:59,999 --> 00:58:57,999
type this sort of much short mass short

1295
00:59:01,259 --> 00:59:00,009
gamma-ray bursts lasts much less lasts

1296
00:59:02,880 --> 00:59:01,269
about a second where the own lasts

1297
00:59:03,989 --> 00:59:02,890
typically tens hundreds of thousand

1298
00:59:05,970 --> 00:59:03,999
seconds um

1299
00:59:07,890 --> 00:59:05,980
this the short ones we thought come from

1300
00:59:09,720 --> 00:59:07,900
the mergers of neutron stars or perhaps

1301
00:59:11,519 --> 00:59:09,730
neutron stars and black holes but never

1302
00:59:14,430 --> 00:59:11,529
able to prove it but where they are

1303
00:59:16,440 --> 00:59:14,440
where we find them all seems to indicate

1304
00:59:19,349 --> 00:59:16,450
that they probably come from your return

1305
00:59:20,970 --> 00:59:19,359
star mergers and Mario Livio who maybe

1306
00:59:24,210 --> 00:59:20,980
you have seen many of us seen used to

1307
00:59:27,390 --> 00:59:24,220
say if the merger of neutron stars

1308
00:59:30,359 --> 00:59:27,400
doesn't produce a gamma-ray burst what

1309
00:59:34,280 --> 00:59:30,369
does it do so that was someone that was

1310
00:59:40,380 --> 00:59:38,220
so but so but now we may have evidence

1311
00:59:42,720 --> 00:59:40,390
that it says because it was on camera

1312
00:59:45,420 --> 00:59:42,730
but the camera verse was very faint so

1313
00:59:47,339 --> 00:59:45,430

it wasn't that that that beam was not

1314
00:59:48,810 --> 00:59:47,349
put if it did produce a true gamma-ray

1315
00:59:54,060 --> 00:59:48,820
burst that beam was not pointing at us

1316
00:59:57,870 --> 00:59:54,070
we were seeing it from a side okay

1317
00:59:59,550 --> 00:59:57,880
now this is so this here we see it sort

1318
01:00:03,120 --> 00:59:59,560
of an this is this is produced by Hubble

1319
01:00:04,500 --> 01:00:03,130
by our own outreach office and because

1320
01:00:06,510 --> 01:00:04,510
we observed this I'll show you later

1321
01:00:08,280 --> 01:00:06,520
admit we observe this with Hubble so

1322
01:00:10,200 --> 01:00:08,290
here's the neutron stars merging then

1323
01:00:13,319 --> 01:00:10,210
they come together they throw out matter

1324
01:00:15,210 --> 01:00:13,329
now this matter is hot and it if you

1325
01:00:17,339 --> 01:00:15,220
look at how much energy it radiates it's

1326
01:00:22,079 --> 01:00:17,349
about a thousand times as much as a nova

1327
01:00:25,170 --> 01:00:22,089
which is a type of a dwarf star that

1328
01:00:26,880 --> 01:00:25,180
burps has a small nuclear explosion

1329
01:00:28,589 --> 01:00:26,890
occasionally and that's called ANOVA and

1330
01:00:30,120 --> 01:00:28,599
there's supernova is a really big Nova

1331
01:00:31,859 --> 01:00:30,130
right but it's actually an explosion of

1332
01:00:33,630 --> 01:00:31,869
a real true explosion of a star and

1333
01:00:36,060 --> 01:00:33,640
these Nova's tend to be sort of surface

1334
01:00:37,800 --> 01:00:36,070
burps surface thermal nuclear reactions

1335
01:00:40,410 --> 01:00:37,810
and this is about a thousand times

1336
01:00:43,740 --> 01:00:40,420
brighter so it's been dubbed the term

1337
01:00:46,349 --> 01:00:43,750
most people use as a killer nova now on

1338
01:00:49,650 --> 01:00:46,359

top of that you'll get the gamma-ray

1339
01:00:51,809 --> 01:00:49,660
burst we think may or may not well go

1340
01:00:55,790 --> 01:00:51,819
into that in a bit and then around that

1341
01:01:00,059 --> 01:00:55,800
you'll get we think a jet quite possibly

1342
01:01:03,300 --> 01:01:00,069
a wind a very strong wind coming out

1343
01:01:06,260 --> 01:01:03,310
near the axis very hot blue winds and

1344
01:01:08,400 --> 01:01:06,270
around it you'll have this red material

1345
01:01:10,500 --> 01:01:08,410
explained away it's this the red the

1346
01:01:16,680 --> 01:01:10,510
neutron star mature why that's red in a

1347
01:01:19,680 --> 01:01:16,690
minute oh right but before that let's

1348
01:01:20,940 --> 01:01:19,690
see NASA just couldn't resist so you had

1349
01:01:22,470 --> 01:01:20,950
to show you the feature the

1350
01:01:23,490 --> 01:01:22,480
feature-length film that was I would

1351
01:01:25,079 --> 01:01:23,500
feature like this but it's

1352
01:01:39,750 --> 01:01:25,089
feature-length productions but feature

1353
01:01:54,150 --> 01:01:51,190
[Music]

1354
01:01:59,050 --> 01:01:54,160
[Applause]

1355
01:02:12,770 --> 01:02:05,359
let's go back a bit I'm gonna go do this

1356
01:02:14,329 --> 01:02:12,780
again a little less sound so the here we

1357
01:02:15,770 --> 01:02:14,339
have the gamma-ray burst we here we have

1358
01:02:20,569 --> 01:02:15,780
the two neutron stars merging putting

1359
01:02:22,910 --> 01:02:20,579
out gravitational waves now they produce

1360
01:02:24,680 --> 01:02:22,920
a gamma-ray burst is the idea now you

1361
01:02:27,319 --> 01:02:24,690
have this hot wind coming out and the

1362
01:02:30,170 --> 01:02:27,329
killer Nova in the center coming out now

1363
01:02:33,109 --> 01:02:30,180

here you see these jets later on

1364
01:02:35,599 --> 01:02:33,119
expanding very large this may be crucial

1365
01:02:40,040 --> 01:02:35,609
to what we've seen but you will see in a

1366
01:02:42,319 --> 01:02:40,050
bit so first we had to go find the thing

1367
01:02:43,550 --> 01:02:42,329
right and some of the I was involved in

1368
01:02:45,710 --> 01:02:43,560
the elbow space followed by the

1369
01:02:47,240 --> 01:02:45,720
telescope follow-ups but few people here

1370
01:02:50,150 --> 01:02:47,250
were actually involved in searching that

1371
01:02:52,099 --> 01:02:50,160
very day right and what a number of

1372
01:02:54,800 --> 01:02:52,109
groups did was they said okay well

1373
01:02:56,270 --> 01:02:54,810
here's the here here's what they this is

1374
01:02:58,220 --> 01:02:56,280
the region that the gamma-ray burst

1375
01:02:59,900 --> 01:02:58,230
could have been in here's the region

1376
01:03:01,430 --> 01:02:59,910
that LIGO could have seen it and then

1377
01:03:03,319 --> 01:03:01,440
there's the region that Virgo could have

1378
01:03:05,599 --> 01:03:03,329
been LIGO could have seen it in so it's

1379
01:03:08,120 --> 01:03:05,609
that but there's that's how Virgo helped

1380
01:03:10,160 --> 01:03:08,130
right and then you look on the sky in

1381
01:03:13,130 --> 01:03:10,170
that region and what the smart groups

1382
01:03:14,780 --> 01:03:13,140
did is they said there probably went off

1383
01:03:16,640 --> 01:03:14,790
you know galaxies probably know how

1384
01:03:18,250 --> 01:03:16,650
about how far away it is cuz again they

1385
01:03:20,359 --> 01:03:18,260
could tell us right away that it's about

1386
01:03:23,240 --> 01:03:20,369
120 million light years they got it

1387
01:03:25,190 --> 01:03:23,250
right on the nose and they and so you

1388
01:03:27,920 --> 01:03:25,200

could look for galaxies in that region

1389
01:03:29,480 --> 01:03:27,930
that were about that distance away and

1390
01:03:31,099 --> 01:03:29,490
you could start with the big ones and

1391
01:03:33,920 --> 01:03:31,109
work down to the small ones and it

1392
01:03:39,400 --> 01:03:33,930
wasn't a big one and that's it right

1393
01:03:44,150 --> 01:03:42,680
now lots and lots of tellus this was one

1394
01:03:46,640 --> 01:03:44,160
of the biggest observing campaigns in

1395
01:03:50,450 --> 01:03:46,650
the history of astronomy look I went too

1396
01:03:52,819 --> 01:03:50,460
far yeah this was a we had a dozen two

1397
01:03:54,880 --> 01:03:52,829
dozen observatories on the ground the

1398
01:03:57,470 --> 01:03:54,890
three gravitationally observatories and

1399
01:03:59,270 --> 01:03:57,480
seven space telescopes observe this

1400
01:04:00,530 --> 01:03:59,280
thing because it was a big event there

1401
01:04:03,790 --> 01:04:00,540
were about a thousand astronomers

1402
01:04:05,350 --> 01:04:03,800
involved in all of the observations what

1403
01:04:07,360 --> 01:04:05,360
action of the Totalus astronomical

1404
01:04:09,790 --> 01:04:07,370
community was involved in some way or

1405
01:04:11,980 --> 01:04:09,800
another most most of them were just like

1406
01:04:13,150 --> 01:04:11,990
I I work at an observatory put my name

1407
01:04:15,430 --> 01:04:13,160
on the day and probably put my name on

1408
01:04:17,410 --> 01:04:15,440
but and in the LIGO group itself is

1409
01:04:19,660 --> 01:04:17,420
around a thousand people it's huge takes

1410
01:04:21,550 --> 01:04:19,670
a true I mean it's a it's like a high

1411
01:04:23,590 --> 01:04:21,560
energy physics experiments incredibly

1412
01:04:25,810 --> 01:04:23,600
involved credibly difficult to build in

1413
01:04:29,590 --> 01:04:25,820

fact I didn't I should have gone we'll

1414
01:04:31,450 --> 01:04:29,600
get there in a minute but like I did

1415
01:04:32,950 --> 01:04:31,460
show them and I didn't go over what each

1416
01:04:35,410 --> 01:04:32,960
of the contributions of the three

1417
01:04:44,850 --> 01:04:35,420
discoverers were maybe three Nobel lists

1418
01:04:47,680 --> 01:04:44,860
were in this case so there was a second

1419
01:04:49,960 --> 01:04:47,690
there ago so I mentioned it was like

1420
01:04:51,730 --> 01:04:49,970
high energy physics experiment Barry

1421
01:04:53,650 --> 01:04:51,740
bearish comes out of the high energy

1422
01:04:55,200 --> 01:04:53,660
physics community and his contribution

1423
01:04:57,850 --> 01:04:55,210
was basically to make the thing work

1424
01:05:01,600 --> 01:04:57,860
he came and became the director and

1425
01:05:03,820 --> 01:05:01,610
really brought it together and Ray Weiss

1426
01:05:06,010 --> 01:05:03,830
as you heard conceptualize the thing way

1427
01:05:08,500 --> 01:05:06,020
back at the very beginning and Kip

1428
01:05:10,030 --> 01:05:08,510
Thorne is a theorist who really was

1429
01:05:12,130 --> 01:05:10,040
behind much of the theoretical

1430
01:05:14,400 --> 01:05:12,140
understanding of what you would see and

1431
01:05:17,080 --> 01:05:14,410
how you would predict what you would see

1432
01:05:19,240 --> 01:05:17,090
and so there's a result and there was

1433
01:05:23,110 --> 01:05:19,250
also ronald ruber who who were totally

1434
01:05:25,960 --> 01:05:23,120
passed away but before the this happened

1435
01:05:27,820 --> 01:05:25,970
but um he the nobel prize can only give

1436
01:05:29,230 --> 01:05:27,830
nobody said is having it over I still

1437
01:05:32,440 --> 01:05:29,240
set up today you can only go to three

1438
01:05:34,560 --> 01:05:32,450

people so and yeah I don't know what

1439
01:05:38,680 --> 01:05:34,570
happened that he was still alive but

1440
01:05:41,500 --> 01:05:38,690
knowing yeah that's a prop that trying

1441
01:05:43,810 --> 01:05:41,510
changing that but they never have okay

1442
01:05:47,560 --> 01:05:43,820
so then it was again it was observed by

1443
01:05:49,660 --> 01:05:47,570
in fact six independent teams discovered

1444
01:05:51,340 --> 01:05:49,670
it the object almost simultaneously I

1445
01:05:53,620 --> 01:05:51,350
showed you the first one but within an

1446
01:05:55,690 --> 01:05:53,630
hour or so lots of other teams found it

1447
01:05:57,580 --> 01:05:55,700
too and it was observed from the gamma

1448
01:05:59,380 --> 01:05:57,590
ray to the radio again one of the

1449
01:06:01,030 --> 01:05:59,390
largest observing campaigns in history

1450
01:06:02,800 --> 01:06:01,040
and this just shows you all the

1451
01:06:04,150 --> 01:06:02,810
different to weighed bands it was

1452
01:06:10,440 --> 01:06:04,160
absorbed in at all different discovery

1453
01:06:19,800 --> 01:06:16,290
Oh baby there we go there we go all

1454
01:06:22,710 --> 01:06:19,810
right so this is the Hubble image of

1455
01:06:26,370 --> 01:06:22,720
that galaxy and there is this source

1456
01:06:28,410 --> 01:06:26,380
right there on this now it's the host is

1457
01:06:30,329 --> 01:06:28,420
a massive elliptical it's named over

1458
01:06:32,099 --> 01:06:30,339
it's an it's it well it's got a catalog

1459
01:06:34,530 --> 01:06:32,109
it's in a catalog it's large it's well

1460
01:06:36,390 --> 01:06:34,540
was known before was studied before fact

1461
01:06:38,520 --> 01:06:36,400
there was a Hubble image of it taken

1462
01:06:40,890 --> 01:06:38,530
before the this object went off this

1463
01:06:43,050 --> 01:06:40,900

explosion happened actually only several

1464
01:06:43,620 --> 01:06:43,060
months before this explosion happened by

1465
01:06:45,660 --> 01:06:43,630
chance

1466
01:06:48,390 --> 01:06:45,670
item and it's about 120 million light

1467
01:06:49,859 --> 01:06:48,400
years away as I said it but what the

1468
01:06:54,060 --> 01:06:49,869
explosion was actually relatively far

1469
01:06:56,970 --> 01:06:54,070
out on the galaxies and elliptical

1470
01:06:58,710 --> 01:06:56,980
galaxies tend to have lots of groups of

1471
01:07:01,319 --> 01:06:58,720
stars we call globular clusters very

1472
01:07:02,579 --> 01:07:01,329
dense concentrations of stars and we

1473
01:07:04,560 --> 01:07:02,589
think that those are actually very good

1474
01:07:06,480 --> 01:07:04,570
places to form neutron star bind to form

1475
01:07:10,020 --> 01:07:06,490
binaries and massive binaries and

1476
01:07:12,060 --> 01:07:10,030
probably neutron star binaries but then

1477
01:07:13,920 --> 01:07:12,070
we see lots of posts are binaries and

1478
01:07:17,069 --> 01:07:13,930
pulsars in our globular clusters in our

1479
01:07:19,079 --> 01:07:17,079
galaxy but as best as we can tell this

1480
01:07:21,000 --> 01:07:19,089
is not on top of one of those globular

1481
01:07:22,650 --> 01:07:21,010
clusters it just seems to be out in the

1482
01:07:25,800 --> 01:07:22,660
field of the galaxy as best as we can

1483
01:07:27,450 --> 01:07:25,810
tell right now we're not down to the we

1484
01:07:31,079 --> 01:07:27,460
haven't gone down as deep as you could

1485
01:07:32,460 --> 01:07:31,089
possibly go to see the very faintest

1486
01:07:34,950 --> 01:07:32,470
globular clusters because there's still

1487
01:07:36,270 --> 01:07:34,960
light from the source there eventually

1488
01:07:38,190 --> 01:07:36,280

we'll be able to get a very deep image

1489
01:07:40,079 --> 01:07:38,200
and tell but you can go most of the way

1490
01:07:41,130 --> 01:07:40,089
down to how faint and probably classical

1491
01:07:44,940 --> 01:07:41,140
every cluster would be and there's

1492
01:07:47,819 --> 01:07:44,950
nothing there now at this started out as

1493
01:07:51,240 --> 01:07:47,829
I mentioned predictably be blue and in

1494
01:08:00,030 --> 01:07:51,250
fact that's what it was and then it very

1495
01:08:02,250 --> 01:08:00,040
slowly turns reddish and the object

1496
01:08:04,470 --> 01:08:02,260
became fainter but not red or after a

1497
01:08:06,089 --> 01:08:04,480
few days and mostly what's really

1498
01:08:09,210 --> 01:08:06,099
remarkable is that most of this behavior

1499
01:08:12,210 --> 01:08:09,220
was predicted before the event Dan

1500
01:08:14,970 --> 01:08:12,220
kaizen a while back predicted that these

1501
01:08:16,829 --> 01:08:14,980
objects will be very red for reasons

1502
01:08:19,769 --> 01:08:16,839
that I'll get into a minute and Mark

1503
01:08:23,039 --> 01:08:19,779
Metzger has predicted that blue central

1504
01:08:24,090 --> 01:08:23,049
core well it's really quite remarkable

1505
01:08:27,900 --> 01:08:24,100
how

1506
01:08:28,920 --> 01:08:27,910
well we had the theory down before it

1507
01:08:30,720 --> 01:08:28,930
actually no no there were other

1508
01:08:31,980 --> 01:08:30,730
competing theories right so you could

1509
01:08:34,740 --> 01:08:31,990
say okay well you could have picked your

1510
01:08:37,349 --> 01:08:34,750
theory but the this was these were the

1511
01:08:40,190 --> 01:08:37,359
most likely candidates and they turned

1512
01:08:47,099 --> 01:08:43,950
now you'll remember that I mentioned to

1513
01:08:48,510 --> 01:08:47,109

you that when you take when you took

1514
01:08:50,340 --> 01:08:48,520
this white dwarf and you put more mass

1515
01:08:52,620 --> 01:08:50,350
on to it you forced the electric by the

1516
01:08:54,990 --> 01:08:52,630
pressure force the electrons into the

1517
01:08:57,120 --> 01:08:55,000
nuclei and turn the protons into

1518
01:08:58,710 --> 01:08:57,130
neutrons right as the electron canceled

1519
01:09:01,530 --> 01:08:58,720
the charge of the proton and they form a

1520
01:09:03,690 --> 01:09:01,540
neutron well if this materials thrown

1521
01:09:07,290 --> 01:09:03,700
off it does I'm free the pressures off

1522
01:09:10,590 --> 01:09:07,300
and the electrons pop at and so it

1523
01:09:18,060 --> 01:09:10,600
undergoes a radioactive decay and here's

1524
01:09:20,130 --> 01:09:18,070
a little okay and so over here is a

1525
01:09:22,470 --> 01:09:20,140
little plot showing you the creation of

1526
01:09:25,080 --> 01:09:22,480
elements as you draw as the material

1527
01:09:27,900 --> 01:09:25,090
comes off the neutron star and it just

1528
01:09:30,630 --> 01:09:27,910
starts off very very radioactive and

1529
01:09:31,620 --> 01:09:30,640
very Neutron rich and slowly moves over

1530
01:09:34,349 --> 01:09:31,630
well that's what slowly this is only a

1531
01:09:35,910 --> 01:09:34,359
few seconds in real time turns into

1532
01:09:38,099 --> 01:09:35,920
something very close to the periodic

1533
01:09:41,010 --> 01:09:38,109
table now there'll be lots of

1534
01:09:43,170 --> 01:09:41,020
radioactive elements that we that died

1535
01:09:47,910 --> 01:09:43,180
the break that go decayed before we see

1536
01:09:51,000 --> 01:09:47,920
them now on earth but if you look at the

1537
01:09:53,070 --> 01:09:51,010
the element that the periodic table you

1538
01:09:57,980 --> 01:09:53,080

can ask where do the elements come from

1539
01:10:01,560 --> 01:09:57,990
and we think that the blue star the blue

1540
01:10:07,650 --> 01:10:01,570
shaded ones here come from exploding

1541
01:10:09,330 --> 01:10:07,660
stars by and large the the big these red

1542
01:10:12,300 --> 01:10:09,340
here is largely left over from the Big

1543
01:10:16,800 --> 01:10:12,310
Bang there's a bit of cosmic ray fission

1544
01:10:19,080 --> 01:10:16,810
and then in the bit of the dark brown is

1545
01:10:21,450 --> 01:10:19,090
sort of planetary nebula dying low mass

1546
01:10:23,910 --> 01:10:21,460
stars but all of this yellow we think

1547
01:10:27,930 --> 01:10:23,920
now is probably merging neutron stars

1548
01:10:31,140 --> 01:10:27,940
all of these elements here and when you

1549
01:10:33,720 --> 01:10:31,150
look at a normal supernova it's it's

1550
01:10:36,030 --> 01:10:33,730
spectrum say that is dominated by the

1551
01:10:37,799 --> 01:10:36,040
iron elements iron cook so it you've

1552
01:10:39,930 --> 01:10:37,809
reduced nickel in that radioactive

1553
01:10:44,459 --> 01:10:39,940
into cobalt and that the Kaizen to the

1554
01:10:46,080 --> 01:10:44,469
iron that lasts now and that produces a

1555
01:10:51,229 --> 01:10:46,090
lot of the energy in a supernova

1556
01:10:53,549 --> 01:10:51,239
that's a k now these elements here are

1557
01:10:55,589 --> 01:10:53,559
transparent in the optical but they

1558
01:10:57,750 --> 01:10:55,599
block the ultraviolet so when you look

1559
01:10:59,549 --> 01:10:57,760
at a regular supernova it's bright in

1560
01:11:02,069 --> 01:10:59,559
the optical but it falls off very

1561
01:11:03,209 --> 01:11:02,079
quickly in the ultraviolet you see very

1562
01:11:04,950 --> 01:11:03,219
little light of it from the ultra bio

1563
01:11:06,450 --> 01:11:04,960

because these elements absorb in the

1564
01:11:12,450 --> 01:11:06,460
ultraviolet but they let light through

1565
01:11:14,010 --> 01:11:12,460
in the optical now these elements down

1566
01:11:18,839 --> 01:11:14,020
here the lanthanides and the actinides

1567
01:11:21,419 --> 01:11:18,849
they absorb in the optical but they let

1568
01:11:23,640 --> 01:11:21,429
light through in the infrared and this

1569
01:11:25,140 --> 01:11:23,650
was what dan Kazan's group realized so

1570
01:11:27,270 --> 01:11:25,150
he said you better produce all of these

1571
01:11:28,649 --> 01:11:27,280
things you won't see it in the optical

1572
01:11:29,700 --> 01:11:28,659
very well you won't see those elements

1573
01:11:31,169 --> 01:11:29,710
in the optical area well because they're

1574
01:11:34,560 --> 01:11:31,179
gonna block all the light you'll see

1575
01:11:38,220 --> 01:11:34,570
them in the infrared and that is what we

1576
01:11:42,209 --> 01:11:38,230
see this is an HST spectrum of the Killa

1577
01:11:45,959 --> 01:11:42,219
nova and that bump there was predicted

1578
01:11:48,000 --> 01:11:45,969
that's the lanthanides if you have a lot

1579
01:11:50,189 --> 01:11:48,010
of land that lanthanide group you'll get

1580
01:11:53,609 --> 01:11:50,199
something like that now in fact the

1581
01:11:55,140 --> 01:11:53,619
actual pasady Xand electron maybe the

1582
01:11:56,729 --> 01:11:55,150
states of the lanthanides are not

1583
01:11:58,950 --> 01:11:56,739
well-known because it could take a lot

1584
01:12:00,750 --> 01:11:58,960
of a it's gonna take a lot more work in

1585
01:12:03,060 --> 01:12:00,760
the lab to really sort that out but it's

1586
01:12:05,160 --> 01:12:03,070
approximately known and then something

1587
01:12:07,500 --> 01:12:05,170
very close to this was predicted right

1588
01:12:09,060 --> 01:12:07,510

exactly how much and it was a little bit

1589
01:12:11,339 --> 01:12:09,070
different cuz so how much do you produce

1590
01:12:13,379 --> 01:12:11,349
exactly how does it come out you know

1591
01:12:15,600 --> 01:12:13,389
what is the geometry but it's very very

1592
01:12:17,910 --> 01:12:15,610
close to what we saw so this is really

1593
01:12:19,890 --> 01:12:17,920
an incredible agreement this this peak

1594
01:12:21,240 --> 01:12:19,900
was very clearly predicted and that was

1595
01:12:24,720 --> 01:12:21,250
the major thing in a spectrum that was

1596
01:12:27,000 --> 01:12:24,730
there so we really think we understand

1597
01:12:29,399 --> 01:12:27,010
the basic mechanics of what's going on

1598
01:12:31,470 --> 01:12:29,409
and we think that this is probably where

1599
01:12:33,540 --> 01:12:31,480
the mote where most of the heavy

1600
01:12:35,729 --> 01:12:33,550
elements of the universe come from now

1601
01:12:36,990 --> 01:12:35,739
of course it depends on wait we've seen

1602
01:12:38,790 --> 01:12:37,000
one of these things or sort of

1603
01:12:40,589 --> 01:12:38,800
guesstimating the rate but it's sort of

1604
01:12:43,859 --> 01:12:40,599
comparable to the rate that we expected

1605
01:12:45,180 --> 01:12:43,869
from neutrons from pulsars if you made a

1606
01:12:47,970 --> 01:12:45,190
couple of assumptions about how many

1607
01:12:49,649 --> 01:12:47,980
posters assume come together so it all

1608
01:12:51,590 --> 01:12:49,659
sorts of agree and so we think that

1609
01:12:53,600 --> 01:12:51,600
we've got that

1610
01:12:56,420 --> 01:12:53,610
there there are some mysteries still

1611
01:13:00,440 --> 01:12:56,430
remaining the about this object this is

1612
01:13:02,090 --> 01:13:00,450
the like curve of the of the optic and

1613
01:13:04,190 --> 01:13:02,100

the optical and the infrared the

1614
01:13:05,990 --> 01:13:04,200
infrared did the braid in green here and

1615
01:13:08,140 --> 01:13:06,000
the blue and the orange are sort of

1616
01:13:10,910 --> 01:13:08,150
optical not the best color choice and

1617
01:13:12,620 --> 01:13:10,920
they went down over about ten days they

1618
01:13:15,080 --> 01:13:12,630
just dropped off a cliff right Gwen

1619
01:13:15,710 --> 01:13:15,090
found very quickly but then we looked at

1620
01:13:17,330 --> 01:13:15,720
it again

1621
01:13:20,480 --> 01:13:17,340
about a hundred days and it was still

1622
01:13:21,860 --> 01:13:20,490
there with home now why did we look at

1623
01:13:24,140 --> 01:13:21,870
it again in a hundred days it was

1624
01:13:29,180 --> 01:13:24,150
because other people had been looking at

1625
01:13:31,670 --> 01:13:29,190
it in the optical sorry in the x-ray and

1626
01:13:34,970 --> 01:13:31,680
the gamma ray and so the x-ray and the

1627
01:13:38,330 --> 01:13:34,980
radio this is the radio and this is the

1628
01:13:41,480 --> 01:13:38,340
x-ray and they took they did not turn on

1629
01:13:43,190 --> 01:13:41,490
until ten days and then they got

1630
01:13:48,860 --> 01:13:43,200
brighter for a while now they looks like

1631
01:13:50,990 --> 01:13:48,870
they may have plateaued maybe not so

1632
01:13:54,230 --> 01:13:51,000
what we think there are two

1633
01:13:55,940 --> 01:13:54,240
possibilities we think one is that we're

1634
01:13:58,160 --> 01:13:55,950
seeing that Chet wasn't pointing to us

1635
01:14:00,200 --> 01:13:58,170
but now it's sort of opening up or we're

1636
01:14:02,450 --> 01:14:00,210
actually it's we're and we're seeing it

1637
01:14:05,180 --> 01:14:02,460
get opened up as we get with time

1638
01:14:07,490 --> 01:14:05,190

basically which we is a prediction that

1639
01:14:09,470 --> 01:14:07,500
gamma a gamma ray bursts will do as they

1640
01:14:12,740 --> 01:14:09,480
slow down they beam to a larger area and

1641
01:14:14,960 --> 01:14:12,750
if this jet has a certain is not just a

1642
01:14:16,640 --> 01:14:14,970
perfect wall but has shaped like

1643
01:14:17,960 --> 01:14:16,650
brighter here and then it dies off to

1644
01:14:21,530 --> 01:14:17,970
the edge it would do this sort of thing

1645
01:14:23,690 --> 01:14:21,540
another possibility is that the jet

1646
01:14:25,850 --> 01:14:23,700
never the the gamma ray bursts never got

1647
01:14:28,250 --> 01:14:25,860
out and bruised a very hot bubble and

1648
01:14:30,650 --> 01:14:28,260
that as that bubble starts out small

1649
01:14:32,180 --> 01:14:30,660
it's not so bright but as it expands

1650
01:14:34,280 --> 01:14:32,190
this hot bubble has more surface area

1651
01:14:35,570 --> 01:14:34,290
and so it's brighter this is what

1652
01:14:37,370 --> 01:14:35,580
basically what happens in the early

1653
01:14:39,860 --> 01:14:37,380
stages of a supernova - they get

1654
01:14:44,330 --> 01:14:39,870
brighter as they expand now so that may

1655
01:14:47,270 --> 01:14:44,340
be what's going on here I think there

1656
01:14:49,220 --> 01:14:47,280
can because of short gamma-ray bursts we

1657
01:14:51,050 --> 01:14:49,230
think that they're probably related to

1658
01:14:52,880 --> 01:14:51,060
short gamma-ray bursts and therefore

1659
01:14:56,000 --> 01:14:52,890
they're by the numbers we've seen there

1660
01:14:58,430 --> 01:14:56,010
can't be too many that you would miss as

1661
01:14:59,810 --> 01:14:58,440
short as gamma-ray bursts because they

1662
01:15:02,240 --> 01:14:59,820
otherwise the rates wouldn't work out

1663
01:15:04,010 --> 01:15:02,250

between the mergers and this and their

1664
01:15:05,130 --> 01:15:04,020
short gamma-ray bursts but it's possible

1665
01:15:06,630 --> 01:15:05,140
that in fact this doesn't have

1666
01:15:08,520 --> 01:15:06,640
hammering burst at all but that the

1667
01:15:10,340 --> 01:15:08,530
gamma ray burst got smothered right

1668
01:15:13,800 --> 01:15:10,350
never quite got out and produced a big

1669
01:15:15,030 --> 01:15:13,810
expanding cocoon of hot material but we

1670
01:15:16,410 --> 01:15:15,040
should there's a good chance we'll be

1671
01:15:20,220 --> 01:15:16,420
able to tell by the shape of the light

1672
01:15:22,740 --> 01:15:20,230
curve later on it may fall off faster if

1673
01:15:24,030 --> 01:15:22,750
it we probably will fall off faster it's

1674
01:15:26,670 --> 01:15:24,040
a gamma-ray burst all this depends on

1675
01:15:28,010 --> 01:15:26,680
the shape of the Jets and it's now this

1676
01:15:30,570 --> 01:15:28,020
gets us the complicated stuff

1677
01:15:32,850 --> 01:15:30,580
astrophysics was sort of there's a

1678
01:15:34,790 --> 01:15:32,860
famous astrophysicist really sort of the

1679
01:15:37,320 --> 01:15:34,800
best at physics is slash-and-burn

1680
01:15:39,300 --> 01:15:37,330
because you can't do real experiments so

1681
01:15:41,760 --> 01:15:39,310
you go and get the you get it's easy to

1682
01:15:43,860 --> 01:15:41,770
get the basic idea it's very hard to get

1683
01:15:44,820 --> 01:15:43,870
the details so we've got to sort out the

1684
01:15:46,830 --> 01:15:44,830
detail here right

1685
01:15:49,020 --> 01:15:46,840
we know it's merging neutron stars we

1686
01:15:50,640 --> 01:15:49,030
know we got lots of material for now

1687
01:15:52,500 --> 01:15:50,650
we've got electromagnetic processes

1688
01:15:53,670 --> 01:15:52,510

going on exactly how it's working is

1689
01:15:55,710 --> 01:15:53,680
gonna take a lot of work because we

1690
01:15:57,300 --> 01:15:55,720
can't do we can't just go and take too

1691
01:16:00,750 --> 01:15:57,310
much neutron stars and merge them in the

1692
01:16:04,110 --> 01:16:00,760
lab and figure and see what happens yeah

1693
01:16:05,730 --> 01:16:04,120
but it's just not part of the budget but

1694
01:16:07,920 --> 01:16:05,740
again we may know by the end of the year

1695
01:16:09,870 --> 01:16:07,930
because of what's going on and again

1696
01:16:12,270 --> 01:16:09,880
we'll probably have because the weight

1697
01:16:15,360 --> 01:16:12,280
falls and again in a couple of years we

1698
01:16:17,940 --> 01:16:15,370
may have them anymore okay so here's

1699
01:16:20,760 --> 01:16:17,950
what here are that the blue here again

1700
01:16:23,850 --> 01:16:20,770
are the the black holes that have been

1701
01:16:25,940 --> 01:16:23,860
seen by LIGO here are the black holes we

1702
01:16:29,970 --> 01:16:25,950
saw before like Oh known as a pattern

1703
01:16:31,530 --> 01:16:29,980
yeah and then here are the neutron stars

1704
01:16:33,900 --> 01:16:31,540
that we've seen before these two neutron

1705
01:16:35,340 --> 01:16:33,910
stars are right in the right in the same

1706
01:16:37,620 --> 01:16:35,350
mass range as all the other neutron

1707
01:16:39,990 --> 01:16:37,630
stars this is probably they don't show

1708
01:16:41,490 --> 01:16:40,000
errors this this has an error bar that

1709
01:16:43,680 --> 01:16:41,500
could get it down to about two solar

1710
01:16:45,540 --> 01:16:43,690
masses we think about somewhere around

1711
01:16:46,980 --> 01:16:45,550
twice as massive of the Sun a little

1712
01:16:48,750 --> 01:16:46,990
maybe a little more than that is where

1713
01:16:50,340 --> 01:16:48,760

neutron stars collapse down to black

1714
01:16:51,630 --> 01:16:50,350
holes we don't know for sure maybe we'll

1715
01:16:54,420 --> 01:16:51,640
learn as a result of this sort of work

1716
01:16:55,620 --> 01:16:54,430
these two objects form did merge to

1717
01:16:57,810 --> 01:16:55,630
something of more like three solar

1718
01:17:00,060 --> 01:16:57,820
masses so we think they probably merged

1719
01:17:01,320 --> 01:17:00,070
into a black hole how quickly that black

1720
01:17:02,700 --> 01:17:01,330
hole formed though is really is an

1721
01:17:04,830 --> 01:17:02,710
important question which we don't have

1722
01:17:07,020 --> 01:17:04,840
answered fully yet we don't and the

1723
01:17:09,750 --> 01:17:07,030
gravitational waves we detector we have

1724
01:17:17,920 --> 01:17:09,760
isn't sensitive in the high frequencies

1725
01:17:35,400 --> 01:17:23,620
so wait you knew let me go back if I can

1726
01:17:50,500 --> 01:17:37,810
should've been let me see if we get it

1727
01:17:51,970 --> 01:17:50,510
to go there it is oh you're not seeing

1728
01:17:59,730 --> 01:17:51,980
it now because it for something because

1729
01:18:02,080 --> 01:17:59,740
I switched the mode No oh that's a shame

1730
01:18:04,090 --> 01:18:02,090
it takes about 30 seconds though it's

1731
01:18:06,520 --> 01:18:04,100
the sound of the neutron stars emerging

1732
01:18:07,900 --> 01:18:06,530
and it worked on any trend it may have

1733
01:18:13,900 --> 01:18:07,910
gotten lost in the trends for to this

1734
01:18:19,330 --> 01:18:13,910
machine from the desktop it's a pretty

1735
01:18:21,190 --> 01:18:19,340
actually pretty good indie there you go

1736
01:18:22,990 --> 01:18:21,200
and it takes about that's about the 30

1737
01:18:25,150 --> 01:18:23,000
seconds so they know earlier for some

1738
01:18:30,700 --> 01:18:25,160

reason or we missed it am I talking and

1739
01:18:37,840 --> 01:18:30,710
it was very loud was it because you see

1740
01:18:40,720 --> 01:18:37,850
this the recording that they got is

1741
01:18:53,040 --> 01:18:40,730
about 30 seconds long and so it takes a

1742
01:19:04,300 --> 01:18:55,270
these new front stars you know they just

1743
01:19:06,280 --> 01:19:04,310
don't go off in you walk and it was it

1744
01:19:08,439 --> 01:19:06,290
was very soft and much lower before that

1745
01:19:10,510 --> 01:19:08,449
but we just hard to here with this set

1746
01:19:13,540 --> 01:19:10,520
up it starts at very low and but it

1747
01:19:15,220 --> 01:19:13,550
starts out sort of off the reason this

1748
01:19:17,770 --> 01:19:15,230
is longer is really because it's better

1749
01:19:21,820 --> 01:19:17,780
suited to the frequency band that the

1750
01:19:24,520 --> 01:19:21,830
LIGO detectors can detect the there's

1751
01:19:27,520 --> 01:19:24,530
too much bass really in the in the black

1752
01:19:30,010 --> 01:19:27,530
holes for Lego and and unfortunately if

1753
01:19:33,070 --> 01:19:30,020
this had more treble it could get it

1754
01:19:34,629 --> 01:19:33,080
could get the the actual spin down and

1755
01:19:35,649 --> 01:19:34,639
merger of the two neutron star so you

1756
01:19:37,600 --> 01:19:35,659
could really see get it form a black

1757
01:19:39,580 --> 01:19:37,610
hole and what is sort of the equation of

1758
01:19:41,680 --> 01:19:39,590
state of the neutron stars that is how

1759
01:19:43,360 --> 01:19:41,690
big are they that was something we

1760
01:20:07,790 --> 01:19:43,370
really like to know I don't think LIGO

1761
01:20:16,439 --> 01:20:13,229
okay so now there's another thing that

1762
01:20:18,959 --> 01:20:16,449
these neutron stars might do and that's

1763
01:20:21,060 --> 01:20:18,969

helped us with cosmology one of the

1764
01:20:23,970 --> 01:20:21,070
really important questions in cosmology

1765
01:20:25,350 --> 01:20:23,980
which turned out we knew it for a while

1766
01:20:28,410 --> 01:20:25,360
you may have heard about this big

1767
01:20:30,600 --> 01:20:28,420
argument between Sandage and huh is a no

1768
01:20:32,250 --> 01:20:30,610
this is what what is the Hubble constant

1769
01:20:35,280 --> 01:20:32,260
which is how fast is the universe

1770
01:20:36,510 --> 01:20:35,290
expanding locally we know it's expanding

1771
01:20:38,760 --> 01:20:36,520
we know the acceleration of the universe

1772
01:20:40,979 --> 01:20:38,770
is actually expanding with time but the

1773
01:20:43,290 --> 01:20:40,989
actual velocity locally how fast is it

1774
01:20:47,189 --> 01:20:43,300
expanding locally is an important issue

1775
01:20:50,100 --> 01:20:47,199
and it turns out that if you look at the

1776
01:20:54,930 --> 01:20:50,110
people looking at the Cosmic Microwave

1777
01:20:56,610 --> 01:20:54,940
Background using satellites to measure

1778
01:20:58,709 --> 01:20:56,620
the Cosmic Microwave you know the most

1779
01:20:59,820 --> 01:20:58,719
plunk the plunk telescope the European

1780
01:21:00,899 --> 01:20:59,830
Bank telescope did a very accurate

1781
01:21:03,660 --> 01:21:00,909
measure to the Cosmic Microwave

1782
01:21:05,280 --> 01:21:03,670
Background and they have to solve many

1783
01:21:09,240 --> 01:21:05,290
things simultaneously but when they do

1784
01:21:11,280 --> 01:21:09,250
that they get a number of about 67 now

1785
01:21:13,110 --> 01:21:11,290
when kilometers per second per

1786
01:21:15,360 --> 01:21:13,120
megaparsec and mayor barzmann it's like

1787
01:21:16,050 --> 01:21:15,370
three light-years so if you're three

1788
01:21:19,020 --> 01:21:16,060

light-years away

1789
01:21:21,270 --> 01:21:19,030
you're receding from me at about 70

1790
01:21:23,640 --> 01:21:21,280
kilometers per second double that we're

1791
01:21:25,830 --> 01:21:23,650
good so six six light-years you tend to

1792
01:21:29,879 --> 01:21:25,840
go away to hunt at 140 kilometers per

1793
01:21:32,430 --> 01:21:29,889
second on and on and on now the number

1794
01:21:34,740 --> 01:21:32,440
that Adam riess here many maybe you've

1795
01:21:36,450 --> 01:21:34,750
heard was speak before he's been

1796
01:21:38,070 --> 01:21:36,460
measuring and he won the Nobel Prize for

1797
01:21:40,050 --> 01:21:38,080
the expansion of the universe I was on

1798
01:21:41,490 --> 01:21:40,060
the other team so Laura Motors team but

1799
01:21:48,300 --> 01:21:41,500
had I'm still a nice guy

1800
01:21:50,669 --> 01:21:48,310
and and and and and the but the number

1801
01:21:55,740 --> 01:21:50,679
that you get that Adam has gotten is

1802
01:21:58,620 --> 01:21:55,750
more like 73 now that's but that's just

1803
01:22:00,479 --> 01:21:58,630
at this 3.8 Sigma say the term that the

1804
01:22:03,930 --> 01:22:00,489
three Sigma is sort of like where you

1805
01:22:06,090 --> 01:22:03,940
start getting this looks bad right now

1806
01:22:08,490 --> 01:22:06,100
if I it really true the three Sigma

1807
01:22:10,140 --> 01:22:08,500
should be if you're broke justit istic

1808
01:22:12,510 --> 01:22:10,150
Scouse IAM statistic three sigma b

1809
01:22:14,910 --> 01:22:12,520
that's definite the world is not things

1810
01:22:17,479 --> 01:22:14,920
go wrong so really five Sigma is like

1811
01:22:20,029 --> 01:22:17,489
beyond any doubt in this in there

1812
01:22:22,399 --> 01:22:20,039
life but three sigma three-point ageism

1813
01:22:24,169 --> 01:22:22,409

is getting pretty serious so and it

1814
01:22:26,870 --> 01:22:24,179
turns out that it looks like multiple

1815
01:22:29,180 --> 01:22:26,880
experiments when you so it looks like

1816
01:22:30,890 --> 01:22:29,190
you cosmic microwave ink master when

1817
01:22:31,939 --> 01:22:30,900
you're measuring the universe very far

1818
01:22:34,100 --> 01:22:31,949
away you get a slightly different answer

1819
01:22:36,739 --> 01:22:34,110
than when you're measuring closer in so

1820
01:22:38,629 --> 01:22:36,749
it may mean there's something wrong with

1821
01:22:39,919 --> 01:22:38,639
the model that we're using it could be

1822
01:22:42,410 --> 01:22:39,929
something as simple as that it was a

1823
01:22:44,689 --> 01:22:42,420
particle that used to exist

1824
01:22:46,129 --> 01:22:44,699
that's a K did maybe a hundred thousand

1825
01:22:48,020 --> 01:22:46,139
years in the image of the universe and

1826
01:22:49,729 --> 01:22:48,030
it's no longer around a massive particle

1827
01:22:51,669 --> 01:22:49,739
we don't really know it could be

1828
01:22:54,910 --> 01:22:51,679
something more interesting it could be

1829
01:22:58,669 --> 01:22:54,920
just that you really need five sigma but

1830
01:23:01,160 --> 01:22:58,679
so but this the interesting thing is

1831
01:23:04,459 --> 01:23:01,170
that as I mentioned to you that you can

1832
01:23:06,379 --> 01:23:04,469
tell by measuring the gravity wave here

1833
01:23:08,600 --> 01:23:06,389
and how strong it is you can get an

1834
01:23:12,169 --> 01:23:08,610
estimate of how far away the object was

1835
01:23:15,290 --> 01:23:12,179
and this is from that single object this

1836
01:23:19,040 --> 01:23:15,300
bar here and this is the that that line

1837
01:23:21,620 --> 01:23:19,050
is the is the Planck measurement and

1838
01:23:24,439 --> 01:23:21,630

this yellow bar here is Adams

1839
01:23:26,299 --> 01:23:24,449
measurement and you can see that this is

1840
01:23:28,669 --> 01:23:26,309
only one object they Adam has you know

1841
01:23:30,859 --> 01:23:28,679
dozens in here and so if you could get

1842
01:23:32,629 --> 01:23:30,869
many more and if you can get the

1843
01:23:34,459 --> 01:23:32,639
systematic errors down on these there

1844
01:23:35,959 --> 01:23:34,469
are some errors to worry about and so

1845
01:23:37,609 --> 01:23:35,969
it's just starting now but you might

1846
01:23:41,180 --> 01:23:37,619
have a completely independent measure

1847
01:23:42,859 --> 01:23:41,190
and with the the local observations that

1848
01:23:45,109 --> 01:23:42,869
the type atom does you have to sort of

1849
01:23:46,669 --> 01:23:45,119
use a distance ladder use a couple of

1850
01:23:48,830 --> 01:23:46,679
different objects to really build out

1851
01:23:50,989 --> 01:23:48,840
how far your things are this this is a

1852
01:23:54,290 --> 01:23:50,999
direct physical measurement of the

1853
01:23:56,390 --> 01:23:54,300
distance so it's it's potentially very

1854
01:23:58,609 --> 01:23:56,400
powerful but there it's not it's tricky

1855
01:23:59,989 --> 01:23:58,619
to do so well we'll see but it's

1856
01:24:01,819 --> 01:23:59,999
possible this will give us another way

1857
01:24:05,540 --> 01:24:01,829
to really get at this physics this

1858
01:24:08,270 --> 01:24:05,550
cosmology and and or the term that's

1859
01:24:10,129 --> 01:24:08,280
been used right to my far that's just

1860
01:24:15,439 --> 01:24:10,139
sort of cute they're called because of

1861
01:24:19,100 --> 01:24:15,449
that okay so coordination is like not my

1862
01:24:21,109 --> 01:24:19,110
greatest ability all right so um these

1863
01:24:24,649 --> 01:24:21,119

the standard sirens this chirp it's

1864
01:24:26,390 --> 01:24:24,659
called also closer chirp is right so

1865
01:24:28,219 --> 01:24:26,400
there's a standard sirens as the term

1866
01:24:29,450 --> 01:24:28,229
that's being used because you can tell

1867
01:24:30,410 --> 01:24:29,460
how far right the stand you get

1868
01:24:31,939 --> 01:24:30,420
standardized on you

1869
01:24:37,340 --> 01:24:31,949
how far away they are and that would be

1870
01:24:40,580 --> 01:24:37,350
the idea so LIGO and Virgo are being

1871
01:24:42,229 --> 01:24:40,590
upgraded LIGO will return in 2019 it's

1872
01:24:44,209 --> 01:24:42,239
expected to be 2 or 3 times more

1873
01:24:46,310 --> 01:24:44,219
sensitive now as I mentioned you already

1874
01:24:48,860 --> 01:24:46,320
the strain if things are twice as far

1875
01:24:50,959 --> 01:24:48,870
away they're half as powerful so that if

1876
01:24:53,120 --> 01:24:50,969
you can go if you have something that's

1877
01:24:55,880 --> 01:24:53,130
two or three times more can measure

1878
01:24:58,550 --> 01:24:55,890
strain that's two or three times smaller

1879
01:25:00,950 --> 01:24:58,560
you can search a volume that's two cubed

1880
01:25:03,320 --> 01:25:00,960
or three cubed larger radius turns into

1881
01:25:06,530 --> 01:25:03,330
you cube the radius to get the volume

1882
01:25:09,520 --> 01:25:06,540
and so you get the volume goes up by a

1883
01:25:13,310 --> 01:25:09,530
factor of eight to maybe thirty so

1884
01:25:15,439 --> 01:25:13,320
instead of one neutron star merging

1885
01:25:17,240 --> 01:25:15,449
neutron star per year and a few black

1886
01:25:20,060 --> 01:25:17,250
holes merging per year we could be

1887
01:25:23,600 --> 01:25:20,070
seeing one neutron star merger per month

1888
01:25:32,600 --> 01:25:23,610

and maybe one black hole merger per week

1889
01:25:34,729 --> 01:25:32,610
right so it could be rather busy now

1890
01:25:41,180 --> 01:25:34,739
what what's going to be coming in the in

1891
01:25:44,720 --> 01:25:41,190
the far future in the 2030s a this is a

1892
01:25:47,450 --> 01:25:44,730
plan this is called Lisa it's three

1893
01:25:50,350 --> 01:25:47,460
satellites forming any durometer in

1894
01:25:54,680 --> 01:25:50,360
space with arms that are about a million

1895
01:25:56,150 --> 01:25:54,690
million year of ly miles long and they

1896
01:26:02,810 --> 01:25:56,160
said a trailing orbit behind the Earth

1897
01:26:04,880 --> 01:26:02,820
and be able to take merging black holes

1898
01:26:08,080 --> 01:26:04,890
in distant galaxies as well as white

1899
01:26:11,720 --> 01:26:08,090
dwarf binaries verging in our galaxy and

1900
01:26:13,939 --> 01:26:11,730
now this may also look crazy but there

1901
01:26:15,350 --> 01:26:13,949
was it was a satellite the Europeans

1902
01:26:18,590 --> 01:26:15,360
with some American help send up was go

1903
01:26:20,930 --> 01:26:18,600
to Lisa Pathfinder which tested the

1904
01:26:22,760 --> 01:26:20,940
sensitivity of the detector there and

1905
01:26:26,630 --> 01:26:22,770
how quiet they could make the whole

1906
01:26:28,550 --> 01:26:26,640
system and it affair exceeded how the

1907
01:26:31,010 --> 01:26:28,560
goal of what they wanted for the

1908
01:26:32,930 --> 01:26:31,020
Pathfinder it in fact exceeded it met

1909
01:26:37,070 --> 01:26:32,940
and even exceeded what they needed for

1910
01:26:39,110 --> 01:26:37,080
Lisa itself in this first try so this

1911
01:26:40,850 --> 01:26:39,120
looks really doable if that's an

1912
01:26:42,919 --> 01:26:40,860
incredible achievement that in this

1913
01:26:44,250 --> 01:26:42,929

first try right they found that they

1914
01:26:45,629 --> 01:26:44,260
were doing better than he wanted to do

1915
01:26:48,899 --> 01:26:45,639
in the thing that they're gonna do 10

1916
01:26:51,299 --> 01:26:48,909
years from now so we maintain somewhere

1917
01:26:53,129 --> 01:26:51,309
in the 20 late 2020s 20 30 we may

1918
01:26:55,890 --> 01:26:53,139
actually have that thing flying in space

1919
01:26:58,890 --> 01:26:55,900
I don't know where it went

1920
01:27:04,529 --> 01:26:58,900
but when it went flying into space okay

1921
01:27:07,589 --> 01:27:04,539
now so there you have there's like oh

1922
01:27:10,229 --> 01:27:07,599
and they 10 and then you have this is

1923
01:27:12,209 --> 01:27:10,239
Lisa is here can get these things now

1924
01:27:15,299 --> 01:27:12,219
you can do other things to look for

1925
01:27:19,729 --> 01:27:15,309
gravitational waves pulsars again clocks

1926
01:27:23,069 --> 01:27:19,739
and they're all over the sky and so if a

1927
01:27:26,100 --> 01:27:23,079
big of a long wave comes and passes by

1928
01:27:28,259 --> 01:27:26,110
right all it'll affect all of the

1929
01:27:29,370 --> 01:27:28,269
objects in one way one way and the other

1930
01:27:31,979 --> 01:27:29,380
way the other way right so it's

1931
01:27:33,959 --> 01:27:31,989
stretching it's making the space so for

1932
01:27:36,180 --> 01:27:33,969
example the pulsars in this direction

1933
01:27:37,979 --> 01:27:36,190
would look further away and the pulsars

1934
01:27:40,200 --> 01:27:37,989
in that direction look closer to us and

1935
01:27:44,790 --> 01:27:40,210
then change right it would change the

1936
01:27:48,589 --> 01:27:44,800
other way so you could potentially use

1937
01:27:51,569 --> 01:27:48,599
this to look for very low-frequency

1938
01:27:53,520 --> 01:27:51,579

gravitational waves very so what sort of

1939
01:27:56,129 --> 01:27:53,530
things with like over time spans of

1940
01:27:58,439 --> 01:27:56,139
years that as they pass the earth and

1941
01:28:01,620 --> 01:27:58,449
those would be found by those can be

1942
01:28:04,589 --> 01:28:01,630
produced both by binary black holes in

1943
01:28:06,089 --> 01:28:04,599
galactic nuclei as they're merging not

1944
01:28:09,359 --> 01:28:06,099
quite at the end but is there close to

1945
01:28:11,729 --> 01:28:09,369
merging and and then it also it is a lot

1946
01:28:14,069 --> 01:28:11,739
of this prediction that the early

1947
01:28:16,319 --> 01:28:14,079
universe would have radiated the black

1948
01:28:18,089 --> 01:28:16,329
the the actual big bang would have

1949
01:28:20,790 --> 01:28:18,099
radiated gravitational waves

1950
01:28:22,830 --> 01:28:20,800
it's basically Hawking radiation from

1951
01:28:25,470 --> 01:28:22,840
the from the horizon Inventor isin of

1952
01:28:27,660 --> 01:28:25,480
the universe so you want to blow your

1953
01:28:29,939 --> 01:28:27,670
mind you can just think about that it's

1954
01:28:32,250 --> 01:28:29,949
in fact for a while there was this there

1955
01:28:33,359 --> 01:28:32,260
was a observation called the bicep may

1956
01:28:36,049 --> 01:28:33,369
some of you may have heard of this there

1957
01:28:38,399 --> 01:28:36,059
was a there was a pro observation of the

1958
01:28:39,870 --> 01:28:38,409
Cosmic Microwave Background from sent

1959
01:28:41,390 --> 01:28:39,880
Antarctica and they thought they had

1960
01:28:43,470 --> 01:28:41,400
found this they thought they had found

1961
01:28:45,509 --> 01:28:43,480
evidence in the Cosmic Microwave

1962
01:28:46,979 --> 01:28:45,519
Background of just that radiation and

1963
01:28:50,250 --> 01:28:46,989

that would have been like for Nobel

1964
01:28:54,859 --> 01:28:50,260
Prizes wrapped in one and it turned out

1965
01:29:00,270 --> 01:28:57,689
dusts you know I just you know it's just

1966
01:29:02,040 --> 01:29:00,280
a pain there are people who are

1967
01:29:03,300 --> 01:29:02,050
astronomers who they get all upset when

1968
01:29:04,649 --> 01:29:03,310
it we've let I say that sort of thing

1969
01:29:07,500 --> 01:29:04,659
but there cuz they're astronomers who

1970
01:29:15,709 --> 01:29:07,510
like study dust I just you know just

1971
01:29:21,000 --> 01:29:18,660
alright they I love that effect no

1972
01:29:23,129 --> 01:29:21,010
matter what you say it's got it you know

1973
01:29:25,109 --> 01:29:23,139
you're right it's important all right so

1974
01:29:26,970 --> 01:29:25,119
so the detection of gravitational waves

1975
01:29:29,189 --> 01:29:26,980
has given us new insights into stellar

1976
01:29:31,109 --> 01:29:29,199
astrophysics and we Martin confirmation

1977
01:29:35,760 --> 01:29:31,119
of general relativity and may give us a

1978
01:29:38,250 --> 01:29:35,770
new test of the cosmological model yeah

1979
01:29:40,740 --> 01:29:38,260
we have seen massive black holes in

1980
01:29:42,390 --> 01:29:40,750
abundance that we did not expect right

1981
01:29:44,609 --> 01:29:42,400
and that's gonna tell us a lot probably

1982
01:29:46,470 --> 01:29:44,619
about how the for probably about stellar

1983
01:29:50,250 --> 01:29:46,480
evolution maybe about primordial black

1984
01:29:52,290 --> 01:29:50,260
holes we have seen a neutron star killer

1985
01:29:54,240 --> 01:29:52,300
merger prusik elenova confirm the

1986
01:29:56,490 --> 01:29:54,250
suggestion that the majority of Hell in

1987
01:29:59,430 --> 01:29:56,500
the elements in the universe are formed

1988
01:30:02,010 --> 01:29:59,440

by neutron star mergers we're not sure

1989
01:30:03,419 --> 01:30:02,020
if we've seen a GRB associated with this

1990
01:30:06,120 --> 01:30:03,429
neutron star merger we but we should

1991
01:30:08,100 --> 01:30:06,130
know soon and there are gonna be if LIGO

1992
01:30:10,740 --> 01:30:08,110
this upgrade succeeds doesn't go

1993
01:30:13,439 --> 01:30:10,750
backwards but goes forward we should

1994
01:30:17,160 --> 01:30:13,449
have lots more to test right and some of

1995
01:30:19,229 --> 01:30:17,170
those should be pointed at us so that

1996
01:30:22,229 --> 01:30:19,239
will help the statistics alone will help

1997
01:30:23,370 --> 01:30:22,239
us there and so again the prospects for

1998
01:30:25,500 --> 01:30:23,380
the future of gravitational wave

1999
01:30:27,100 --> 01:30:25,510
astronomy look very good indeed so thank

2000
01:30:36,540 --> 01:30:27,110
you very much

2001
01:30:39,909 --> 01:30:36,550
[Applause]

2002
01:30:42,189 --> 01:30:39,919
okay so we have hit our sort of neutral

2003
01:30:45,250 --> 01:30:42,199
limit of 9:30 so if you need to leave

2004
01:30:48,069 --> 01:30:45,260
please get up and leave them we went on

2005
01:30:50,560 --> 01:30:48,079
for a while for those who want to stay

2006
01:30:51,879 --> 01:30:50,570
and ask some questions um we have a few

2007
01:31:03,609 --> 01:30:51,889
questions I'm going to start without a

2008
01:31:08,500 --> 01:31:06,700
so Brenda asks if there were two black

2009
01:31:10,990 --> 01:31:08,510
holes in the center of our galaxy that

2010
01:31:13,600 --> 01:31:11,000
merged and emitted gravitational waves

2011
01:31:22,240 --> 01:31:13,610
what if any effect would this have on

2012
01:31:24,760 --> 01:31:22,250
earth so I don't know it hurt I don't

2013
01:31:26,859 --> 01:31:24,770

think you would notice um but because

2014
01:31:30,760 --> 01:31:26,869
we're small and so the stretch is very

2015
01:31:34,240 --> 01:31:30,770
tiny but why would the gravitational

2016
01:31:36,669 --> 01:31:34,250
wave detectors have a field day yet so I

2017
01:31:38,500 --> 01:31:36,679
don't I haven't done the culture I don't

2018
01:31:41,520 --> 01:31:38,510
think seismologists would didn't know it

2019
01:31:43,959 --> 01:31:41,530
do you have a question no she she wants

2020
01:31:47,189 --> 01:31:43,969
just in case you guys need a refresher

2021
01:31:49,930 --> 01:31:47,199
for this Nancy brought up this book and

2022
01:31:54,729 --> 01:31:49,940
it's called general relativity for

2023
01:31:56,890 --> 01:31:54,739
babies in which the one of the last

2024
01:32:06,070 --> 01:31:56,900
parts of it is about gravitational waves

2025
01:32:47,440 --> 01:32:08,200
[Applause]

2026
01:32:49,120 --> 01:32:47,450
that is other questions we have that

2027
01:32:53,860 --> 01:32:49,130
gravitational waves are actually a

2028
01:32:57,010 --> 01:32:53,870
superposition of okay I'm trying to

2029
01:32:58,090 --> 01:32:57,020
repeat that for the online audience then

2030
01:32:59,590 --> 01:32:58,100
you talked about the compression and

2031
01:33:03,250 --> 01:32:59,600
rarefaction of the wave it's that

2032
01:33:05,740 --> 01:33:03,260
indicate of the wave is polarized and if

2033
01:33:07,750 --> 01:33:05,750
so does that mean that the waves are

2034
01:33:10,479 --> 01:33:07,760
super positions of polarization States

2035
01:33:12,070 --> 01:33:10,489
yes so the average wave you see is the

2036
01:33:14,260 --> 01:33:12,080
superposition of polarization States

2037
01:33:17,709 --> 01:33:14,270
this is one polarization you stretch

2038
01:33:20,860 --> 01:33:17,719

like this in a this then 90 degrees away

2039
01:33:23,590 --> 01:33:20,870
now hopefully if this works yeah you can

2040
01:33:25,810 --> 01:33:23,600
rotate by 45 degrees and then the

2041
01:33:27,940 --> 01:33:25,820
stretching 45 degrees in the expansion

2042
01:33:30,220 --> 01:33:27,950
45 degrees that's the other polarization

2043
01:33:31,810 --> 01:33:30,230
if that's the way gravitational waves

2044
01:33:33,430 --> 01:33:31,820
work they're not quite like the dipoles

2045
01:33:35,200 --> 01:33:33,440
of electromagnetism that you think of

2046
01:33:37,870 --> 01:33:35,210
where it's typically like a vector one

2047
01:33:41,280 --> 01:33:37,880
direction and then it's the 90 degrees

2048
01:33:43,000 --> 01:33:41,290
here you've got basically it's this is a

2049
01:33:46,090 --> 01:33:43,010
electromagnet is called dipole radiation

2050
01:33:49,030 --> 01:33:46,100
it's along basically along a line this

2051
01:33:51,370 --> 01:33:49,040
is a quadrupole it's basically a sort of

2052
01:33:55,900 --> 01:33:51,380
elliptical shape right a two-dimensional

2053
01:33:57,729 --> 01:33:55,910
shape that radiates and and so you get

2054
01:33:59,770 --> 01:33:57,739
that the polarization is actually just

2055
01:34:01,900 --> 01:33:59,780
the stretching and compression being

2056
01:34:03,310 --> 01:34:01,910
rotated by 45 degrees and the

2057
01:34:04,990 --> 01:34:03,320
polarization is important in

2058
01:34:07,900 --> 01:34:05,000
understanding the orientation of the

2059
01:34:09,970 --> 01:34:07,910
object from you that come right and so

2060
01:34:11,350 --> 01:34:09,980
so when you measure these gravitational

2061
01:34:13,870 --> 01:34:11,360
waves trying to measure the polarization

2062
01:34:19,530 --> 01:34:13,880
is important if you want to solve for

2063
01:34:44,950 --> 01:34:23,290

no no these are in generality these are

2064
01:34:47,680 --> 01:34:44,960
the two modes okay down here no let me

2065
01:34:49,390 --> 01:34:47,690
so in a supernova the neutrinos are part

2066
01:34:51,970 --> 01:34:49,400
of the thing that blows the star apart

2067
01:34:54,730 --> 01:34:51,980
is there a similar release here it

2068
01:34:56,740 --> 01:34:54,740
probably was but our neutrino detectors

2069
01:34:59,110 --> 01:34:56,750
aren't sensitive enough to detect it so

2070
01:35:01,960 --> 01:34:59,120
the neutrino detectors can detect things

2071
01:35:04,030 --> 01:35:01,970
in our in our galaxy and in the local

2072
01:35:05,980 --> 01:35:04,040
with the nearby galaxies these the

2073
01:35:08,020 --> 01:35:05,990
things we're seeing here are too distant

2074
01:35:09,940 --> 01:35:08,030
we think for the neutrino detectors but

2075
01:35:12,820 --> 01:35:09,950
it's an important question you ask in

2076
01:35:14,740 --> 01:35:12,830
the way that so gravity this is called

2077
01:35:17,020 --> 01:35:14,750
multi in the astronomy communities it's

2078
01:35:18,820 --> 01:35:17,030
called multi messenger astrophysics in a

2079
01:35:21,690 --> 01:35:18,830
sense that you're using different types

2080
01:35:23,620 --> 01:35:21,700
of particles or form right so

2081
01:35:26,080 --> 01:35:23,630
electromagnetic radiation is one

2082
01:35:28,240 --> 01:35:26,090
messenger gravity is another message

2083
01:35:29,830 --> 01:35:28,250
messenger neutrinos are another type of

2084
01:35:31,570 --> 01:35:29,840
completely different type of messenger

2085
01:35:33,280 --> 01:35:31,580
and so if you had something close enough

2086
01:35:36,220 --> 01:35:33,290
or we had much more sensitive neutrino

2087
01:35:37,840 --> 01:35:36,230
detectors you could get that yeah I mean

2088
01:35:42,030 --> 01:35:37,850

we talked about gravitational wave

2089
01:35:46,450 --> 01:35:42,040
astronomy neutrino astronomy is also a

2090
01:35:48,220 --> 01:35:46,460
very infancy type development and you

2091
01:35:53,260 --> 01:35:48,230
know there are talks of being able to

2092
01:35:55,840 --> 01:35:53,270
see neutrinos from or in early cosmology

2093
01:35:58,420 --> 01:35:55,850
right well such so I mean there's

2094
01:36:01,530 --> 01:35:58,430
there's possibilities of other non

2095
01:36:04,080 --> 01:36:01,540
optical yeah oh yeah especially from a

2096
01:36:07,330 --> 01:36:04,090
supernova going off in the local group

2097
01:36:10,000 --> 01:36:07,340
in fact it right so neutrinos were

2098
01:36:12,970 --> 01:36:10,010
detected from nineteen supernova 1987a

2099
01:36:15,250 --> 01:36:12,980
right right and so a handful but they

2100
01:36:17,020 --> 01:36:15,260
were detected and so but that was a very

2101
01:36:32,760 --> 01:36:17,030
closed galaxy right and so that's the

2102
01:36:37,980 --> 01:36:35,790
not really no and it's not quite

2103
01:36:39,360 --> 01:36:37,990
analogous and in some ways I was

2104
01:36:41,370 --> 01:36:39,370
thinking about this earlier I think that

2105
01:36:42,780 --> 01:36:41,380
part of it is also that in fact what

2106
01:36:45,120 --> 01:36:42,790
we've learned from quantum mechanics is

2107
01:36:48,840 --> 01:36:45,130
that the way to think of it isn't really

2108
01:36:51,600 --> 01:36:48,850
has it's to think the elect the the

2109
01:36:53,280 --> 01:36:51,610
Elektra E&M modes the E&B modes are

2110
01:36:55,530 --> 01:36:53,290
actually different derivatives of a

2111
01:36:58,770 --> 01:36:55,540
thing we call of a potential away call

2112
01:37:00,300 --> 01:36:58,780
vector potential and the quantity it's

2113
01:37:01,860 --> 01:37:00,310

only quantum mechanically people thought

2114
01:37:02,670 --> 01:37:01,870
that was just a mathematic for a long

2115
01:37:04,680 --> 01:37:02,680
time people thought that was just a

2116
01:37:06,510 --> 01:37:04,690
mathematical creation but there's some

2117
01:37:08,400 --> 01:37:06,520
cosmic account to quantum mechanical

2118
01:37:09,450 --> 01:37:08,410
tests where there's no electric field or

2119
01:37:11,580 --> 01:37:09,460
magnetic field but there's just this

2120
01:37:13,740 --> 01:37:11,590
potential and it affects the way grab

2121
01:37:17,250 --> 01:37:13,750
onto mechanical particles propagate so

2122
01:37:20,190 --> 01:37:17,260
that in some sense maybe the real real

2123
01:37:22,140 --> 01:37:20,200
deal and right rather than the E and the

2124
01:37:25,770 --> 01:37:22,150
B and so that in some ways it's more

2125
01:37:27,330 --> 01:37:25,780
known is that way yeah but there's no

2126
01:37:29,940 --> 01:37:27,340
real comfort there is no real difference

2127
01:37:31,800 --> 01:37:29,950
it's just the different polarization all

2128
01:37:42,600 --> 01:37:31,810
right two more questions here and then

2129
01:37:47,730 --> 01:37:42,610
the over there yeah directionality that

2130
01:37:55,740 --> 01:37:47,740
seems like it's not it's clear it's

2131
01:37:58,260 --> 01:37:55,750
clear reason so you have to use timing

2132
01:38:00,720 --> 01:37:58,270
basically that's right so you the major

2133
01:38:02,550 --> 01:38:00,730
thing is that you say okay the grave

2134
01:38:05,250 --> 01:38:02,560
came you know hit me here and then he

2135
01:38:07,140 --> 01:38:05,260
hit me here and then I know so that if

2136
01:38:08,970 --> 01:38:07,150
it hit here first then it had to be sort

2137
01:38:10,770 --> 01:38:08,980
of you just draw circles right where

2138
01:38:14,250 --> 01:38:10,780

where is that where is it going to be

2139
01:38:16,140 --> 01:38:14,260
that much closer right and and that

2140
01:38:17,640 --> 01:38:16,150
third object gives you it so that's why

2141
01:38:19,410 --> 01:38:17,650
the position it's so it's like if you do

2142
01:38:20,820 --> 01:38:19,420
reckoning right if you drew if I tell

2143
01:38:23,220 --> 01:38:20,830
you the distance of something is from

2144
01:38:25,050 --> 01:38:23,230
two objects you'll get two points right

2145
01:38:26,370 --> 01:38:25,060
so solutions you draw two circles and

2146
01:38:30,270 --> 01:38:26,380
these are sexually two circles is

2147
01:38:31,830 --> 01:38:30,280
usually two points right and and the but

2148
01:38:34,200 --> 01:38:31,840
you put if I give you a third point and

2149
01:38:35,730 --> 01:38:34,210
it tell you that you get one one

2150
01:38:39,030 --> 01:38:35,740
distance and the same thing happens here

2151
01:38:40,590 --> 01:38:39,040
right and wasn't it sort of like a

2152
01:38:41,930 --> 01:38:40,600
confirmation that gravitational waves

2153
01:38:44,640 --> 01:38:41,940
travel at the speed of light by the

2154
01:38:46,470 --> 01:38:44,650
timing between Hanford and Livingston no

2155
01:38:48,630 --> 01:38:46,480
well yeah I guess the better the better

2156
01:38:51,540 --> 01:38:48,640
one was the 1.7 seconds of the gamma

2157
01:38:54,470 --> 01:38:51,550
rays and the gamma rays coming only 1.7

2158
01:38:56,160 --> 01:38:54,480
seconds after the arrival of the

2159
01:38:58,410 --> 01:38:56,170
gravitational waves there's much more

2160
01:39:00,360 --> 01:38:58,420
precise and proportionally right but

2161
01:39:08,100 --> 01:39:00,370
fortunately are there I and Peter you

2162
01:39:09,360 --> 01:39:08,110
get the last question any chance the

2163
01:39:12,240 --> 01:39:09,370

gravitational waves could be a useful

2164
01:39:15,090 --> 01:39:12,250
source of energy so as you saw you mean

2165
01:39:16,980 --> 01:39:15,100
well so you know this is not really I

2166
01:39:18,660 --> 01:39:16,990
mean because just like the moonlight

2167
01:39:19,950 --> 01:39:18,670
wouldn't be of useful source of a bright

2168
01:39:21,270 --> 01:39:19,960
the brother full moon isn't a useful

2169
01:39:23,910 --> 01:39:21,280
source of energies like that sort sort

2170
01:39:26,310 --> 01:39:23,920
of talking about but even so harvesting

2171
01:39:27,750 --> 01:39:26,320
that energy is not easy right I was

2172
01:39:29,720 --> 01:39:27,760
saying well if you could you know focus

2173
01:39:31,440 --> 01:39:29,730
if the way you could focus

2174
01:39:32,580 --> 01:39:31,450
electromagnetism we look at they would

2175
01:39:34,050 --> 01:39:32,590
look like a point source as bright as

2176
01:39:38,400 --> 01:39:34,060
the full moon but focusing in

2177
01:39:39,720 --> 01:39:38,410
gravitational ways not easy so yeah so

2178
01:39:41,760 --> 01:39:39,730
there's a lot of energy at the source

2179
01:39:45,210 --> 01:39:41,770
but we'd rather keep it over at the

2180
01:39:48,060 --> 01:39:45,220
source than get to close space honey

2181
01:39:50,670 --> 01:39:48,070
turns out that space if you do the

2182
01:39:52,050 --> 01:39:50,680
calculation of like space time there's a

2183
01:39:53,940 --> 01:39:52,060
lot of energy but space time doesn't

2184
01:39:56,700 --> 01:39:53,950
move very much and you can say well how

2185
01:39:58,380 --> 01:39:56,710
how stiff is space-time and its tenth

2186
01:40:01,100 --> 01:39:58,390
but it's about 10 to the 20 times

2187
01:40:04,980 --> 01:40:01,110
stiffer than steel okay yeah it's like

2188
01:40:07,650 --> 01:40:04,990

it's like it's like a billion billion

2189
01:40:08,820 --> 01:40:07,660
million or something million a thousand

2190
01:40:11,970 --> 01:40:08,830
yeah all right

2191
01:40:15,540 --> 01:40:11,980
so space-time is very are very very

2192
01:40:19,800 --> 01:40:15,550
stiff only translates a little bit of

2193
01:40:22,590 --> 01:40:19,810
the energy all right so next month we

2194
01:40:23,790 --> 01:40:22,600
have star formation in Orion and June I

2195
01:40:26,700 --> 01:40:23,800
think it's third or something like that

2196
01:40:28,680 --> 01:40:26,710
it's on the calendar hope to see you all

2197
01:40:30,960 --> 01:40:28,690
there you have now just been

2198
01:40:32,400 --> 01:40:30,970
indoctrinating the brand-new great brave

2199
01:40:35,130 --> 01:40:32,410
new world of gravitational wave

2200
01:40:35,650 --> 01:40:35,140
astronomy let's give dr. Richter one