

1
00:00:00,000 --> 00:00:06,509
like outreach and if you walked in today

2
00:00:03,509 --> 00:00:10,410
you came in and hopefully you got one of

3
00:00:06,509 --> 00:00:12,960
these the lithograph that we have for

4
00:00:10,410 --> 00:00:16,769
you tonight this one is of the veil

5
00:00:12,960 --> 00:00:19,500
nebula which is a piece of a supernova

6
00:00:16,769 --> 00:00:22,019
remnant it's actually a very small piece

7
00:00:19,500 --> 00:00:24,149
I believe this is in the area called the

8
00:00:22,019 --> 00:00:26,460
broom handle of the width the handle of

9
00:00:24,149 --> 00:00:28,439
the witch's broom in the veil supernova

10
00:00:26,460 --> 00:00:30,179
remnant on the front you see the Hubble

11
00:00:28,439 --> 00:00:32,189
picture and on the back there's a

12
00:00:30,178 --> 00:00:34,140
context picture to show you what a small

13
00:00:32,189 --> 00:00:36,450
piece of the supernova remnant that it

14
00:00:34,140 --> 00:00:40,558
is and this of course relates to

15
00:00:36,450 --> 00:00:45,359
tonight's speakers topic the death and

16
00:00:40,558 --> 00:00:50,988
after lives of massive stars our speaker

17
00:00:45,359 --> 00:00:50,988
Dan mili salvific close enough yeah okay

18
00:00:51,198 --> 00:00:58,079
University upcoming as you know this one

19
00:00:55,738 --> 00:01:00,179
has was delayed several weeks because we

20
00:00:58,079 --> 00:01:03,000
had such a special speaker for the

21
00:01:00,179 --> 00:01:05,519
conference that's here today so the next

22
00:01:03,000 --> 00:01:06,719
one will only be two weeks away may 7th

23
00:01:05,519 --> 00:01:10,409
Joleen Karlberg

24
00:01:06,719 --> 00:01:11,760
the fiery fate of exoplanets and then we

25
00:01:10,409 --> 00:01:15,630
go back to our normal once a month

26
00:01:11,760 --> 00:01:17,100
scheduled in June Chris Britt also the

27
00:01:15,629 --> 00:01:20,368
office of public outreach a colleague of

28
00:01:17,099 --> 00:01:23,969
mine can pulsar recycling produce a

29

00:01:20,368 --> 00:01:27,000
gamma-ray excess do you guys do you do

30
00:01:23,969 --> 00:01:30,359
recycle your pulsars don't you okay well

31
00:01:27,000 --> 00:01:32,400
actually the universe might be recycling

32
00:01:30,359 --> 00:01:36,420
its pulsars okay and you can see what

33
00:01:32,400 --> 00:01:41,070
that that does and then in July on July

34
00:01:36,420 --> 00:01:45,118
2nd Jodha Pasquale our new relatively

35
00:01:41,069 --> 00:01:46,559
new astronomical image processor will

36
00:01:45,118 --> 00:01:50,368
talk on the art and science of

37
00:01:46,560 --> 00:01:52,109
astronomical image processing okay if

38
00:01:50,368 --> 00:01:54,688
you want to find out this schedule you

39
00:01:52,109 --> 00:01:56,188
go to your favorite web browser in

40
00:01:54,688 --> 00:01:58,139
favorite search engine and type in the

41
00:01:56,188 --> 00:02:00,898
Space Telescope public lectures and you

42
00:01:58,140 --> 00:02:03,989
should find this webpage we have a go

43
00:02:00,899 --> 00:02:05,609

link Hubble site or go talks where you

44

00:02:03,989 --> 00:02:08,250

can see on the right side we have the

45

00:02:05,609 --> 00:02:11,969

list of the upcoming on the left side we

46

00:02:08,250 --> 00:02:13,889

have the links to the live both on our

47

00:02:11,969 --> 00:02:17,609

webcasting and on you too

48

00:02:13,889 --> 00:02:21,029

as well as our archive on YouTube and on

49

00:02:17,610 --> 00:02:24,180

the stsci webcasts finally you can of

50

00:02:21,030 --> 00:02:26,250

course subscribe or unsubscribe to our

51

00:02:24,180 --> 00:02:28,469

email list which sends out about two or

52

00:02:26,250 --> 00:02:31,019

three emails a month telling you just

53

00:02:28,469 --> 00:02:33,060

what's up and coming

54

00:02:31,019 --> 00:02:35,370

the email announcements you can sign up

55

00:02:33,060 --> 00:02:38,819

the website there are however some

56

00:02:35,370 --> 00:02:40,110

people who don't like to do that you can

57

00:02:38,818 --> 00:02:41,488

just write down your email address and

58
00:02:40,110 --> 00:02:44,640
give it to me and I'll make sure you get

59
00:02:41,489 --> 00:02:47,250
on there if you have questions the email

60
00:02:44,639 --> 00:02:51,479
address is public lecture at STScI dot

61
00:02:47,250 --> 00:02:53,579
edu our social media for the hubble

62
00:02:51,479 --> 00:02:55,560
space telescope the upcoming James Webb

63
00:02:53,579 --> 00:02:57,810
Space Telescope and for the Space

64
00:02:55,560 --> 00:03:00,620
Telescope Science Institute are here on

65
00:02:57,810 --> 00:03:03,930
Facebook Twitter YouTube and Instagram

66
00:03:00,620 --> 00:03:07,650
if you want to hear more of my diet of

67
00:03:03,930 --> 00:03:09,659
mine my spew you can see what I do on

68
00:03:07,650 --> 00:03:13,950
Facebook and Twitter although I only do

69
00:03:09,658 --> 00:03:17,548
that occasionally not all the time all

70
00:03:13,949 --> 00:03:20,759
right the observatory will not be open

71
00:03:17,549 --> 00:03:22,950
tonight he saw the clouds moving in and

72
00:03:20,759 --> 00:03:25,828
he said sorry we're just not gonna have

73
00:03:22,949 --> 00:03:28,979
a clear night top view but as always if

74
00:03:25,829 --> 00:03:30,540
you go to MD dot Space Grant at orj you

75
00:03:28,979 --> 00:03:33,149
can find this page for the Maryland

76
00:03:30,539 --> 00:03:35,578
Space Grant Observatory on Friday nights

77
00:03:33,150 --> 00:03:37,889
they do observing if you check there at

78
00:03:35,579 --> 00:03:39,150
Friday night at 6:00 or 7:00 p.m. they

79
00:03:37,889 --> 00:03:41,219
will have posted whether or not they're

80
00:03:39,150 --> 00:03:42,659
going to be open on Friday night to do

81
00:03:41,219 --> 00:03:46,348
observing and you can come down and do

82
00:03:42,659 --> 00:03:47,370
that okay all right and now the news

83
00:03:46,348 --> 00:03:52,969
from the universe for

84
00:03:47,370 --> 00:03:57,750
April 2019 our first story tonight

85
00:03:52,969 --> 00:04:01,378
Hubble's 29th anniversary today is April

86

00:03:57,750 --> 00:04:04,829
23rd and 29 years ago today

87
00:04:01,378 --> 00:04:10,590
years ago too tomorrow is when Hubble

88
00:04:04,829 --> 00:04:14,090
launched April 24 1990 and of course

89
00:04:10,590 --> 00:04:16,738
every year we have to come up with a

90
00:04:14,090 --> 00:04:19,199
interesting press release for you and

91
00:04:16,738 --> 00:04:22,108
you know sometimes it gets harder and

92
00:04:19,199 --> 00:04:24,030
harder to top ourselves okay so we went

93
00:04:22,108 --> 00:04:25,918
in an interesting direction this year

94
00:04:24,029 --> 00:04:26,759
okay we wanted to remind you something

95
00:04:25,918 --> 00:04:29,789
very

96
00:04:26,759 --> 00:04:32,430
and about Hubble observations now who

97
00:04:29,790 --> 00:04:34,260
here has heard of the Crab Nebula when

98
00:04:32,430 --> 00:04:36,959
you think of the Crab Nebula you think

99
00:04:34,259 --> 00:04:39,120
of this and this is a supernova

100
00:04:36,959 --> 00:04:41,609

explosion that our speaker tonight will

101

00:04:39,120 --> 00:04:43,860

might mention in one of his - in his

102

00:04:41,610 --> 00:04:45,540

talk but this is what everyone thinks of

103

00:04:43,860 --> 00:04:49,139

the Crab Nebula but there is also

104

00:04:45,540 --> 00:04:51,000

another Crab Nebula okay this is a

105

00:04:49,139 --> 00:04:54,060

supernova explosion a star that exploded

106

00:04:51,000 --> 00:04:55,889

blew its guts out into space there is

107

00:04:54,060 --> 00:04:58,530

something called the southern Crab

108

00:04:55,889 --> 00:05:04,529

Nebula and this is an image from Hubble

109

00:04:58,529 --> 00:05:08,669

from 1999 in a nitrogen filter okay this

110

00:05:04,529 --> 00:05:12,269

is not a supernova explosion this one

111

00:05:08,670 --> 00:05:13,620

and by the way whenever we say oh it's

112

00:05:12,269 --> 00:05:15,120

the Crab Nebula it's supposed to look

113

00:05:13,620 --> 00:05:17,550

like an crab just squint your eyes a

114

00:05:15,120 --> 00:05:20,310

little bit okay you know then you might

115
00:05:17,550 --> 00:05:21,810
be able to see it honestly this one

116
00:05:20,310 --> 00:05:25,500
looks a little bit more like a tick okay

117
00:05:21,810 --> 00:05:27,360
then a crab to me but you know don't

118
00:05:25,500 --> 00:05:29,399
tell the guys who discovered it new high

119
00:05:27,360 --> 00:05:33,840
released who named it okay so this was

120
00:05:29,399 --> 00:05:35,429
back in 1999 and it was done in with

121
00:05:33,839 --> 00:05:37,289
wide field planetary camera - can we

122
00:05:35,430 --> 00:05:42,480
take the lights down a bit there's a lot

123
00:05:37,290 --> 00:05:43,080
of scattered light on the screen there

124
00:05:42,480 --> 00:05:44,879
you go

125
00:05:43,079 --> 00:05:46,979
so now you can see in the center you can

126
00:05:44,879 --> 00:05:48,870
see this cut off of the edges that's

127
00:05:46,980 --> 00:05:52,740
characteristic of the with pic -

128
00:05:48,870 --> 00:05:55,769
footprint okay so we were going to come

129
00:05:52,740 --> 00:05:58,230
back and do this again and I'm gonna

130
00:05:55,769 --> 00:06:01,049
reorient it for a little bit there okay

131
00:05:58,230 --> 00:06:03,390
and then we have we went and redid this

132
00:06:01,050 --> 00:06:04,860
we also did the nitrogen filter right

133
00:06:03,389 --> 00:06:07,769
but this time we did it with wide field

134
00:06:04,860 --> 00:06:10,470
camera 3 so this is the nitrogen filter

135
00:06:07,769 --> 00:06:12,479
that we did that we also did several

136
00:06:10,470 --> 00:06:15,150
other filters we only had one filter on

137
00:06:12,480 --> 00:06:19,259
this in 1999 we did the oxygen filter

138
00:06:15,149 --> 00:06:22,739
okay and we did the hydrogen alpha

139
00:06:19,259 --> 00:06:25,199
filter and then we did the sulfur filter

140
00:06:22,740 --> 00:06:27,360
so we have four very specific

141
00:06:25,199 --> 00:06:30,420
observations that are these very tiny

142
00:06:27,360 --> 00:06:32,850
filter band passes all right that only

143

00:06:30,420 --> 00:06:36,990
pick out the emission from specific

144
00:06:32,850 --> 00:06:40,000
elements okay and together this was our

145
00:06:36,990 --> 00:06:44,389
release that we came out with last week

146
00:06:40,000 --> 00:06:47,509
all right decide to go ooh this side go

147
00:06:44,389 --> 00:06:49,220
ah thank you very much all right if

148
00:06:47,509 --> 00:06:51,829
we're gonna do this we got to do this

149
00:06:49,220 --> 00:06:54,650
all right so this is the southern Crab

150
00:06:51,829 --> 00:06:56,659
Nebula in four specific filters and you

151
00:06:54,649 --> 00:06:59,599
can see how like at the end of the crabs

152
00:06:56,660 --> 00:07:01,160
legs how it gets green okay well that

153
00:06:59,600 --> 00:07:02,990
indicates that there's only specific

154
00:07:01,160 --> 00:07:04,610
emission in there versus the other

155
00:07:02,990 --> 00:07:06,740
colors you can see how colorful it is

156
00:07:04,610 --> 00:07:10,340
but those colors really mean something

157
00:07:06,740 --> 00:07:13,100

to astronomers all right now this is

158

00:07:10,339 --> 00:07:15,168

what we call a proto planetary nebula

159

00:07:13,100 --> 00:07:17,090

okay you may have heard of planetary

160

00:07:15,168 --> 00:07:19,519

nebulae that's a end stage of a star

161

00:07:17,089 --> 00:07:21,619

where it blows off is it in a nice wind

162

00:07:19,519 --> 00:07:24,228

blows off its outer layers Ince's it

163

00:07:21,620 --> 00:07:26,060

into interstellar space well what we

164

00:07:24,228 --> 00:07:28,519

believe is going on here is that there

165

00:07:26,060 --> 00:07:30,860

is a evolved star well actually a

166

00:07:28,519 --> 00:07:33,680

stellar remnant a white dwarf and then a

167

00:07:30,860 --> 00:07:35,180

dying star a red giant and they're in

168

00:07:33,680 --> 00:07:37,728

orbit around each other in a binary

169

00:07:35,180 --> 00:07:39,350

system and this red giant is giving off

170

00:07:37,728 --> 00:07:41,269

some gas it hasn't quite gotten to the

171

00:07:39,350 --> 00:07:43,430

planetary nebula stays that's why it's

172
00:07:41,269 --> 00:07:45,319
proto planet area Beulah and some of the

173
00:07:43,430 --> 00:07:48,500
material is formed to disk around them

174
00:07:45,319 --> 00:07:50,509
stopping the flow in this direction but

175
00:07:48,500 --> 00:07:53,509
letting the flow go in purple

176
00:07:50,509 --> 00:07:56,060
perpendicular to the disk so that the

177
00:07:53,509 --> 00:07:59,538
flow that you see is coming out in two

178
00:07:56,060 --> 00:08:01,339
bubbles on here and one here that sort

179
00:07:59,538 --> 00:08:03,288
of resembles an hourglass you know where

180
00:08:01,339 --> 00:08:06,138
it's pinched at the center and bulbs

181
00:08:03,288 --> 00:08:08,959
going above and below and so this is a

182
00:08:06,139 --> 00:08:10,910
protoplanetary nebula it probably will

183
00:08:08,959 --> 00:08:14,930
become a full-blown planetary nebula

184
00:08:10,910 --> 00:08:16,939
yeah few million years from now okay all

185
00:08:14,930 --> 00:08:20,329
right now what we really wanted to do

186
00:08:16,939 --> 00:08:22,819
was remind you of what we did to see all

187
00:08:20,329 --> 00:08:25,159
these different features of it so one of

188
00:08:22,819 --> 00:08:27,860
the actually I think the more important

189
00:08:25,160 --> 00:08:32,209
besides the image is this diagram that

190
00:08:27,860 --> 00:08:35,209
takes the southern Crab Nebula breaks it

191
00:08:32,208 --> 00:08:37,819
up into those four filters and then

192
00:08:35,208 --> 00:08:40,278
relates those four filters to a spectrum

193
00:08:37,820 --> 00:08:42,560
okay so this spectrum was taken of the

194
00:08:40,278 --> 00:08:45,039
inner region here and it shows the full

195
00:08:42,559 --> 00:08:48,588
emission across the various wavelengths

196
00:08:45,039 --> 00:08:51,549
of the visible light to remind you that

197
00:08:48,589 --> 00:08:53,270
you know Hubble gets a lot of its

198
00:08:51,549 --> 00:08:56,719
science done by

199
00:08:53,269 --> 00:09:00,588
imaging but it gets just as much science

200

00:08:56,720 --> 00:09:03,200
done using spectra this spectrum that

201
00:09:00,589 --> 00:09:04,670
we're showing here you know I know it's

202
00:09:03,200 --> 00:09:08,149
not the pretty pictures that you're used

203
00:09:04,669 --> 00:09:11,028
to with Hubble but 50% of Hubble science

204
00:09:08,149 --> 00:09:12,919
is done by examining these spectra and

205
00:09:11,028 --> 00:09:14,870
looking for the temperature and the

206
00:09:12,919 --> 00:09:17,240
composition and the motion of these

207
00:09:14,870 --> 00:09:19,879
individual elements of gas to really get

208
00:09:17,240 --> 00:09:22,820
the details of what's going on so it's a

209
00:09:19,879 --> 00:09:25,250
combination of both the imaging and the

210
00:09:22,820 --> 00:09:29,778
spectra that produces the Hubble science

211
00:09:25,250 --> 00:09:32,450
that has advanced astronomy so much now

212
00:09:29,778 --> 00:09:34,490
this is a visualization done by our

213
00:09:32,450 --> 00:09:38,180
department just to sort of get that

214
00:09:34,490 --> 00:09:41,200

point across here you can see that

215

00:09:38,179 --> 00:09:45,879
spectra taken of that central region

216

00:09:41,200 --> 00:09:48,560
pulled out into the full spectrum and

217

00:09:45,879 --> 00:09:51,189
then we take the individual images and

218

00:09:48,559 --> 00:09:51,189
correlate them

219

00:10:07,049 --> 00:10:11,338
now is just one example of how both

220

00:10:09,028 --> 00:10:13,409
imaging and spectrum spectra work

221

00:10:11,339 --> 00:10:17,190
together to get us the science that we

222

00:10:13,409 --> 00:10:19,079
do with Hubble our second story tonight

223

00:10:17,190 --> 00:10:20,550
you might have guessed you I'm sure

224

00:10:19,080 --> 00:10:21,839
you've all seen this before but I

225

00:10:20,549 --> 00:10:24,569
hopefully I'll tell you a few things

226

00:10:21,839 --> 00:10:27,000
that you didn't hear at least from the

227

00:10:24,570 --> 00:10:30,870
mainstream media the black hole in

228

00:10:27,000 --> 00:10:34,769
Messier 87 now first of all what is

229

00:10:30,870 --> 00:10:36,959

Messier 87 it is a giant elliptical

230

00:10:34,769 --> 00:10:39,959

galaxy in the center of the Virgo

231

00:10:36,958 --> 00:10:41,909

cluster it is the larger I think it may

232

00:10:39,958 --> 00:10:44,489

be the largest galaxy in Virgo it's one

233

00:10:41,909 --> 00:10:46,289

of the largest galaxies in Virgo K it's

234

00:10:44,490 --> 00:10:49,320

a giant elliptical all right and this is

235

00:10:46,289 --> 00:10:51,240

the Sloan Digital Sky Survey and down at

236

00:10:49,320 --> 00:10:54,360

its core it has a supermassive black

237

00:10:51,240 --> 00:10:55,799

hole and you can sort of see it in the

238

00:10:54,360 --> 00:10:58,289

center of this image but if we take the

239

00:10:55,799 --> 00:11:01,078

Hubble image and then we zoom in on that

240

00:10:58,289 --> 00:11:03,240

Hubble image you start to see this jet

241

00:11:01,078 --> 00:11:04,259

coming out of the center let me zoom in

242

00:11:03,240 --> 00:11:05,909

one more time

243
00:11:04,259 --> 00:11:08,669
alright now you can definitely see it

244
00:11:05,909 --> 00:11:09,870
okay so there is a bright spot in the

245
00:11:08,669 --> 00:11:12,449
center which is where the supermassive

246
00:11:09,870 --> 00:11:14,370
black hole is and there the material

247
00:11:12,450 --> 00:11:17,490
around the supermassive black hole is

248
00:11:14,370 --> 00:11:19,560
spewing out some material at such speeds

249
00:11:17,490 --> 00:11:22,860
that that material is extending across

250
00:11:19,559 --> 00:11:26,338
five thousand light-years of space okay

251
00:11:22,860 --> 00:11:27,659
yes so we're seeing this jet here and

252
00:11:26,339 --> 00:11:29,550
it's actually kind of cool if you look

253
00:11:27,659 --> 00:11:31,350
at this in infrared of a friend who

254
00:11:29,549 --> 00:11:33,149
works at spitzer he said yeah but in

255
00:11:31,350 --> 00:11:35,220
infrared we can see the jet on the other

256
00:11:33,149 --> 00:11:36,690
side do you see the jet there's no in

257

00:11:35,220 --> 00:11:38,370
the Hubble image you can't see the jet

258
00:11:36,690 --> 00:11:40,170
on the other side but the infrared image

259
00:11:38,370 --> 00:11:41,399
it does glow in the infrared you could

260
00:11:40,169 --> 00:11:45,449
actually see it it was really kind of

261
00:11:41,399 --> 00:11:47,519
cool we were comparing images but you

262
00:11:45,450 --> 00:11:50,129
see that bright spot way down in there

263
00:11:47,519 --> 00:11:50,939
is the supermassive black hole how far

264
00:11:50,129 --> 00:11:54,419
down in there

265
00:11:50,940 --> 00:11:56,910
I wanted to know so I put together this

266
00:11:54,419 --> 00:11:59,490
series of images all right so I had to

267
00:11:56,909 --> 00:12:01,289
go from Hubble to the radio

268
00:11:59,490 --> 00:12:03,680
this is from the Very Large Array radio

269
00:12:01,289 --> 00:12:05,939
at two centimeter and we zoom in to that

270
00:12:03,679 --> 00:12:09,229
and then we had to go to another radio

271
00:12:05,940 --> 00:12:13,040

image from the VLA at seven millimeter

272

00:12:09,230 --> 00:12:15,180

and then we had to start using arrays of

273

00:12:13,039 --> 00:12:17,639

telescopes very long baseline

274

00:12:15,179 --> 00:12:20,578

interferometry this was 18 centimeter

275

00:12:17,639 --> 00:12:20,879

observations here right and then we had

276

00:12:20,578 --> 00:12:23,759

to go

277

00:12:20,879 --> 00:12:25,409

even further using another very long

278

00:12:23,759 --> 00:12:27,929

baseline array but this was back at the

279

00:12:25,409 --> 00:12:31,230

2-centimeter thing and then we had to go

280

00:12:27,929 --> 00:12:34,169

using more very long baseline array at

281

00:12:31,230 --> 00:12:35,909

43 gigahertz and then at the 43

282

00:12:34,169 --> 00:12:38,939

gigahertz we're gonna zoom in on this

283

00:12:35,909 --> 00:12:40,980

yet one more time and finally we're down

284

00:12:38,940 --> 00:12:44,100

to just the emission from the material

285

00:12:40,980 --> 00:12:48,420

around the black hole and see that tiny

286
00:12:44,100 --> 00:12:52,139
little black spot there zoom in and this

287
00:12:48,419 --> 00:12:57,419
is the image of the black hole at the

288
00:12:52,139 --> 00:13:00,179
core of Messier 87 now it's not actually

289
00:12:57,419 --> 00:13:03,719
the black hole okay because facing black

290
00:13:00,179 --> 00:13:06,299
holes are black no light can escape them

291
00:13:03,720 --> 00:13:08,430
they cannot emit any light by definition

292
00:13:06,299 --> 00:13:09,779
okay so this is not an image of the

293
00:13:08,429 --> 00:13:13,409
black hole it's a bunch of the stuff

294
00:13:09,779 --> 00:13:16,980
around the black hole okay so this is

295
00:13:13,409 --> 00:13:20,879
the event horizon is in here the size of

296
00:13:16,980 --> 00:13:23,100
this dark region here is about one and a

297
00:13:20,879 --> 00:13:24,629
half to two times the event horizon of

298
00:13:23,100 --> 00:13:27,000
the black hole and the BLET horizon is

299
00:13:24,629 --> 00:13:30,779
the actual edge and when around that

300
00:13:27,000 --> 00:13:33,179
black hole the okay come on guys let's

301
00:13:30,779 --> 00:13:37,110
turn off the phones here around that

302
00:13:33,179 --> 00:13:39,359
black hole the faces warped so much that

303
00:13:37,110 --> 00:13:41,190
light actually starts circling around

304
00:13:39,360 --> 00:13:43,740
the black hole there's a photon sphere

305
00:13:41,190 --> 00:13:45,060
and such and light gets warped around it

306
00:13:43,740 --> 00:13:46,769
and stretched around and pressed around

307
00:13:45,059 --> 00:13:49,979
and we can predict what it would look

308
00:13:46,769 --> 00:13:52,590
like and actually we predicted it would

309
00:13:49,980 --> 00:13:53,879
look pretty much like this okay now how

310
00:13:52,590 --> 00:13:56,250
many people saw the movie interstellar

311
00:13:53,879 --> 00:13:58,230
right and there was a somewhat

312
00:13:56,250 --> 00:14:00,600
scientific visualization of a black hole

313
00:13:58,230 --> 00:14:02,460
in interstellar and it looked a lot

314

00:14:00,600 --> 00:14:07,680
better than this but then again it was

315
00:14:02,460 --> 00:14:09,240
CG this is real okay this is real and if

316
00:14:07,679 --> 00:14:11,339
you take that interstellar one and you

317
00:14:09,240 --> 00:14:11,730
fuzz it out into the resolution that you

318
00:14:11,340 --> 00:14:13,170
can't

319
00:14:11,730 --> 00:14:15,870
so as you can't see it it actually looks

320
00:14:13,169 --> 00:14:17,909
a lot like this okay all right so this

321
00:14:15,870 --> 00:14:20,399
is what was basically what was predicted

322
00:14:17,909 --> 00:14:22,980
general ativy has been really really

323
00:14:20,399 --> 00:14:26,970
good at predicting what we were going to

324
00:14:22,980 --> 00:14:29,850
see you saw how many times I had to zoom

325
00:14:26,970 --> 00:14:33,690
in in order to show you this this

326
00:14:29,850 --> 00:14:36,960
resolution is 2500

327
00:14:33,690 --> 00:14:40,890
times greater resolution than the Hubble

328
00:14:36,960 --> 00:14:43,889

Space Telescope yeah how did they

329

00:14:40,889 --> 00:14:46,649

achieve that they used eight radio

330

00:14:43,889 --> 00:14:48,899

telescopes across our entire planet

331

00:14:46,649 --> 00:14:52,220

one down itself Pole others spread out

332

00:14:48,899 --> 00:14:55,500

around the world to basically

333

00:14:52,220 --> 00:14:58,740

synthesize a telescope as large as our

334

00:14:55,500 --> 00:15:00,570

entire planet okay now it doesn't have

335

00:14:58,740 --> 00:15:03,600

the collecting area of our entire planet

336

00:15:00,570 --> 00:15:05,700

but it can achieve the resolution of a

337

00:15:03,600 --> 00:15:07,710

telescope as large as our entire planet

338

00:15:05,700 --> 00:15:11,580

so this is basically out as good as we

339

00:15:07,710 --> 00:15:15,060

can do okay and this black hole is 55

340

00:15:11,580 --> 00:15:19,680

million light years away and you know

341

00:15:15,059 --> 00:15:23,729

what it's size is about the size of our

342

00:15:19,679 --> 00:15:28,469

solar system that's the size of

343
00:15:23,730 --> 00:15:30,269
Neptune's orbit compared to black hole

344
00:15:28,470 --> 00:15:33,540
they're complicated and then the event

345
00:15:30,269 --> 00:15:35,899
horizon of the black hole and so being

346
00:15:33,539 --> 00:15:39,389
able to resolve this black hole is

347
00:15:35,899 --> 00:15:43,889
analogous to being able to see a quarter

348
00:15:39,389 --> 00:15:50,879
on the surface of the Moon this is one

349
00:15:43,889 --> 00:15:53,460
incredible achievement here yeah now

350
00:15:50,879 --> 00:15:55,559
there's only one problem with this

351
00:15:53,460 --> 00:15:57,840
alright is we've already created a

352
00:15:55,559 --> 00:15:59,489
telescope as large as our planet it's

353
00:15:57,840 --> 00:16:01,050
kind of hard to create one larger unless

354
00:15:59,490 --> 00:16:03,149
you start sending telescopes out into

355
00:16:01,049 --> 00:16:05,039
space for interferometry and well that's

356
00:16:03,149 --> 00:16:09,329
not gonna be solved anytime soon

357
00:16:05,039 --> 00:16:10,860
the second problem is that if you see

358
00:16:09,330 --> 00:16:12,120
one black hole you've sort of seen them

359
00:16:10,860 --> 00:16:15,389
all all right they're gonna get better

360
00:16:12,120 --> 00:16:17,310
at this but they the photon sphere at

361
00:16:15,389 --> 00:16:19,679
all this this photon wrapping around it

362
00:16:17,309 --> 00:16:21,299
doesn't going to change that much what's

363
00:16:19,679 --> 00:16:22,889
gonna make the next observations

364
00:16:21,299 --> 00:16:24,000
interesting is one they're gonna look at

365
00:16:22,889 --> 00:16:26,730
the black hole at the center of our

366
00:16:24,000 --> 00:16:28,500
galaxy that'll be kind of cool it may

367
00:16:26,730 --> 00:16:30,539
look very similar to this but at least

368
00:16:28,500 --> 00:16:32,759
you know it'll be our black hole not the

369
00:16:30,539 --> 00:16:35,399
one from some other galaxy so I'll have

370
00:16:32,759 --> 00:16:38,159
a sense of pride and - they want to be

371

00:16:35,399 --> 00:16:41,159
able to watch these over time and see

372
00:16:38,159 --> 00:16:43,230
the undulations in the photon the

373
00:16:41,159 --> 00:16:44,969
photons that are happening they want to

374
00:16:43,230 --> 00:16:46,710
see the changes in the emission from

375
00:16:44,970 --> 00:16:47,720
around the black hole and that will

376
00:16:46,710 --> 00:16:50,870
start to tell us more

377
00:16:47,720 --> 00:16:52,610
so just like we started to have a new

378
00:16:50,870 --> 00:16:55,220
field of astronomy with gravitational

379
00:16:52,610 --> 00:16:57,440
wave astronomy a few years ago this is

380
00:16:55,220 --> 00:17:01,009
the beginning of using interferometry to

381
00:16:57,440 --> 00:17:03,830
actually see and study black holes up

382
00:17:01,009 --> 00:17:08,509
close and personal all right so just to

383
00:17:03,830 --> 00:17:11,809
remind you here is the that zoom in but

384
00:17:08,509 --> 00:17:23,910
with a little bit of piano music

385
00:17:11,809 --> 00:17:23,909

[Music]

386

00:17:26,309 --> 00:18:43,849

[Music]

387

00:18:36,519 --> 00:18:45,710

so so really I just put this together

388

00:18:43,849 --> 00:18:47,148

afterwards to try it understand it for

389

00:18:45,710 --> 00:18:49,038

myself and I knew I'd want to show it to

390

00:18:47,148 --> 00:18:51,168

you guys here and then I just threw it

391

00:18:49,038 --> 00:18:52,278

up on YouTube thinking that all right

392

00:18:51,169 --> 00:18:55,070

well maybe other people would like it

393

00:18:52,278 --> 00:18:58,548

it's our second most popular video of

394

00:18:55,069 --> 00:18:59,868

the last nine months obviously we

395

00:18:58,548 --> 00:19:03,970

provided a little bit of context that

396

00:18:59,868 --> 00:19:08,528

that was necessary for tonight alright

397

00:19:03,970 --> 00:19:11,569

you did great so thank you for watching

398

00:19:08,528 --> 00:19:15,729

and now let's go to our featured speaker

399

00:19:11,569 --> 00:19:20,269

tonight dan Millis al millas Savio Vic

400
00:19:15,729 --> 00:19:23,058
is from Purdue University and I did not

401
00:19:20,269 --> 00:19:25,700
get a chance to get his resume before

402
00:19:23,058 --> 00:19:27,858
him so I will let me introduce you to

403
00:19:25,700 --> 00:19:37,970
and let him tell you all about himself

404
00:19:27,858 --> 00:19:39,648
ladies gentlemen Dan Frank thanks very

405
00:19:37,970 --> 00:19:42,169
much for the introduction you are a

406
00:19:39,648 --> 00:19:44,898
difficult act to follow you have lots of

407
00:19:42,169 --> 00:19:49,179
energy I hope I can match it in some

408
00:19:44,898 --> 00:19:52,998
scale now let me just get set up here

409
00:19:49,179 --> 00:19:55,879
make sure that we're live

410
00:19:52,999 --> 00:20:08,179
oh and that didn't work don't look at my

411
00:19:55,878 --> 00:20:11,839
password okay there we go all right it

412
00:20:08,179 --> 00:20:13,489
truly is a pleasure to be here at the

413
00:20:11,839 --> 00:20:16,308
headquarters of some of the most

414
00:20:13,489 --> 00:20:20,659
important scientific instruments ever

415
00:20:16,308 --> 00:20:22,729
designed by humankind like a kid I've

416
00:20:20,659 --> 00:20:25,159
always admired the Hubble Space

417
00:20:22,729 --> 00:20:27,440
Telescope and so to be here today

418
00:20:25,159 --> 00:20:29,869
talking about my use of the Hubble Space

419
00:20:27,440 --> 00:20:32,929
Telescope and other space observatories

420
00:20:29,868 --> 00:20:34,819
is truly a pleasure as was mentioned

421
00:20:32,929 --> 00:20:38,538
we're having a scientific meeting right

422
00:20:34,819 --> 00:20:40,368
now where a lot of experts are getting

423
00:20:38,538 --> 00:20:42,408
together to talk about some of the

424
00:20:40,368 --> 00:20:43,848
phenomena that I'm gonna be reviewing in

425
00:20:42,409 --> 00:20:45,559
this talk and I've tried my best to

426
00:20:43,848 --> 00:20:46,278
incorporate their signs although there

427
00:20:45,558 --> 00:20:49,339
is a lot

428

00:20:46,278 --> 00:20:52,430
yes I'm Daniel e salvage currently

429
00:20:49,339 --> 00:20:55,220
at Purdue University at the Department

430
00:20:52,430 --> 00:20:57,740
of physics and astronomy and I'll be

431
00:20:55,220 --> 00:21:00,680
talking today about the deaths and after

432
00:20:57,740 --> 00:21:03,349
lives of massive stars the workshop

433
00:21:00,680 --> 00:21:05,960
we're doing over the last couple days is

434
00:21:03,349 --> 00:21:08,299
the deaths and after lives of stars so

435
00:21:05,960 --> 00:21:09,710
just to narrow down the focus a little

436
00:21:08,299 --> 00:21:11,930
bit because there are a lot of stars

437
00:21:09,710 --> 00:21:15,230
I'll just be talking about massive stars

438
00:21:11,930 --> 00:21:17,269
and this picture is chosen in particular

439
00:21:15,230 --> 00:21:20,720
you're going to see it a lot the name is

440
00:21:17,269 --> 00:21:22,609
the supernova remnant Cassiopeia A it'll

441
00:21:20,720 --> 00:21:27,170
be the poster child for a lot of what is

442
00:21:22,609 --> 00:21:30,019

to follow I'm here alone up front here

443

00:21:27,170 --> 00:21:32,150

and yet I am backed by a whole Legion of

444

00:21:30,019 --> 00:21:35,259

super nova superheroes that help me on a

445

00:21:32,150 --> 00:21:39,070

daily basis I just want to flash their

446

00:21:35,259 --> 00:21:43,039

pictures up front in the audience is my

447

00:21:39,069 --> 00:21:44,779

trusty CL yes honor ACL Johnson

448

00:21:43,039 --> 00:21:48,319

postdoctoral fellow at higher Kesava

449

00:21:44,779 --> 00:21:51,349

part of the Boilermakers at Purdue

450

00:21:48,319 --> 00:21:54,200

University as part of my group just

451

00:21:51,349 --> 00:21:56,419

brilliant students and experts that I

452

00:21:54,200 --> 00:21:58,549

get to work with on a daily basis to

453

00:21:56,420 --> 00:22:03,200

tackle these pressing problems all right

454

00:21:58,549 --> 00:22:05,089

that's that's the introduction the first

455

00:22:03,200 --> 00:22:11,000

thing I want to talk about is that we

456

00:22:05,089 --> 00:22:14,750

have watched stars explode up front is

457
00:22:11,000 --> 00:22:17,720
an image of a star San juliek - 69 - OH

458
00:22:14,750 --> 00:22:18,829
- it's in the Large Magellanic Cloud now

459
00:22:17,720 --> 00:22:21,650
has anybody been in the southern

460
00:22:18,829 --> 00:22:24,019
hemisphere before some people okay for

461
00:22:21,650 --> 00:22:26,450
those who have if you look up at the sky

462
00:22:24,019 --> 00:22:28,430
first you see oh my gosh the

463
00:22:26,450 --> 00:22:30,980
constellations they're upside down right

464
00:22:28,430 --> 00:22:32,600
and then if you look a little bit more

465
00:22:30,980 --> 00:22:35,210
closely you may notice that there's

466
00:22:32,599 --> 00:22:37,339
these fuzzy patches these two fuzzy

467
00:22:35,210 --> 00:22:39,319
patches are actually satellite galaxies

468
00:22:37,339 --> 00:22:40,609
neighboring galaxies the large imagina

469
00:22:39,319 --> 00:22:44,269
antic clouds and in the Large Magellanic

470
00:22:40,609 --> 00:22:47,269
Cloud is this star now if it weren't for

471
00:22:44,269 --> 00:22:48,769
the arrow nothing would be really that

472
00:22:47,269 --> 00:22:50,359
different about this star from many

473
00:22:48,769 --> 00:22:52,039
others that we see in the field here we

474
00:22:50,359 --> 00:22:54,439
see something of comparable brightness

475
00:22:52,039 --> 00:22:57,799
up in the corner something even bigger

476
00:22:54,440 --> 00:23:00,320
and brighter right but the arrow tells

477
00:22:57,799 --> 00:23:04,579
you something's gonna happen right

478
00:23:00,319 --> 00:23:07,398
and indeed on February 23rd 1987 this is

479
00:23:04,579 --> 00:23:09,109
what was observed okay a supernova the

480
00:23:07,398 --> 00:23:11,658
star had exploded

481
00:23:09,109 --> 00:23:13,729
well actually the star exploded about a

482
00:23:11,659 --> 00:23:15,230
hundred and sixty thousand years ago and

483
00:23:13,730 --> 00:23:17,058
it took that amount of time for the

484
00:23:15,230 --> 00:23:18,500
light to actually come to the earth

485

00:23:17,058 --> 00:23:21,859
which is something to think about

486
00:23:18,500 --> 00:23:23,148
I mean 160,000 years ago modern man

487
00:23:21,859 --> 00:23:25,459
would have been involved probably not

488
00:23:23,148 --> 00:23:28,668
migrated out of africa at that point

489
00:23:25,460 --> 00:23:30,230
there's just a lot a lot of history that

490
00:23:28,669 --> 00:23:33,559
has happened since then but an on

491
00:23:30,230 --> 00:23:38,240
February 23rd 1987 it was sighted now

492
00:23:33,558 --> 00:23:42,710
the naming convention supernova SN 1987a

493
00:23:38,240 --> 00:23:44,720
and then it goes to quench ABCDE etc

494
00:23:42,710 --> 00:23:47,419
right so this was the first supernova of

495
00:23:44,720 --> 00:23:52,970
1987 and appropriately it was Co

496
00:23:47,419 --> 00:23:55,460
discovered by a Canadian 1987a I I'm

497
00:23:52,970 --> 00:23:58,639
Canadian I'm Canadian so I could make

498
00:23:55,460 --> 00:24:01,069
that joke every time by Ian Shelton and

499
00:23:58,638 --> 00:24:02,990

one of the observing assistants Oscar

500

00:24:01,069 --> 00:24:05,269

Duhalde it at last Campanas Observatory

501

00:24:02,990 --> 00:24:07,370

have had the fortune of met meeting and

502

00:24:05,269 --> 00:24:10,278

has told me the whole story of their

503

00:24:07,369 --> 00:24:12,979

exciting discovery so that was the

504

00:24:10,278 --> 00:24:14,898

explosion and then returning years later

505

00:24:12,980 --> 00:24:16,250

with the razor-sharp vision of the

506

00:24:14,898 --> 00:24:18,079

Hubble Space Telescope

507

00:24:16,250 --> 00:24:20,929

there it is drifting in the center of

508

00:24:18,079 --> 00:24:24,500

the field let's do an enlargement here

509

00:24:20,929 --> 00:24:26,149

okay the star has vanished now for the

510

00:24:24,500 --> 00:24:28,369

untrained eye there's a lot of structure

511

00:24:26,148 --> 00:24:29,148

going on don't be distracted by these

512

00:24:28,369 --> 00:24:31,819

rings

513

00:24:29,148 --> 00:24:34,069

this was actually shed by the progenitor

514
00:24:31,819 --> 00:24:35,808
star system what we think is not

515
00:24:34,069 --> 00:24:37,878
necessarily one star but potentially two

516
00:24:35,808 --> 00:24:40,250
stars in orbit that flung off this

517
00:24:37,878 --> 00:24:42,469
material prior to the explosion and this

518
00:24:40,250 --> 00:24:44,509
ring as well is also thought to be

519
00:24:42,470 --> 00:24:47,000
associated with the star prior to

520
00:24:44,509 --> 00:24:49,960
explosion but in the middle this debris

521
00:24:47,000 --> 00:24:54,009
right that's associated with the

522
00:24:49,960 --> 00:24:59,329
explosion itself truly the star is gone

523
00:24:54,009 --> 00:25:02,839
Sandu Lake my -69 202 is no more we're

524
00:24:59,329 --> 00:25:05,628
gonna use this as a kind of a prototype

525
00:25:02,839 --> 00:25:07,128
to understand all the various supernova

526
00:25:05,628 --> 00:25:10,058
explosions that are happening in the

527
00:25:07,128 --> 00:25:12,859
universe in all their various forms I

528
00:25:10,058 --> 00:25:13,859
like to put this up front why is this

529
00:25:12,859 --> 00:25:16,139
important why

530
00:25:13,859 --> 00:25:18,719
do I care right what and why should you

531
00:25:16,140 --> 00:25:20,580
care so among other things supernova

532
00:25:18,720 --> 00:25:23,429
influence the energy balance structure

533
00:25:20,579 --> 00:25:25,710
and chemical makeup of galaxies they can

534
00:25:23,429 --> 00:25:27,559
help trigger stars new stars so that one

535
00:25:25,710 --> 00:25:30,120
death can trigger new stars from forming

536
00:25:27,558 --> 00:25:31,829
they're a major source of dust in the

537
00:25:30,119 --> 00:25:33,659
universe and not the dust that you get

538
00:25:31,829 --> 00:25:36,928
on a table from not dusting for a while

539
00:25:33,660 --> 00:25:38,759
but Astrophysical dust they produce a

540
00:25:36,929 --> 00:25:40,559
variety of exotic objects that maybe

541
00:25:38,759 --> 00:25:42,269
you've heard about before things like

542

00:25:40,558 --> 00:25:44,460
neutron stars which we'll talk about

543
00:25:42,269 --> 00:25:47,519
black holes and some gamma-ray bursts

544
00:25:44,460 --> 00:25:49,110
they produce copious neutrinos the

545
00:25:47,519 --> 00:25:51,000
subatomic particle that we're going to

546
00:25:49,109 --> 00:25:53,639
come across later their progenitors of

547
00:25:51,000 --> 00:25:55,230
gravitational wave systems so we've

548
00:25:53,640 --> 00:25:57,929
heard about maybe merging black holes

549
00:25:55,230 --> 00:26:00,870
those black holes came from supernova

550
00:25:57,929 --> 00:26:02,910
explosions and as we'll learn they

551
00:26:00,869 --> 00:26:06,569
produce gravitational waves themselves

552
00:26:02,910 --> 00:26:09,240
and most important for us they produce

553
00:26:06,569 --> 00:26:12,509
all the raw materials that make life

554
00:26:09,240 --> 00:26:14,400
possible right so thus as citizens of

555
00:26:12,509 --> 00:26:16,289
the universe it's terribly important

556
00:26:14,400 --> 00:26:19,470

that we understand this fundamental

557

00:26:16,289 --> 00:26:21,178
process that goes on right so it

558

00:26:19,470 --> 00:26:24,720
emphasized I mean the iron in our blood

559

00:26:21,179 --> 00:26:29,250
the calcium in our bones and the oxygen

560

00:26:24,720 --> 00:26:32,940
we breathe love that oxygen it's all

561

00:26:29,250 --> 00:26:35,069
thanks to supernova explosions so if I

562

00:26:32,940 --> 00:26:37,440
gotten you some interest are you you

563

00:26:35,069 --> 00:26:41,639
wanting to learn a little bit more okay

564

00:26:37,440 --> 00:26:43,500
very good I always find this helpful so

565

00:26:41,640 --> 00:26:45,750
this is a little movie that's going to

566

00:26:43,500 --> 00:26:47,579
show a comparison of star sizes and it

567

00:26:45,750 --> 00:26:51,839
starts off with things familiar like the

568

00:26:47,579 --> 00:26:52,659
moon okay and it has some cool Harry

569

00:26:51,839 --> 00:26:54,559
Potter like

570

00:26:52,660 --> 00:26:56,310
[Music]

571
00:26:54,559 --> 00:26:58,990
there's the moon and Mercury

572
00:26:56,309 --> 00:27:01,990
[Music]

573
00:26:58,990 --> 00:27:03,609
Mars the Red Planet

574
00:27:01,990 --> 00:27:05,680
[Music]

575
00:27:03,609 --> 00:27:09,139
is hot don't wanna live there want to

576
00:27:05,680 --> 00:27:10,960
live on earth yes we're there

577
00:27:09,140 --> 00:27:14,370
nice place to be

578
00:27:10,960 --> 00:27:17,970
step back and we see Neptune

579
00:27:14,369 --> 00:27:20,019
Saturn without the Rings just palpable

580
00:27:17,970 --> 00:27:21,610
in size of Jupiter

581
00:27:20,019 --> 00:27:24,420
but now we're going to step back to some

582
00:27:21,609 --> 00:27:26,619
stars the Sun and many people are

583
00:27:24,420 --> 00:27:27,519
surprised to learn that the Sun is not a

584
00:27:26,619 --> 00:27:28,659
big star

585
00:27:27,519 --> 00:27:30,220
it's not the biggest star there are

586
00:27:28,660 --> 00:27:32,769
other stars like Sirius the brightest

587
00:27:30,220 --> 00:27:34,569
star player right now polish now we're

588
00:27:32,769 --> 00:27:36,960
getting to an orange giant and looking

589
00:27:34,569 --> 00:27:36,960
we're getting

590
00:27:37,509 --> 00:27:44,480
our tourists are a giant Aldebaran

591
00:27:41,690 --> 00:27:47,450
the color changes right function of the

592
00:27:44,480 --> 00:27:48,710
temperature now Rigel alcohol now we get

593
00:27:47,450 --> 00:27:49,940
back

594
00:27:48,710 --> 00:27:53,410
this is a star we're gonna get even

595
00:27:49,940 --> 00:27:55,799
larger Qatar is a bleep

596
00:27:53,410 --> 00:27:55,800
it's long gone

597
00:27:56,329 --> 00:28:01,129
[Music]

598
00:27:57,650 --> 00:28:04,970
and then VOR Canis Majoris one of the

599

00:28:01,130 --> 00:28:08,090
largest stars in the universe and now

600
00:28:04,970 --> 00:28:12,529
we're gonna zoom into a long-term

601
00:28:08,089 --> 00:28:15,549
horizon and I think there's the size of

602
00:28:12,529 --> 00:28:20,079
Earth by comparison and so just imagine

603
00:28:15,549 --> 00:28:22,819
this star exploding with us there right

604
00:28:20,079 --> 00:28:23,869
no it's not gonna happen but that's the

605
00:28:22,819 --> 00:28:26,119
context okay

606
00:28:23,869 --> 00:28:28,339
the takeaway point is that the Sun is

607
00:28:26,119 --> 00:28:30,139
actually a very modest size stars and

608
00:28:28,339 --> 00:28:35,058
there are a lot larger stars in the

609
00:28:30,140 --> 00:28:38,179
universe some other background material

610
00:28:35,058 --> 00:28:42,410
is understanding that the more mass of a

611
00:28:38,179 --> 00:28:45,170
star is the shorter its life the

612
00:28:42,410 --> 00:28:48,290
benchmark is the Sun we take things in

613
00:28:45,170 --> 00:28:50,539

terms of the masses of the Sun so one

614

00:28:48,289 --> 00:28:52,909
solar mass is like the Sun and the

615

00:28:50,539 --> 00:28:55,700
lifespan of the Sun is a healthy 10

616

00:28:52,910 --> 00:28:58,040
billion years but as we increase in mass

617

00:28:55,700 --> 00:28:59,660
you can see that the time frame gets

618

00:28:58,039 --> 00:29:02,869
shorter such that around ten million

619

00:28:59,660 --> 00:29:05,000
years we're getting more towards sorry

620

00:29:02,869 --> 00:29:07,729
ten solar masses we're getting towards

621

00:29:05,000 --> 00:29:10,308
about 30 million years and then getting

622

00:29:07,730 --> 00:29:14,329
heavier towards 60 it's shorter so in

623

00:29:10,308 --> 00:29:16,940
terms of stellar life they the more

624

00:29:14,329 --> 00:29:21,409
massive they are the shorter the more

625

00:29:16,940 --> 00:29:24,320
vigorous life span that they have also

626

00:29:21,410 --> 00:29:26,750
the more massive it is generally

627

00:29:24,319 --> 00:29:30,189
speaking the different kind of remnant

628
00:29:26,750 --> 00:29:32,750
product that it may have yeah so I

629
00:29:30,190 --> 00:29:34,039
forgot to mention something and this is

630
00:29:32,750 --> 00:29:35,808
very important a lot of people get

631
00:29:34,039 --> 00:29:37,369
nervous that the Sun will go this

632
00:29:35,808 --> 00:29:41,240
supernova explosion that I'm talking

633
00:29:37,369 --> 00:29:42,949
about but that will not happen this

634
00:29:41,240 --> 00:29:45,410
there's a cut-off mass somewhere in

635
00:29:42,950 --> 00:29:46,940
between here maybe around eight to ten

636
00:29:45,410 --> 00:29:48,410
solar masses and in fact this is a

637
00:29:46,940 --> 00:29:50,299
discussion that we've had at this

638
00:29:48,410 --> 00:29:52,580
meeting is determining what the critical

639
00:29:50,299 --> 00:29:54,710
mass is for core collapse but it's

640
00:29:52,579 --> 00:29:56,329
certainly well above the sun's mass so

641
00:29:54,710 --> 00:29:58,490
we will not have to worry about a fate

642
00:29:56,329 --> 00:30:01,730
of a supernova The Sun will has other

643
00:29:58,490 --> 00:30:05,960
things in mind for us when it dies yeah

644
00:30:01,730 --> 00:30:08,150
but once it reaches that supernova

645
00:30:05,960 --> 00:30:10,190
ability massive about eight to ten solar

646
00:30:08,150 --> 00:30:11,120
masses you can develop compact object

647
00:30:10,190 --> 00:30:13,700
like a neutron

648
00:30:11,119 --> 00:30:15,829
star or if you're even much larger in

649
00:30:13,700 --> 00:30:18,890
mass you may develop into a black hole

650
00:30:15,829 --> 00:30:21,109
you have the gravitational potentially

651
00:30:18,890 --> 00:30:24,050
needed to continue that collapse down

652
00:30:21,109 --> 00:30:26,269
into a singularity now there isn't a

653
00:30:24,049 --> 00:30:28,279
one-to-one correspondence and I'm gonna

654
00:30:26,269 --> 00:30:31,279
put a caveat here another thing

655
00:30:28,279 --> 00:30:33,799
addressed in this meeting is that

656

00:30:31,279 --> 00:30:36,680
sometimes you can have more massive

657
00:30:33,799 --> 00:30:38,869
stars that have alternative pathways to

658
00:30:36,680 --> 00:30:41,330
becoming a neutron star so it's it's

659
00:30:38,869 --> 00:30:43,939
fairly complex but if you understand

660
00:30:41,329 --> 00:30:45,859
that there's a certain mass range for

661
00:30:43,940 --> 00:30:48,500
which you have compact objects of

662
00:30:45,859 --> 00:30:49,308
neutron stars and black holes that's

663
00:30:48,500 --> 00:30:51,140
very good

664
00:30:49,308 --> 00:30:53,750
whereas more modest stars like the Sun

665
00:30:51,140 --> 00:30:56,450
will not develop these they'll collapse

666
00:30:53,750 --> 00:30:59,569
into something like a white dwarf and

667
00:30:56,450 --> 00:31:01,130
this can go on to a different supernova

668
00:30:59,569 --> 00:31:02,869
progenitors system the type 1a

669
00:31:01,130 --> 00:31:05,450
supernovae that are associated with

670
00:31:02,869 --> 00:31:07,369

measurements of in cosmology which is

671

00:31:05,450 --> 00:31:09,710

not the focus of our talk we will be

672

00:31:07,369 --> 00:31:13,969

focusing on the more massive stars about

673

00:31:09,710 --> 00:31:16,100

10 solar masses and larger now a lot of

674

00:31:13,970 --> 00:31:19,490

things can happen with these compact

675

00:31:16,099 --> 00:31:22,969

object they're highly compressed right I

676

00:31:19,490 --> 00:31:24,650

mean I could like sit on it and compress

677

00:31:22,970 --> 00:31:27,620

those neutrons to get as far as they

678

00:31:24,650 --> 00:31:29,120

could and we have because they're so far

679

00:31:27,619 --> 00:31:30,859

compressed there's strong gravitational

680

00:31:29,119 --> 00:31:33,379

sources that can be now be detected with

681

00:31:30,859 --> 00:31:35,750

gravitational wave facilities the first

682

00:31:33,380 --> 00:31:38,690

hubbub was over the detection thanks to

683

00:31:35,750 --> 00:31:41,119

advanced LIGO of merging black holes and

684

00:31:38,690 --> 00:31:43,759

maybe there is some discussion here at

685
00:31:41,119 --> 00:31:46,419
some point about that right and now more

686
00:31:43,759 --> 00:31:49,700
recently they've been able to detect

687
00:31:46,420 --> 00:31:51,380
merging neutron stars okay so these must

688
00:31:49,700 --> 00:31:53,150
have been two supernova explosions in

689
00:31:51,380 --> 00:31:56,270
close enough proximity that that remnant

690
00:31:53,150 --> 00:31:58,730
neutron stars came into a final orbit

691
00:31:56,269 --> 00:32:01,609
and what's exciting about these systems

692
00:31:58,730 --> 00:32:04,849
is that it's not just left to the

693
00:32:01,609 --> 00:32:09,049
gravitational wave facilities but these

694
00:32:04,849 --> 00:32:10,849
emit and other messengers in the e/m

695
00:32:09,049 --> 00:32:12,409
frequencies so here we have gamma rays

696
00:32:10,849 --> 00:32:16,039
and here we have an image with the

697
00:32:12,410 --> 00:32:17,840
Hubble Space Telescope so this is a new

698
00:32:16,039 --> 00:32:19,159
era of multi messenger astronomy and

699
00:32:17,839 --> 00:32:20,269
perhaps you've heard of this this is

700
00:32:19,160 --> 00:32:22,340
something that's gaining a lot of

701
00:32:20,269 --> 00:32:26,500
traction traction is very exciting and

702
00:32:22,339 --> 00:32:26,500
something I'll come back to at the

703
00:32:26,888 --> 00:32:34,178
okay what about my science or what is it

704
00:32:32,569 --> 00:32:37,490
that I want to talk to you most

705
00:32:34,179 --> 00:32:39,919
particularly one is what are the types

706
00:32:37,490 --> 00:32:41,868
of stars that explode in the supernova

707
00:32:39,919 --> 00:32:44,480
explosions we've come across there's

708
00:32:41,868 --> 00:32:46,339
great diversity in their properties in

709
00:32:44,480 --> 00:32:49,099
the chemical elements and the amount of

710
00:32:46,339 --> 00:32:51,408
energy that they have this can be traced

711
00:32:49,099 --> 00:32:54,829
to the type of star that gives way to

712
00:32:51,409 --> 00:32:57,769
the explosion the other question is the

713

00:32:54,829 --> 00:33:00,048
physical one how is it that stars

714
00:32:57,769 --> 00:33:02,569
explode what is the mechanism that

715
00:33:00,048 --> 00:33:04,190
allows this process to take place and

716
00:33:02,569 --> 00:33:06,019
we're going to get into the details

717
00:33:04,190 --> 00:33:07,610
about that a little bit but these are

718
00:33:06,019 --> 00:33:12,288
the guiding questions that I'm going to

719
00:33:07,609 --> 00:33:14,658
provide context for one is the single

720
00:33:12,288 --> 00:33:17,298
star scenario right and this has been

721
00:33:14,659 --> 00:33:21,159
one that has driven the community for a

722
00:33:17,298 --> 00:33:24,408
long time but as we pay more as we

723
00:33:21,159 --> 00:33:27,200
investigate the the matter more in

724
00:33:24,409 --> 00:33:30,049
detail we find that single stars are not

725
00:33:27,200 --> 00:33:32,028
the majority of the systems that we find

726
00:33:30,048 --> 00:33:34,668
in fact the more massive you get the

727
00:33:32,028 --> 00:33:37,490

more often it is that a massive star has

728

00:33:34,669 --> 00:33:40,369

a binary companion and this affects the

729

00:33:37,490 --> 00:33:42,109

evolution of the star so this isn't

730

00:33:40,368 --> 00:33:44,720

getting into the question are what are

731

00:33:42,109 --> 00:33:46,878

the types of stars that explode now I

732

00:33:44,720 --> 00:33:49,129

grew up in the age where this was the

733

00:33:46,878 --> 00:33:50,538

type of supernova progenitors system but

734

00:33:49,128 --> 00:33:52,398

now we're getting in the aged and trying

735

00:33:50,538 --> 00:33:54,109

to understand binary evolution and this

736

00:33:52,398 --> 00:33:55,579

is why I've hired this brilliantly

737

00:33:54,109 --> 00:33:56,928

hawkish Robin to help me with this

738

00:33:55,579 --> 00:34:00,349

because she understands this too much

739

00:33:56,929 --> 00:34:02,990

greater detail than I do so it's a

740

00:34:00,349 --> 00:34:04,939

beautiful dance of the two stars as they

741

00:34:02,990 --> 00:34:08,898

go back and forth and material can be

742
00:34:04,940 --> 00:34:10,878
drawn from one into another and here's a

743
00:34:08,898 --> 00:34:12,648
statistic here so more than 70% of

744
00:34:10,878 --> 00:34:14,568
massive stars will exchange mass with a

745
00:34:12,648 --> 00:34:17,719
companion at some point leading to a

746
00:34:14,568 --> 00:34:19,308
binary merger in 1/3 of the classes I've

747
00:34:17,719 --> 00:34:21,168
heard the analogy actually if you take

748
00:34:19,309 --> 00:34:24,200
two of these massive stars and you

749
00:34:21,168 --> 00:34:26,779
imagine them be about the size of a fist

750
00:34:24,199 --> 00:34:29,868
and they start off at at this distance

751
00:34:26,780 --> 00:34:34,639
apart at some point in the evolution the

752
00:34:29,869 --> 00:34:37,669
star will expand to such a size will

753
00:34:34,639 --> 00:34:38,419
occupy almost this room in size so

754
00:34:37,668 --> 00:34:40,539
certainly

755
00:34:38,418 --> 00:34:42,588
they'll consume the star next to him

756
00:34:40,539 --> 00:34:47,119
certainly that has effect on its

757
00:34:42,588 --> 00:34:49,449
evolution the Hubble Space Telescope has

758
00:34:47,119 --> 00:34:52,608
played a critical role in identifying

759
00:34:49,449 --> 00:34:54,939
the types of stars that give way to the

760
00:34:52,608 --> 00:34:59,269
different types of supernova explosions

761
00:34:54,940 --> 00:35:01,818
so here we have pre explosion images and

762
00:34:59,269 --> 00:35:04,280
the actual supernova explosions on the

763
00:35:01,818 --> 00:35:06,318
right panel so you can see that big blur

764
00:35:04,280 --> 00:35:09,769
that's that's a bright source that's a

765
00:35:06,318 --> 00:35:13,940
supernova supernova so what one does is

766
00:35:09,769 --> 00:35:15,440
if a supernova is detected can I go back

767
00:35:13,940 --> 00:35:17,659
to the scene of the crime before it

768
00:35:15,440 --> 00:35:20,119
happened kind of rewind the tape and

769
00:35:17,659 --> 00:35:22,368
look at the perpetrator what star was

770

00:35:20,119 --> 00:35:24,559
there before hands so did hub will

771
00:35:22,369 --> 00:35:27,170
happen to take an image of that field

772
00:35:24,559 --> 00:35:30,048
before the explosion took place and

773
00:35:27,170 --> 00:35:32,690
indeed Hubble has been able to and it's

774
00:35:30,048 --> 00:35:35,420
been color-coded in a very clever way by

775
00:35:32,690 --> 00:35:38,480
Stephen Smart such that red is

776
00:35:35,420 --> 00:35:42,588
indicative of a red supergiant red star

777
00:35:38,480 --> 00:35:45,170
and you can see red sources here so we

778
00:35:42,588 --> 00:35:47,409
can fit these with stellar tracks which

779
00:35:45,170 --> 00:35:49,700
is to say understanding the the

780
00:35:47,409 --> 00:35:52,279
distribution of light across its

781
00:35:49,699 --> 00:35:54,909
wavelengths and how bright it is to

782
00:35:52,280 --> 00:35:58,309
constrain the properties of the star

783
00:35:54,909 --> 00:35:59,808
these are the explosions where the

784
00:35:58,309 --> 00:36:02,150

ejecta contain a lot of hydrogen

785

00:35:59,809 --> 00:36:05,839

hydrogen rich supernova explosions

786

00:36:02,150 --> 00:36:08,838

however this process has been difficult

787

00:36:05,838 --> 00:36:11,150

for the stars where there is little

788

00:36:08,838 --> 00:36:14,000

hydrogen left behind or perhaps none at

789

00:36:11,150 --> 00:36:16,880

all that process that I showed of two

790

00:36:14,000 --> 00:36:18,798

stars dancing around potentially one can

791

00:36:16,880 --> 00:36:21,950

give its hydrogen to another star

792

00:36:18,798 --> 00:36:24,199

stripping it behind and when we try to

793

00:36:21,949 --> 00:36:26,598

do the same game of finding the

794

00:36:24,199 --> 00:36:28,960

progenitor star in the locations of

795

00:36:26,599 --> 00:36:32,329

these stripped envelope supernovae

796

00:36:28,960 --> 00:36:34,818

sometimes we come up empty and it's

797

00:36:32,329 --> 00:36:36,500

happened a lot so much that it kind of

798

00:36:34,818 --> 00:36:39,829

makes us nervous that we don't really

799
00:36:36,500 --> 00:36:41,838
understand what's going on now patience

800
00:36:39,829 --> 00:36:44,210
has paid off and we've been able to do

801
00:36:41,838 --> 00:36:46,969
this for a number of systems but it's

802
00:36:44,210 --> 00:36:49,608
challenging so here you can see a lot of

803
00:36:46,969 --> 00:36:51,230
pixels but scientists that can actually

804
00:36:49,608 --> 00:36:51,750
make use of that to try and make a

805
00:36:51,230 --> 00:36:53,880
little bit of

806
00:36:51,750 --> 00:36:58,199
constraint about what kind of star was

807
00:36:53,880 --> 00:37:00,119
there before heads here is a star that

808
00:36:58,199 --> 00:37:02,460
has been more stripped than these other

809
00:37:00,119 --> 00:37:04,949
systems but you can see we're at the

810
00:37:02,460 --> 00:37:06,840
level we're straining for information

811
00:37:04,949 --> 00:37:09,329
but we can still extract it because

812
00:37:06,840 --> 00:37:12,690
Hubble has such great resolution at this

813
00:37:09,329 --> 00:37:14,489
level you see those little little darker

814
00:37:12,690 --> 00:37:16,980
areas compared to the surrounding

815
00:37:14,489 --> 00:37:18,689
there's a star buried in there we're

816
00:37:16,980 --> 00:37:21,389
able to understand its properties and

817
00:37:18,690 --> 00:37:23,610
this is always amusing sometimes you

818
00:37:21,389 --> 00:37:25,230
know this is the image the field Hubble

819
00:37:23,610 --> 00:37:27,300
has only a certain field of view so you

820
00:37:25,230 --> 00:37:29,670
take an image it's not necessarily the

821
00:37:27,300 --> 00:37:32,039
case that it'll cover the field of view

822
00:37:29,670 --> 00:37:35,490
so in this case we can't just at the

823
00:37:32,039 --> 00:37:37,230
edge of the chip and I can't tell you

824
00:37:35,489 --> 00:37:39,299
how many times I've gone through the

825
00:37:37,230 --> 00:37:45,320
archive to look at a supernovae position

826
00:37:39,300 --> 00:37:48,030
and find it there instead not good yeah

827

00:37:45,320 --> 00:37:50,100
okay so that is the type of progenitor

828
00:37:48,030 --> 00:37:52,080
star let's think a little bit more about

829
00:37:50,099 --> 00:37:53,789
physics now whenever I tell people I

830
00:37:52,079 --> 00:37:55,799
teach physics or physics astronomy

831
00:37:53,789 --> 00:37:58,199
sometimes they stand back and you know

832
00:37:55,800 --> 00:37:59,670
they say I was never very good at

833
00:37:58,199 --> 00:38:01,859
physics but I'm gonna hold your hand

834
00:37:59,670 --> 00:38:08,400
we're just gonna go over the the basic

835
00:38:01,860 --> 00:38:12,059
top process here a star starts off as a

836
00:38:08,400 --> 00:38:14,450
big ball of hydrogen and that center all

837
00:38:12,059 --> 00:38:16,920
this gravity allows it to go through

838
00:38:14,449 --> 00:38:20,099
nuclear fusion taking that hydrogen

839
00:38:16,920 --> 00:38:22,230
producing helium now when it runs out of

840
00:38:20,099 --> 00:38:24,029
hydrogen in the core okay then it has to

841
00:38:22,230 --> 00:38:25,679

start burning the helium that started

842

00:38:24,030 --> 00:38:28,170

depositing in its place because of the

843

00:38:25,679 --> 00:38:29,639

Steven and then when that helium runs

844

00:38:28,170 --> 00:38:31,139

out that it has to run to the next fuel

845

00:38:29,639 --> 00:38:33,389

and so what it ends up doing through

846

00:38:31,139 --> 00:38:35,869

successive stages of nuclear fusion you

847

00:38:33,389 --> 00:38:39,799

have this kind of onion skin interior

848

00:38:35,869 --> 00:38:42,690

now this works until you get to iron

849

00:38:39,800 --> 00:38:45,420

when you get to iron this process of

850

00:38:42,690 --> 00:38:46,950

fusion is no longer exothermic do you

851

00:38:45,420 --> 00:38:49,230

know that that name so it no longer

852

00:38:46,949 --> 00:38:52,379

releases energy it actually absorbs

853

00:38:49,230 --> 00:38:55,289

energy so the core no longer has the

854

00:38:52,380 --> 00:38:59,730

radiative pressure it needs for gravity

855

00:38:55,289 --> 00:39:04,019

that wants to bring it together that's

856
00:38:59,730 --> 00:39:05,858
the core collapse here there's a diagram

857
00:39:04,019 --> 00:39:08,048
going showing so we're

858
00:39:05,858 --> 00:39:13,630
near the core there's originally a core

859
00:39:08,048 --> 00:39:16,239
collapse now the core collapses a lot of

860
00:39:13,630 --> 00:39:19,088
stuff happens yeah

861
00:39:16,239 --> 00:39:21,670
in essence you have a lot of protons so

862
00:39:19,088 --> 00:39:25,119
all these years of making heavier

863
00:39:21,670 --> 00:39:27,459
elements gets disrupted you come down to

864
00:39:25,119 --> 00:39:30,278
protons but they gets squished down with

865
00:39:27,458 --> 00:39:32,199
electrons forming neutrons yeah this

866
00:39:30,278 --> 00:39:33,880
releases copious neutrinos these

867
00:39:32,199 --> 00:39:36,909
subatomic particles they're released in

868
00:39:33,880 --> 00:39:39,880
in the process but it reaches to this

869
00:39:36,909 --> 00:39:42,670
point of neutrons and in the neutrons

870
00:39:39,880 --> 00:39:46,059
say I'm not getting any closer together

871
00:39:42,670 --> 00:39:48,670
sorry I'm making my space so the mid

872
00:39:46,059 --> 00:39:50,798
there is a bounce so it reaches this

873
00:39:48,670 --> 00:39:53,079
neutron degeneracy pressure and then it

874
00:39:50,798 --> 00:39:56,288
tries to read like it bounces off that

875
00:39:53,079 --> 00:39:58,239
it's a hard core now it was thought that

876
00:39:56,289 --> 00:40:01,299
that would be what would drive the

877
00:39:58,239 --> 00:40:03,458
supernova explosion but decades of

878
00:40:01,298 --> 00:40:06,728
simulations have shown it just doesn't

879
00:40:03,458 --> 00:40:09,728
work so comes down to this Neutron core

880
00:40:06,728 --> 00:40:12,548
Neutron rich core bounces but then all

881
00:40:09,728 --> 00:40:15,218
the material the star still continues to

882
00:40:12,548 --> 00:40:18,548
push onward on it it needs an additional

883
00:40:15,219 --> 00:40:22,269
heating source to reinvigorate the shock

884

00:40:18,548 --> 00:40:24,429
to push it out and disrupt the star we

885
00:40:22,268 --> 00:40:26,439
think that that heating source is

886
00:40:24,429 --> 00:40:28,028
largely associated with the neutrinos

887
00:40:26,440 --> 00:40:30,849
that I mentioned so these are these

888
00:40:28,028 --> 00:40:33,759
subatomic particles produced when these

889
00:40:30,849 --> 00:40:37,410
protons except electrons and through the

890
00:40:33,759 --> 00:40:37,409
process of photos to the disintegration

891
00:40:38,248 --> 00:40:43,988
that's one idea and so they're yes and

892
00:40:42,130 --> 00:40:47,318
there has been a series of simulations

893
00:40:43,989 --> 00:40:49,208
to try and harness that idea yeah that

894
00:40:47,318 --> 00:40:52,958
there's either copious neutrino

895
00:40:49,208 --> 00:40:56,679
production that aid in revival of the

896
00:40:52,958 --> 00:40:59,528
straw the shock or if there is enough

897
00:40:56,679 --> 00:41:02,798
rotation to begin with in that neutron

898
00:40:59,528 --> 00:41:04,809

in sorry that Neutron the proto neutron

899

00:41:02,798 --> 00:41:06,190

star in the beginning that rotation can

900

00:41:04,809 --> 00:41:08,559

be associated with strong magnetic

901

00:41:06,190 --> 00:41:11,739

fields that set up a symmetry axis that

902

00:41:08,559 --> 00:41:13,930

can drive a jet okay and totally disrupt

903

00:41:11,739 --> 00:41:17,588

the store and what in another extreme

904

00:41:13,929 --> 00:41:19,690

scenario so that's the jet scenario here

905

00:41:17,588 --> 00:41:22,269

we see this is the core of the Explo

906

00:41:19,690 --> 00:41:25,568

this is in terms of think of this in

907

00:41:22,269 --> 00:41:28,000

terms of that here's the boundary of the

908

00:41:25,568 --> 00:41:30,460

shock material is coming in we see the

909

00:41:28,000 --> 00:41:34,030

sloshing back and forth there's heating

910

00:41:30,460 --> 00:41:36,039

by these neutrinos okay and it goes back

911

00:41:34,030 --> 00:41:37,539

and forth the sloshing and something

912

00:41:36,039 --> 00:41:40,180

that called the standing accretion shock

913
00:41:37,539 --> 00:41:42,460
instability Sassie it's a great name

914
00:41:40,179 --> 00:41:45,298
back and forth until finally it can

915
00:41:42,460 --> 00:41:48,068
disrupt the star okay

916
00:41:45,298 --> 00:41:50,309
case in point though can you see that

917
00:41:48,068 --> 00:41:57,429
there's a difference in the morphology

918
00:41:50,309 --> 00:42:02,349
between this and this okay keep that in

919
00:41:57,429 --> 00:42:06,940
mind as we move forward in order to be

920
00:42:02,349 --> 00:42:09,730
able to explore that mechanism of the

921
00:42:06,940 --> 00:42:12,780
supernova we need a lot of examples and

922
00:42:09,730 --> 00:42:15,369
we need to get good at finding supernova

923
00:42:12,780 --> 00:42:15,910
supernova thankfully happened pretty

924
00:42:15,369 --> 00:42:17,740
often

925
00:42:15,909 --> 00:42:21,489
they happen at a rate of approximately

926
00:42:17,739 --> 00:42:29,288
one per galaxy per century maybe to four

927
00:42:21,489 --> 00:42:31,358
century and if you listen you can hear

928
00:42:29,289 --> 00:42:34,299
one going off every second in the

929
00:42:31,358 --> 00:42:35,798
universe no you can but it is actually

930
00:42:34,298 --> 00:42:37,690
happening approximately once every

931
00:42:35,798 --> 00:42:40,538
second there's a supernova that's going

932
00:42:37,690 --> 00:42:43,720
off in the universe now clearly we don't

933
00:42:40,539 --> 00:42:45,760
have access to a lot of them but a lot

934
00:42:43,719 --> 00:42:48,338
of them we do right and here is actually

935
00:42:45,760 --> 00:42:50,349
postage stamps of the many supernovae

936
00:42:48,338 --> 00:42:53,440
discovered in a particular survey and

937
00:42:50,349 --> 00:42:59,318
you can see them all as point sources in

938
00:42:53,440 --> 00:43:01,000
their host galaxies here are some of the

939
00:42:59,318 --> 00:43:04,179
efforts that are trying to find

940
00:43:01,000 --> 00:43:08,250
supernovae this pan-starrs survey that I

941

00:43:04,179 --> 00:43:11,078
was associated with the assassin survey

942
00:43:08,250 --> 00:43:13,690
Palomar transient fact a factory now

943
00:43:11,079 --> 00:43:18,210
known as as wiki transient factory run

944
00:43:13,690 --> 00:43:21,099
largely by Caltech and an army of

945
00:43:18,210 --> 00:43:24,338
amateur astronomers that I work with

946
00:43:21,099 --> 00:43:26,470
that I you know bite by by day Stu

947
00:43:24,338 --> 00:43:28,420
Parker and New Zealand is a dairy farmer

948
00:43:26,469 --> 00:43:31,618
and he's a great guy he knows all seven

949
00:43:28,420 --> 00:43:33,690
hundred cows by name but by night

950
00:43:31,619 --> 00:43:35,730
instead of buying fancy

951
00:43:33,690 --> 00:43:38,159
cars he's bought some really nice

952
00:43:35,730 --> 00:43:43,800
telescopes and he helps in the discovery

953
00:43:38,159 --> 00:43:45,989
of supernova explosions ah I don't know

954
00:43:43,800 --> 00:43:48,450
if we can get the lights down but people

955
00:43:45,989 --> 00:43:52,589

here do you think you can spot the

956

00:43:48,449 --> 00:43:56,699

supernovae can you see where it's

957

00:43:52,590 --> 00:44:00,150

developing you somebody sees it right

958

00:43:56,699 --> 00:44:02,909

there you're right there it is there

959

00:44:00,150 --> 00:44:04,619

okay so clearly this is an inefficient

960

00:44:02,909 --> 00:44:09,109

process by just looking at it visually

961

00:44:04,619 --> 00:44:11,639

in these days what one does is look at a

962

00:44:09,110 --> 00:44:13,680

taken and by the way what it was

963

00:44:11,639 --> 00:44:16,199

happening here we take an image of the

964

00:44:13,679 --> 00:44:20,480

sky at some point and then return some

965

00:44:16,199 --> 00:44:22,710

time later months later weeks days

966

00:44:20,480 --> 00:44:26,610

currently we're at the point where we're

967

00:44:22,710 --> 00:44:29,190

monitoring hourly almost in some fields

968

00:44:26,610 --> 00:44:32,010

to look for changes instead of doing it

969

00:44:29,190 --> 00:44:33,900

by eye you use computers to take a

970
00:44:32,010 --> 00:44:36,540
subtraction of one image from another

971
00:44:33,900 --> 00:44:39,210
and you look for a difference but still

972
00:44:36,539 --> 00:44:42,480
there's a rich history of people finding

973
00:44:39,210 --> 00:44:43,889
supernovae by eye and I just wanted to

974
00:44:42,480 --> 00:44:46,590
give you a flavor of that here's another

975
00:44:43,889 --> 00:44:49,889
scenario so this was images donated by

976
00:44:46,590 --> 00:44:54,410
stu parker and here you can see this you

977
00:44:49,889 --> 00:45:04,230
know tiny adorable spiral galaxies and

978
00:44:54,409 --> 00:45:06,869
then sometime later alright now to some

979
00:45:04,230 --> 00:45:09,119
it may not look like much but recognize

980
00:45:06,869 --> 00:45:10,889
that this is a galaxy let's say

981
00:45:09,119 --> 00:45:14,130
something like the Milky Way with a

982
00:45:10,889 --> 00:45:16,619
hundred billion stars or so and this

983
00:45:14,130 --> 00:45:20,010
fuzz is actually just you know the

984
00:45:16,619 --> 00:45:22,799
nature of many stars that are spaced out

985
00:45:20,010 --> 00:45:28,170
and then all of a sudden one of those

986
00:45:22,800 --> 00:45:30,150
stars explodes and becomes as luminous

987
00:45:28,170 --> 00:45:34,680
you know with a luminosity that rivals

988
00:45:30,150 --> 00:45:36,840
the entire host galaxy as supernovae can

989
00:45:34,679 --> 00:45:42,079
be brighter than billions of stars put

990
00:45:36,840 --> 00:45:42,079
together it's quite remarkable

991
00:45:42,880 --> 00:45:48,250
what's also remarkable is when this

992
00:45:45,639 --> 00:45:50,829
happens in our own neighborhood okay we

993
00:45:48,250 --> 00:45:53,800
live in a galaxy with stars with lots of

994
00:45:50,829 --> 00:45:55,539
massive stars so obviously every so

995
00:45:53,800 --> 00:45:56,440
often something has to happen in our own

996
00:45:55,539 --> 00:45:59,710
backyard

997
00:45:56,440 --> 00:46:03,760
and here I'm showing a well-known

998

00:45:59,710 --> 00:46:07,470
engraving of chika brow or Tycho Brahe

999
00:46:03,760 --> 00:46:10,300
he who spotted this supernova of 1527

1000
00:46:07,469 --> 00:46:13,079
when galactic supernova occurred they

1001
00:46:10,300 --> 00:46:16,060
can they can be visible for many months

1002
00:46:13,079 --> 00:46:19,029
maybe even over a year and they can be

1003
00:46:16,059 --> 00:46:21,219
even be visible during the day right

1004
00:46:19,030 --> 00:46:23,500
there are stories about people reading

1005
00:46:21,219 --> 00:46:29,199
at night to the light of a supernova and

1006
00:46:23,500 --> 00:46:31,030
all the confusion in people being afraid

1007
00:46:29,199 --> 00:46:34,960
of this source that came out of

1008
00:46:31,030 --> 00:46:36,820
seemingly nowhere but Tycho Brahe he was

1009
00:46:34,960 --> 00:46:38,230
prepared because he had the right

1010
00:46:36,820 --> 00:46:40,150
instruments to be able to make

1011
00:46:38,230 --> 00:46:44,199
measurements of the system so we're

1012
00:46:40,150 --> 00:46:47,079

gonna do that and we can now go there

1013

00:46:44,199 --> 00:46:48,730

today again with razor sharp vision of

1014

00:46:47,079 --> 00:46:51,579

Hubble but in this case it's actually

1015

00:46:48,730 --> 00:46:54,730

Chandra x-ray Observatory and look at

1016

00:46:51,579 --> 00:46:56,769

what it looks like today and here we see

1017

00:46:54,730 --> 00:47:02,800

the Tycho's supernova remnant or the

1018

00:46:56,769 --> 00:47:06,369

supernova 1520 72 and I wasn't able he

1019

00:47:02,800 --> 00:47:08,620

wrote down in his log and then which

1020

00:47:06,369 --> 00:47:11,859

turned into a book this entry and I

1021

00:47:08,619 --> 00:47:13,559

wasn't able to skim it down so it's

1022

00:47:11,860 --> 00:47:16,000

quite amazing

1023

00:47:13,559 --> 00:47:19,210

here let's emphasize here a miracle

1024

00:47:16,000 --> 00:47:20,860

indeed either the greatest of all that

1025

00:47:19,210 --> 00:47:22,659

have occurred in the whole range of

1026

00:47:20,860 --> 00:47:26,019

nature since the beginning of the world

1027
00:47:22,659 --> 00:47:28,420
or one certainly that is to be classed

1028
00:47:26,019 --> 00:47:30,610
with those attested by the holy Oracle's

1029
00:47:28,420 --> 00:47:32,440
the staying of the Sun and its course an

1030
00:47:30,610 --> 00:47:34,809
answer to the prayers of Joshua and the

1031
00:47:32,440 --> 00:47:36,760
darkening of the Sun's face at the time

1032
00:47:34,809 --> 00:47:39,279
of crucifixion thought that appropriate

1033
00:47:36,760 --> 00:47:41,260
close to Easter I mean it was either the

1034
00:47:39,280 --> 00:47:44,290
most important thing that ever happened

1035
00:47:41,260 --> 00:47:47,490
or like the second most important thing

1036
00:47:44,289 --> 00:47:47,489
that ever happened right

1037
00:47:48,449 --> 00:47:55,809
now interestingly enough not that many

1038
00:47:52,780 --> 00:47:56,650
years later there is another sighting by

1039
00:47:55,809 --> 00:48:00,099
Tycho's

1040
00:47:56,650 --> 00:48:02,170
distant Johannes Keplar and by the way

1041
00:48:00,099 --> 00:48:04,000
there's a whole personality of Tycho

1042
00:48:02,170 --> 00:48:06,278
Brahe he I would encourage you to

1043
00:48:04,000 --> 00:48:08,798
investigate I mean the one that comes to

1044
00:48:06,278 --> 00:48:12,250
mind right now is that he lost a portion

1045
00:48:08,798 --> 00:48:19,170
of his nose in a duel with somebody at a

1046
00:48:12,250 --> 00:48:22,000
wedding over a mathematical formula now

1047
00:48:19,170 --> 00:48:23,500
Kepler was hired by Tycho Brahe he to

1048
00:48:22,000 --> 00:48:27,400
help him with all the measurements of

1049
00:48:23,500 --> 00:48:29,949
the the planets that he had done and the

1050
00:48:27,400 --> 00:48:32,289
the relationship was fraught with with

1051
00:48:29,949 --> 00:48:34,868
tension because Tycho had decades of

1052
00:48:32,289 --> 00:48:37,210
observations but he only gave them in

1053
00:48:34,869 --> 00:48:39,460
little pieces to Kepler and Kepler

1054
00:48:37,210 --> 00:48:41,019
pleaded please give me the data but he

1055

00:48:39,460 --> 00:48:43,059
wouldn't he would give him now Tycho

1056
00:48:41,019 --> 00:48:45,009
died less than a year after they started

1057
00:48:43,059 --> 00:48:47,349
working together so there's a little bit

1058
00:48:45,010 --> 00:48:49,028
of gossip about how did that happen how

1059
00:48:47,349 --> 00:48:52,000
did Tycho Brahe he come to such an

1060
00:48:49,028 --> 00:48:53,798
accelerated death they actually exhumed

1061
00:48:52,000 --> 00:48:55,480
the body of Tycho Brahe he to see if

1062
00:48:53,798 --> 00:48:57,190
he'd been poisoned to see if they could

1063
00:48:55,480 --> 00:48:59,380
find evidence of poison in him and they

1064
00:48:57,190 --> 00:49:02,079
didn't so Kepler was cleared on that

1065
00:48:59,380 --> 00:49:04,000
account anyhow I'm distracted I'm sorry

1066
00:49:02,079 --> 00:49:07,690
there's a lot of historical anecdotes

1067
00:49:04,000 --> 00:49:10,719
here Kepler in 1604 spotted another

1068
00:49:07,690 --> 00:49:13,539
galactic supernova his take was a little

1069
00:49:10,719 --> 00:49:15,429

bit different the star significant is a

1070

00:49:13,539 --> 00:49:17,829

difficult matter to establish and we

1071

00:49:15,429 --> 00:49:20,318

could be sure of only one thing that

1072

00:49:17,829 --> 00:49:23,440

either the star signifies nothing at all

1073

00:49:20,318 --> 00:49:25,869

for mankind or it signifies something of

1074

00:49:23,440 --> 00:49:28,298

such exalted importance that is beyond

1075

00:49:25,869 --> 00:49:32,619

the grasp and understanding of any man

1076

00:49:28,298 --> 00:49:35,980

or woman let's say so either it's most

1077

00:49:32,619 --> 00:49:41,980

important or let's move on nothing

1078

00:49:35,980 --> 00:49:42,429

nothing here right okay and where's

1079

00:49:41,980 --> 00:49:44,469

Frank

1080

00:49:42,429 --> 00:49:47,858

we're time for about eight o'clock ish

1081

00:49:44,469 --> 00:49:49,538

or okay all right I will try not to try

1082

00:49:47,858 --> 00:49:56,528

your patience I've gotten distracted but

1083

00:49:49,539 --> 00:49:58,119

I'm having a lot of fun oh my goodness

1084
00:49:56,528 --> 00:49:59,980
okay I will definitely not keep you here

1085
00:49:58,119 --> 00:50:03,160
that long but thank you thank you for

1086
00:49:59,980 --> 00:50:06,309
the the info all right we saw this

1087
00:50:03,159 --> 00:50:08,858
earlier okay Crab Nebula shown a lot

1088
00:50:06,309 --> 00:50:10,450
this is the remnant of a supernova

1089
00:50:08,858 --> 00:50:14,500
explosion that had

1090
00:50:10,449 --> 00:50:16,598
in 1054 and we have that date chronicled

1091
00:50:14,500 --> 00:50:18,699
by the Chinese so we know that it

1092
00:50:16,599 --> 00:50:20,079
happened on that time it's quite

1093
00:50:18,699 --> 00:50:22,149
beautiful this is a Hubble Space

1094
00:50:20,079 --> 00:50:24,180
Telescope image largely sensitive so

1095
00:50:22,150 --> 00:50:27,280
this is optical emission but

1096
00:50:24,179 --> 00:50:29,679
cherry-picking like the demonstration

1097
00:50:27,280 --> 00:50:31,089
that you showed at certain wavelengths

1098
00:50:29,679 --> 00:50:33,129
and then you combine them in the right

1099
00:50:31,088 --> 00:50:35,170
way to make a pretty picture this

1100
00:50:33,130 --> 00:50:37,809
diffuse submission is associated lot

1101
00:50:35,170 --> 00:50:39,608
with the neutron star that is rapidly

1102
00:50:37,809 --> 00:50:41,410
rotating we call it a pulsar because

1103
00:50:39,608 --> 00:50:43,420
every in this case every 30 seconds

1104
00:50:41,409 --> 00:50:45,848
there's a strong wave of energy that

1105
00:50:43,420 --> 00:50:47,829
comes in in our direction it's

1106
00:50:45,849 --> 00:50:51,490
illuminating this pulsar wind in the

1107
00:50:47,829 --> 00:50:57,010
middle and around it okay is a other

1108
00:50:51,489 --> 00:50:58,808
ejecta I want to highlight this it's an

1109
00:50:57,010 --> 00:51:00,809
energetic phenomena so here we're

1110
00:50:58,809 --> 00:51:03,160
looking multiple years

1111
00:51:00,809 --> 00:51:05,829
beautiful work by again another

1112

00:51:03,159 --> 00:51:07,529
quote-unquote amateur astronomer I mean

1113
00:51:05,829 --> 00:51:11,530
this would put professional astronomers

1114
00:51:07,530 --> 00:51:13,960
to shame to get this stable image over

1115
00:51:11,530 --> 00:51:15,940
these multiple years and you can see the

1116
00:51:13,960 --> 00:51:18,039
swirling right remember this is a

1117
00:51:15,940 --> 00:51:21,460
rotating effect you can see it pushing

1118
00:51:18,039 --> 00:51:28,900
out the wind around it it's almost

1119
00:51:21,460 --> 00:51:32,440
looking like a living thing right all

1120
00:51:28,900 --> 00:51:35,829
right one thing I want to capture for

1121
00:51:32,440 --> 00:51:37,900
you is that when we look at objects like

1122
00:51:35,829 --> 00:51:40,809
super novae and supernovae remnants at

1123
00:51:37,900 --> 00:51:42,400
different wavelengths that often means

1124
00:51:40,809 --> 00:51:44,530
different space telescopes or

1125
00:51:42,400 --> 00:51:47,079
ground-based observatories we capture

1126
00:51:44,530 --> 00:51:49,119

different physics and that usually is

1127

00:51:47,079 --> 00:51:51,940

reflective of different temperatures and

1128

00:51:49,119 --> 00:51:54,220

densities so we have the Crab Nebula

1129

00:51:51,940 --> 00:51:57,250

there you can see a different take but

1130

00:51:54,219 --> 00:51:59,798

when we look at it radio or spitzer in

1131

00:51:57,250 --> 00:52:02,798

the infrared or hubble in the optical or

1132

00:51:59,798 --> 00:52:07,239

chandra at x-ray wavelengths they're all

1133

00:52:02,798 --> 00:52:09,190

privy to another piece of the remnant so

1134

00:52:07,239 --> 00:52:11,939

in order to do a comprehensive

1135

00:52:09,190 --> 00:52:15,730

investigation we want to try to utilize

1136

00:52:11,940 --> 00:52:19,929

the full span of the electromagnetic

1137

00:52:15,730 --> 00:52:23,079

spectrum and to give you a little bit

1138

00:52:19,929 --> 00:52:23,989

more I mean each of these supernova

1139

00:52:23,079 --> 00:52:26,480

remnants needs it so

1140

00:52:23,989 --> 00:52:28,399

origin stories this is a remnant in the

1141
00:52:26,480 --> 00:52:31,250
small Magellanic Cloud

1142
00:52:28,400 --> 00:52:33,050
we have no confirmed sighting so we

1143
00:52:31,250 --> 00:52:35,088
can't pinpoint the date so we have to

1144
00:52:33,050 --> 00:52:36,800
use other means to estimate that state

1145
00:52:35,088 --> 00:52:38,029
and we think it'd be larger than a

1146
00:52:36,800 --> 00:52:40,430
thousand years ago

1147
00:52:38,030 --> 00:52:44,630
here's something different again we

1148
00:52:40,429 --> 00:52:46,250
don't have a certain date of explosion

1149
00:52:44,630 --> 00:52:48,190
but we know it to be over a thousand

1150
00:52:46,250 --> 00:52:51,199
years old and it's a combination of

1151
00:52:48,190 --> 00:52:56,059
wavelengths another this one now

1152
00:52:51,199 --> 00:52:58,098
primarily a Chandra x-ray Observatory we

1153
00:52:56,059 --> 00:53:01,309
don't know the date it's fairly old and

1154
00:52:58,099 --> 00:53:02,960
then this okay I showed the

1155
00:53:01,309 --> 00:53:05,119
multi-wavelength image we'll come back

1156
00:53:02,960 --> 00:53:07,940
to that at a moment but this is the

1157
00:53:05,119 --> 00:53:09,980
Hubble Space Telescope image and a

1158
00:53:07,940 --> 00:53:12,320
shadow to our Effie's in who I think is

1159
00:53:09,980 --> 00:53:15,079
watching right now who is responsible in

1160
00:53:12,320 --> 00:53:18,140
arranging these observations to make

1161
00:53:15,079 --> 00:53:20,509
this beautiful mosaic so what are we

1162
00:53:18,139 --> 00:53:24,079
looking at the debris zuv a star that

1163
00:53:20,510 --> 00:53:26,510
exploded about 340 years ago the red is

1164
00:53:24,079 --> 00:53:29,569
self is sensitive to sulfur rich

1165
00:53:26,510 --> 00:53:32,000
material the green is oxygen-rich the

1166
00:53:29,570 --> 00:53:33,980
purple blue stuff that's actually

1167
00:53:32,000 --> 00:53:36,380
associated with this the star before it

1168
00:53:33,980 --> 00:53:41,480
exploded and the material it released to

1169

00:53:36,380 --> 00:53:43,369
the surrounding environment we're gonna

1170
00:53:41,480 --> 00:53:45,199
go back to the multi wavelengths so now

1171
00:53:43,369 --> 00:53:47,119
we're not just looking at HST but we're

1172
00:53:45,199 --> 00:53:48,980
looking at Spitzer we're also in that

1173
00:53:47,119 --> 00:53:50,890
that's infrared wavelengths and we're

1174
00:53:48,980 --> 00:53:54,108
also looking at Chandra at various

1175
00:53:50,889 --> 00:53:57,858
wavelengths sensitive to different parts

1176
00:53:54,108 --> 00:54:01,009
different elements the x-ray here is

1177
00:53:57,858 --> 00:54:07,670
sensitive to iron rich material of the

1178
00:54:01,010 --> 00:54:09,380
supernova there's different kind of

1179
00:54:07,670 --> 00:54:12,760
things that we can point out in the

1180
00:54:09,380 --> 00:54:15,800
anatomy of the supernova remnant at the

1181
00:54:12,760 --> 00:54:19,970
the periphery here do you see this thin

1182
00:54:15,800 --> 00:54:22,039
band this is actually associated with

1183
00:54:19,969 --> 00:54:24,169

the original shockwave of the supernova

1184

00:54:22,039 --> 00:54:26,570

right you can imagine explosion has a

1185

00:54:24,170 --> 00:54:27,980

shockwave and that's the forefront of it

1186

00:54:26,570 --> 00:54:34,010

and we've been able to watch it with

1187

00:54:27,980 --> 00:54:37,599

time expand also in the center is that

1188

00:54:34,010 --> 00:54:39,580

neutron star the core collapse

1189

00:54:37,599 --> 00:54:40,690

the material being compressed down to

1190

00:54:39,579 --> 00:54:41,529

such densities that would have

1191

00:54:40,690 --> 00:54:46,090

neutron-rich

1192

00:54:41,530 --> 00:54:52,300

material if we could get the lights down

1193

00:54:46,090 --> 00:54:55,780

on this here is time-lapse of about 50

1194

00:54:52,300 --> 00:54:59,289

years of images of casa PA and you

1195

00:54:55,780 --> 00:55:01,930

mentioned Joe Joe helped create this we

1196

00:54:59,289 --> 00:55:05,108

scanned in plates the dating back

1197

00:55:01,929 --> 00:55:07,960

decades and we smoothly transitioned

1198
00:55:05,108 --> 00:55:10,480
into Hubble Space Telescope image at the

1199
00:55:07,960 --> 00:55:14,829
end and you can see the remnant

1200
00:55:10,480 --> 00:55:17,500
expanding and so my PhD thesis was

1201
00:55:14,829 --> 00:55:19,960
largely done on castor PA I'm grateful

1202
00:55:17,500 --> 00:55:22,329
for doing it now ish because I've done

1203
00:55:19,960 --> 00:55:26,108
it 50 years ago it just wasn't nearly as

1204
00:55:22,329 --> 00:55:28,659
bright as it is today and this the

1205
00:55:26,108 --> 00:55:31,599
origin of this heating has let's just

1206
00:55:28,659 --> 00:55:33,730
say as the shock wave moves out there is

1207
00:55:31,599 --> 00:55:35,469
another shock wave that propagates in

1208
00:55:33,730 --> 00:55:38,730
the opposite direction with respect to

1209
00:55:35,469 --> 00:55:42,639
that forward shock wave that heats and

1210
00:55:38,730 --> 00:55:49,059
excites the optical emission that we see

1211
00:55:42,639 --> 00:55:50,589
today ah so what can we do I want to

1212
00:55:49,059 --> 00:55:52,509
understand how this thing exploded and I

1213
00:55:50,590 --> 00:55:55,480
tried to point out those simulations and

1214
00:55:52,510 --> 00:55:57,910
the extremes and the morphology right so

1215
00:55:55,480 --> 00:56:00,159
being clever with our spectra and

1216
00:55:57,909 --> 00:56:02,349
measuring velocities we can do a

1217
00:56:00,159 --> 00:56:04,868
three-dimensional reconstruction of the

1218
00:56:02,349 --> 00:56:06,279
remnant and this is kind of my niche

1219
00:56:04,869 --> 00:56:08,200
this is something that I'm trying to get

1220
00:56:06,280 --> 00:56:10,119
at I'm looking at the large-scale

1221
00:56:08,199 --> 00:56:12,210
structure of the remnant and try to

1222
00:56:10,119 --> 00:56:15,640
piece together how the the bomb exploded

1223
00:56:12,210 --> 00:56:18,280
it's like a bomb scene investigation I

1224
00:56:15,639 --> 00:56:20,199
go into the room and I look around it

1225
00:56:18,280 --> 00:56:22,390
explode equally in all directions or is

1226

00:56:20,199 --> 00:56:24,519
there a preferential access and then I

1227
00:56:22,389 --> 00:56:26,679
can go and scrape off bits of pieces of

1228
00:56:24,519 --> 00:56:28,210
the the bomb and do a chemical analysis

1229
00:56:26,679 --> 00:56:31,329
to understand what it was made of this

1230
00:56:28,210 --> 00:56:33,760
is kind of what I'm doing now this is

1231
00:56:31,329 --> 00:56:36,039
thanks to my contributors I honestly got

1232
00:56:33,760 --> 00:56:38,260
this about an hour ago

1233
00:56:36,039 --> 00:56:40,539
nobody really none of my grad students

1234
00:56:38,260 --> 00:56:43,390
and not even the Haraka wanted to travel

1235
00:56:40,539 --> 00:56:45,190
to a supernova in space to study it so

1236
00:56:43,389 --> 00:56:49,599
we're making a virtual reality

1237
00:56:45,190 --> 00:56:51,490
environment for which to study it safely

1238
00:56:49,599 --> 00:56:53,349
I guess so as you can see they have

1239
00:56:51,489 --> 00:56:56,679
the goggles on so we have this

1240
00:56:53,349 --> 00:56:59,230

collaborative environment right so we

1241
00:56:56,679 --> 00:57:01,239
can see that's Jordan who's helping out

1242
00:56:59,230 --> 00:57:02,860
right now I wish I was there with them

1243
00:57:01,239 --> 00:57:05,079
but with virtual reality at some point I

1244
00:57:02,860 --> 00:57:07,000
will be able to do it remotely so here

1245
00:57:05,079 --> 00:57:09,429
we can see we have all these people

1246
00:57:07,000 --> 00:57:11,619
together we're making a collaborative

1247
00:57:09,429 --> 00:57:13,750
virtual reality environment it's both

1248
00:57:11,619 --> 00:57:15,250
the teaching tool and an area of

1249
00:57:13,750 --> 00:57:16,840
investigation there's the avatar so you

1250
00:57:15,250 --> 00:57:18,190
can see their faces so that's what

1251
00:57:16,840 --> 00:57:20,590
they're seeing right now and he's

1252
00:57:18,190 --> 00:57:22,300
sketching out in real time the

1253
00:57:20,590 --> 00:57:25,480
large-scale structures that were being

1254
00:57:22,300 --> 00:57:27,970
shown in that animation okay I mean as

1255
00:57:25,480 --> 00:57:31,090
an investigation I can look at pictures

1256
00:57:27,969 --> 00:57:33,339
of a crime scene but unless I go there

1257
00:57:31,090 --> 00:57:34,990
right that's the only way to really

1258
00:57:33,340 --> 00:57:36,700
understand what's going on and I can't

1259
00:57:34,989 --> 00:57:42,129
go to seek a stay so I'm gonna bring it

1260
00:57:36,699 --> 00:57:43,569
into my laboratory oh great so one thing

1261
00:57:42,130 --> 00:57:45,369
is visual the other thing is to be able

1262
00:57:43,570 --> 00:57:46,630
to compare it with simulations and

1263
00:57:45,369 --> 00:57:48,760
that's something that we're doing also

1264
00:57:46,630 --> 00:57:50,579
so this is a simulation that you know

1265
00:57:48,760 --> 00:57:54,190
that sloshing you saw back and forth

1266
00:57:50,579 --> 00:57:56,199
they've advanced those and taking

1267
00:57:54,190 --> 00:57:58,389
snapshots this is seconds after

1268
00:57:56,199 --> 00:58:01,000
explosion and hours after explosion and

1269
00:57:58,389 --> 00:58:03,460
the blue is representative nickel rich

1270
00:58:01,000 --> 00:58:06,639
material very heavy material that love

1271
00:58:03,460 --> 00:58:09,220
roughly translate into the iron rich

1272
00:58:06,639 --> 00:58:11,319
material that we see in Casa PA and the

1273
00:58:09,219 --> 00:58:12,669
large structures that we see in Casa and

1274
00:58:11,320 --> 00:58:14,920
I didn't get a chance to talk about it

1275
00:58:12,670 --> 00:58:17,200
but you see a large ring in the back

1276
00:58:14,920 --> 00:58:19,358
there that's where a large deposit of

1277
00:58:17,199 --> 00:58:21,759
iron rich material is this is giving us

1278
00:58:19,358 --> 00:58:24,250
insight into the explosion which is to

1279
00:58:21,760 --> 00:58:27,790
say that it's not homogeneous it's not

1280
00:58:24,250 --> 00:58:31,500
this sphere that is exploding but it's

1281
00:58:27,789 --> 00:58:34,000
messy and it's dominated by a few

1282
00:58:31,500 --> 00:58:35,590
instabilities where you have this nickel

1283

00:58:34,000 --> 00:58:40,750
rich material stream out ahead of the

1284
00:58:35,590 --> 00:58:44,410
lighter elements okay coming on to the

1285
00:58:40,750 --> 00:58:46,150
good stuff now remember I said to be

1286
00:58:44,409 --> 00:58:48,639
able to do our investigations we have to

1287
00:58:46,150 --> 00:58:51,160
look with the right wavelengths so now

1288
00:58:48,639 --> 00:58:54,159
this is x-ray but now enhanced around

1289
00:58:51,159 --> 00:58:56,469
the silicon lines and now hold on I told

1290
00:58:54,159 --> 00:58:58,440
you that this was a morphology that's

1291
00:58:56,469 --> 00:59:00,849
consistent with this neutrino kind of

1292
00:58:58,440 --> 00:59:03,490
instabilities but now we see something

1293
00:59:00,849 --> 00:59:04,929
like the other model remember that kind

1294
00:59:03,489 --> 00:59:10,539
of like the jet model

1295
00:59:04,929 --> 00:59:13,719
here huh and again help with the Hubble

1296
00:59:10,539 --> 00:59:15,789
Space Telescope we took images purposely

1297
00:59:13,719 --> 00:59:18,009

along that direction and tried to follow

1298

00:59:15,789 --> 00:59:22,469

a material out as far as it could

1299

00:59:18,010 --> 00:59:25,440

go and now I'm gonna zoom in here so

1300

00:59:22,469 --> 00:59:29,859

images separated only a year apart and

1301

00:59:25,440 --> 00:59:33,099

you can see this is stellar debris being

1302

00:59:29,860 --> 00:59:38,440

flung out over 15,000 kilometers per

1303

00:59:33,099 --> 00:59:40,089

second right those with sharp eyes may

1304

00:59:38,440 --> 00:59:42,639

notice funny things like this do you see

1305

00:59:40,090 --> 00:59:44,500

how that pops in and out yeah all that

1306

00:59:42,639 --> 00:59:46,509

means is that it's running into some

1307

00:59:44,500 --> 00:59:48,840

kind of a over density in the

1308

00:59:46,510 --> 00:59:51,310

surrounding environment and lights it up

1309

00:59:48,840 --> 00:59:54,269

is that saying time out somebody's

1310

00:59:51,309 --> 00:59:59,500

making their way okay

1311

00:59:54,269 --> 01:00:04,559

as that pass is on it's actually good

1312
00:59:59,500 --> 01:00:07,929
soundtrack for this right okay but

1313
01:00:04,559 --> 01:00:11,829
ladies and gentlemen ladies and

1314
01:00:07,929 --> 01:00:16,569
gentlemen this truly is okay this is raw

1315
01:00:11,829 --> 01:00:19,750
material for future stars future planets

1316
01:00:16,570 --> 01:00:22,090
maybe life okay being seeded in

1317
01:00:19,750 --> 01:00:29,980
surrounding interstellar space we're

1318
01:00:22,090 --> 01:00:32,800
watching it happen here okay debris this

1319
01:00:29,980 --> 01:00:34,269
is actually sulfur and rich debris but

1320
01:00:32,800 --> 01:00:37,780
it has other chemical elements there

1321
01:00:34,269 --> 01:00:40,840
maybe yeah the heavy elements in there

1322
01:00:37,780 --> 01:00:44,170
yes star stuff that's right that's going

1323
01:00:40,840 --> 01:00:48,390
to go support the manufacture of new

1324
01:00:44,170 --> 01:00:51,010
systems okay so now we're gonna go into

1325
01:00:48,389 --> 01:00:53,500
what we're looking to into the future

1326
01:00:51,010 --> 01:00:57,250
what we anticipate to be investigating

1327
01:00:53,500 --> 01:00:59,230
in the future I show this plot up in it

1328
01:00:57,250 --> 01:01:02,800
let me take a second to explain it this

1329
01:00:59,230 --> 01:01:06,250
is time and this is how bright the

1330
01:01:02,800 --> 01:01:08,410
system is and remember I said how

1331
01:01:06,250 --> 01:01:09,820
supernovae are designated by the year

1332
01:01:08,409 --> 01:01:13,629
that they're discovered and this is a

1333
01:01:09,820 --> 01:01:16,780
system called supernova 2009 IP now it's

1334
01:01:13,630 --> 01:01:18,338
a dumb name because the supernova

1335
01:01:16,780 --> 01:01:22,420
actually took place in two

1336
01:01:18,338 --> 01:01:24,728
and twelve now why did it get 2009 well

1337
01:01:22,420 --> 01:01:27,639
in 2009 people jumped the gun they saw

1338
01:01:24,728 --> 01:01:29,548
that it went got brighter but didn't

1339
01:01:27,639 --> 01:01:33,848
quite get the brightness the luminosity

1340

01:01:29,548 --> 01:01:35,228
needed for a terminal explosion actually

1341
01:01:33,849 --> 01:01:37,298
associated with the system maybe you've

1342
01:01:35,228 --> 01:01:39,879
heard of eight a car it's a star that

1343
01:01:37,298 --> 01:01:42,429
ejected a lot of material at all at once

1344
01:01:39,880 --> 01:01:45,219
and then it went down but people were

1345
01:01:42,429 --> 01:01:47,198
clever to monitor it with time and then

1346
01:01:45,219 --> 01:01:49,479
you know monitoring the like her we saw

1347
01:01:47,199 --> 01:01:52,229
a lot of fluctuations leading up to the

1348
01:01:49,478 --> 01:01:57,728
final core collapse explosion

1349
01:01:52,228 --> 01:01:59,588
potentially the thought is that the star

1350
01:01:57,728 --> 01:02:01,478
as I said had some kind of major

1351
01:01:59,588 --> 01:02:04,208
eruption like a Dakar now this is a

1352
01:02:01,478 --> 01:02:05,828
dramatic mega example but maybe

1353
01:02:04,208 --> 01:02:08,618
something like this has happened in that

1354
01:02:05,829 --> 01:02:13,209

other thing where the stars death was

1355

01:02:08,619 --> 01:02:17,318

pray looted with a giant eruption that

1356

01:02:13,208 --> 01:02:19,358

becomes very exciting because now we're

1357

01:02:17,318 --> 01:02:23,739

at the point where we may be able to

1358

01:02:19,358 --> 01:02:25,358

predict supernova explosions now when I

1359

01:02:23,739 --> 01:02:27,728

sat in public lectures like that and I

1360

01:02:25,358 --> 01:02:30,420

still do but locate let's say what about

1361

01:02:27,728 --> 01:02:32,889

twenty years ago I remember you'll never

1362

01:02:30,420 --> 01:02:34,688

looking at a star you'd never be able to

1363

01:02:32,889 --> 01:02:36,818

know when it's going to explode because

1364

01:02:34,688 --> 01:02:39,338

all them all that activities happening

1365

01:02:36,818 --> 01:02:40,958

at the core right and it'd take tens of

1366

01:02:39,338 --> 01:02:44,108

thousands or hundreds of thousands of

1367

01:02:40,958 --> 01:02:47,558

years to evolve and yet in this case we

1368

01:02:44,108 --> 01:02:49,688

say see things happening right the star

1369
01:02:47,559 --> 01:02:51,339
is signaling its demise with this pre

1370
01:02:49,688 --> 01:02:53,978
stellar activity before the actual

1371
01:02:51,338 --> 01:02:56,978
explosions so what we're in the position

1372
01:02:53,978 --> 01:03:00,218
to doing and we we have done is when one

1373
01:02:56,978 --> 01:03:02,259
of these supernova imposters happen we

1374
01:03:00,219 --> 01:03:06,369
can continue to monitor this system and

1375
01:03:02,259 --> 01:03:09,548
wait for the supernova to happen we can

1376
01:03:06,369 --> 01:03:14,890
predict stellar explosions we will

1377
01:03:09,548 --> 01:03:16,478
someday okay ah Porton caveat to that if

1378
01:03:14,889 --> 01:03:18,848
you believe the story that that

1379
01:03:16,478 --> 01:03:21,728
precursor activity is associated with

1380
01:03:18,849 --> 01:03:23,949
the launching of stellar envelope the

1381
01:03:21,728 --> 01:03:26,169
transmission of information from the

1382
01:03:23,949 --> 01:03:27,969
core region core collapse to the

1383
01:03:26,170 --> 01:03:29,499
envelope means that that stellar

1384
01:03:27,969 --> 01:03:31,820
interior must be inter

1385
01:03:29,498 --> 01:03:34,250
perturbed so this

1386
01:03:31,820 --> 01:03:37,789
skin interior that I showed you was fine

1387
01:03:34,250 --> 01:03:40,039
enough for main-sequence but towards the

1388
01:03:37,789 --> 01:03:42,170
end of the star's life that is not what

1389
01:03:40,039 --> 01:03:44,690
it looks like must be much more

1390
01:03:42,170 --> 01:03:48,320
turbulent and dynamic okay and the

1391
01:03:44,690 --> 01:03:54,559
explosion is taking place here into this

1392
01:03:48,320 --> 01:03:56,570
turbulent progenitor star structure okay

1393
01:03:54,559 --> 01:03:59,779
now the last couple slides and then

1394
01:03:56,570 --> 01:04:01,610
we'll end it off I've set up for you the

1395
01:03:59,780 --> 01:04:03,560
motivation for understanding core

1396
01:04:01,610 --> 01:04:05,510
collapse supernova I've talked about the

1397

01:04:03,559 --> 01:04:09,409
types of stars explode and try and

1398
01:04:05,510 --> 01:04:11,240
understand the explosion mechanism I've

1399
01:04:09,409 --> 01:04:13,069
actually made life a lot more difficult

1400
01:04:11,239 --> 01:04:17,659
for myself because not only do I need to

1401
01:04:13,070 --> 01:04:19,820
understand the origins of that core

1402
01:04:17,659 --> 01:04:22,399
collapse whether it's purely driven by

1403
01:04:19,820 --> 01:04:26,030
that neutrino instability or the jet

1404
01:04:22,400 --> 01:04:28,340
driven but now there's added mess by the

1405
01:04:26,030 --> 01:04:31,370
progenitor star structure how am I gonna

1406
01:04:28,340 --> 01:04:35,420
be able to tell which specific processes

1407
01:04:31,369 --> 01:04:38,960
lead to the explosion and the remnant

1408
01:04:35,420 --> 01:04:41,630
structure that I see okay there's a

1409
01:04:38,960 --> 01:04:43,760
couple of facilities that are coming

1410
01:04:41,630 --> 01:04:45,920
online or that are online already that

1411
01:04:43,760 --> 01:04:48,860

you the taxpayer are helping to support

1412

01:04:45,920 --> 01:04:51,409

so you should be aware of it one is a

1413

01:04:48,860 --> 01:04:53,630

large synoptic survey telescope Alice's

1414

01:04:51,409 --> 01:04:56,509

T which is being developed in Chile and

1415

01:04:53,630 --> 01:04:58,940

this is gonna come in online around 2021

1416

01:04:56,510 --> 01:05:02,810

2022 development depending on how things

1417

01:04:58,940 --> 01:05:04,880

go now we already have surveys sky

1418

01:05:02,809 --> 01:05:08,029

surveys which I mentioned this one will

1419

01:05:04,880 --> 01:05:10,760

have a unique depth so how faint it can

1420

01:05:08,030 --> 01:05:13,070

see objects and how routinely it will be

1421

01:05:10,760 --> 01:05:15,200

mapping the regular sky the cadence has

1422

01:05:13,070 --> 01:05:16,700

yet to be finalized but let's just say

1423

01:05:15,199 --> 01:05:19,039

every three to four nights it will

1424

01:05:16,699 --> 01:05:20,659

return to the same piece of sky and

1425

01:05:19,039 --> 01:05:23,809

different filter but it'll return and

1426
01:05:20,659 --> 01:05:26,359
then image again image again image again

1427
01:05:23,809 --> 01:05:29,329
it'll do this for approximately 10 maybe

1428
01:05:26,360 --> 01:05:32,200
longer years so it'll be sampling with

1429
01:05:29,329 --> 01:05:34,579
such regularity that we'll be able to

1430
01:05:32,199 --> 01:05:37,189
potentially trace this kind of precursor

1431
01:05:34,579 --> 01:05:39,739
activity I fail to mention before that

1432
01:05:37,190 --> 01:05:43,789
this is kind of the only light curve

1433
01:05:39,739 --> 01:05:45,529
that we have that is able to sample such

1434
01:05:43,789 --> 01:05:47,420
back because there's a large divide

1435
01:05:45,530 --> 01:05:49,970
I mean the the supernovae luminosity and

1436
01:05:47,420 --> 01:05:52,250
the level of this precursor activity and

1437
01:05:49,969 --> 01:05:55,009
actually we saw a talk today by a very

1438
01:05:52,250 --> 01:05:56,869
bright grad student at Caltech and a ho

1439
01:05:55,010 --> 01:05:58,640
showed hey I got something like this

1440
01:05:56,869 --> 01:06:01,279
because of the Rickey transient Factory

1441
01:05:58,639 --> 01:06:03,619
so we're inching towards this notion of

1442
01:06:01,280 --> 01:06:05,750
if a supernova goes off let's look at

1443
01:06:03,619 --> 01:06:08,449
what's happening beforehand to get a

1444
01:06:05,750 --> 01:06:12,619
sense of what the star is doing and can

1445
01:06:08,449 --> 01:06:14,329
we connect that to the explosion the

1446
01:06:12,619 --> 01:06:16,880
other way that we're gonna be able to do

1447
01:06:14,329 --> 01:06:18,619
it is as I said multi messenger

1448
01:06:16,880 --> 01:06:20,720
astronomy so not just looking at the

1449
01:06:18,619 --> 01:06:23,119
electromagnetic spectrum which has been

1450
01:06:20,719 --> 01:06:24,739
the focus of the talk here but now we

1451
01:06:23,119 --> 01:06:28,779
have facilities sensitive to

1452
01:06:24,739 --> 01:06:31,189
gravitational waves and neutrinos

1453
01:06:28,780 --> 01:06:35,320
gravitational waves there's a lot of

1454

01:06:31,190 --> 01:06:38,179
jargon in here but let me just say this

1455
01:06:35,320 --> 01:06:41,269
instead of trying to ascertain what's

1456
01:06:38,179 --> 01:06:45,279
happening at the core of the star by way

1457
01:06:41,269 --> 01:06:47,420
of everything that's happening around it

1458
01:06:45,280 --> 01:06:48,980
gravitational waves and neutrinos are

1459
01:06:47,420 --> 01:06:51,710
coming from the heart and they're

1460
01:06:48,980 --> 01:06:53,780
unimpeded by the the the the stellar

1461
01:06:51,710 --> 01:06:56,269
ejecta around it so we're getting direct

1462
01:06:53,780 --> 01:06:58,490
live information about the core collapse

1463
01:06:56,269 --> 01:07:01,000
as it's happening and this is going to

1464
01:06:58,489 --> 01:07:08,269
revolutionize our understanding of

1465
01:07:01,000 --> 01:07:12,230
supernova explosion I I cannot

1466
01:07:08,269 --> 01:07:13,880
understand this underestimate the amount

1467
01:07:12,230 --> 01:07:17,500
of excitement that the people have in

1468
01:07:13,880 --> 01:07:19,940

all my students use animated gifts for

1469

01:07:17,500 --> 01:07:24,050

expressing excitement so this is what I

1470

01:07:19,940 --> 01:07:29,179

chose here okay going back remember that

1471

01:07:24,050 --> 01:07:31,070

first supernova 1987a right there were a

1472

01:07:29,179 --> 01:07:33,230

new training facilities working

1473

01:07:31,070 --> 01:07:35,750

operating at that time and they detected

1474

01:07:33,230 --> 01:07:37,610

approximately 20 neutrinos these are

1475

01:07:35,750 --> 01:07:39,260

very difficult nor though you know there

1476

01:07:37,610 --> 01:07:40,760

are neutrinos passing through us right

1477

01:07:39,260 --> 01:07:42,590

at this moment they normally don't

1478

01:07:40,760 --> 01:07:44,440

interact you need to have a lot of stuff

1479

01:07:42,590 --> 01:07:46,490

a lot of Tanks water they're often

1480

01:07:44,440 --> 01:07:49,909

underground to be able to make these

1481

01:07:46,489 --> 01:07:52,879

detections here is and to give you a

1482

01:07:49,909 --> 01:07:55,039

sense of the difficulty so here's this

1483
01:07:52,880 --> 01:07:57,920
is in minutes okay and just can you

1484
01:07:55,039 --> 01:07:59,079
imagine the flatline four years

1485
01:07:57,920 --> 01:08:03,880
beforehand

1486
01:07:59,079 --> 01:08:08,079
waiting for the ten seconds for which

1487
01:08:03,880 --> 01:08:10,959
the 20 or so neutrinos came through but

1488
01:08:08,079 --> 01:08:12,999
from those 10 seconds okay and those 20

1489
01:08:10,958 --> 01:08:15,759
tree nose came I've heard anywhere from

1490
01:08:12,998 --> 01:08:17,889
five six seven hundred scientific papers

1491
01:08:15,759 --> 01:08:20,588
that were published on because each one

1492
01:08:17,889 --> 01:08:22,868
were so valuable in understanding what

1493
01:08:20,588 --> 01:08:26,170
was happening at the core process I mean

1494
01:08:22,868 --> 01:08:28,960
that truly was verification of our model

1495
01:08:26,170 --> 01:08:31,480
of a core collapse forming the neutron

1496
01:08:28,960 --> 01:08:36,368
star because the neutrinos were produced

1497
01:08:31,479 --> 01:08:37,539
in that process so the with present so

1498
01:08:36,368 --> 01:08:39,608
we've come some time

1499
01:08:37,539 --> 01:08:42,009
we've count we've developed quite far

1500
01:08:39,609 --> 01:08:43,929
from the original facilities with

1501
01:08:42,009 --> 01:08:46,179
present facilities we will detect

1502
01:08:43,929 --> 01:08:49,210
thousands of neutrinos from the next

1503
01:08:46,179 --> 01:08:51,460
galactic supernova and there is much

1504
01:08:49,210 --> 01:08:56,139
more rich science to be able to be to be

1505
01:08:51,460 --> 01:08:58,509
done I'm affiliated now with something

1506
01:08:56,139 --> 01:09:03,639
called the supernova early warning

1507
01:08:58,509 --> 01:09:06,099
system snooze so the idea is if this is

1508
01:09:03,639 --> 01:09:08,409
our galaxy and there's a supernova that

1509
01:09:06,099 --> 01:09:10,719
happens on the other side the first

1510
01:09:08,408 --> 01:09:12,519
messenger to arrive on the scene will be

1511

01:09:10,719 --> 01:09:15,908
the neutrinos and there they'll be

1512
01:09:12,520 --> 01:09:17,920
streaming everything else will come

1513
01:09:15,908 --> 01:09:20,229
afterwards the gravitational waves will

1514
01:09:17,920 --> 01:09:21,699
be around there but it's likely that the

1515
01:09:20,229 --> 01:09:24,608
gravitational waves will not be as

1516
01:09:21,698 --> 01:09:26,848
strongly detected as the neutrinos

1517
01:09:24,609 --> 01:09:34,000
because just the way it all works and

1518
01:09:26,849 --> 01:09:37,270
there we are detecting it right the the

1519
01:09:34,000 --> 01:09:40,000
neutrino community will give the rest of

1520
01:09:37,270 --> 01:09:43,270
the world depending on the type of star

1521
01:09:40,000 --> 01:09:47,460
it could be as small as you know minutes

1522
01:09:43,270 --> 01:09:49,810
tens of minutes two hours on hey

1523
01:09:47,460 --> 01:09:51,698
something big really happening right

1524
01:09:49,810 --> 01:09:53,770
and they're going to be sending alerts

1525
01:09:51,698 --> 01:09:56,379

we're working it all out two-foot what

1526

01:09:53,770 --> 01:09:58,719

is the proper communication channels etc

1527

01:09:56,380 --> 01:10:02,139

to alert the world about the next

1528

01:09:58,719 --> 01:10:03,908

galactic supernova now we could be

1529

01:10:02,139 --> 01:10:07,000

waiting awhile I'll admit that

1530

01:10:03,908 --> 01:10:09,129

right it could happen tonight or it

1531

01:10:07,000 --> 01:10:12,859

could happen when I'm not around anymore

1532

01:10:09,130 --> 01:10:14,420

right we've been waiting some time and

1533

01:10:12,859 --> 01:10:16,549

you know with statistics unfortunately

1534

01:10:14,420 --> 01:10:19,100

there are two of these type 1a supernova

1535

01:10:16,550 --> 01:10:21,199

explosions the Tycho's remnant and

1536

01:10:19,100 --> 01:10:23,960

Kepler's remnant that happened fairly

1537

01:10:21,198 --> 01:10:25,519

closely within one another but we've

1538

01:10:23,960 --> 01:10:27,408

been waiting you know a couple hundred

1539

01:10:25,520 --> 01:10:31,340

years for another one to take place in

1540
01:10:27,408 --> 01:10:33,049
our own galaxy 1987 a kind of counts but

1541
01:10:31,340 --> 01:10:35,539
it was in a satellite galaxy we'd like

1542
01:10:33,050 --> 01:10:38,090
something to happen now but thankfully

1543
01:10:35,539 --> 01:10:40,760
with the neutrino and maybe even the

1544
01:10:38,090 --> 01:10:42,440
gravitational wave facilities even if a

1545
01:10:40,760 --> 01:10:45,230
supernova galactic one happens on the

1546
01:10:42,439 --> 01:10:47,960
other side of the galaxy you know it has

1547
01:10:45,229 --> 01:10:50,868
to go through this messy swamp forest of

1548
01:10:47,960 --> 01:10:52,579
dust that could minimize the light that

1549
01:10:50,868 --> 01:10:54,198
we see in the optical the one that we're

1550
01:10:52,579 --> 01:10:56,389
familiar with so it may not be visible

1551
01:10:54,198 --> 01:10:57,799
necessarily to the naked eye but the

1552
01:10:56,389 --> 01:11:02,420
neutrinos and the gravitational waves

1553
01:10:57,800 --> 01:11:04,730
will surely certainly catch it okay well

1554
01:11:02,420 --> 01:11:06,710
with that ladies and gentlemen I think

1555
01:11:04,729 --> 01:11:08,539
if you looked in the in the far west at

1556
01:11:06,710 --> 01:11:14,029
Twilight you may have been able to see

1557
01:11:08,539 --> 01:11:15,738
Oh Ryan but you might have to wait until

1558
01:11:14,029 --> 01:11:18,130
the the winter to be able to see it

1559
01:11:15,738 --> 01:11:20,868
again but you know in the the armpit of

1560
01:11:18,130 --> 01:11:22,670
Orion we have Betelgeuse and that's kind

1561
01:11:20,868 --> 01:11:25,158
of one of our favorite stars that we

1562
01:11:22,670 --> 01:11:27,139
like to think about as the next

1563
01:11:25,158 --> 01:11:29,359
supernova candidate so when that

1564
01:11:27,139 --> 01:11:30,739
happened next time it's visible to you

1565
01:11:29,359 --> 01:11:32,929
and you noticed it have a look and think

1566
01:11:30,738 --> 01:11:36,919
about all the things that I've discussed

1567
01:11:32,929 --> 01:11:38,719
I mean the fact that it's when these

1568

01:11:36,920 --> 01:11:42,050
fundamental processes in the universe

1569
01:11:38,719 --> 01:11:43,579
that makes life possible and all the

1570
01:11:42,050 --> 01:11:46,060
exciting science that we're doing behind

1571
01:11:43,579 --> 01:11:48,149
to understand it in all its full glory

1572
01:11:46,060 --> 01:12:01,740
thank you very much

1573
01:11:48,149 --> 01:12:01,739
[Applause]

1574
01:12:03,579 --> 01:12:15,010
okay hold up you've got the microphone

1575
01:12:12,350 --> 01:12:15,010
okay

1576
01:12:16,630 --> 01:12:28,969
okay in the graph of 2009 IP yes when it

1577
01:12:24,680 --> 01:12:33,710
gets to that far right peak is that by

1578
01:12:28,969 --> 01:12:36,109
definition a supernova and is it just a

1579
01:12:33,710 --> 01:12:37,789
luminosity that defines it there or are

1580
01:12:36,109 --> 01:12:41,179
there other things so what I'm guessing

1581
01:12:37,789 --> 01:12:44,569
at is that will sometime in ten years

1582
01:12:41,180 --> 01:12:45,770

it'll go up another 50% above that point

1583

01:12:44,569 --> 01:12:49,069

is that possible

1584

01:12:45,770 --> 01:12:53,360

I was hoping somebody wouldn't ask a

1585

01:12:49,069 --> 01:12:55,670

question like that for a public lot talk

1586

01:12:53,359 --> 01:12:57,380

I like to give clear explanations but

1587

01:12:55,670 --> 01:13:02,090

you're actually hitting on a very

1588

01:12:57,380 --> 01:13:04,730

important part point yeah it's not a

1589

01:13:02,090 --> 01:13:06,860

hundred percent clear of whether or not

1590

01:13:04,729 --> 01:13:10,369

this was the terminal explosion of the

1591

01:13:06,859 --> 01:13:13,969

supernova you're absolutely right it's

1592

01:13:10,369 --> 01:13:16,760

gone there's a lot of circumstantial

1593

01:13:13,969 --> 01:13:19,340

evidence that suggests that this the the

1594

01:13:16,760 --> 01:13:22,369

supernova is actually this small peak

1595

01:13:19,340 --> 01:13:24,409

and then this is when it ran into this

1596

01:13:22,369 --> 01:13:27,170

is luminosity generated as it ran into

1597
01:13:24,409 --> 01:13:29,479
this precursor activity okay

1598
01:13:27,170 --> 01:13:31,819
that's one of the understand but

1599
01:13:29,479 --> 01:13:33,019
depending if there are other experts in

1600
01:13:31,819 --> 01:13:34,488
the room here they would potentially

1601
01:13:33,020 --> 01:13:36,880
argue that this was actually the

1602
01:13:34,488 --> 01:13:39,619
supernova and this was just a minor

1603
01:13:36,880 --> 01:13:42,109
eruption before the the actual supernova

1604
01:13:39,619 --> 01:13:44,390
explosion but you make the point oh

1605
01:13:42,109 --> 01:13:46,549
sorry but you make the point that this

1606
01:13:44,390 --> 01:13:48,829
may not necessarily be the terminal

1607
01:13:46,550 --> 01:13:52,369
explosion it's possible that sometime

1608
01:13:48,829 --> 01:13:55,069
later it may do something else but you

1609
01:13:52,369 --> 01:13:57,500
know to be fair it's them consider to be

1610
01:13:55,069 --> 01:13:58,698
the more unlikely scenario yeah that's

1611
01:13:57,500 --> 01:14:01,250
only three-and-a-half magnitudes

1612
01:13:58,698 --> 01:14:05,359
difference between your peak and the

1613
01:14:01,250 --> 01:14:08,270
2009 peak as well supernote so this was

1614
01:14:05,359 --> 01:14:10,549
just above almost fifteen fourteen and

1615
01:14:08,270 --> 01:14:13,040
that's three yeah so that so this

1616
01:14:10,550 --> 01:14:14,510
exciting because it became long the

1617
01:14:13,039 --> 01:14:16,880
anticipation was that it would continue

1618
01:14:14,510 --> 01:14:18,739
to get higher and then this low-level

1619
01:14:16,880 --> 01:14:22,159
activity I mean this is where the the

1620
01:14:18,738 --> 01:14:24,709
the large difference is okay

1621
01:14:22,158 --> 01:14:28,069
okay the reason that came to me was that

1622
01:14:24,710 --> 01:14:35,179
this graph has a striking resemblance to

1623
01:14:28,069 --> 01:14:38,420
the net worth of Tesla stock I have one

1624
01:14:35,179 --> 01:14:40,908
more question um with the neutrinos and

1625

01:14:38,420 --> 01:14:42,710
the gravitational waves what's the what

1626
01:14:40,908 --> 01:14:45,289
is the prop of the speed of propagation

1627
01:14:42,710 --> 01:14:47,359
through space for those two odd are they

1628
01:14:45,289 --> 01:14:49,250
identical speed of light they should be

1629
01:14:47,359 --> 01:14:52,158
propagating throath both are at the

1630
01:14:49,250 --> 01:15:01,189
speed of light near speed of light I

1631
01:14:52,158 --> 01:15:02,359
would say okay over there you choose you

1632
01:15:01,189 --> 01:15:07,969
get you got the mic here you're in

1633
01:15:02,359 --> 01:15:09,529
charge so neutrinos I don't remember the

1634
01:15:07,969 --> 01:15:11,539
mass that we've given them trance but

1635
01:15:09,529 --> 01:15:12,920
it's an extremely small mass so it's

1636
01:15:11,539 --> 01:15:15,279
just slightly slower than the speed of

1637
01:15:12,920 --> 01:15:17,840
light right that's right thank you for

1638
01:15:15,279 --> 01:15:20,059
filling gravitational wave that's

1639
01:15:17,840 --> 01:15:22,760

radiation that's yeah speed of light but

1640

01:15:20,059 --> 01:15:25,329

then the neutrinos believed has a bit of

1641

01:15:22,760 --> 01:15:29,239

a mass that kind of slows it yes

1642

01:15:25,328 --> 01:15:31,460

so just an amateur science fan here but

1643

01:15:29,238 --> 01:15:34,759

we have all these constant supernovas

1644

01:15:31,460 --> 01:15:37,429

going off all over the universe why

1645

01:15:34,760 --> 01:15:40,309

isn't the sky just filled with clouds of

1646

01:15:37,429 --> 01:15:42,368

nebulae everywhere like do they like

1647

01:15:40,309 --> 01:15:44,630

what causes them to like fade away or

1648

01:15:42,368 --> 01:15:46,848

you know it seemed like there'd be all

1649

01:15:44,630 --> 01:15:49,578

over the place well I'll tell you if you

1650

01:15:46,849 --> 01:15:52,340

had eyes with the right resolution and

1651

01:15:49,578 --> 01:15:55,759

wavelengths you would see remnants of

1652

01:15:52,340 --> 01:15:57,800

supernova explosions across if you look

1653

01:15:55,760 --> 01:15:59,719

at in there's different surveys

1654
01:15:57,800 --> 01:16:03,139
depending on what you do but I'm very

1655
01:15:59,719 --> 01:16:05,840
familiar with a survey that sensitive to

1656
01:16:03,139 --> 01:16:09,489
light of hydrogen-alpha transition okay

1657
01:16:05,840 --> 01:16:13,909
H hydrogen gas you see these very large

1658
01:16:09,488 --> 01:16:16,039
round blobs of sorts across the Galactic

1659
01:16:13,908 --> 01:16:19,250
plane okay and this has all been carved

1660
01:16:16,039 --> 01:16:21,078
out by supernova explosions yeah so they

1661
01:16:19,250 --> 01:16:23,118
are there absolutely you just need to

1662
01:16:21,078 --> 01:16:23,750
have the right resolving power and

1663
01:16:23,118 --> 01:16:26,659
wavelength

1664
01:16:23,750 --> 01:16:29,090
see them ok so we have a question on

1665
01:16:26,659 --> 01:16:31,309
from online says what was the toughest

1666
01:16:29,090 --> 01:16:37,489
part of getting the debris-filled into

1667
01:16:31,310 --> 01:16:40,970
your virtual reality oh okay well let's

1668
01:16:37,489 --> 01:16:43,760
see here so the I think the the the most

1669
01:16:40,970 --> 01:16:48,350
difficult part of creating that dataset

1670
01:16:43,760 --> 01:16:53,510
was just the man-hours Dan hours I

1671
01:16:48,350 --> 01:16:57,530
should say yes so I think that I I went

1672
01:16:53,510 --> 01:17:01,520
on observing trips over several years I

1673
01:16:57,529 --> 01:17:04,159
think I must have banked at least four

1674
01:17:01,520 --> 01:17:06,710
weeks of my life at a telescope to make

1675
01:17:04,159 --> 01:17:09,139
those measurements and then you know

1676
01:17:06,710 --> 01:17:12,699
five years of my life in front of a

1677
01:17:09,140 --> 01:17:14,930
computer to reduce them to make them the

1678
01:17:12,699 --> 01:17:16,760
construction that you see and actually

1679
01:17:14,930 --> 01:17:19,030
the measurements were simple enough this

1680
01:17:16,760 --> 01:17:21,980
is just an aside but the visualization

1681
01:17:19,029 --> 01:17:26,769
finding the right way to do the shadings

1682

01:17:21,979 --> 01:17:31,189
and to make that skin representation

1683
01:17:26,770 --> 01:17:35,980
that took a lot of time okay we've got

1684
01:17:31,189 --> 01:17:39,349
it next be when it's supernova explodes

1685
01:17:35,979 --> 01:17:42,379
but almost all the matter is ejected and

1686
01:17:39,350 --> 01:17:44,660
the neutron stars the collapse collapse

1687
01:17:42,380 --> 01:17:48,020
the of matter what is the radiation

1688
01:17:44,659 --> 01:17:53,059
source that generates light from the

1689
01:17:48,020 --> 01:17:55,250
neutron star the the light of the

1690
01:17:53,060 --> 01:17:59,630
neutron star okay where's that coming

1691
01:17:55,250 --> 01:18:05,810
from it all the B elements are found

1692
01:17:59,630 --> 01:18:08,000
through iron ore okay so way so let me

1693
01:18:05,810 --> 01:18:09,530
try and make sure so the neutron star

1694
01:18:08,000 --> 01:18:12,500
itself is something separate from the

1695
01:18:09,529 --> 01:18:15,050
ejecta and the ejecta depending on the

1696
01:18:12,500 --> 01:18:17,600

type of remnant so in the case of the

1697

01:18:15,050 --> 01:18:21,039

crab the ejecta may be illuminated by

1698

01:18:17,600 --> 01:18:23,570

that neutron star which has a rapidly

1699

01:18:21,039 --> 01:18:25,670

which the neutron star itself is rapidly

1700

01:18:23,569 --> 01:18:28,549

rotating and has a strong magnetic field

1701

01:18:25,670 --> 01:18:30,980

and it can accelerate particles nearby

1702

01:18:28,550 --> 01:18:33,650

that can excite the the surrounding

1703

01:18:30,979 --> 01:18:35,779

ejecta the neutron star itself may have

1704

01:18:33,649 --> 01:18:37,859

a temperature associated with it right

1705

01:18:35,779 --> 01:18:41,448

and emit like a blackbody so

1706

01:18:37,859 --> 01:18:45,839

that that would be its energy source

1707

01:18:41,448 --> 01:18:48,029

right there making you work grant there

1708

01:18:45,840 --> 01:18:51,389

next questions or the exact opposite

1709

01:18:48,029 --> 01:18:53,609

corner of the room and then of course

1710

01:18:51,389 --> 01:18:55,889

you've got pulsar emissions from a

1711
01:18:53,609 --> 01:19:01,079
neutron star you want to fill those why

1712
01:18:55,889 --> 01:19:04,289
we well that's associated with the rapid

1713
01:19:01,079 --> 01:19:08,698
rotation the development of an axis and

1714
01:19:04,289 --> 01:19:11,579
you may have beaming of these highly

1715
01:19:08,698 --> 01:19:16,319
accelerated energy towards us depending

1716
01:19:11,579 --> 01:19:18,448
on the orientation earlier you mentioned

1717
01:19:16,319 --> 01:19:21,329
that you gave an example of using your

1718
01:19:18,448 --> 01:19:23,729
two-fifths to think about two stars that

1719
01:19:21,329 --> 01:19:27,118
are similar size and then one consumes

1720
01:19:23,729 --> 01:19:29,368
the other and I'm wondering how if both

1721
01:19:27,118 --> 01:19:32,189
stars start off roughly at the same size

1722
01:19:29,368 --> 01:19:36,899
what determines which star consumes the

1723
01:19:32,189 --> 01:19:39,239
other oh well may I defer to Niharika

1724
01:19:36,899 --> 01:19:42,329
who is the the stellar evolution expert

1725
01:19:39,239 --> 01:19:42,329
[Applause]

1726
01:19:43,850 --> 01:19:53,250
although I'd hold on alright that's an

1727
01:19:50,550 --> 01:19:55,560
excellent question and as such you know

1728
01:19:53,250 --> 01:19:58,250
we've only begin to start to understand

1729
01:19:55,560 --> 01:20:02,280
what happens when two stars interact

1730
01:19:58,250 --> 01:20:04,020
it's very complicated so usually you

1731
01:20:02,279 --> 01:20:06,960
would not expect both stars to be off

1732
01:20:04,020 --> 01:20:08,880
with same mass there would be marginal

1733
01:20:06,960 --> 01:20:11,460
differences in which case if you

1734
01:20:08,880 --> 01:20:13,020
remember dance one of these slides in

1735
01:20:11,460 --> 01:20:15,000
which he had said that there is a mass

1736
01:20:13,020 --> 01:20:18,570
you know when you were going down in

1737
01:20:15,000 --> 01:20:21,719
mass that's the longer you live right so

1738
01:20:18,569 --> 01:20:24,719
the lower mass stars lives longer and

1739

01:20:21,719 --> 01:20:27,779
higher mass stars evolves faster and it

1740
01:20:24,719 --> 01:20:30,118
becomes big so because it becomes big it

1741
01:20:27,779 --> 01:20:33,840
has a tendency to transfer mass in one

1742
01:20:30,118 --> 01:20:35,789
direction preferentially so in an ideal

1743
01:20:33,840 --> 01:20:37,199
in a world where both stars are not the

1744
01:20:35,789 --> 01:20:39,000
same they would serve engulf each other

1745
01:20:37,198 --> 01:20:42,089
and that can also happen in complicated

1746
01:20:39,000 --> 01:20:45,000
physics but usually the more massive

1747
01:20:42,090 --> 01:20:46,319
star because it's faster to evolve it

1748
01:20:45,000 --> 01:20:48,840
will be the one that will transfer mass

1749
01:20:46,319 --> 01:20:51,139
but if you want to know more find me

1750
01:20:48,840 --> 01:20:51,139
after the

1751
01:20:51,840 --> 01:20:58,510
okay one more question from online it

1752
01:20:54,609 --> 01:21:01,119
says how close to Earth does a supernova

1753
01:20:58,510 --> 01:21:03,610

have to be before we have to worry about

1754

01:21:01,119 --> 01:21:05,769

the dangerous cosmic rays another thing

1755

01:21:03,609 --> 01:21:08,079

in other words you know if they were

1756

01:21:05,770 --> 01:21:09,970

supernovae certain close distance way it

1757

01:21:08,079 --> 01:21:14,050

could cause some problems here yeah in

1758

01:21:09,970 --> 01:21:16,690

its distance and and certainly it has it

1759

01:21:14,050 --> 01:21:20,050

has affected the Earth's evolutionary

1760

01:21:16,689 --> 01:21:21,909

status at some point there's a lot of

1761

01:21:20,050 --> 01:21:23,529

caveats to that which is to say

1762

01:21:21,909 --> 01:21:27,010

depending on the type of supernova

1763

01:21:23,529 --> 01:21:29,349

explosion and whether or not a jet is

1764

01:21:27,010 --> 01:21:31,690

beamed towards us but I can say I used

1765

01:21:29,350 --> 01:21:35,070

the example of Beetlejuice Beetlejuice

1766

01:21:31,689 --> 01:21:37,449

were to explode it would cause

1767

01:21:35,069 --> 01:21:39,399

non-negligible influence on us and I've

1768
01:21:37,449 --> 01:21:40,420
I worked out this number sometime

1769
01:21:39,399 --> 01:21:43,319
because somebody asked me this before

1770
01:21:40,420 --> 01:21:46,720
and I just don't have it prepared but

1771
01:21:43,319 --> 01:21:48,069
there is a there's a great book by Craig

1772
01:21:46,720 --> 01:21:51,280
wheeler who was at the meeting today

1773
01:21:48,069 --> 01:21:53,590
cosmic explosions that goes into detail

1774
01:21:51,279 --> 01:21:55,090
about what happens here on earth nabil

1775
01:21:53,590 --> 01:21:59,260
juice explodes but I know that's a good

1776
01:21:55,090 --> 01:22:02,020
example so we can watch basically safely

1777
01:21:59,260 --> 01:22:04,510
from from Earth's vantage point about

1778
01:22:02,020 --> 01:22:06,430
beale juice but it would cause some kind

1779
01:22:04,510 --> 01:22:09,190
of noticeable changes here all right so

1780
01:22:06,430 --> 01:22:09,909
the internet says baitul juice is 642

1781
01:22:09,189 --> 01:22:14,379
light-years away

1782
01:22:09,909 --> 01:22:16,359
yes it's somewhere 600 or so light if

1783
01:22:14,380 --> 01:22:18,970
it's a if it if you hear that it's 10

1784
01:22:16,359 --> 01:22:21,639
parsecs away you better crawl under any

1785
01:22:18,970 --> 01:22:24,039
hole or any but they won't understand

1786
01:22:21,640 --> 01:22:27,369
parsecs right that's right 30

1787
01:22:24,039 --> 01:22:32,289
light-years we have a question way back

1788
01:22:27,369 --> 01:22:36,220
there so if the neutron star is a as a

1789
01:22:32,289 --> 01:22:38,680
possible result of the core collapse I

1790
01:22:36,220 --> 01:22:40,210
don't even know if quark stars are a

1791
01:22:38,680 --> 01:22:42,970
real thing or science fiction but I've

1792
01:22:40,210 --> 01:22:45,609
heard of them so would that result from

1793
01:22:42,970 --> 01:22:48,250
the same kind of process just a slightly

1794
01:22:45,609 --> 01:22:49,839
larger precursor star yeah we had a

1795
01:22:48,250 --> 01:22:54,279
couple of questions online as well could

1796

01:22:49,840 --> 01:22:56,970
quark stars result from this I I didn't

1797
01:22:54,279 --> 01:22:59,529
know but I should have known right I'm

1798
01:22:56,970 --> 01:23:02,740
unfamiliar with that literature but I do

1799
01:22:59,529 --> 01:23:03,670
know that that has been posited I mean

1800
01:23:02,739 --> 01:23:05,859
if you have new try

1801
01:23:03,670 --> 01:23:09,279
rich matter why couldn't you have some

1802
01:23:05,859 --> 01:23:11,409
strange quark matter as well and I know

1803
01:23:09,279 --> 01:23:13,800
some scientists have have tried to

1804
01:23:11,409 --> 01:23:16,750
explain some of the interesting

1805
01:23:13,800 --> 01:23:19,980
phenomena we observe in supernovae by

1806
01:23:16,750 --> 01:23:22,300
these transitions into quark matter yeah

1807
01:23:19,979 --> 01:23:23,529
okay I've heard other people say that

1808
01:23:22,300 --> 01:23:25,270
they felt that the quark matter would be

1809
01:23:23,529 --> 01:23:27,789
an unstable would go straight down to a

1810
01:23:25,270 --> 01:23:29,350

black hole well I don't want get a

1811
01:23:27,789 --> 01:23:31,719
stable form of matter in there but you

1812
01:23:29,350 --> 01:23:35,739
know I I want to make a judgment call I

1813
01:23:31,719 --> 01:23:36,760
was being neutral but that's not I'm

1814
01:23:35,738 --> 01:23:40,238
okay with speculate

1815
01:23:36,760 --> 01:23:42,070
okay because it's not my field all right

1816
01:23:40,238 --> 01:23:46,509
you're gonna get the last question

1817
01:23:42,069 --> 01:23:49,899
because we're almost at 9:30 so you've

1818
01:23:46,510 --> 01:23:53,170
got a chart out for soup is over 2009 i

1819
01:23:49,899 --> 01:23:56,920
peak have we found similar patterns that

1820
01:23:53,170 --> 01:24:00,489
are enabling this to say we gotta watch

1821
01:23:56,920 --> 01:24:02,199
these guys real soon right excellent

1822
01:24:00,488 --> 01:24:06,399
question and I tried to make that point

1823
01:24:02,198 --> 01:24:08,259
in that we have such scant details at

1824
01:24:06,399 --> 01:24:11,109
the moment this is kind of pointing us

1825
01:24:08,260 --> 01:24:13,840
that direction I was associated with

1826
01:24:11,109 --> 01:24:16,839
another object where it had this

1827
01:24:13,840 --> 01:24:19,420
luminous outburst okay we continued to

1828
01:24:16,840 --> 01:24:21,819
monitor it and nine months later there

1829
01:24:19,420 --> 01:24:24,190
was a supernova explosion so it is

1830
01:24:21,819 --> 01:24:26,619
happening but I mean I could count all

1831
01:24:24,189 --> 01:24:28,779
these events on my hand the fingers on

1832
01:24:26,619 --> 01:24:30,869
my hands as far as how many that's

1833
01:24:28,779 --> 01:24:33,789
happened even just one hand I think yes

1834
01:24:30,869 --> 01:24:35,738
but see but the the the point that I was

1835
01:24:33,789 --> 01:24:38,289
trying to make is with these new

1836
01:24:35,738 --> 01:24:40,479
facilities the hope is that we'll have

1837
01:24:38,289 --> 01:24:43,000
not just know this hand but all the

1838
01:24:40,479 --> 01:24:45,059
hands in the audience as far as examples

1839
01:24:43,000 --> 01:24:46,929
of this to be able to make real

1840
01:24:45,060 --> 01:24:49,840
anticipations maybe there's certain

1841
01:24:46,929 --> 01:24:53,529
patterns related to the explosion that

1842
01:24:49,840 --> 01:24:55,810
we can exploit yeah and this is just and

1843
01:24:53,529 --> 01:24:58,059
this is just one example of how time

1844
01:24:55,810 --> 01:25:00,130
domain astronomy is taking off with

1845
01:24:58,060 --> 01:25:02,440
things like LSST it's going to change a

1846
01:25:00,130 --> 01:25:04,150
lot in the next decade all right you can

1847
01:25:02,439 --> 01:25:06,329
get that one follow-up question in real

1848
01:25:04,149 --> 01:25:06,329
quick

1849
01:25:12,260 --> 01:25:20,579
that's the hope yes we have a short

1850
01:25:15,389 --> 01:25:23,699
turnaround that is well triangulation

1851
01:25:20,578 --> 01:25:25,018
amongst the various facilities we put in

1852
01:25:23,698 --> 01:25:26,668
a proposal for the National Science

1853

01:25:25,019 --> 01:25:28,469
Foundation maybe they'll give us some

1854
01:25:26,668 --> 01:25:30,868
funding to do that but I just have to

1855
01:25:28,469 --> 01:25:33,479
comment that the for the online audience

1856
01:25:30,868 --> 01:25:36,028
that the question inside was about

1857
01:25:33,479 --> 01:25:37,559
neutrinos and that not getting a

1858
01:25:36,029 --> 01:25:39,629
directionality but yes

1859
01:25:37,559 --> 01:25:41,639
triangulation can do it okay we've got

1860
01:25:39,628 --> 01:25:43,498
to stop folks I know this was a fence

1861
01:25:41,639 --> 01:25:45,798
fascinating talk give them another big

1862
01:25:43,498 --> 01:25:45,798
hand

1863
01:25:50,840 --> 01:25:57,460
all right we'll see here in two weeks

1864
01:25:52,939 --> 01:25:57,460
the fiery fate of exoplanets goodnight