PUBLIC LECTURE SERIES

The Deaths and Afterlives of Massive Stars

Featuring Guest Speaker:
Dan Milisavljevic

1
00:00:06,499 --> 00:00:03,500
like outreach and if you walked in today

2
00:00:10,400 --> 00:00:06,509
you came in and hopefully you got one of

3
00:00:12,950 --> 00:00:10,410
these the lithograph that we have for

4
00:00:16,760 --> 00:00:12,960
you tonight this one is of the veil

5
00:00:19,490 --> 00:00:16,770
nebula which is a piece of a supernova

6
00:00:22,010 --> 00:00:19,500
remnant it's actually a very small piece

7
00:00:24,140 --> 00:00:22,020
I believe this is in the area called the

8
00:00:26,450 --> 00:00:24,150
broom handle of the width the handle of

9
00:00:28,429 --> 00:00:26,460
the witch's broom in the veil supernova

10
00:00:30,169 --> 00:00:28,439
remnant on the front you see the Hubble

11
00:00:32,179 --> 00:00:30,179
picture and on the back there's a

12
00:00:34,130 --> 00:00:32,189
context picture to show you what a small

13
00:00:36,440 --> 00:00:34,140

piece of the supernova remnant that it

14
00:00:40,549 --> 00:00:36,450
is and this of course relates to

15
00:00:45,350 --> 00:00:40,559
tonight's speakers topic the death and

16
00:00:51,189 --> 00:00:45,360
after lives of massive stars our speaker

17
00:00:58,069 --> 00:00:55,729
University upcoming as you know this one

18
00:01:00,170 --> 00:00:58,079
has was delayed several weeks because we

19
00:01:02,990 --> 00:01:00,180
had such a special speaker for the

20
00:01:05,509 --> 00:01:03,000
conference that's here today so the next

21
00:01:06,710 --> 00:01:05,519
one will only be two weeks away may 7th

22
00:01:10,399 --> 00:01:06,720
Joleen Karlberg

23
00:01:11,750 --> 00:01:10,409
the fiery fate of exoplanets and then we

24
00:01:15,620 --> 00:01:11,760
go back to our normal once a month

25
00:01:17,090 --> 00:01:15,630
scheduled in June Chris Britt also the

26
00:01:20,359 --> 00:01:17,100
office of public outreach a colleague of

27
00:01:23,960 --> 00:01:20,369
mine can pulsar recycling produce a

28
00:01:26,990 --> 00:01:23,970
gamma-ray excess do you guys do you do

29
00:01:30,350 --> 00:01:27,000
recycle your pulsars don't you okay well

30
00:01:32,390 --> 00:01:30,360
actually the universe might be recycling

31
00:01:36,410 --> 00:01:32,400
its pulsars okay and you can see what

32
00:01:41,060 --> 00:01:36,420
that that does and then in July on July

33
00:01:45,109 --> 00:01:41,070
2nd Jodha Pasquale our new relatively

34
00:01:46,550 --> 00:01:45,119
new astronomical image processor will

35
00:01:50,359 --> 00:01:46,560
talk on the art and science of

36
00:01:52,100 --> 00:01:50,369
astronomical image processing okay if

37
00:01:54,679 --> 00:01:52,110
you want to find out this schedule you

38
00:01:56,179 --> 00:01:54,689

go to your favorite web browser in

39
00:01:58,130 --> 00:01:56,189
favorite search engine and type in the

40
00:02:00,889 --> 00:01:58,140
Space Telescope public lectures and you

41
00:02:03,980 --> 00:02:00,899
should find this webpage we have a go

42
00:02:05,600 --> 00:02:03,990
link Hubble site or go talks where you

43
00:02:08,240 --> 00:02:05,610
can see on the right side we have the

44
00:02:11,960 --> 00:02:08,250
list of the upcoming on the left side we

45
00:02:13,880 --> 00:02:11,970
have the links to the live both on our

46
00:02:17,600 --> 00:02:13,890
webcasting and on you too

47
00:02:21,020 --> 00:02:17,610
as well as our archive on YouTube and on

48
00:02:24,170 --> 00:02:21,030
the stsci webcasts finally you can of

49
00:02:26,240 --> 00:02:24,180
course subscribe or unsubscribe to our

50
00:02:28,460 --> 00:02:26,250
email list which sends out about two or

51
00:02:31,009 --> 00:02:28,470
three emails a month telling you just

52
00:02:33,050 --> 00:02:31,019
what's up and coming

53
00:02:35,360 --> 00:02:33,060
the email announcements you can sign up

54
00:02:38,809 --> 00:02:35,370
the website there are however some

55
00:02:40,100 --> 00:02:38,819
people who don't like to do that you can

56
00:02:41,479 --> 00:02:40,110
just write down your email address and

57
00:02:44,630 --> 00:02:41,489
give it to me and I'll make sure you get

58
00:02:47,240 --> 00:02:44,640
on there if you have questions the email

59
00:02:51,470 --> 00:02:47,250
address is public lecture at STScI dot

60
00:02:53,569 --> 00:02:51,480
edu our social media for the hubble

61
00:02:55,550 --> 00:02:53,579
space telescope the upcoming James Webb

62
00:02:57,800 --> 00:02:55,560
Space Telescope and for the Space

63
00:03:00,610 --> 00:02:57,810

Telescope Science Institute are here on

64
00:03:03,920 --> 00:03:00,620
Facebook Twitter YouTube and Instagram

65
00:03:07,640 --> 00:03:03,930
if you want to hear more of my diet of

66
00:03:09,649 --> 00:03:07,650
mine my spew you can see what I do on

67
00:03:13,940 --> 00:03:09,659
Facebook and Twitter although I only do

68
00:03:17,539 --> 00:03:13,950
that occasionally not all the time all

69
00:03:20,750 --> 00:03:17,549
right the observatory will not be open

70
00:03:22,940 --> 00:03:20,760
tonight he saw the clouds moving in and

71
00:03:25,819 --> 00:03:22,950
he said sorry we're just not gonna have

72
00:03:28,970 --> 00:03:25,829
a clear night top view but as always if

73
00:03:30,530 --> 00:03:28,980
you go to MD dot Space Grant at orj you

74
00:03:33,140 --> 00:03:30,540
can find this page for the Maryland

75
00:03:35,569 --> 00:03:33,150
Space Grant Observatory on Friday nights

76
00:03:37,879 --> 00:03:35,579
they do observing if you check there at

77
00:03:39,140 --> 00:03:37,889
Friday night at 6:00 or 7:00 p.m. they

78
00:03:41,210 --> 00:03:39,150
will have posted whether or not they're

79
00:03:42,650 --> 00:03:41,220
going to be open on Friday night to do

80
00:03:46,339 --> 00:03:42,660
observing and you can come down and do

81
00:03:47,360 --> 00:03:46,349
that okay all right and now the news

82
00:03:52,960 --> 00:03:47,370
from the universe for

83
00:03:57,740 --> 00:03:52,970
April 2019 our first story tonight

84
00:04:01,369 --> 00:03:57,750
Hubble's 29th anniversary today is April

85
00:04:04,819 --> 00:04:01,379
23rd and 29 years ago today

86
00:04:10,580 --> 00:04:04,829
years ago too tomorrow is when Hubble

87
00:04:14,080 --> 00:04:10,590
launched April 24 1990 and of course

88
00:04:16,729 --> 00:04:14,090

every year we have to come up with a

89
00:04:19,189 --> 00:04:16,739
interesting press release for you and

90
00:04:22,099 --> 00:04:19,199
you know sometimes it gets harder and

91
00:04:24,020 --> 00:04:22,109
harder to top ourselves okay so we went

92
00:04:25,909 --> 00:04:24,030
in an interesting direction this year

93
00:04:26,750 --> 00:04:25,919
okay we wanted to remind you something

94
00:04:29,780 --> 00:04:26,760
very

95
00:04:32,420 --> 00:04:29,790
and about Hubble observations now who

96
00:04:34,250 --> 00:04:32,430
here has heard of the Crab Nebula when

97
00:04:36,950 --> 00:04:34,260
you think of the Crab Nebula you think

98
00:04:39,110 --> 00:04:36,960
of this and this is a supernova

99
00:04:41,600 --> 00:04:39,120
explosion that our speaker tonight will

100
00:04:43,850 --> 00:04:41,610
might mention in one of his - in his

101
00:04:45,530 --> 00:04:43,860
talk but this is what everyone thinks of

102
00:04:49,130 --> 00:04:45,540
the Crab Nebula but there is also

103
00:04:50,990 --> 00:04:49,140
another Crab Nebula okay this is a

104
00:04:54,050 --> 00:04:51,000
supernova explosion a star that exploded

105
00:04:55,880 --> 00:04:54,060
blew its guts out into space there is

106
00:04:58,520 --> 00:04:55,890
something called the southern Crab

107
00:05:04,520 --> 00:04:58,530
Nebula and this is an image from Hubble

108
00:05:08,660 --> 00:05:04,530
from 1999 in a nitrogen filter okay this

109
00:05:12,260 --> 00:05:08,670
is not a supernova explosion this one

110
00:05:13,610 --> 00:05:12,270
and by the way whenever we say oh it's

111
00:05:15,110 --> 00:05:13,620
the Crab Nebula it's supposed to look

112
00:05:17,540 --> 00:05:15,120
like an crab just squint your eyes a

113
00:05:20,300 --> 00:05:17,550

little bit okay you know then you might

114
00:05:21,800 --> 00:05:20,310
be able to see it honestly this one

115
00:05:25,490 --> 00:05:21,810
looks a little bit more like a tick okay

116
00:05:27,350 --> 00:05:25,500
then a crab to me but you know don't

117
00:05:29,390 --> 00:05:27,360
tell the guys who discovered it new high

118
00:05:33,830 --> 00:05:29,400
released who named it okay so this was

119
00:05:35,420 --> 00:05:33,840
back in 1999 and it was done in with

120
00:05:37,280 --> 00:05:35,430
wide field planetary camera - can we

121
00:05:42,470 --> 00:05:37,290
take the lights down a bit there's a lot

122
00:05:43,070 --> 00:05:42,480
of scattered light on the screen there

123
00:05:44,870 --> 00:05:43,080
you go

124
00:05:46,970 --> 00:05:44,880
so now you can see in the center you can

125
00:05:48,860 --> 00:05:46,980
see this cut off of the edges that's

126
00:05:52,730 --> 00:05:48,870
characteristic of the with pic -

127
00:05:55,760 --> 00:05:52,740
footprint okay so we were going to come

128
00:05:58,220 --> 00:05:55,770
back and do this again and I'm gonna

129
00:06:01,040 --> 00:05:58,230
reorient it for a little bit there okay

130
00:06:03,380 --> 00:06:01,050
and then we have we went and redid this

131
00:06:04,850 --> 00:06:03,390
we also did the nitrogen filter right

132
00:06:07,760 --> 00:06:04,860
but this time we did it with wide field

133
00:06:10,460 --> 00:06:07,770
camera 3 so this is the nitrogen filter

134
00:06:12,470 --> 00:06:10,470
that we did that we also did several

135
00:06:15,140 --> 00:06:12,480
other filters we only had one filter on

136
00:06:19,250 --> 00:06:15,150
this in 1999 we did the oxygen filter

137
00:06:22,730 --> 00:06:19,260
okay and we did the hydrogen alpha

138
00:06:25,190 --> 00:06:22,740

filter and then we did the sulfur filter

139
00:06:27,350 --> 00:06:25,200
so we have four very specific

140
00:06:30,410 --> 00:06:27,360
observations that are these very tiny

141
00:06:32,840 --> 00:06:30,420
filter band passes all right that only

142
00:06:36,980 --> 00:06:32,850
pick out the emission from specific

143
00:06:39,990 --> 00:06:36,990
elements okay and together this was our

144
00:06:44,379 --> 00:06:40,000
release that we came out with last week

145
00:06:47,500 --> 00:06:44,389
all right decide to go ooh this side go

146
00:06:49,210 --> 00:06:47,510
ah thank you very much all right if

147
00:06:51,820 --> 00:06:49,220
we're gonna do this we got to do this

148
00:06:54,640 --> 00:06:51,830
all right so this is the southern Crab

149
00:06:56,650 --> 00:06:54,650
Nebula in four specific filters and you

150
00:06:59,590 --> 00:06:56,660
can see how like at the end of the crabs

151
00:07:01,150 --> 00:06:59,600
legs how it gets green okay well that

152
00:07:02,980 --> 00:07:01,160
indicates that there's only specific

153
00:07:04,600 --> 00:07:02,990
emission in there versus the other

154
00:07:06,730 --> 00:07:04,610
colors you can see how colorful it is

155
00:07:10,330 --> 00:07:06,740
but those colors really mean something

156
00:07:13,090 --> 00:07:10,340
to astronomers all right now this is

157
00:07:15,159 --> 00:07:13,100
what we call a proto planetary nebula

158
00:07:17,080 --> 00:07:15,169
okay you may have heard of planetary

159
00:07:19,510 --> 00:07:17,090
nebulae that's a end stage of a star

160
00:07:21,610 --> 00:07:19,520
where it blows off is it in a nice wind

161
00:07:24,219 --> 00:07:21,620
blows off its outer layers Ince's it

162
00:07:26,050 --> 00:07:24,229
into interstellar space well what we

163
00:07:28,510 --> 00:07:26,060

believe is going on here is that there

164
00:07:30,850 --> 00:07:28,520
is a evolved star well actually a

165
00:07:33,670 --> 00:07:30,860
stellar remnant a white dwarf and then a

166
00:07:35,170 --> 00:07:33,680
dying star a red giant and they're in

167
00:07:37,719 --> 00:07:35,180
orbit around each other in a binary

168
00:07:39,340 --> 00:07:37,729
system and this red giant is giving off

169
00:07:41,260 --> 00:07:39,350
some gas it hasn't quite gotten to the

170
00:07:43,420 --> 00:07:41,270
planetary nebula stays that's why it's

171
00:07:45,310 --> 00:07:43,430
proto planet area Beulah and some of the

172
00:07:48,490 --> 00:07:45,320
material is formed to disk around them

173
00:07:50,500 --> 00:07:48,500
stopping the flow in this direction but

174
00:07:53,500 --> 00:07:50,510
letting the flow go in purple

175
00:07:56,050 --> 00:07:53,510
perpendicular to the disk so that the

176
00:07:59,529 --> 00:07:56,060
flow that you see is coming out in two

177
00:08:01,330 --> 00:07:59,539
bubbles on here and one here that sort

178
00:08:03,279 --> 00:08:01,340
of resembles an hourglass you know where

179
00:08:06,129 --> 00:08:03,289
it's pinched at the center and bulbs

180
00:08:08,950 --> 00:08:06,139
going above and below and so this is a

181
00:08:10,900 --> 00:08:08,960
protoplanetary nebula it probably will

182
00:08:14,920 --> 00:08:10,910
become a full-blown planetary nebula

183
00:08:16,930 --> 00:08:14,930
yeah few million years from now okay all

184
00:08:20,320 --> 00:08:16,940
right now what we really wanted to do

185
00:08:22,810 --> 00:08:20,330
was remind you of what we did to see all

186
00:08:25,150 --> 00:08:22,820
these different features of it so one of

187
00:08:27,850 --> 00:08:25,160
the actually I think the more important

188
00:08:32,199 --> 00:08:27,860

besides the image is this diagram that

189
00:08:35,199 --> 00:08:32,209
takes the southern Crab Nebula breaks it

190
00:08:37,810 --> 00:08:35,209
up into those four filters and then

191
00:08:40,269 --> 00:08:37,820
relates those four filters to a spectrum

192
00:08:42,550 --> 00:08:40,279
okay so this spectrum was taken of the

193
00:08:45,030 --> 00:08:42,560
inner region here and it shows the full

194
00:08:48,579 --> 00:08:45,040
emission across the various wavelengths

195
00:08:51,540 --> 00:08:48,589
of the visible light to remind you that

196
00:08:53,260 --> 00:08:51,550
you know Hubble gets a lot of its

197
00:08:56,710 --> 00:08:53,270
science done by

198
00:09:00,579 --> 00:08:56,720
imaging but it gets just as much science

199
00:09:03,190 --> 00:09:00,589
done using spectra this spectrum that

200
00:09:04,660 --> 00:09:03,200
we're showing here you know I know it's

201
00:09:08,139 --> 00:09:04,670
not the pretty pictures that you're used

202
00:09:11,019 --> 00:09:08,149
to with Hubble but 50% of Hubble science

203
00:09:12,910 --> 00:09:11,029
is done by examining these spectra and

204
00:09:14,860 --> 00:09:12,920
looking for the temperature and the

205
00:09:17,230 --> 00:09:14,870
composition and the motion of these

206
00:09:19,870 --> 00:09:17,240
individual elements of gas to really get

207
00:09:22,810 --> 00:09:19,880
the details of what's going on so it's a

208
00:09:25,240 --> 00:09:22,820
combination of both the imaging and the

209
00:09:29,769 --> 00:09:25,250
spectra that produces the Hubble science

210
00:09:32,440 --> 00:09:29,779
that has advanced astronomy so much now

211
00:09:34,480 --> 00:09:32,450
this is a visualization done by our

212
00:09:38,170 --> 00:09:34,490
department just to sort of get that

213
00:09:41,190 --> 00:09:38,180

point across here you can see that

214
00:09:45,870 --> 00:09:41,200
spectra taken of that central region

215
00:09:48,550 --> 00:09:45,880
pulled out into the full spectrum and

216
00:10:07,040 --> 00:09:48,560
then we take the individual images and

217
00:10:11,329 --> 00:10:09,019
now is just one example of how both

218
00:10:13,400 --> 00:10:11,339
imaging and spectrum spectra work

219
00:10:17,180 --> 00:10:13,410
together to get us the science that we

220
00:10:19,070 --> 00:10:17,190
do with Hubble our second story tonight

221
00:10:20,540 --> 00:10:19,080
you might have guessed you I'm sure

222
00:10:21,829 --> 00:10:20,550
you've all seen this before but I

223
00:10:24,560 --> 00:10:21,839
hopefully I'll tell you a few things

224
00:10:26,990 --> 00:10:24,570
that you didn't hear at least from the

225
00:10:30,860 --> 00:10:27,000
mainstream media the black hole in

226
00:10:34,759 --> 00:10:30,870
Messier 87 now first of all what is

227
00:10:36,949 --> 00:10:34,769
Messier 87 it is a giant elliptical

228
00:10:39,949 --> 00:10:36,959
galaxy in the center of the Virgo

229
00:10:41,900 --> 00:10:39,959
cluster it is the larger I think it may

230
00:10:44,480 --> 00:10:41,910
be the largest galaxy in Virgo it's one

231
00:10:46,280 --> 00:10:44,490
of the largest galaxies in Virgo K it's

232
00:10:49,310 --> 00:10:46,290
a giant elliptical all right and this is

233
00:10:51,230 --> 00:10:49,320
the Sloan Digital Sky Survey and down at

234
00:10:54,350 --> 00:10:51,240
its core it has a supermassive black

235
00:10:55,790 --> 00:10:54,360
hole and you can sort of see it in the

236
00:10:58,280 --> 00:10:55,800
center of this image but if we take the

237
00:11:01,069 --> 00:10:58,290
Hubble image and then we zoom in on that

238
00:11:03,230 --> 00:11:01,079

Hubble image you start to see this jet

239
00:11:04,250 --> 00:11:03,240
coming out of the center let me zoom in

240
00:11:05,900 --> 00:11:04,260
one more time

241
00:11:08,660 --> 00:11:05,910
alright now you can definitely see it

242
00:11:09,860 --> 00:11:08,670
okay so there is a bright spot in the

243
00:11:12,440 --> 00:11:09,870
center which is where the supermassive

244
00:11:14,360 --> 00:11:12,450
black hole is and there the material

245
00:11:17,480 --> 00:11:14,370
around the supermassive black hole is

246
00:11:19,550 --> 00:11:17,490
spewing out some material at such speeds

247
00:11:22,850 --> 00:11:19,560
that that material is extending across

248
00:11:26,329 --> 00:11:22,860
five thousand light-years of space okay

249
00:11:27,650 --> 00:11:26,339
yes so we're seeing this jet here and

250
00:11:29,540 --> 00:11:27,660
it's actually kind of cool if you look

251
00:11:31,340 --> 00:11:29,550
at this in infrared of a friend who

252
00:11:33,139 --> 00:11:31,350
works at spitzer he said yeah but in

253
00:11:35,210 --> 00:11:33,149
infrared we can see the jet on the other

254
00:11:36,680 --> 00:11:35,220
side do you see the jet there's no in

255
00:11:38,360 --> 00:11:36,690
the Hubble image you can't see the jet

256
00:11:40,160 --> 00:11:38,370
on the other side but the infrared image

257
00:11:41,389 --> 00:11:40,170
it does glow in the infrared you could

258
00:11:45,440 --> 00:11:41,399
actually see it it was really kind of

259
00:11:47,510 --> 00:11:45,450
cool we were comparing images but you

260
00:11:50,120 --> 00:11:47,520
see that bright spot way down in there

261
00:11:50,930 --> 00:11:50,130
is the supermassive black hole how far

262
00:11:54,410 --> 00:11:50,940
down in there

263
00:11:56,900 --> 00:11:54,420

I wanted to know so I put together this

264
00:11:59,480 --> 00:11:56,910
series of images all right so I had to

265
00:12:01,280 --> 00:11:59,490
go from Hubble to the radio

266
00:12:03,670 --> 00:12:01,290
this is from the Very Large Array radio

267
00:12:05,930 --> 00:12:03,680
at two centimeter and we zoom in to that

268
00:12:09,220 --> 00:12:05,940
and then we had to go to another radio

269
00:12:13,030 --> 00:12:09,230
image from the VLA at seven millimeter

270
00:12:15,170 --> 00:12:13,040
and then we had to start using arrays of

271
00:12:17,630 --> 00:12:15,180
telescopes very long baseline

272
00:12:20,569 --> 00:12:17,640
interferometry this was 18 centimeter

273
00:12:20,870 --> 00:12:20,579
observations here right and then we had

274
00:12:23,750 --> 00:12:20,880
to go

275
00:12:25,400 --> 00:12:23,760
even further using another very long

276
00:12:27,920 --> 00:12:25,410
baseline array but this was back at the

277
00:12:31,220 --> 00:12:27,930
2-centimeter thing and then we had to go

278
00:12:34,160 --> 00:12:31,230
using more very long baseline array at

279
00:12:35,900 --> 00:12:34,170
43 gigahertz and then at the 43

280
00:12:38,930 --> 00:12:35,910
gigahertz we're gonna zoom in on this

281
00:12:40,970 --> 00:12:38,940
yet one more time and finally we're down

282
00:12:44,090 --> 00:12:40,980
to just the emission from the material

283
00:12:48,410 --> 00:12:44,100
around the black hole and see that tiny

284
00:12:52,130 --> 00:12:48,420
little black spot there zoom in and this

285
00:12:57,410 --> 00:12:52,140
is the image of the black hole at the

286
00:13:00,170 --> 00:12:57,420
core of Messier 87 now it's not actually

287
00:13:03,710 --> 00:13:00,180
the black hole okay because facing black

288
00:13:06,290 --> 00:13:03,720

holes are black no light can escape them

289
00:13:08,420 --> 00:13:06,300
they cannot emit any light by definition

290
00:13:09,770 --> 00:13:08,430
okay so this is not an image of the

291
00:13:13,400 --> 00:13:09,780
black hole it's a bunch of the stuff

292
00:13:16,970 --> 00:13:13,410
around the black hole okay so this is

293
00:13:20,870 --> 00:13:16,980
the event horizon is in here the size of

294
00:13:23,090 --> 00:13:20,880
this dark region here is about one and a

295
00:13:24,620 --> 00:13:23,100
half to two times the event horizon of

296
00:13:26,990 --> 00:13:24,630
the black hole and the BLET horizon is

297
00:13:30,770 --> 00:13:27,000
the actual edge and when around that

298
00:13:33,170 --> 00:13:30,780
black hole the okay come on guys let's

299
00:13:37,100 --> 00:13:33,180
turn off the phones here around that

300
00:13:39,350 --> 00:13:37,110
black hole the faces warped so much that

301
00:13:41,180 --> 00:13:39,360
light actually starts circling around

302
00:13:43,730 --> 00:13:41,190
the black hole there's a photon sphere

303
00:13:45,050 --> 00:13:43,740
and such and light gets warped around it

304
00:13:46,760 --> 00:13:45,060
and stretched around and pressed around

305
00:13:49,970 --> 00:13:46,770
and we can predict what it would look

306
00:13:52,580 --> 00:13:49,980
like and actually we predicted it would

307
00:13:53,870 --> 00:13:52,590
look pretty much like this okay now how

308
00:13:56,240 --> 00:13:53,880
many people saw the movie interstellar

309
00:13:58,220 --> 00:13:56,250
right and there was a somewhat

310
00:14:00,590 --> 00:13:58,230
scientific visualization of a black hole

311
00:14:02,450 --> 00:14:00,600
in interstellar and it looked a lot

312
00:14:07,670 --> 00:14:02,460
better than this but then again it was

313
00:14:09,230 --> 00:14:07,680

CG this is real okay this is real and if

314
00:14:11,330 --> 00:14:09,240
you take that interstellar one and you

315
00:14:11,720 --> 00:14:11,340
fuzz it out into the resolution that you

316
00:14:15,860 --> 00:14:11,730
can't

317
00:14:17,900 --> 00:14:15,870
a lot like this okay all right so this

318
00:14:20,390 --> 00:14:17,910
is what was basically what was predicted

319
00:14:22,970 --> 00:14:20,400
general ativy has been really really

320
00:14:26,960 --> 00:14:22,980
good at predicting what we were going to

321
00:14:29,840 --> 00:14:26,970
see you saw how many times I had to zoom

322
00:14:33,680 --> 00:14:29,850
in in order to show you this this

323
00:14:36,950 --> 00:14:33,690
resolution is 2500

324
00:14:40,880 --> 00:14:36,960
times greater resolution than the Hubble

325
00:14:43,880 --> 00:14:40,890
Space Telescope yeah how did they

326
00:14:46,640 --> 00:14:43,890
achieve that they used eight radio

327
00:14:48,890 --> 00:14:46,650
telescopes across our entire planet

328
00:14:52,210 --> 00:14:48,900
one down itself Pole others spread out

329
00:14:55,490 --> 00:14:52,220
around the world to basically

330
00:14:58,730 --> 00:14:55,500
synthesize a telescope as large as our

331
00:15:00,560 --> 00:14:58,740
entire planet okay now it doesn't have

332
00:15:03,590 --> 00:15:00,570
the collecting area of our entire planet

333
00:15:05,690 --> 00:15:03,600
but it can achieve the resolution of a

334
00:15:07,700 --> 00:15:05,700
telescope as large as our entire planet

335
00:15:11,570 --> 00:15:07,710
so this is basically out as good as we

336
00:15:15,050 --> 00:15:11,580
can do okay and this black hole is 55

337
00:15:19,670 --> 00:15:15,060
million light years away and you know

338
00:15:23,720 --> 00:15:19,680

what it's size is about the size of our

339
00:15:28,460 --> 00:15:23,730
solar system that's the size of

340
00:15:30,260 --> 00:15:28,470
Neptune's orbit compared to black hole

341
00:15:33,530 --> 00:15:30,270
they're complicated and then the event

342
00:15:35,890 --> 00:15:33,540
horizon of the black hole and so being

343
00:15:39,380 --> 00:15:35,900
able to resolve this black hole is

344
00:15:43,880 --> 00:15:39,390
analogous to being able to see a quarter

345
00:15:50,870 --> 00:15:43,890
on the surface of the Moon this is one

346
00:15:53,450 --> 00:15:50,880
incredible achievement here yeah now

347
00:15:55,550 --> 00:15:53,460
there's only one problem with this

348
00:15:57,830 --> 00:15:55,560
alright is we've already created a

349
00:15:59,480 --> 00:15:57,840
telescope as large as our planet it's

350
00:16:01,040 --> 00:15:59,490
kind of hard to create one larger unless

351
00:16:03,140 --> 00:16:01,050
you start sending telescopes out into

352
00:16:05,030 --> 00:16:03,150
space for interferometry and well that's

353
00:16:09,320 --> 00:16:05,040
not gonna be solved anytime soon

354
00:16:10,850 --> 00:16:09,330
the second problem is that if you see

355
00:16:12,110 --> 00:16:10,860
one black hole you've sort of seen them

356
00:16:15,380 --> 00:16:12,120
all all right they're gonna get better

357
00:16:17,300 --> 00:16:15,390
at this but they the photon sphere at

358
00:16:19,670 --> 00:16:17,310
all this this photon wrapping around it

359
00:16:21,290 --> 00:16:19,680
doesn't going to change that much what's

360
00:16:22,880 --> 00:16:21,300
gonna make the next observations

361
00:16:23,990 --> 00:16:22,890
interesting is one they're gonna look at

362
00:16:26,720 --> 00:16:24,000
the black hole at the center of our

363
00:16:28,490 --> 00:16:26,730

galaxy that'll be kind of cool it may

364
00:16:30,530 --> 00:16:28,500
look very similar to this but at least

365
00:16:32,750 --> 00:16:30,540
you know it'll be our black hole not the

366
00:16:35,390 --> 00:16:32,760
one from some other galaxy so I'll have

367
00:16:38,150 --> 00:16:35,400
a sense of pride and - they want to be

368
00:16:41,150 --> 00:16:38,160
able to watch these over time and see

369
00:16:43,220 --> 00:16:41,160
the undulations in the photon the

370
00:16:44,960 --> 00:16:43,230
photons that are happening they want to

371
00:16:46,700 --> 00:16:44,970
see the changes in the emission from

372
00:16:47,710 --> 00:16:46,710
around the black hole and that will

373
00:16:50,860 --> 00:16:47,720
start to tell us more

374
00:16:52,600 --> 00:16:50,870
so just like we started to have a new

375
00:16:55,210 --> 00:16:52,610
field of astronomy with gravitational

376
00:16:57,430 --> 00:16:55,220
wave astronomy a few years ago this is

377
00:17:01,000 --> 00:16:57,440
the beginning of using interferometry to

378
00:17:03,820 --> 00:17:01,010
actually see and study black holes up

379
00:17:08,500 --> 00:17:03,830
close and personal all right so just to

380
00:17:11,800 --> 00:17:08,510
remind you here is the that zoom in but

381
00:17:26,300 --> 00:17:11,810
with a little bit of piano music

382
00:18:43,840 --> 00:18:36,509
[Music]

383
00:18:45,700 --> 00:18:43,850
so so really I just put this together

384
00:18:47,139 --> 00:18:45,710
afterwards to try it understand it for

385
00:18:49,029 --> 00:18:47,149
myself and I knew I'd want to show it to

386
00:18:51,159 --> 00:18:49,039
you guys here and then I just threw it

387
00:18:52,269 --> 00:18:51,169
up on YouTube thinking that all right

388
00:18:55,060 --> 00:18:52,279

well maybe other people would like it

389
00:18:58,539 --> 00:18:55,070
it's our second most popular video of

390
00:18:59,859 --> 00:18:58,549
the last nine months obviously we

391
00:19:03,960 --> 00:18:59,869
provided a little bit of context that

392
00:19:08,519 --> 00:19:03,970
that was necessary for tonight alright

393
00:19:11,560 --> 00:19:08,529
you did great so thank you for watching

394
00:19:15,719 --> 00:19:11,570
and now let's go to our featured speaker

395
00:19:20,259 --> 00:19:15,729
tonight dan Millis al millas Savio Vic

396
00:19:23,049 --> 00:19:20,269
is from Purdue University and I did not

397
00:19:25,690 --> 00:19:23,059
get a chance to get his resume before

398
00:19:27,849 --> 00:19:25,700
him so I will les introduce into to you

399
00:19:37,960 --> 00:19:27,859
and let him tell you all about himself

400
00:19:39,639 --> 00:19:37,970
ladies gentlemen Dan Frank thanks very

401
00:19:42,159 --> 00:19:39,649
much for the introduction you are a

402
00:19:44,889 --> 00:19:42,169
difficult act to follow you have lots of

403
00:19:49,169 --> 00:19:44,899
energy I hope I can match it in some

404
00:19:52,989 --> 00:19:49,179
scale now let me just get set up here

405
00:19:55,869 --> 00:19:52,999
make sure that we're live

406
00:20:08,169 --> 00:19:55,879
oh and that didn't work don't look at my

407
00:20:11,830 --> 00:20:08,179
password okay there we go all right it

408
00:20:13,479 --> 00:20:11,840
truly is a pleasure to be here at the

409
00:20:16,299 --> 00:20:13,489
headquarters of some of the most

410
00:20:20,649 --> 00:20:16,309
important scientific instruments ever

411
00:20:22,719 --> 00:20:20,659
designed by humankind like a kid I've

412
00:20:25,149 --> 00:20:22,729
always admired the Hubble Space

413
00:20:27,430 --> 00:20:25,159

Telescope and so to be here today

414
00:20:29,859 --> 00:20:27,440
talking about my use of the Hubble Space

415
00:20:32,919 --> 00:20:29,869
Telescope and other space observatories

416
00:20:34,810 --> 00:20:32,929
is truly a pleasure as was mentioned

417
00:20:38,529 --> 00:20:34,820
we're having a scientific meeting right

418
00:20:40,359 --> 00:20:38,539
now where a lot of experts are getting

419
00:20:42,399 --> 00:20:40,369
together to talk about some of the

420
00:20:43,839 --> 00:20:42,409
phenomena that I'm gonna be reviewing in

421
00:20:45,549 --> 00:20:43,849
this talk and I've tried my best to

422
00:20:46,269 --> 00:20:45,559
incorporate their signs although there

423
00:20:49,330 --> 00:20:46,279
is a lot

424
00:20:52,420 --> 00:20:49,340
yes I'm Daniel e salvage currently

425
00:20:55,210 --> 00:20:52,430
at Purdue University at the Department

426
00:20:57,730 --> 00:20:55,220
of physics and astronomy and I'll be

427
00:21:00,670 --> 00:20:57,740
talking today about the deaths and after

428
00:21:03,340 --> 00:21:00,680
lives of massive stars the workshop

429
00:21:05,950 --> 00:21:03,350
we're doing over the last couple days is

430
00:21:08,290 --> 00:21:05,960
the deaths and after lives of stars so

431
00:21:09,700 --> 00:21:08,300
just to narrow down the focus a little

432
00:21:11,920 --> 00:21:09,710
bit because there are a lot of stars

433
00:21:15,220 --> 00:21:11,930
I'll just be talking about massive stars

434
00:21:17,260 --> 00:21:15,230
and this picture is chosen in particular

435
00:21:20,710 --> 00:21:17,270
you're going to see it a lot the name is

436
00:21:22,600 --> 00:21:20,720
the supernova remnant Cassiopeia A it'll

437
00:21:27,160 --> 00:21:22,610
be the poster child for a lot of what is

438
00:21:30,010 --> 00:21:27,170

to follow I'm here alone up front here

439
00:21:32,140 --> 00:21:30,020
and yet I am backed by a whole Legion of

440
00:21:35,250 --> 00:21:32,150
super nova superheroes that help me on a

441
00:21:39,060 --> 00:21:35,260
daily basis I just want to flash their

442
00:21:43,030 --> 00:21:39,070
pictures up front in the audience is my

443
00:21:44,770 --> 00:21:43,040
trusty CL yes honor ACL Johnson

444
00:21:48,310 --> 00:21:44,780
postdoctoral fellow at higher Kesava

445
00:21:51,340 --> 00:21:48,320
part of the Boilermakers at Purdue

446
00:21:54,190 --> 00:21:51,350
University as part of my group just

447
00:21:56,410 --> 00:21:54,200
brilliant students and experts that I

448
00:21:58,540 --> 00:21:56,420
get to work with on a daily basis to

449
00:22:03,190 --> 00:21:58,550
tackle these pressing problems all right

450
00:22:05,080 --> 00:22:03,200
that's that's the introduction the first

451
00:22:10,990 --> 00:22:05,090
thing I want to talk about is that we

452
00:22:14,740 --> 00:22:11,000
have watched stars explode up front is

453
00:22:17,710 --> 00:22:14,750
an image of a star San juliek - 69 - OH

454
00:22:18,820 --> 00:22:17,720
- it's in the Large Magellanic Cloud now

455
00:22:21,640 --> 00:22:18,830
has anybody been in the southern

456
00:22:24,010 --> 00:22:21,650
hemisphere before some people okay for

457
00:22:26,440 --> 00:22:24,020
those who have if you look up at the sky

458
00:22:28,420 --> 00:22:26,450
first you see oh my gosh the

459
00:22:30,970 --> 00:22:28,430
constellations they're upside down right

460
00:22:32,590 --> 00:22:30,980
and then if you look a little bit more

461
00:22:35,200 --> 00:22:32,600
closely you may notice that there's

462
00:22:37,330 --> 00:22:35,210
these fuzzy patches these two fuzzy

463
00:22:39,310 --> 00:22:37,340

patches are actually satellite galaxies

464
00:22:40,600 --> 00:22:39,320
neighboring galaxies the large imagina

465
00:22:44,260 --> 00:22:40,610
antic clouds and in the Large Magellanic

466
00:22:47,260 --> 00:22:44,270
Cloud is this star now if it weren't for

467
00:22:48,760 --> 00:22:47,270
the arrow nothing would be really that

468
00:22:50,350 --> 00:22:48,770
different about this star from many

469
00:22:52,030 --> 00:22:50,360
others that we see in the field here we

470
00:22:54,430 --> 00:22:52,040
see something of comparable brightness

471
00:22:57,790 --> 00:22:54,440
up in the corner something even bigger

472
00:23:00,310 --> 00:22:57,800
and brighter right but the arrow tells

473
00:23:04,570 --> 00:23:00,320
you something's gonna happen right

474
00:23:07,389 --> 00:23:04,580
and indeed on February 23rd 1987 this is

475
00:23:09,100 --> 00:23:07,399
what was observed okay a supernova the

476
00:23:11,649 --> 00:23:09,110
star had exploded

477
00:23:13,720 --> 00:23:11,659
well actually the start exploded about a

478
00:23:15,220 --> 00:23:13,730
hundred and sixty thousand years ago and

479
00:23:17,049 --> 00:23:15,230
it took that amount of time for the

480
00:23:18,490 --> 00:23:17,059
light to actually come to the earth

481
00:23:21,850 --> 00:23:18,500
which is something to think about

482
00:23:23,139 --> 00:23:21,860
I mean 160,000 years ago modern man

483
00:23:25,450 --> 00:23:23,149
would have been involved probably not

484
00:23:28,659 --> 00:23:25,460
migrated out of africa at that point

485
00:23:30,220 --> 00:23:28,669
there's just a lot a lot of history that

486
00:23:33,549 --> 00:23:30,230
has happened since then but an on

487
00:23:38,230 --> 00:23:33,559
February 23rd 1987 it was sighted now

488
00:23:42,700 --> 00:23:38,240

the naming convention supernova SN 1987a

489
00:23:44,710 --> 00:23:42,710
and then it goes to quench ABCDE etc

490
00:23:47,409 --> 00:23:44,720
right so this was the first supernova of

491
00:23:52,960 --> 00:23:47,419
1987 and appropriately it was Co

492
00:23:55,450 --> 00:23:52,970
discovered by a Canadian 1987a I I'm

493
00:23:58,629 --> 00:23:55,460
Canadian I'm Canadian so I could make

494
00:24:01,060 --> 00:23:58,639
that joke every time by Ian Shelton and

495
00:24:02,980 --> 00:24:01,070
one of the observing assistants Oscar

496
00:24:05,259 --> 00:24:02,990
Duhalde it at last Campanas Observatory

497
00:24:07,360 --> 00:24:05,269
have had the fortune of met meeting and

498
00:24:10,269 --> 00:24:07,370
has told me the whole story of their

499
00:24:12,970 --> 00:24:10,279
exciting discovery so that was the

500
00:24:14,889 --> 00:24:12,980
explosion and then returning years later

501
00:24:16,240 --> 00:24:14,899
with the razor-sharp vision of the

502
00:24:18,070 --> 00:24:16,250
Hubble Space Telescope

503
00:24:20,919 --> 00:24:18,080
there it is drifting in the center of

504
00:24:24,490 --> 00:24:20,929
the field let's do an enlargement here

505
00:24:26,139 --> 00:24:24,500
okay the star has vanished now for the

506
00:24:28,360 --> 00:24:26,149
untrained eye there's a lot of structure

507
00:24:29,139 --> 00:24:28,370
going on don't be distracted by these

508
00:24:31,810 --> 00:24:29,149
rings

509
00:24:34,060 --> 00:24:31,820
this was actually shed by the progenitor

510
00:24:35,799 --> 00:24:34,070
star system what we think is not

511
00:24:37,869 --> 00:24:35,809
necessarily one star but potentially two

512
00:24:40,240 --> 00:24:37,879
stars in orbit that flung off this

513
00:24:42,460 --> 00:24:40,250

material prior to the explosion and this

514
00:24:44,499 --> 00:24:42,470
ring as well is also thought to be

515
00:24:46,990 --> 00:24:44,509
associated with the star prior to

516
00:24:49,950 --> 00:24:47,000
explosion but in the middle this debris

517
00:24:53,999 --> 00:24:49,960
right that's associated with the

518
00:24:59,320 --> 00:24:54,009
explosion itself truly the star is gone

519
00:25:02,830 --> 00:24:59,330
Sandu Lake my -69 202 is no more we're

520
00:25:05,619 --> 00:25:02,840
gonna use this as a kind of a prototype

521
00:25:07,119 --> 00:25:05,629
to understand all the various supernova

522
00:25:10,049 --> 00:25:07,129
explosions that are happening in the

523
00:25:12,850 --> 00:25:10,059
universe in all their various forms I

524
00:25:13,850 --> 00:25:12,860
like to put this up front why is this

525
00:25:16,130 --> 00:25:13,860
important why

526
00:25:18,710 --> 00:25:16,140
do I care right what and why should you

527
00:25:20,570 --> 00:25:18,720
care so among other things supernova

528
00:25:23,419 --> 00:25:20,580
influence the energy balance structure

529
00:25:25,700 --> 00:25:23,429
and chemical makeup of galaxies they can

530
00:25:27,549 --> 00:25:25,710
help trigger stars new stars so that one

531
00:25:30,110 --> 00:25:27,559
death can trigger new stars from forming

532
00:25:31,820 --> 00:25:30,120
they're a major source of dust in the

533
00:25:33,650 --> 00:25:31,830
universe and not the dust that you get

534
00:25:36,919 --> 00:25:33,660
on a table from not dusting for a while

535
00:25:38,750 --> 00:25:36,929
but Astrophysical dust they produce a

536
00:25:40,549 --> 00:25:38,760
variety of exotic objects that maybe

537
00:25:42,260 --> 00:25:40,559
you've heard about before things like

538
00:25:44,450 --> 00:25:42,270

neutron stars which we'll talk about

539
00:25:47,510 --> 00:25:44,460
black holes and some gamma-ray bursts

540
00:25:49,100 --> 00:25:47,520
they produce copious neutrinos the

541
00:25:50,990 --> 00:25:49,110
subatomic particle that we're going to

542
00:25:53,630 --> 00:25:51,000
come across later their progenitors of

543
00:25:55,220 --> 00:25:53,640
gravitational wave systems so we've

544
00:25:57,919 --> 00:25:55,230
heard about maybe merging black holes

545
00:26:00,860 --> 00:25:57,929
those black holes came from supernova

546
00:26:02,900 --> 00:26:00,870
explosions and as we'll learn they

547
00:26:06,560 --> 00:26:02,910
produce gravitational waves themselves

548
00:26:09,230 --> 00:26:06,570
and most important for us they produce

549
00:26:12,500 --> 00:26:09,240
all the raw materials that make life

550
00:26:14,390 --> 00:26:12,510
possible right so thus as citizens of

551
00:26:16,280 --> 00:26:14,400
the universe it's terribly important

552
00:26:19,460 --> 00:26:16,290
that we understand this fundamental

553
00:26:21,169 --> 00:26:19,470
process that goes on right so it

554
00:26:24,710 --> 00:26:21,179
emphasized I mean the iron in our blood

555
00:26:29,240 --> 00:26:24,720
the calcium in our bones and the oxygen

556
00:26:32,930 --> 00:26:29,250
we breathe love that oxygen it's all

557
00:26:35,060 --> 00:26:32,940
thanks to supernova explosions so if I

558
00:26:37,430 --> 00:26:35,070
gotten you some interest are you you

559
00:26:41,630 --> 00:26:37,440
wanting to learn a little bit more okay

560
00:26:43,490 --> 00:26:41,640
very good I always find this helpful so

561
00:26:45,740 --> 00:26:43,500
this is a little movie that's going to

562
00:26:47,570 --> 00:26:45,750
show a comparison of star sizes and it

563
00:26:51,830 --> 00:26:47,580

starts off with things familiar like the

564
00:26:52,650 --> 00:26:51,840
moon okay and it has some cool Harry

565
00:26:54,550 --> 00:26:52,660
Potter like

566
00:26:56,300 --> 00:26:54,560
[Music]

567
00:26:58,980 --> 00:26:56,310
there's the moon and Mercury

568
00:27:01,980 --> 00:26:58,990
[Music]

569
00:27:03,600 --> 00:27:01,990
Mars the Red Planet

570
00:27:05,670 --> 00:27:03,610
[Music]

571
00:27:09,130 --> 00:27:05,680
is hot don't wanna live there want to

572
00:27:10,950 --> 00:27:09,140
live on earth yes we're there

573
00:27:14,360 --> 00:27:10,960
nice place to be

574
00:27:17,960 --> 00:27:14,370
step back and we see Neptune

575
00:27:20,010 --> 00:27:17,970
Saturn without the Rings just palpable

576
00:27:21,600 --> 00:27:20,020
in size of Jupiter

577
00:27:24,410 --> 00:27:21,610
but now we're going to step back to some

578
00:27:26,610 --> 00:27:24,420
stars the Sun and many people are

579
00:27:27,510 --> 00:27:26,620
surprised to learn that the Sun is not a

580
00:27:28,650 --> 00:27:27,520
big star

581
00:27:30,210 --> 00:27:28,660
it's not the biggest star there are

582
00:27:32,760 --> 00:27:30,220
other stars like Sirius the brightest

583
00:27:34,560 --> 00:27:32,770
star player right now polish now we're

584
00:27:37,500 --> 00:27:34,570
getting to an orange giant and looking

585
00:27:44,470 --> 00:27:41,680
our tourists are a giant Aldebaran

586
00:27:47,440 --> 00:27:44,480
the color changes right function of the

587
00:27:48,700 --> 00:27:47,450
temperature now Rigel alcohol now we get

588
00:27:49,930 --> 00:27:48,710

back

589
00:27:53,400 --> 00:27:49,940
this is a star we're gonna get even

590
00:27:56,320 --> 00:27:53,410
larger Qatar is a bleep

591
00:28:01,120 --> 00:27:57,640
[Music]

592
00:28:04,960 --> 00:28:01,130
and then VOR Canis Majoris one of the

593
00:28:08,080 --> 00:28:04,970
largest stars in the universe and now

594
00:28:12,520 --> 00:28:08,090
we're gonna zoom into a long-term

595
00:28:15,540 --> 00:28:12,530
horizon and I think there's the size of

596
00:28:20,070 --> 00:28:15,550
Earth by comparison and so just imagine

597
00:28:22,810 --> 00:28:20,080
this star exploding with us there right

598
00:28:23,860 --> 00:28:22,820
no it's not gonna happen but that's the

599
00:28:26,110 --> 00:28:23,870
context okay

600
00:28:28,330 --> 00:28:26,120
the takeaway point is that the Sun is

601
00:28:30,130 --> 00:28:28,340
actually a very modest size stars and

602
00:28:35,049 --> 00:28:30,140
there are a lot larger stars in the

603
00:28:38,169 --> 00:28:35,059
universe some other background material

604
00:28:42,400 --> 00:28:38,179
is understanding that the more mass of a

605
00:28:45,160 --> 00:28:42,410
star is the shorter its life the

606
00:28:48,280 --> 00:28:45,170
benchmark is the Sun we take things in

607
00:28:50,530 --> 00:28:48,290
terms of the masses of the Sun so one

608
00:28:52,900 --> 00:28:50,540
solar mass is like the Sun and the

609
00:28:55,690 --> 00:28:52,910
lifespan of the Sun is a healthy 10

610
00:28:58,030 --> 00:28:55,700
billion years but as we increase in mass

611
00:28:59,650 --> 00:28:58,040
you can see that the time frame gets

612
00:29:02,860 --> 00:28:59,660
shorter such that around ten million

613
00:29:04,990 --> 00:29:02,870

years we're getting more towards sorry

614
00:29:07,720 --> 00:29:05,000
ten solar masses we're getting towards

615
00:29:10,299 --> 00:29:07,730
about 30 million years and then getting

616
00:29:14,320 --> 00:29:10,309
heavier towards 60 it's shorter so in

617
00:29:16,930 --> 00:29:14,330
terms of stellar life they the more

618
00:29:21,400 --> 00:29:16,940
massive they are the shorter the more

619
00:29:24,310 --> 00:29:21,410
vigorous life span that they have also

620
00:29:26,740 --> 00:29:24,320
the more massive it is generally

621
00:29:30,180 --> 00:29:26,750
speaking the different kind of remnant

622
00:29:32,740 --> 00:29:30,190
product that it may have yeah so I

623
00:29:34,030 --> 00:29:32,750
forgot to mention something and this is

624
00:29:35,799 --> 00:29:34,040
very important a lot of people get

625
00:29:37,360 --> 00:29:35,809
nervous that the Sun will go this

626
00:29:41,230 --> 00:29:37,370
supernova explosion that I'm talking

627
00:29:42,940 --> 00:29:41,240
about but that will not happen this

628
00:29:45,400 --> 00:29:42,950
there's a cut-off mass somewhere in

629
00:29:46,930 --> 00:29:45,410
between here maybe around eight to ten

630
00:29:48,400 --> 00:29:46,940
solar masses and in fact this is a

631
00:29:50,290 --> 00:29:48,410
discussion that we've had at this

632
00:29:52,570 --> 00:29:50,300
meeting is determining what the critical

633
00:29:54,700 --> 00:29:52,580
mass is for core collapse but it's

634
00:29:56,320 --> 00:29:54,710
certainly well above the sun's mass so

635
00:29:58,480 --> 00:29:56,330
we will not have to worry about a fate

636
00:30:01,720 --> 00:29:58,490
of a supernova The Sun will has other

637
00:30:05,950 --> 00:30:01,730
things in mind for us when it dies yeah

638
00:30:08,140 --> 00:30:05,960

but once it reaches that supernova

639
00:30:10,180 --> 00:30:08,150
ability massive about eight to ten solar

640
00:30:11,110 --> 00:30:10,190
masses you can develop compact object

641
00:30:13,690 --> 00:30:11,120
like a neutron

642
00:30:15,820 --> 00:30:13,700
star or if you're even much larger in

643
00:30:18,880 --> 00:30:15,830
mass you may develop into a black hole

644
00:30:21,100 --> 00:30:18,890
you have the gravitational potentially

645
00:30:24,040 --> 00:30:21,110
needed to continue that collapse down

646
00:30:26,260 --> 00:30:24,050
into a singularity now there isn't a

647
00:30:28,270 --> 00:30:26,270
one-to-one correspondence and I'm gonna

648
00:30:31,270 --> 00:30:28,280
put a caveat here another thing

649
00:30:33,790 --> 00:30:31,280
addressed in this meeting is that

650
00:30:36,670 --> 00:30:33,800
sometimes you can have more massive

651
00:30:38,860 --> 00:30:36,680
stars that have alternative pathways to

652
00:30:41,320 --> 00:30:38,870
becoming a neutron star so it's it's

653
00:30:43,930 --> 00:30:41,330
fairly complex but if you understand

654
00:30:45,850 --> 00:30:43,940
that there's a certain mass range for

655
00:30:48,490 --> 00:30:45,860
which you have compact objects of

656
00:30:49,299 --> 00:30:48,500
neutron stars and black holes that's

657
00:30:51,130 --> 00:30:49,309
very good

658
00:30:53,740 --> 00:30:51,140
whereas more modest stars like the Sun

659
00:30:56,440 --> 00:30:53,750
will not develop these they'll collapse

660
00:30:59,560 --> 00:30:56,450
into something like a white dwarf and

661
00:31:01,120 --> 00:30:59,570
this can go on to a different supernova

662
00:31:02,860 --> 00:31:01,130
progenitors system the type 1a

663
00:31:05,440 --> 00:31:02,870

supernovae that are associated with

664
00:31:07,360 --> 00:31:05,450
measurements of in cosmology which is

665
00:31:09,700 --> 00:31:07,370
not the focus of our talk we will be

666
00:31:13,960 --> 00:31:09,710
focusing on the more massive stars about

667
00:31:16,090 --> 00:31:13,970
10 solar masses and larger now a lot of

668
00:31:19,480 --> 00:31:16,100
things can happen with these compact

669
00:31:22,960 --> 00:31:19,490
object they're highly compressed right I

670
00:31:24,640 --> 00:31:22,970
mean I could like sit on it and compress

671
00:31:27,610 --> 00:31:24,650
those neutrons to get as far as they

672
00:31:29,110 --> 00:31:27,620
could and we have because they're so far

673
00:31:30,850 --> 00:31:29,120
compressed there's strong gravitational

674
00:31:33,370 --> 00:31:30,860
sources that can be now be detected with

675
00:31:35,740 --> 00:31:33,380
gravitational wave facilities the first

676
00:31:38,680 --> 00:31:35,750
hubbub was over the detection thanks to

677
00:31:41,110 --> 00:31:38,690
advanced LIGO of merging black holes and

678
00:31:43,750 --> 00:31:41,120
maybe there is some discussion here at

679
00:31:46,410 --> 00:31:43,760
some point about that right and now more

680
00:31:49,690 --> 00:31:46,420
recently they've been able to detect

681
00:31:51,370 --> 00:31:49,700
merging neutron stars okay so these must

682
00:31:53,140 --> 00:31:51,380
have been two supernova explosions in

683
00:31:56,260 --> 00:31:53,150
close enough proximity that that remnant

684
00:31:58,720 --> 00:31:56,270
neutron stars came into a final orbit

685
00:32:01,600 --> 00:31:58,730
and what's exciting about these systems

686
00:32:04,840 --> 00:32:01,610
is that it's not just left to the

687
00:32:09,040 --> 00:32:04,850
gravitational wave facilities but these

688
00:32:10,840 --> 00:32:09,050

emit and other messengers in the e/m

689
00:32:12,400 --> 00:32:10,850
frequencies so here we have gamma rays

690
00:32:16,030 --> 00:32:12,410
and here we have an image with the

691
00:32:17,830 --> 00:32:16,040
Hubble Space Telescope so this is a new

692
00:32:19,150 --> 00:32:17,840
era of multi messenger astronomy and

693
00:32:20,260 --> 00:32:19,160
perhaps you've heard of this this is

694
00:32:22,330 --> 00:32:20,270
something that's gaining a lot of

695
00:32:26,879 --> 00:32:22,340
traction traction is very exciting and

696
00:32:34,169 --> 00:32:32,560
okay what about my science or what is it

697
00:32:37,480 --> 00:32:34,179
that I want to talk to you most

698
00:32:39,909 --> 00:32:37,490
particularly one is what are the types

699
00:32:41,859 --> 00:32:39,919
of stars that explode in the supernova

700
00:32:44,470 --> 00:32:41,869
explosions we've come across there's

701
00:32:46,330 --> 00:32:44,480
great diversity in their properties in

702
00:32:49,090 --> 00:32:46,340
the chemical elements and the amount of

703
00:32:51,399 --> 00:32:49,100
energy that they have this can be traced

704
00:32:54,820 --> 00:32:51,409
to the type of star that gives way to

705
00:32:57,759 --> 00:32:54,830
the explosion the other question is the

706
00:33:00,039 --> 00:32:57,769
physical one how is it that stars

707
00:33:02,560 --> 00:33:00,049
explode what is the mechanism that

708
00:33:04,180 --> 00:33:02,570
allows this process to take place and

709
00:33:06,009 --> 00:33:04,190
we're going to get into the details

710
00:33:07,600 --> 00:33:06,019
about that a little bit but these are

711
00:33:12,279 --> 00:33:07,610
the guiding questions that I'm going to

712
00:33:14,649 --> 00:33:12,289
provide context for one is the single

713
00:33:17,289 --> 00:33:14,659

star scenario right and this has been

714
00:33:21,149 --> 00:33:17,299
one that has driven the community for a

715
00:33:24,399 --> 00:33:21,159
long time but as we pay more as we

716
00:33:27,190 --> 00:33:24,409
investigate the the matter more in

717
00:33:30,039 --> 00:33:27,200
detail we find that single stars are not

718
00:33:32,019 --> 00:33:30,049
the majority of the systems that we find

719
00:33:34,659 --> 00:33:32,029
in fact the more massive you get the

720
00:33:37,480 --> 00:33:34,669
more often it is that a massive star has

721
00:33:40,359 --> 00:33:37,490
a binary companion and this affects the

722
00:33:42,100 --> 00:33:40,369
evolution of the star so this isn't

723
00:33:44,710 --> 00:33:42,110
getting into the question are what are

724
00:33:46,869 --> 00:33:44,720
the types of stars that explode now I

725
00:33:49,119 --> 00:33:46,879
grew up in the age where this was the

726
00:33:50,529 --> 00:33:49,129
type of supernova progenitors system but

727
00:33:52,389 --> 00:33:50,539
now we're getting in the aged and trying

728
00:33:54,100 --> 00:33:52,399
to understand binary evolution and this

729
00:33:55,570 --> 00:33:54,110
is why I've hired this brilliantly

730
00:33:56,919 --> 00:33:55,580
hawkish Robin to help me with this

731
00:34:00,340 --> 00:33:56,929
because she understands this too much

732
00:34:02,980 --> 00:34:00,350
greater detail than I do so it's a

733
00:34:04,930 --> 00:34:02,990
beautiful dance of the two stars as they

734
00:34:08,889 --> 00:34:04,940
go back and forth and material can be

735
00:34:10,869 --> 00:34:08,899
drawn from one into another and here's a

736
00:34:12,639 --> 00:34:10,879
statistic here so more than 70% of

737
00:34:14,559 --> 00:34:12,649
massive stars will exchange mass with a

738
00:34:17,710 --> 00:34:14,569

companion at some point leading to a

739
00:34:19,299 --> 00:34:17,720
binary merger in 1/3 of the classes I've

740
00:34:21,159 --> 00:34:19,309
heard the analogy actually if you take

741
00:34:24,190 --> 00:34:21,169
two of these massive stars and you

742
00:34:26,770 --> 00:34:24,200
imagine them be about the size of a fist

743
00:34:29,859 --> 00:34:26,780
and they start off at at this distance

744
00:34:34,629 --> 00:34:29,869
apart at some point in the evolution the

745
00:34:37,659 --> 00:34:34,639
star will expand to such a size will

746
00:34:38,409 --> 00:34:37,669
occupy almost this room in size so

747
00:34:40,530 --> 00:34:38,419
certainly

748
00:34:42,579 --> 00:34:40,540
they'll consume the star next to him

749
00:34:47,109 --> 00:34:42,589
certainly that has effect on its

750
00:34:49,440 --> 00:34:47,119
evolution the Hubble Space Telescope has

751
00:34:52,599 --> 00:34:49,450
played a critical role in identifying

752
00:34:54,930 --> 00:34:52,609
the types of stars that give way to the

753
00:34:59,260 --> 00:34:54,940
different types of supernova explosions

754
00:35:01,809 --> 00:34:59,270
so here we have pre explosion images and

755
00:35:04,270 --> 00:35:01,819
the actual supernova explosions on the

756
00:35:06,309 --> 00:35:04,280
right panel so you can see that big blur

757
00:35:09,760 --> 00:35:06,319
that's that's a bright source that's a

758
00:35:13,930 --> 00:35:09,770
supernova supernova so what one does is

759
00:35:15,430 --> 00:35:13,940
if a supernova is detected can I go back

760
00:35:17,650 --> 00:35:15,440
to the scene of the crime before it

761
00:35:20,109 --> 00:35:17,660
happened kind of rewind the tape and

762
00:35:22,359 --> 00:35:20,119
look at the perpetrator what star was

763
00:35:24,549 --> 00:35:22,369

there before hands so did hub will

764
00:35:27,160 --> 00:35:24,559
happen to take an image of that field

765
00:35:30,039 --> 00:35:27,170
before the explosion took place and

766
00:35:32,680 --> 00:35:30,049
indeed Hubble has been able to and it's

767
00:35:35,410 --> 00:35:32,690
been color-coded in a very clever way by

768
00:35:38,470 --> 00:35:35,420
Stephen Smart such that red is

769
00:35:42,579 --> 00:35:38,480
indicative of a red supergiant red star

770
00:35:45,160 --> 00:35:42,589
and you can see red sources here so we

771
00:35:47,400 --> 00:35:45,170
can fit these with stellar tracks which

772
00:35:49,690 --> 00:35:47,410
is to say understanding the the

773
00:35:52,270 --> 00:35:49,700
distribution of light across its

774
00:35:54,900 --> 00:35:52,280
wavelengths and how bright it is to

775
00:35:58,299 --> 00:35:54,910
constrain the properties of the star

776
00:35:59,799 --> 00:35:58,309
these are the explosions where the

777
00:36:02,140 --> 00:35:59,809
ejecta contain a lot of hydrogen

778
00:36:05,829 --> 00:36:02,150
hydrogen rich supernova explosions

779
00:36:08,829 --> 00:36:05,839
however this process has been difficult

780
00:36:11,140 --> 00:36:08,839
for the stars where there is little

781
00:36:13,990 --> 00:36:11,150
hydrogen left behind or perhaps none at

782
00:36:16,870 --> 00:36:14,000
all that process that I showed of two

783
00:36:18,789 --> 00:36:16,880
stars dancing around potentially one can

784
00:36:21,940 --> 00:36:18,799
give its hydrogen to another star

785
00:36:24,190 --> 00:36:21,950
stripping it behind and when we try to

786
00:36:26,589 --> 00:36:24,200
do the same game of finding the

787
00:36:28,950 --> 00:36:26,599
progenitor star in the locations of

788
00:36:32,319 --> 00:36:28,960

these stripped envelope supernovae

789
00:36:34,809 --> 00:36:32,329
sometimes we come up empty and it's

790
00:36:36,490 --> 00:36:34,819
happened a lot so much that it kind of

791
00:36:39,819 --> 00:36:36,500
makes us nervous that we don't really

792
00:36:41,829 --> 00:36:39,829
understand what's going on now patience

793
00:36:44,200 --> 00:36:41,839
has paid off and we've been able to do

794
00:36:46,960 --> 00:36:44,210
this for a number of systems but it's

795
00:36:49,599 --> 00:36:46,970
challenging so here you can see a lot of

796
00:36:51,220 --> 00:36:49,609
pixels but scientists that can actually

797
00:36:51,740 --> 00:36:51,230
make use of that to try and make a

798
00:36:53,870 --> 00:36:51,750
little bit of

799
00:36:58,190 --> 00:36:53,880
constraint about what kind of star was

800
00:37:00,110 --> 00:36:58,200
there before heads here is a star that

801
00:37:02,450 --> 00:37:00,120
has been more stripped than these other

802
00:37:04,940 --> 00:37:02,460
systems but you can see we're at the

803
00:37:06,830 --> 00:37:04,950
level we're straining for information

804
00:37:09,320 --> 00:37:06,840
but we can still extract it because

805
00:37:12,680 --> 00:37:09,330
Hubble has such great resolution at this

806
00:37:14,480 --> 00:37:12,690
level you see those little little darker

807
00:37:16,970 --> 00:37:14,490
areas compared to the surrounding

808
00:37:18,680 --> 00:37:16,980
there's a star buried in there we're

809
00:37:21,380 --> 00:37:18,690
able to understand its properties and

810
00:37:23,600 --> 00:37:21,390
this is always amusing sometimes you

811
00:37:25,220 --> 00:37:23,610
know this is the image the field Hubble

812
00:37:27,290 --> 00:37:25,230
has only a certain field of view so you

813
00:37:29,660 --> 00:37:27,300

take an image it's not necessarily the

814
00:37:32,030 --> 00:37:29,670
case that it'll cover the field of view

815
00:37:35,480 --> 00:37:32,040
so in this case we can't just at the

816
00:37:37,220 --> 00:37:35,490
edge of the chip and I can't tell you

817
00:37:39,290 --> 00:37:37,230
how many times I've gone through the

818
00:37:45,310 --> 00:37:39,300
archive to look at a supernovae position

819
00:37:48,020 --> 00:37:45,320
and find it there instead not good yeah

820
00:37:50,090 --> 00:37:48,030
okay so that is the type of progenitor

821
00:37:52,070 --> 00:37:50,100
star let's think a little bit more about

822
00:37:53,780 --> 00:37:52,080
physics now whenever I tell people I

823
00:37:55,790 --> 00:37:53,790
teach physics or physics astronomy

824
00:37:58,190 --> 00:37:55,800
sometimes they stand back and you know

825
00:37:59,660 --> 00:37:58,200
they say I was never very good at

826
00:38:01,850 --> 00:37:59,670
physics but I'm gonna hold your hand

827
00:38:08,390 --> 00:38:01,860
we're just gonna go over the the basic

828
00:38:12,050 --> 00:38:08,400
top process here a star starts off as a

829
00:38:14,440 --> 00:38:12,060
big ball of hydrogen and that Center all

830
00:38:16,910 --> 00:38:14,450
this gravity allows it to go through

831
00:38:20,090 --> 00:38:16,920
nuclear fusion taking that hydrogen

832
00:38:22,220 --> 00:38:20,100
producing helium now when it runs out of

833
00:38:24,020 --> 00:38:22,230
hydrogen in the core okay then it has to

834
00:38:25,670 --> 00:38:24,030
start burning the helium that started

835
00:38:28,160 --> 00:38:25,680
depositing in its place because of the

836
00:38:29,630 --> 00:38:28,170
Steven and then when that helium runs

837
00:38:31,130 --> 00:38:29,640
out that it has to run to the next fuel

838
00:38:33,380 --> 00:38:31,140

and so what it ends up doing through

839
00:38:35,860 --> 00:38:33,390
successive stages of nuclear fusion you

840
00:38:39,790 --> 00:38:35,870
have this kind of onion skin interior

841
00:38:42,680 --> 00:38:39,800
now this works until you get to iron

842
00:38:45,410 --> 00:38:42,690
when you get to iron this process of

843
00:38:46,940 --> 00:38:45,420
fusion is no longer exothermic do you

844
00:38:49,220 --> 00:38:46,950
know that that name so it no longer

845
00:38:52,370 --> 00:38:49,230
releases energy it actually absorbs

846
00:38:55,280 --> 00:38:52,380
energy so the core no longer has the

847
00:38:59,720 --> 00:38:55,290
radiative pressure it needs for gravity

848
00:39:04,010 --> 00:38:59,730
that wants to bring it together that's

849
00:39:05,849 --> 00:39:04,020
the core collapse here there's a diagram

850
00:39:08,039 --> 00:39:05,859
going showing so we're

851
00:39:13,620 --> 00:39:08,049
near the core there's originally a core

852
00:39:16,229 --> 00:39:13,630
collapse now the core collapses a lot of

853
00:39:19,079 --> 00:39:16,239
stuff happens yeah

854
00:39:21,660 --> 00:39:19,089
in essence you have a lot of protons so

855
00:39:25,109 --> 00:39:21,670
all these years of making heavier

856
00:39:27,449 --> 00:39:25,119
elements gets disrupted you come down to

857
00:39:30,269 --> 00:39:27,459
protons but they gets squished down with

858
00:39:32,190 --> 00:39:30,279
electrons forming neutrons yeah this

859
00:39:33,870 --> 00:39:32,200
releases copious neutrinos these

860
00:39:36,900 --> 00:39:33,880
subatomic particles they're released in

861
00:39:39,870 --> 00:39:36,910
in the process but it reaches to this

862
00:39:42,660 --> 00:39:39,880
point of neutrons and in the neutrons

863
00:39:46,049 --> 00:39:42,670

say I'm not getting any closer together

864
00:39:48,660 --> 00:39:46,059
sorry I'm making my space so the mid

865
00:39:50,789 --> 00:39:48,670
there is a bounce so it reaches this

866
00:39:53,069 --> 00:39:50,799
neutron degeneracy pressure and then it

867
00:39:56,279 --> 00:39:53,079
tries to read like it bounces off that

868
00:39:58,229 --> 00:39:56,289
it's a hard core now it was thought that

869
00:40:01,289 --> 00:39:58,239
that would be what would drive the

870
00:40:03,449 --> 00:40:01,299
supernova explosion but decades of

871
00:40:06,719 --> 00:40:03,459
simulations have shown it just doesn't

872
00:40:09,719 --> 00:40:06,729
work so comes down to this Neutron core

873
00:40:12,539 --> 00:40:09,729
Neutron rich core bounces but then all

874
00:40:15,209 --> 00:40:12,549
the material the star still continues to

875
00:40:18,539 --> 00:40:15,219
push onward on it it needs an additional

876
00:40:22,259 --> 00:40:18,549
heating source to reinvigorate the shock

877
00:40:24,420 --> 00:40:22,269
to push it out and disrupt the star we

878
00:40:26,430 --> 00:40:24,430
think that that heating source is

879
00:40:28,019 --> 00:40:26,440
largely associated with the neutrinos

880
00:40:30,839 --> 00:40:28,029
that I mentioned so these are these

881
00:40:33,749 --> 00:40:30,849
subatomic particles produced when these

882
00:40:38,239 --> 00:40:33,759
protons except electrons and through the

883
00:40:43,979 --> 00:40:42,120
that's one idea and so they're yes and

884
00:40:47,309 --> 00:40:43,989
there has been a series of simulations

885
00:40:49,199 --> 00:40:47,319
to try and harness that idea yeah that

886
00:40:52,949 --> 00:40:49,209
there's either copious neutrino

887
00:40:56,670 --> 00:40:52,959
production that aid in revival of the

888
00:40:59,519 --> 00:40:56,680

straw the shock or if there is enough

889
00:41:02,789 --> 00:40:59,529
rotation to begin with in that neutron

890
00:41:04,799 --> 00:41:02,799
in sorry that Neutron the proto neutron

891
00:41:06,180 --> 00:41:04,809
star in the beginning that rotation can

892
00:41:08,549 --> 00:41:06,190
be associated with strong magnetic

893
00:41:11,729 --> 00:41:08,559
fields that set up a symmetry axis that

894
00:41:13,920 --> 00:41:11,739
can drive a jet okay and totally disrupt

895
00:41:17,579 --> 00:41:13,930
the store and what in another extreme

896
00:41:19,680 --> 00:41:17,589
scenario so that's the jet scenario here

897
00:41:22,260 --> 00:41:19,690
we see this is the core of the Explo

898
00:41:25,559 --> 00:41:22,270
this is in terms of think of this in

899
00:41:27,990 --> 00:41:25,569
terms of that here's the boundary of the

900
00:41:30,450 --> 00:41:28,000
shock material is coming in we see the

901
00:41:34,020 --> 00:41:30,460
sloshing back and forth there's heating

902
00:41:36,029 --> 00:41:34,030
by these neutrinos okay and it goes back

903
00:41:37,529 --> 00:41:36,039
and forth the sloshing and something

904
00:41:40,170 --> 00:41:37,539
that called the standing accretion shock

905
00:41:42,450 --> 00:41:40,180
instability Sassie it's a great name

906
00:41:45,289 --> 00:41:42,460
back and forth until finally it can

907
00:41:48,059 --> 00:41:45,299
disrupt the star okay

908
00:41:50,299 --> 00:41:48,069
case in point though can you see that

909
00:41:57,420 --> 00:41:50,309
there's a difference in the morphology

910
00:42:02,339 --> 00:41:57,430
between this and this okay keep that in

911
00:42:06,930 --> 00:42:02,349
mind as we move forward in order to be

912
00:42:09,720 --> 00:42:06,940
able to explore that mechanism of the

913
00:42:12,770 --> 00:42:09,730

supernova we need a lot of examples and

914
00:42:15,359 --> 00:42:12,780
we need to get good at finding supernova

915
00:42:15,900 --> 00:42:15,369
supernova thankfully happened pretty

916
00:42:17,730 --> 00:42:15,910
often

917
00:42:21,480 --> 00:42:17,740
they happen at a rate of approximately

918
00:42:29,279 --> 00:42:21,490
one per galaxy per century maybe to four

919
00:42:31,349 --> 00:42:29,289
century and if you listen you can hear

920
00:42:34,289 --> 00:42:31,359
one going off every second in the

921
00:42:35,789 --> 00:42:34,299
universe no you can but it is actually

922
00:42:37,680 --> 00:42:35,799
happening approximately once every

923
00:42:40,529 --> 00:42:37,690
second there's a supernova that's going

924
00:42:43,710 --> 00:42:40,539
off in the universe now clearly we don't

925
00:42:45,750 --> 00:42:43,720
have access to a lot of them but a lot

926
00:42:48,329 --> 00:42:45,760
of them we do right and here is actually

927
00:42:50,339 --> 00:42:48,339
postage stamps of the many supernovae

928
00:42:53,430 --> 00:42:50,349
discovered in a particular survey and

929
00:42:59,309 --> 00:42:53,440
you can see them all as point sources in

930
00:43:00,990 --> 00:42:59,319
their host galaxies here are some of the

931
00:43:04,170 --> 00:43:01,000
efforts that are trying to find

932
00:43:08,240 --> 00:43:04,180
supernovae this pan-starrs survey that I

933
00:43:11,069 --> 00:43:08,250
was associated with the assassin survey

934
00:43:13,680 --> 00:43:11,079
Palomar transient fact a factory now

935
00:43:18,200 --> 00:43:13,690
known as as wiki transient factory run

936
00:43:21,089 --> 00:43:18,210
largely by Caltech and an army of

937
00:43:24,329 --> 00:43:21,099
amateur astronomers that I work with

938
00:43:26,460 --> 00:43:24,339

that I you know bite by by day Stu

939
00:43:28,410 --> 00:43:26,470
Parker and New Zealand is a dairy farmer

940
00:43:31,609 --> 00:43:28,420
and he's a great guy he knows all seven

941
00:43:33,680 --> 00:43:31,619
hundred cows by name but by night

942
00:43:35,720 --> 00:43:33,690
instead of buying fancy

943
00:43:38,150 --> 00:43:35,730
cars he's bought some really nice

944
00:43:43,790 --> 00:43:38,160
telescopes and he helps in the discovery

945
00:43:45,980 --> 00:43:43,800
of supernova explosions ah I don't know

946
00:43:48,440 --> 00:43:45,990
if we can get the lights down but people

947
00:43:52,580 --> 00:43:48,450
here do you think you can spot the

948
00:43:56,690 --> 00:43:52,590
supernovae can you see where it's

949
00:44:00,140 --> 00:43:56,700
developing you somebody sees it right

950
00:44:02,900 --> 00:44:00,150
there you're right there it is there

951
00:44:04,610 --> 00:44:02,910
okay so clearly this is an inefficient

952
00:44:09,100 --> 00:44:04,620
process by just looking at it visually

953
00:44:11,630 --> 00:44:09,110
in these days what one does is look at a

954
00:44:13,670 --> 00:44:11,640
taken and by the way what it was

955
00:44:16,190 --> 00:44:13,680
happening here we take an image of the

956
00:44:20,470 --> 00:44:16,200
sky at some point and then return some

957
00:44:22,700 --> 00:44:20,480
time later months later weeks days

958
00:44:26,600 --> 00:44:22,710
currently we're at the point where we're

959
00:44:29,180 --> 00:44:26,610
monitoring hourly almost in some fields

960
00:44:32,000 --> 00:44:29,190
to look for changes instead of doing it

961
00:44:33,890 --> 00:44:32,010
by eye you use computers to take a

962
00:44:36,530 --> 00:44:33,900
subtraction of one image from another

963
00:44:39,200 --> 00:44:36,540

and you look for a difference but still

964
00:44:42,470 --> 00:44:39,210
there's a rich history of people finding

965
00:44:43,880 --> 00:44:42,480
supernovae by eye and I just wanted to

966
00:44:46,580 --> 00:44:43,890
give you a flavor of that here's another

967
00:44:49,880 --> 00:44:46,590
scenario so this was images donated by

968
00:44:54,400 --> 00:44:49,890
stu parker and here you can see this you

969
00:45:04,220 --> 00:44:54,410
know tiny adorable spiral galaxies and

970
00:45:06,860 --> 00:45:04,230
then sometime later alright now to some

971
00:45:09,110 --> 00:45:06,870
it may not look like much but recognize

972
00:45:10,880 --> 00:45:09,120
that this is a galaxy let's say

973
00:45:14,120 --> 00:45:10,890
something like the Milky Way with a

974
00:45:16,610 --> 00:45:14,130
hundred billion stars or so and this

975
00:45:20,000 --> 00:45:16,620
fuzz is actually just you know the

976
00:45:22,790 --> 00:45:20,010
nature of many stars that are spaced out

977
00:45:28,160 --> 00:45:22,800
and then all of a sudden one of those

978
00:45:30,140 --> 00:45:28,170
stars explodes and becomes as luminous

979
00:45:34,670 --> 00:45:30,150
you know with a luminosity that rivals

980
00:45:36,830 --> 00:45:34,680
the entire host galaxy as supernovae can

981
00:45:42,870 --> 00:45:36,840
be brighter than billions of stars put

982
00:45:48,240 --> 00:45:45,630
what's also remarkable is when this

983
00:45:50,820 --> 00:45:48,250
happens in our own neighborhood okay we

984
00:45:53,790 --> 00:45:50,830
live in a galaxy with stars with lots of

985
00:45:55,530 --> 00:45:53,800
massive stars so obviously every so

986
00:45:56,430 --> 00:45:55,540
often something has to happen in our own

987
00:45:59,700 --> 00:45:56,440
backyard

988
00:46:03,750 --> 00:45:59,710

and here I'm showing a well-known

989
00:46:07,460 --> 00:46:03,760
engraving of chika brow or Tycho Brahe

990
00:46:10,290 --> 00:46:07,470
he who spotted this supernova of 1527

991
00:46:13,070 --> 00:46:10,300
when galactic supernova occurred they

992
00:46:16,050 --> 00:46:13,080
can they can be visible for many months

993
00:46:19,020 --> 00:46:16,060
maybe even over a year and they can be

994
00:46:21,210 --> 00:46:19,030
even be visible during the day right

995
00:46:23,490 --> 00:46:21,220
there are stories about people reading

996
00:46:29,190 --> 00:46:23,500
at night to the light of a supernova and

997
00:46:31,020 --> 00:46:29,200
all the confusion in people being afraid

998
00:46:34,950 --> 00:46:31,030
of this source that came out of

999
00:46:36,810 --> 00:46:34,960
seemingly nowhere but Tycho Brahe he was

1000
00:46:38,220 --> 00:46:36,820
prepared because he had the right

1001
00:46:40,140 --> 00:46:38,230
instruments to be able to make

1002
00:46:44,190 --> 00:46:40,150
measurements of the system so we're

1003
00:46:47,070 --> 00:46:44,200
gonna do that and we can now go there

1004
00:46:48,720 --> 00:46:47,080
today again with razor sharp vision of

1005
00:46:51,570 --> 00:46:48,730
Hubble but in this case it's actually

1006
00:46:54,720 --> 00:46:51,580
Chandra x-ray Observatory and look at

1007
00:46:56,760 --> 00:46:54,730
what it looks like today and here we see

1008
00:47:02,790 --> 00:46:56,770
the Tycho's supernova remnant or the

1009
00:47:06,360 --> 00:47:02,800
supernova 1520 72 and I wasn't able he

1010
00:47:08,610 --> 00:47:06,370
wrote down in his log and then which

1011
00:47:11,850 --> 00:47:08,620
turned into a book this entry and I

1012
00:47:13,550 --> 00:47:11,860
wasn't able to skim it down so it's

1013
00:47:15,990 --> 00:47:13,560

quite amazing

1014
00:47:19,200 --> 00:47:16,000
here let's emphasize here a miracle

1015
00:47:20,850 --> 00:47:19,210
indeed either the greatest of all that

1016
00:47:22,650 --> 00:47:20,860
have occurred in the whole range of

1017
00:47:26,010 --> 00:47:22,660
nature since the beginning of the world

1018
00:47:28,410 --> 00:47:26,020
or one certainly that is to be classed

1019
00:47:30,600 --> 00:47:28,420
with those attested by the holy Oracle's

1020
00:47:32,430 --> 00:47:30,610
the staying of the Sun and its course an

1021
00:47:34,800 --> 00:47:32,440
answer to the prayers of Joshua and the

1022
00:47:36,750 --> 00:47:34,810
darkening of the Sun's face at the time

1023
00:47:39,270 --> 00:47:36,760
of crucifixion thought that appropriate

1024
00:47:41,250 --> 00:47:39,280
close to Easter I mean it was either the

1025
00:47:44,280 --> 00:47:41,260
most important thing that ever happened

1026
00:47:48,440 --> 00:47:44,290
or like the second most important thing

1027
00:47:55,800 --> 00:47:52,770
now interestingly enough not that many

1028
00:47:56,640 --> 00:47:55,810
years later there is another sighting by

1029
00:48:00,089 --> 00:47:56,650
Tycho's

1030
00:48:02,160 --> 00:48:00,099
distant Johannes Keplar and by the way

1031
00:48:03,990 --> 00:48:02,170
there's a whole personality of Tycho

1032
00:48:06,269 --> 00:48:04,000
Brahe he I would encourage you to

1033
00:48:08,789 --> 00:48:06,279
investigate I mean the one that comes to

1034
00:48:12,240 --> 00:48:08,799
mind right now is that he lost a portion

1035
00:48:19,160 --> 00:48:12,250
of his nose in a duel with somebody at a

1036
00:48:21,990 --> 00:48:19,170
wedding over a mathematical formula now

1037
00:48:23,490 --> 00:48:22,000
Kepler was hired by Tycho Brahe he to

1038
00:48:27,390 --> 00:48:23,500

help him with all the measurements of

1039
00:48:29,940 --> 00:48:27,400
the the planets that he had done and the

1040
00:48:32,279 --> 00:48:29,950
the relationship was fraught with with

1041
00:48:34,859 --> 00:48:32,289
tension because Tycho had decades of

1042
00:48:37,200 --> 00:48:34,869
observations but he only gave them in

1043
00:48:39,450 --> 00:48:37,210
little pieces to Kepler and Kepler

1044
00:48:41,010 --> 00:48:39,460
pleaded please give me the data but he

1045
00:48:43,049 --> 00:48:41,020
wouldn't he would give him now Tycho

1046
00:48:45,000 --> 00:48:43,059
died less than a year after they started

1047
00:48:47,339 --> 00:48:45,010
working together so there's a little bit

1048
00:48:49,019 --> 00:48:47,349
of gossip about how did that happen how

1049
00:48:51,990 --> 00:48:49,029
did Tycho Brahe he come to such an

1050
00:48:53,789 --> 00:48:52,000
accelerated death they actually exhumed

1051
00:48:55,470 --> 00:48:53,799
the body of Tycho Brahe he to see if

1052
00:48:57,180 --> 00:48:55,480
he'd been poisoned to see if they could

1053
00:48:59,370 --> 00:48:57,190
find evidence of poison in him and they

1054
00:49:02,069 --> 00:48:59,380
didn't so Kepler was cleared on that

1055
00:49:03,990 --> 00:49:02,079
account anyhow I'm distracted I'm sorry

1056
00:49:07,680 --> 00:49:04,000
there's a lot of historical anecdotes

1057
00:49:10,710 --> 00:49:07,690
here Kepler in 1604 spotted another

1058
00:49:13,529 --> 00:49:10,720
galactic supernova his take was a little

1059
00:49:15,420 --> 00:49:13,539
bit different the star significant is a

1060
00:49:17,819 --> 00:49:15,430
difficult matter to establish and we

1061
00:49:20,309 --> 00:49:17,829
could be sure of only one thing that

1062
00:49:23,430 --> 00:49:20,319
either the star signifies nothing at all

1063
00:49:25,859 --> 00:49:23,440

for mankind or it signifies something of

1064
00:49:28,289 --> 00:49:25,869
such exalted importance that is beyond

1065
00:49:32,609 --> 00:49:28,299
the grasp and understanding of any man

1066
00:49:35,970 --> 00:49:32,619
or woman let's say so either it's most

1067
00:49:41,970 --> 00:49:35,980
important or let's move on nothing

1068
00:49:42,420 --> 00:49:41,980
nothing here right okay and where's

1069
00:49:44,460 --> 00:49:42,430
Frank

1070
00:49:47,849 --> 00:49:44,470
we're time for about eight o'clock ish

1071
00:49:49,529 --> 00:49:47,859
or okay all right I will try not to try

1072
00:49:56,519 --> 00:49:49,539
your patience I've gotten distracted but

1073
00:49:58,109 --> 00:49:56,529
I'm having a lot of fun oh my goodness

1074
00:49:59,970 --> 00:49:58,119
okay I will definitely not keep you here

1075
00:50:03,150 --> 00:49:59,980
that long but thank you thank you for

1076
00:50:06,299 --> 00:50:03,160
the the info all right we saw this

1077
00:50:08,849 --> 00:50:06,309
earlier okay Crab Nebula shown a lot

1078
00:50:10,440 --> 00:50:08,859
this is the remnant of a supernova

1079
00:50:14,490 --> 00:50:10,450
explosion that had

1080
00:50:16,589 --> 00:50:14,500
in 1054 and we have that date chronicled

1081
00:50:18,690 --> 00:50:16,599
by the Chinese so we know that it

1082
00:50:20,069 --> 00:50:18,700
happened on that time it's quite

1083
00:50:22,140 --> 00:50:20,079
beautiful this is a Hubble Space

1084
00:50:24,170 --> 00:50:22,150
Telescope image largely sensitive so

1085
00:50:27,270 --> 00:50:24,180
this is optical emission but

1086
00:50:29,670 --> 00:50:27,280
cherry-picking like the demonstration

1087
00:50:31,079 --> 00:50:29,680
that you showed at certain wavelengths

1088
00:50:33,120 --> 00:50:31,089

and then you combine them in the right

1089
00:50:35,160 --> 00:50:33,130
way to make a pretty picture this

1090
00:50:37,799 --> 00:50:35,170
diffuse submission is associated lot

1091
00:50:39,599 --> 00:50:37,809
with the neutron star that is rapidly

1092
00:50:41,400 --> 00:50:39,609
rotating we call it a pulsar because

1093
00:50:43,410 --> 00:50:41,410
every in this case every 30 seconds

1094
00:50:45,839 --> 00:50:43,420
there's a strong wave of energy that

1095
00:50:47,819 --> 00:50:45,849
comes in in our direction it's

1096
00:50:51,480 --> 00:50:47,829
illuminating this pulsar wind in the

1097
00:50:57,000 --> 00:50:51,490
middle and around it okay is a other

1098
00:50:58,799 --> 00:50:57,010
ejecta I want to highlight this it's an

1099
00:51:00,799 --> 00:50:58,809
energetic phenomena so here we're

1100
00:51:03,150 --> 00:51:00,809
looking multiple years

1101
00:51:05,819 --> 00:51:03,160
beautiful work by again another

1102
00:51:07,520 --> 00:51:05,829
quote-unquote amateur astronomer I mean

1103
00:51:11,520 --> 00:51:07,530
this would put professional astronomers

1104
00:51:13,950 --> 00:51:11,530
to shame to get this stable image over

1105
00:51:15,930 --> 00:51:13,960
these multiple years and you can see the

1106
00:51:18,030 --> 00:51:15,940
swirling right remember this is a

1107
00:51:21,450 --> 00:51:18,040
rotating effect you can see it pushing

1108
00:51:28,890 --> 00:51:21,460
out the wind around it it's almost

1109
00:51:32,430 --> 00:51:28,900
looking like a living thing right all

1110
00:51:35,819 --> 00:51:32,440
right one thing I want to capture for

1111
00:51:37,890 --> 00:51:35,829
you is that when we look at objects like

1112
00:51:40,799 --> 00:51:37,900
super novae and supernovae remnants at

1113
00:51:42,390 --> 00:51:40,809

different wavelengths that often means

1114
00:51:44,520 --> 00:51:42,400
different space telescopes or

1115
00:51:47,069 --> 00:51:44,530
ground-based observatories we capture

1116
00:51:49,109 --> 00:51:47,079
different physics and that usually is

1117
00:51:51,930 --> 00:51:49,119
reflective of different temperatures and

1118
00:51:54,210 --> 00:51:51,940
densities so we have the Crab Nebula

1119
00:51:57,240 --> 00:51:54,220
there you can see a different take but

1120
00:51:59,789 --> 00:51:57,250
when we look at it radio or spitzer in

1121
00:52:02,789 --> 00:51:59,799
the infrared or hubble in the optical or

1122
00:52:07,230 --> 00:52:02,799
chandra at x-ray wavelengths they're all

1123
00:52:09,180 --> 00:52:07,240
privy to another piece of the remnant so

1124
00:52:11,930 --> 00:52:09,190
in order to do a comprehensive

1125
00:52:15,720 --> 00:52:11,940
investigation we want to try to utilize

1126
00:52:19,920 --> 00:52:15,730
the full span of the electromagnetic

1127
00:52:23,069 --> 00:52:19,930
spectrum and to give you a little bit

1128
00:52:23,980 --> 00:52:23,079
more I mean each of these supernova

1129
00:52:26,470 --> 00:52:23,990
remnants needs it so

1130
00:52:28,390 --> 00:52:26,480
origin stories this is a remnant in the

1131
00:52:31,240 --> 00:52:28,400
small Magellanic Cloud

1132
00:52:33,040 --> 00:52:31,250
we have no confirmed sighting so we

1133
00:52:35,079 --> 00:52:33,050
can't pinpoint the date so we have to

1134
00:52:36,790 --> 00:52:35,089
use other means to estimate that state

1135
00:52:38,020 --> 00:52:36,800
and we think it'd be larger than a

1136
00:52:40,420 --> 00:52:38,030
thousand years ago

1137
00:52:44,620 --> 00:52:40,430
here's something different again we

1138
00:52:46,240 --> 00:52:44,630

don't have a certain date of explosion

1139
00:52:48,180 --> 00:52:46,250
but we know it to be over a thousand

1140
00:52:51,190 --> 00:52:48,190
years old and it's a combination of

1141
00:52:56,050 --> 00:52:51,200
wavelengths another this one now

1142
00:52:58,089 --> 00:52:56,060
primarily a Chandra x-ray Observatory we

1143
00:53:01,300 --> 00:52:58,099
don't know the date it's fairly old and

1144
00:53:02,950 --> 00:53:01,310
then this okay I showed the

1145
00:53:05,109 --> 00:53:02,960
multi-wavelength image we'll come back

1146
00:53:07,930 --> 00:53:05,119
to that at a moment but this is the

1147
00:53:09,970 --> 00:53:07,940
Hubble Space Telescope image and a

1148
00:53:12,310 --> 00:53:09,980
shadow to our Effie's in who I think is

1149
00:53:15,070 --> 00:53:12,320
watching right now who is responsible in

1150
00:53:18,130 --> 00:53:15,080
arranging these observations to make

1151
00:53:20,500 --> 00:53:18,140
this beautiful mosaic so what are we

1152
00:53:24,070 --> 00:53:20,510
looking at the debris zuv a star that

1153
00:53:26,500 --> 00:53:24,080
exploded about 340 years ago the red is

1154
00:53:29,560 --> 00:53:26,510
self is sensitive to sulfur rich

1155
00:53:31,990 --> 00:53:29,570
material the green is oxygen-rich the

1156
00:53:33,970 --> 00:53:32,000
purpley blue stuff that's actually

1157
00:53:36,370 --> 00:53:33,980
associated with this the star before it

1158
00:53:41,470 --> 00:53:36,380
exploded and the material it released to

1159
00:53:43,359 --> 00:53:41,480
the surrounding environment we're gonna

1160
00:53:45,190 --> 00:53:43,369
go back to the multi wavelengths so now

1161
00:53:47,109 --> 00:53:45,200
we're not just looking at HST but we're

1162
00:53:48,970 --> 00:53:47,119
looking at Spitzer we're also in that

1163
00:53:50,880 --> 00:53:48,980

that's infrared wavelengths and we're

1164
00:53:54,099 --> 00:53:50,890
also looking at Chandra at various

1165
00:53:57,849 --> 00:53:54,109
wavelengths sensitive to different parts

1166
00:54:01,000 --> 00:53:57,859
different elements the x-ray here is

1167
00:54:07,660 --> 00:54:01,010
sensitive to iron rich material of the

1168
00:54:09,370 --> 00:54:07,670
supernova there's different kind of

1169
00:54:12,750 --> 00:54:09,380
things that we can point out in the

1170
00:54:15,790 --> 00:54:12,760
anatomy of the supernova remnant at the

1171
00:54:19,960 --> 00:54:15,800
the periphery here do you see this thin

1172
00:54:22,030 --> 00:54:19,970
band this is actually associated with

1173
00:54:24,160 --> 00:54:22,040
the original shockwave of the supernova

1174
00:54:26,560 --> 00:54:24,170
right you can imagine explosion has a

1175
00:54:27,970 --> 00:54:26,570
shockwave and that's the forefront of it

1176
00:54:34,000 --> 00:54:27,980
and we've been able to watch it with

1177
00:54:37,590 --> 00:54:34,010
time expand also in the center is that

1178
00:54:39,570 --> 00:54:37,600
neutron star the core collapse

1179
00:54:40,680 --> 00:54:39,580
the material being compressed down to

1180
00:54:41,520 --> 00:54:40,690
such densities that would have

1181
00:54:46,080 --> 00:54:41,530
neutron-rich

1182
00:54:52,290 --> 00:54:46,090
material if we could get the lights down

1183
00:54:55,770 --> 00:54:52,300
on this here is time-lapse of about 50

1184
00:54:59,280 --> 00:54:55,780
years of images of casa PA and you

1185
00:55:01,920 --> 00:54:59,290
mentioned Joe Joe helped create this we

1186
00:55:05,099 --> 00:55:01,930
scanned in plates the dating back

1187
00:55:07,950 --> 00:55:05,109
decades and we smoothly transitioned

1188
00:55:10,470 --> 00:55:07,960

into Hubble Space Telescope image at the

1189
00:55:14,820 --> 00:55:10,480
end and you can see the remnant

1190
00:55:17,490 --> 00:55:14,830
expanding and so my PhD thesis was

1191
00:55:19,950 --> 00:55:17,500
largely done on castor PA I'm grateful

1192
00:55:22,320 --> 00:55:19,960
for doing it now ish because I've done

1193
00:55:26,099 --> 00:55:22,330
it 50 years ago it just wasn't nearly as

1194
00:55:28,650 --> 00:55:26,109
bright as it is today and this the

1195
00:55:31,590 --> 00:55:28,660
origin of this heating has let's just

1196
00:55:33,720 --> 00:55:31,600
say as the shock wave moves out there is

1197
00:55:35,460 --> 00:55:33,730
another shock wave that propagates in

1198
00:55:38,720 --> 00:55:35,470
the opposite direction with respect to

1199
00:55:42,630 --> 00:55:38,730
that forward shock wave that heats and

1200
00:55:49,050 --> 00:55:42,640
excites the optical emission that we see

1201
00:55:50,580 --> 00:55:49,060
today ah so what can we do I want to

1202
00:55:52,500 --> 00:55:50,590
understand how this thing exploded and I

1203
00:55:55,470 --> 00:55:52,510
tried to point out those simulations and

1204
00:55:57,900 --> 00:55:55,480
the extremes and the morphology right so

1205
00:56:00,150 --> 00:55:57,910
being clever with our spectra and

1206
00:56:02,340 --> 00:56:00,160
measuring velocities we can do a

1207
00:56:04,859 --> 00:56:02,350
three-dimensional reconstruction of the

1208
00:56:06,270 --> 00:56:04,869
remnant and this is kind of my niche

1209
00:56:08,190 --> 00:56:06,280
this is something that I'm trying to get

1210
00:56:10,109 --> 00:56:08,200
at I'm looking at the large-scale

1211
00:56:12,200 --> 00:56:10,119
structure of the remnant and try to

1212
00:56:15,630 --> 00:56:12,210
piece together how the the bomb exploded

1213
00:56:18,270 --> 00:56:15,640

it's like a bomb scene investigation I

1214
00:56:20,190 --> 00:56:18,280
go into the room and I look around it

1215
00:56:22,380 --> 00:56:20,200
explode equally in all directions or is

1216
00:56:24,510 --> 00:56:22,390
there a preferential access and then I

1217
00:56:26,670 --> 00:56:24,520
can go and scrape off bits of pieces of

1218
00:56:28,200 --> 00:56:26,680
the the bomb and do a chemical analysis

1219
00:56:31,320 --> 00:56:28,210
to understand what it was made of this

1220
00:56:33,750 --> 00:56:31,330
is kind of what I'm doing now this is

1221
00:56:36,030 --> 00:56:33,760
thanks to my contributors I honestly got

1222
00:56:38,250 --> 00:56:36,040
this about an hour ago

1223
00:56:40,530 --> 00:56:38,260
nobody really none of my grad students

1224
00:56:43,380 --> 00:56:40,540
and not even the Haraka wanted to travel

1225
00:56:45,180 --> 00:56:43,390
to a supernova in space to study it so

1226
00:56:49,590 --> 00:56:45,190
we're making a virtual reality

1227
00:56:51,480 --> 00:56:49,600
environment for which to study it safely

1228
00:56:53,340 --> 00:56:51,490
I guess so as you can see they have

1229
00:56:56,670 --> 00:56:53,350
the goggles on so we have this

1230
00:56:59,220 --> 00:56:56,680
collaborative environment right so we

1231
00:57:01,230 --> 00:56:59,230
can see that's Jordan who's helping out

1232
00:57:02,850 --> 00:57:01,240
right now I wish I was there with them

1233
00:57:05,070 --> 00:57:02,860
but with virtual reality at some point I

1234
00:57:06,990 --> 00:57:05,080
will be able to do it remotely so here

1235
00:57:09,420 --> 00:57:07,000
we can see we have all these people

1236
00:57:11,609 --> 00:57:09,430
together we're making a collaborative

1237
00:57:13,740 --> 00:57:11,619
virtual reality environment it's both

1238
00:57:15,240 --> 00:57:13,750

the teaching tool and an area of

1239
00:57:16,830 --> 00:57:15,250
investigation there's the avatar so you

1240
00:57:18,180 --> 00:57:16,840
can see their faces so that's what

1241
00:57:20,580 --> 00:57:18,190
they're seeing right now and he's

1242
00:57:22,290 --> 00:57:20,590
sketching out in real time the

1243
00:57:25,470 --> 00:57:22,300
large-scale structures that were being

1244
00:57:27,960 --> 00:57:25,480
shown in that animation okay I mean as

1245
00:57:31,080 --> 00:57:27,970
an investigation I can look at pictures

1246
00:57:33,330 --> 00:57:31,090
of a crime scene but unless I go there

1247
00:57:34,980 --> 00:57:33,340
right that's the only way to really

1248
00:57:36,690 --> 00:57:34,990
understand what's going on and I can't

1249
00:57:42,120 --> 00:57:36,700
go to seek a stay so I'm gonna bring it

1250
00:57:43,560 --> 00:57:42,130
into my laboratory oh great so one thing

1251
00:57:45,359 --> 00:57:43,570
is visual the other thing is to be able

1252
00:57:46,620 --> 00:57:45,369
to compare it with simulations and

1253
00:57:48,750 --> 00:57:46,630
that's something that we're doing also

1254
00:57:50,570 --> 00:57:48,760
so this is a simulation that you know

1255
00:57:54,180 --> 00:57:50,580
that sloshing you saw back and forth

1256
00:57:56,190 --> 00:57:54,190
they've advanced those and taking

1257
00:57:58,380 --> 00:57:56,200
snapshots this is seconds after

1258
00:58:00,990 --> 00:57:58,390
explosion and hours after explosion and

1259
00:58:03,450 --> 00:58:01,000
the blue is representative nickel rich

1260
00:58:06,630 --> 00:58:03,460
material very heavy material that love

1261
00:58:09,210 --> 00:58:06,640
roughly translate into the iron rich

1262
00:58:11,310 --> 00:58:09,220
material that we see in Casa PA and the

1263
00:58:12,660 --> 00:58:11,320

large structures that we see in Casa and

1264
00:58:14,910 --> 00:58:12,670
I didn't get a chance to talk about it

1265
00:58:17,190 --> 00:58:14,920
but you see a large ring in the back

1266
00:58:19,349 --> 00:58:17,200
there that's where a large deposit of

1267
00:58:21,750 --> 00:58:19,359
iron rich material is this is giving us

1268
00:58:24,240 --> 00:58:21,760
insight into the explosion which is to

1269
00:58:27,780 --> 00:58:24,250
say that it's not homogeneous it's not

1270
00:58:31,490 --> 00:58:27,790
this sphere that is exploding but it's

1271
00:58:33,990 --> 00:58:31,500
messy and it's dominated by a few

1272
00:58:35,580 --> 00:58:34,000
instabilities where you have this nickel

1273
00:58:40,740 --> 00:58:35,590
rich material stream out ahead of the

1274
00:58:44,400 --> 00:58:40,750
lighter elements okay coming on to the

1275
00:58:46,140 --> 00:58:44,410
good stuff now remember I said to be

1276
00:58:48,630 --> 00:58:46,150
able to do our investigations we have to

1277
00:58:51,150 --> 00:58:48,640
look with the right wavelengths so now

1278
00:58:54,150 --> 00:58:51,160
this is x-ray but now enhanced around

1279
00:58:56,460 --> 00:58:54,160
the silicon lines and now hold on I told

1280
00:58:58,430 --> 00:58:56,470
you that this was a morphology that's

1281
00:59:00,840 --> 00:58:58,440
consistent with this neutrino kind of

1282
00:59:03,480 --> 00:59:00,850
instabilities but now we see something

1283
00:59:04,920 --> 00:59:03,490
like the other model remember that kind

1284
00:59:10,530 --> 00:59:04,930
of like the jet model

1285
00:59:13,710 --> 00:59:10,540
here huh and again help with the Hubble

1286
00:59:15,780 --> 00:59:13,720
Space Telescope we took images purposely

1287
00:59:18,000 --> 00:59:15,790
along that direction and tried to follow

1288
00:59:22,460 --> 00:59:18,010

a material out as fat as far as it could

1289
00:59:25,430 --> 00:59:22,470
go and now I'm gonna zoom in here so

1290
00:59:29,850 --> 00:59:25,440
images separated only a year apart and

1291
00:59:33,090 --> 00:59:29,860
you can see this is stellar debris being

1292
00:59:38,430 --> 00:59:33,100
flung out over 15,000 kilometers per

1293
00:59:40,080 --> 00:59:38,440
second right those with sharp eyes may

1294
00:59:42,630 --> 00:59:40,090
notice funny things like this do you see

1295
00:59:44,490 --> 00:59:42,640
how that pops in and out yeah all that

1296
00:59:46,500 --> 00:59:44,500
means is that it's running into some

1297
00:59:48,830 --> 00:59:46,510
kind of a over density in the

1298
00:59:51,300 --> 00:59:48,840
surrounding environment and lights it up

1299
00:59:54,260 --> 00:59:51,310
is that saying time out somebody's

1300
00:59:59,490 --> 00:59:54,270
making their way okay

1301
01:00:04,550 --> 00:59:59,500
as that pass is on it's actually good

1302
01:00:07,920 --> 01:00:04,560
soundtrack for this right okay but

1303
01:00:11,820 --> 01:00:07,930
ladies and gentlemen ladies and

1304
01:00:16,560 --> 01:00:11,830
gentlemen this truly is okay this is raw

1305
01:00:19,740 --> 01:00:16,570
material for future stars future planets

1306
01:00:22,080 --> 01:00:19,750
maybe life okay being seeded in

1307
01:00:29,970 --> 01:00:22,090
surrounding interstellar space we're

1308
01:00:32,790 --> 01:00:29,980
watching it happen here okay debris this

1309
01:00:34,260 --> 01:00:32,800
is actually sulfur and rich debris but

1310
01:00:37,770 --> 01:00:34,270
it has other chemical elements there

1311
01:00:40,830 --> 01:00:37,780
maybe yeah the heavy elements in there

1312
01:00:44,160 --> 01:00:40,840
yes star stuff that's right that's going

1313
01:00:48,380 --> 01:00:44,170

to go support the manufacture of new

1314
01:00:51,000 --> 01:00:48,390
systems okay so now we're gonna go into

1315
01:00:53,490 --> 01:00:51,010
what we're looking to into the future

1316
01:00:57,240 --> 01:00:53,500
what we anticipate to be investigating

1317
01:00:59,220 --> 01:00:57,250
in the future I show this plot up in it

1318
01:01:02,790 --> 01:00:59,230
let me take a second to explain it this

1319
01:01:06,240 --> 01:01:02,800
is time and this is how bright the

1320
01:01:08,400 --> 01:01:06,250
system is and remember I said how

1321
01:01:09,810 --> 01:01:08,410
supernovae are designated by the year

1322
01:01:13,620 --> 01:01:09,820
that they're discovered and this is a

1323
01:01:16,770 --> 01:01:13,630
system called supernova 2009 IP now it's

1324
01:01:18,329 --> 01:01:16,780
a dumb name because the supernova

1325
01:01:22,410 --> 01:01:18,339
actually took place in two

1326
01:01:24,719 --> 01:01:22,420
and twelve now why did it get 2009 well

1327
01:01:27,630 --> 01:01:24,729
in 2009 people jumped the gun they saw

1328
01:01:29,539 --> 01:01:27,640
that it went got brighter but didn't

1329
01:01:33,839 --> 01:01:29,549
quite get the brightness the luminosity

1330
01:01:35,219 --> 01:01:33,849
needed for a terminal explosion actually

1331
01:01:37,289 --> 01:01:35,229
associated with the system maybe you've

1332
01:01:39,870 --> 01:01:37,299
heard of eight a car it's a star that

1333
01:01:42,420 --> 01:01:39,880
ejected a lot of material at all at once

1334
01:01:45,209 --> 01:01:42,430
and then it went down but people were

1335
01:01:47,189 --> 01:01:45,219
clever to monitor it with time and then

1336
01:01:49,469 --> 01:01:47,199
you know monitoring the like her we saw

1337
01:01:52,219 --> 01:01:49,479
a lot of fluctuations leading up to the

1338
01:01:57,719 --> 01:01:52,229

final core collapse explosion

1339
01:01:59,579 --> 01:01:57,729
potentially the thought is that the star

1340
01:02:01,469 --> 01:01:59,589
as I said had some kind of major

1341
01:02:04,199 --> 01:02:01,479
eruption like a Dakar now this is a

1342
01:02:05,819 --> 01:02:04,209
dramatic mega example but maybe

1343
01:02:08,609 --> 01:02:05,829
something like this has happened in that

1344
01:02:13,199 --> 01:02:08,619
other thing where the stars death was

1345
01:02:17,309 --> 01:02:13,209
pray looted with a giant eruption that

1346
01:02:19,349 --> 01:02:17,319
becomes very exciting because now we're

1347
01:02:23,729 --> 01:02:19,359
at the point where we may be able to

1348
01:02:25,349 --> 01:02:23,739
predict supernova explosions now when I

1349
01:02:27,719 --> 01:02:25,359
sat in public lectures like that and I

1350
01:02:30,410 --> 01:02:27,729
still do but locate let's say what about

1351
01:02:32,880 --> 01:02:30,420
twenty years ago I remember you'll never

1352
01:02:34,679 --> 01:02:32,890
looking at a star you'd never be able to

1353
01:02:36,809 --> 01:02:34,689
know when it's going to explode because

1354
01:02:39,329 --> 01:02:36,819
all them all that activities happening

1355
01:02:40,949 --> 01:02:39,339
at the core right and it'd take tens of

1356
01:02:44,099 --> 01:02:40,959
thousands or hundreds of thousands of

1357
01:02:47,549 --> 01:02:44,109
years to evolve and yet in this case we

1358
01:02:49,679 --> 01:02:47,559
say see things happening right the star

1359
01:02:51,329 --> 01:02:49,689
is signaling its demise with this pre

1360
01:02:53,969 --> 01:02:51,339
stellar activity before the actual

1361
01:02:56,969 --> 01:02:53,979
explosions so what we're in the position

1362
01:03:00,209 --> 01:02:56,979
to doing and we we have done is when one

1363
01:03:02,249 --> 01:03:00,219

of these supernova imposters happen we

1364
01:03:06,359 --> 01:03:02,259
can continue to monitor this system and

1365
01:03:09,539 --> 01:03:06,369
wait for the supernova to happen we can

1366
01:03:14,880 --> 01:03:09,549
predict stellar explosions we will

1367
01:03:16,469 --> 01:03:14,890
someday okay ah Porton caveat to that if

1368
01:03:18,839 --> 01:03:16,479
you believe the story that that

1369
01:03:21,719 --> 01:03:18,849
precursor activity is associated with

1370
01:03:23,939 --> 01:03:21,729
the launching of stellar envelope the

1371
01:03:26,160 --> 01:03:23,949
transmission of information from the

1372
01:03:27,959 --> 01:03:26,170
core region core collapse to the

1373
01:03:29,489 --> 01:03:27,969
envelope means that that stellar

1374
01:03:31,810 --> 01:03:29,499
interior must be inter

1375
01:03:34,240 --> 01:03:31,820
perturbed so this

1376
01:03:37,780 --> 01:03:34,250
skin interior that I showed you was fine

1377
01:03:40,030 --> 01:03:37,790
enough for main-sequence but towards the

1378
01:03:42,160 --> 01:03:40,040
end of the star's life that is not what

1379
01:03:44,680 --> 01:03:42,170
it looks like must be much more

1380
01:03:48,310 --> 01:03:44,690
turbulent and dynamic okay and the

1381
01:03:54,550 --> 01:03:48,320
explosion is taking place here into this

1382
01:03:56,560 --> 01:03:54,560
turbulent progenitor star structure okay

1383
01:03:59,770 --> 01:03:56,570
now the last couple slides and then

1384
01:04:01,600 --> 01:03:59,780
we'll end it off I've set up for you the

1385
01:04:03,550 --> 01:04:01,610
motivation for understanding core

1386
01:04:05,500 --> 01:04:03,560
collapse supernova I've talked about the

1387
01:04:09,400 --> 01:04:05,510
types of stars explode and try and

1388
01:04:11,230 --> 01:04:09,410

understand the explosion mechanism I've

1389
01:04:13,060 --> 01:04:11,240
actually made life a lot more difficult

1390
01:04:17,650 --> 01:04:13,070
for myself because not only do I need to

1391
01:04:19,810 --> 01:04:17,660
understand the origins of that core

1392
01:04:22,390 --> 01:04:19,820
collapse whether it's purely driven by

1393
01:04:26,020 --> 01:04:22,400
that neutrino instability or the jet

1394
01:04:28,330 --> 01:04:26,030
driven but now there's added mess by the

1395
01:04:31,360 --> 01:04:28,340
progenitor star structure how am I gonna

1396
01:04:35,410 --> 01:04:31,370
be able to tell which specific processes

1397
01:04:38,950 --> 01:04:35,420
lead to the explosion and the remnant

1398
01:04:41,620 --> 01:04:38,960
structure that I see okay there's a

1399
01:04:43,750 --> 01:04:41,630
couple of facilities that are coming

1400
01:04:45,910 --> 01:04:43,760
online or that are online already that

1401
01:04:48,850 --> 01:04:45,920
you the taxpayer are helping to support

1402
01:04:51,400 --> 01:04:48,860
so you should be aware of it one is a

1403
01:04:53,620 --> 01:04:51,410
large synoptic survey telescope Alice's

1404
01:04:56,500 --> 01:04:53,630
T which is being developed in Chile and

1405
01:04:58,930 --> 01:04:56,510
this is gonna come in online around 2021

1406
01:05:02,800 --> 01:04:58,940
2022 development depending on how things

1407
01:05:04,870 --> 01:05:02,810
go now we already have surveys sky

1408
01:05:08,020 --> 01:05:04,880
surveys which I mentioned this one will

1409
01:05:10,750 --> 01:05:08,030
have a unique depth so how faint it can

1410
01:05:13,060 --> 01:05:10,760
see objects and how routinely it will be

1411
01:05:15,190 --> 01:05:13,070
mapping the regular sky the cadence has

1412
01:05:16,690 --> 01:05:15,200
yet to be finalized but let's just say

1413
01:05:19,030 --> 01:05:16,700

every three to four nights it will

1414
01:05:20,650 --> 01:05:19,040
return to the same piece of sky and

1415
01:05:23,800 --> 01:05:20,660
different filter but it'll return and

1416
01:05:26,350 --> 01:05:23,810
then image again image again image again

1417
01:05:29,320 --> 01:05:26,360
it'll do this for approximately 10 maybe

1418
01:05:32,190 --> 01:05:29,330
longer years so it'll be sampling with

1419
01:05:34,570 --> 01:05:32,200
such regularity that we'll be able to

1420
01:05:37,180 --> 01:05:34,580
potentially trace this kind of precursor

1421
01:05:39,730 --> 01:05:37,190
activity I fail to mention before that

1422
01:05:43,780 --> 01:05:39,740
this is kind of the only light curve

1423
01:05:45,520 --> 01:05:43,790
that we have that is able to sample such

1424
01:05:47,410 --> 01:05:45,530
back because there's a large divide

1425
01:05:49,960 --> 01:05:47,420
I mean the the supernovae luminosity and

1426
01:05:52,240 --> 01:05:49,970
the level of this precursor activity and

1427
01:05:55,000 --> 01:05:52,250
actually we saw a talk today by a very

1428
01:05:56,860 --> 01:05:55,010
bright grad student at Caltech and a ho

1429
01:05:58,630 --> 01:05:56,870
showed hey I got something like this

1430
01:06:01,270 --> 01:05:58,640
because of the Rickey transient Factory

1431
01:06:03,610 --> 01:06:01,280
so we're inching towards this notion of

1432
01:06:05,740 --> 01:06:03,620
if a supernova goes off let's look at

1433
01:06:08,440 --> 01:06:05,750
what's happening beforehand to get a

1434
01:06:12,610 --> 01:06:08,450
sense of what the star is doing and can

1435
01:06:14,320 --> 01:06:12,620
we connect that to the explosion the

1436
01:06:16,870 --> 01:06:14,330
other way that we're gonna be able to do

1437
01:06:18,610 --> 01:06:16,880
it is as I said multi messenger

1438
01:06:20,710 --> 01:06:18,620

astronomy so not just looking at the

1439
01:06:23,110 --> 01:06:20,720
electromagnetic spectrum which has been

1440
01:06:24,730 --> 01:06:23,120
the focus of the talk here but now we

1441
01:06:28,770 --> 01:06:24,740
have facilities sensitive to

1442
01:06:31,180 --> 01:06:28,780
gravitational waves and neutrinos

1443
01:06:35,310 --> 01:06:31,190
gravitational waves there's a lot of

1444
01:06:38,170 --> 01:06:35,320
jargon in here but let me just say this

1445
01:06:41,260 --> 01:06:38,180
instead of trying to ascertain what's

1446
01:06:45,270 --> 01:06:41,270
happening at the core of the star by way

1447
01:06:47,410 --> 01:06:45,280
of everything that's happening around it

1448
01:06:48,970 --> 01:06:47,420
gravitational waves and neutrinos are

1449
01:06:51,700 --> 01:06:48,980
coming from the heart and they're

1450
01:06:53,770 --> 01:06:51,710
unimpeded by the the the the stellar

1451
01:06:56,260 --> 01:06:53,780
ejecta around it so we're getting direct

1452
01:06:58,480 --> 01:06:56,270
live information about the core collapse

1453
01:07:00,990 --> 01:06:58,490
as it's happening and this is going to

1454
01:07:08,260 --> 01:07:01,000
revolutionize our understanding of

1455
01:07:12,220 --> 01:07:08,270
supernova explosion I I cannot

1456
01:07:13,870 --> 01:07:12,230
understand this underestimate the amount

1457
01:07:17,490 --> 01:07:13,880
of excitement that the people have in

1458
01:07:19,930 --> 01:07:17,500
all my students use animated gifts for

1459
01:07:24,040 --> 01:07:19,940
expressing excitement so this is what I

1460
01:07:29,170 --> 01:07:24,050
chose here okay going back remember that

1461
01:07:31,060 --> 01:07:29,180
first supernova 1987a right there were a

1462
01:07:33,220 --> 01:07:31,070
new training facilities working

1463
01:07:35,740 --> 01:07:33,230

operating at that time and they detected

1464
01:07:37,600 --> 01:07:35,750
approximately 20 neutrinos these are

1465
01:07:39,250 --> 01:07:37,610
very difficult nor though you know there

1466
01:07:40,750 --> 01:07:39,260
are neutrinos passing through us right

1467
01:07:42,580 --> 01:07:40,760
at this moment they normally don't

1468
01:07:44,430 --> 01:07:42,590
interact you need to have a lot of stuff

1469
01:07:46,480 --> 01:07:44,440
a lot of Tanks water they're often

1470
01:07:49,900 --> 01:07:46,490
underground to be able to make these

1471
01:07:52,870 --> 01:07:49,910
detections here is and to give you a

1472
01:07:55,030 --> 01:07:52,880
sense of the difficulty so here's this

1473
01:07:57,910 --> 01:07:55,040
is in minutes okay and just can you

1474
01:07:59,069 --> 01:07:57,920
imagine the flatline four years

1475
01:08:03,870 --> 01:07:59,079
beforehand

1476
01:08:08,069 --> 01:08:03,880
waiting for the ten seconds for which

1477
01:08:10,949 --> 01:08:08,079
the 20 or so neutrinos came through but

1478
01:08:12,989 --> 01:08:10,959
from those 10 seconds okay and those 20

1479
01:08:15,749 --> 01:08:12,999
tree nose came I've heard anywhere from

1480
01:08:17,879 --> 01:08:15,759
five six seven hundred scientific papers

1481
01:08:20,579 --> 01:08:17,889
that were published on because each one

1482
01:08:22,859 --> 01:08:20,589
were so valuable in understanding what

1483
01:08:26,160 --> 01:08:22,869
was happening at the core process I mean

1484
01:08:28,950 --> 01:08:26,170
that truly was verification of our model

1485
01:08:31,470 --> 01:08:28,960
of a core collapse forming the neutron

1486
01:08:36,359 --> 01:08:31,480
star because the neutrinos were produced

1487
01:08:37,530 --> 01:08:36,369
in that process so the with present so

1488
01:08:39,599 --> 01:08:37,540

we've come some time

1489
01:08:41,999 --> 01:08:39,609
we've count we've developed quite far

1490
01:08:43,919 --> 01:08:42,009
from the original facilities with

1491
01:08:46,169 --> 01:08:43,929
present facilities we will detect

1492
01:08:49,200 --> 01:08:46,179
thousands of neutrinos from the next

1493
01:08:51,450 --> 01:08:49,210
galactic supernova and there is much

1494
01:08:56,129 --> 01:08:51,460
more rich science to be able to be to be

1495
01:08:58,499 --> 01:08:56,139
done I'm affiliated now with something

1496
01:09:03,629 --> 01:08:58,509
called the supernova early warning

1497
01:09:06,089 --> 01:09:03,639
system snooze so the idea is if this is

1498
01:09:08,399 --> 01:09:06,099
our galaxy and there's a supernova that

1499
01:09:10,709 --> 01:09:08,409
happens on the other side the first

1500
01:09:12,510 --> 01:09:10,719
messenger to arrive on the scene will be

1501
01:09:15,899 --> 01:09:12,520
the neutrinos and there they'll be

1502
01:09:17,910 --> 01:09:15,909
streaming everything else will come

1503
01:09:20,220 --> 01:09:17,920
afterwards the gravitational waves will

1504
01:09:21,689 --> 01:09:20,230
be around there but it's likely that the

1505
01:09:24,599 --> 01:09:21,699
gravitational waves will not be as

1506
01:09:26,839 --> 01:09:24,609
strongly detected as the neutrinos

1507
01:09:33,990 --> 01:09:26,849
because just the way it all works and

1508
01:09:37,260 --> 01:09:34,000
there we are detecting it right the the

1509
01:09:39,990 --> 01:09:37,270
neutrino community will give the rest of

1510
01:09:43,260 --> 01:09:40,000
the world depending on the type of star

1511
01:09:47,450 --> 01:09:43,270
it could be as small as you know minutes

1512
01:09:49,800 --> 01:09:47,460
tens of minutes two hours on hey

1513
01:09:51,689 --> 01:09:49,810

something bigs really happening right

1514
01:09:53,760 --> 01:09:51,699
and they're going to be sending alerts

1515
01:09:56,370 --> 01:09:53,770
we're working it all out two-foot what

1516
01:09:58,709 --> 01:09:56,380
is the proper communication channels etc

1517
01:10:02,129 --> 01:09:58,719
to alert the world about the next

1518
01:10:03,899 --> 01:10:02,139
galactic supernova now we could be

1519
01:10:06,990 --> 01:10:03,909
waiting awhile I'll admit that

1520
01:10:09,120 --> 01:10:07,000
right it could happen tonight or it

1521
01:10:12,850 --> 01:10:09,130
could happen when I'm not around anymore

1522
01:10:14,410 --> 01:10:12,860
right we've been waiting some time and

1523
01:10:16,540 --> 01:10:14,420
you know with statistics unfortunately

1524
01:10:19,090 --> 01:10:16,550
there are two of these type 1a supernova

1525
01:10:21,189 --> 01:10:19,100
explosions the Tycho's remnant and

1526
01:10:23,950 --> 01:10:21,199
Kepler's remnant that happened fairly

1527
01:10:25,510 --> 01:10:23,960
closely within one another but we've

1528
01:10:27,399 --> 01:10:25,520
been waiting you know a couple hundred

1529
01:10:31,330 --> 01:10:27,409
years for another one to take place in

1530
01:10:33,040 --> 01:10:31,340
our own galaxy 1987 a kind of counts but

1531
01:10:35,530 --> 01:10:33,050
it was in a satellite galaxy we'd like

1532
01:10:38,080 --> 01:10:35,540
something to happen now but thankfully

1533
01:10:40,750 --> 01:10:38,090
with the neutrino and maybe even the

1534
01:10:42,430 --> 01:10:40,760
gravitational wave facilities even if a

1535
01:10:45,220 --> 01:10:42,440
supernova galactic one happens on the

1536
01:10:47,950 --> 01:10:45,230
other side of the galaxy you know it has

1537
01:10:50,859 --> 01:10:47,960
to go through this messy swamp forest of

1538
01:10:52,570 --> 01:10:50,869

dust that could minimize the light that

1539
01:10:54,189 --> 01:10:52,580
we see in the optical the one that we're

1540
01:10:56,379 --> 01:10:54,199
familiar with so it may not be visible

1541
01:10:57,790 --> 01:10:56,389
necessarily to the naked eye but the

1542
01:11:02,410 --> 01:10:57,800
neutrinos and the gravitational waves

1543
01:11:04,720 --> 01:11:02,420
will surely certainly catch it okay well

1544
01:11:06,700 --> 01:11:04,730
with that ladies and gentlemen I think

1545
01:11:08,530 --> 01:11:06,710
if you looked in the in the far west at

1546
01:11:14,020 --> 01:11:08,540
Twilight you may have been able to see

1547
01:11:15,729 --> 01:11:14,030
Oh Ryan but you might have to wait until

1548
01:11:18,120 --> 01:11:15,739
the the winter to be able to see it

1549
01:11:20,859 --> 01:11:18,130
again but you know in the the armpit of

1550
01:11:22,660 --> 01:11:20,869
Orion we have Betelgeuse and that's kind

1551
01:11:25,149 --> 01:11:22,670
of one of our favorite stars that we

1552
01:11:27,129 --> 01:11:25,159
like to think about as the next

1553
01:11:29,350 --> 01:11:27,139
supernova candidate so when that

1554
01:11:30,729 --> 01:11:29,360
happened next time it's visible to you

1555
01:11:32,919 --> 01:11:30,739
and you noticed it have a look and think

1556
01:11:36,910 --> 01:11:32,929
about all the things that I've discussed

1557
01:11:38,709 --> 01:11:36,920
I mean the fact that it's when these

1558
01:11:42,040 --> 01:11:38,719
fundamental processes in the universe

1559
01:11:43,570 --> 01:11:42,050
that makes life possible and all the

1560
01:11:46,050 --> 01:11:43,580
exciting science that we're doing behind

1561
01:11:48,140 --> 01:11:46,060
to understand it in all its full glory

1562
01:12:03,570 --> 01:11:48,150
thank you very much

1563
01:12:16,620 --> 01:12:12,340

okay hold up you've got the microphone

1564
01:12:28,959 --> 01:12:24,670
okay in the graph of 2009 IP yes when it

1565
01:12:33,700 --> 01:12:28,969
gets to that far right peak is that by

1566
01:12:36,100 --> 01:12:33,710
definition a supernova and is it just a

1567
01:12:37,780 --> 01:12:36,110
luminosity that defines it there or are

1568
01:12:41,170 --> 01:12:37,790
there other things so what I'm guessing

1569
01:12:44,560 --> 01:12:41,180
at is that will sometime in ten years

1570
01:12:45,760 --> 01:12:44,570
it'll go up another 50% above that point

1571
01:12:49,060 --> 01:12:45,770
is that possible

1572
01:12:53,350 --> 01:12:49,070
I was hoping somebody wouldn't ask a

1573
01:12:55,660 --> 01:12:53,360
question like that for a public lot talk

1574
01:12:57,370 --> 01:12:55,670
I like to give clear explanations but

1575
01:13:02,080 --> 01:12:57,380
you're actually hitting on a very

1576
01:13:04,720 --> 01:13:02,090
important part point yeah it's not a

1577
01:13:06,850 --> 01:13:04,730
hundred percent clear of whether or not

1578
01:13:10,360 --> 01:13:06,860
this was the terminal explosion of the

1579
01:13:13,959 --> 01:13:10,370
supernova you're absolutely right it's

1580
01:13:16,750 --> 01:13:13,969
gone there's a lot of circumstantial

1581
01:13:19,330 --> 01:13:16,760
evidence that suggests that this the the

1582
01:13:22,360 --> 01:13:19,340
supernova is actually this small peak

1583
01:13:24,400 --> 01:13:22,370
and then this is when it ran into this

1584
01:13:27,160 --> 01:13:24,410
is luminosity generated as it ran into

1585
01:13:29,470 --> 01:13:27,170
this precursor activity okay

1586
01:13:31,810 --> 01:13:29,480
that's one of the understand but

1587
01:13:33,010 --> 01:13:31,820
depending if there are other experts in

1588
01:13:34,479 --> 01:13:33,020

the room here they would potentially

1589
01:13:36,870 --> 01:13:34,489
argue that this was actually the

1590
01:13:39,610 --> 01:13:36,880
supernova and this was just a minor

1591
01:13:42,100 --> 01:13:39,620
eruption before the the actual supernova

1592
01:13:44,380 --> 01:13:42,110
explosion but you make the point oh

1593
01:13:46,540 --> 01:13:44,390
sorry but you make the point that this

1594
01:13:48,820 --> 01:13:46,550
may not necessarily be the terminal

1595
01:13:52,360 --> 01:13:48,830
explosion it's possible that sometime

1596
01:13:55,060 --> 01:13:52,370
later it may do something else but you

1597
01:13:57,490 --> 01:13:55,070
know to be fair it's them consider to be

1598
01:13:58,689 --> 01:13:57,500
the more unlikely scenario yeah that's

1599
01:14:01,240 --> 01:13:58,699
only three-and-a-half magnitudes

1600
01:14:05,350 --> 01:14:01,250
difference between your peak and the

1601
01:14:08,260 --> 01:14:05,360
2009 peak as well supernote so this was

1602
01:14:10,540 --> 01:14:08,270
just above almost fifteen fourteen and

1603
01:14:13,030 --> 01:14:10,550
that's three yeah so that so this

1604
01:14:14,500 --> 01:14:13,040
exciting because it became long the

1605
01:14:16,870 --> 01:14:14,510
anticipation was that it would continue

1606
01:14:18,729 --> 01:14:16,880
to get higher and then this low-level

1607
01:14:22,149 --> 01:14:18,739
activity I mean this is where the the

1608
01:14:24,700 --> 01:14:22,159
the large difference is okay

1609
01:14:28,060 --> 01:14:24,710
okay the reason that came to me was that

1610
01:14:35,169 --> 01:14:28,070
this graph has a striking resemblance to

1611
01:14:38,410 --> 01:14:35,179
the net worth of Tesla stock I have one

1612
01:14:40,899 --> 01:14:38,420
more question um with the neutrinos and

1613
01:14:42,700 --> 01:14:40,909

the gravitational waves what's the what

1614
01:14:45,280 --> 01:14:42,710
is the prop of the speed of propagation

1615
01:14:47,350 --> 01:14:45,290
through space for those two odd are they

1616
01:14:49,240 --> 01:14:47,360
identical speed of light they should be

1617
01:14:52,149 --> 01:14:49,250
propagating throath both are at the

1618
01:15:01,180 --> 01:14:52,159
speed of light near speed of light I

1619
01:15:02,350 --> 01:15:01,190
would say okay over there you choose you

1620
01:15:07,959 --> 01:15:02,360
get you got the mic here you're in

1621
01:15:09,520 --> 01:15:07,969
charge so neutrinos I don't remember the

1622
01:15:11,530 --> 01:15:09,530
mass that we've given them trance but

1623
01:15:12,910 --> 01:15:11,540
it's an extremely small mass so it's

1624
01:15:15,270 --> 01:15:12,920
just slightly slower than the speed of

1625
01:15:17,830 --> 01:15:15,280
light right that's right thank you for

1626
01:15:20,049 --> 01:15:17,840
filling gravitational wave that's

1627
01:15:22,750 --> 01:15:20,059
radiation that's yeah speed of light but

1628
01:15:25,319 --> 01:15:22,760
then the neutrinos believed has a bit of

1629
01:15:29,229 --> 01:15:25,329
a mass that kind of slows it yes

1630
01:15:31,450 --> 01:15:29,239
so just an amateur science fan here but

1631
01:15:34,750 --> 01:15:31,460
we have all these constant supernovas

1632
01:15:37,419 --> 01:15:34,760
going off all over the universe why

1633
01:15:40,299 --> 01:15:37,429
isn't the sky just filled with clouds of

1634
01:15:42,359 --> 01:15:40,309
nebulae everywhere like do they like

1635
01:15:44,620 --> 01:15:42,369
what causes them to like fade away or

1636
01:15:46,839 --> 01:15:44,630
you know it seemed like there'd be all

1637
01:15:49,569 --> 01:15:46,849
over the place well I'll tell you if you

1638
01:15:52,330 --> 01:15:49,579

had eyes with the right resolution and

1639
01:15:55,750 --> 01:15:52,340
wavelengths you would see remnants of

1640
01:15:57,790 --> 01:15:55,760
supernova explosions across if you look

1641
01:15:59,709 --> 01:15:57,800
at in there's different surveys

1642
01:16:03,129 --> 01:15:59,719
depending on what you do but I'm very

1643
01:16:05,830 --> 01:16:03,139
familiar with a survey that sensitive to

1644
01:16:09,479 --> 01:16:05,840
light of hydrogen-alpha transition okay

1645
01:16:13,899 --> 01:16:09,489
H hydrogen gas you see these very large

1646
01:16:16,030 --> 01:16:13,909
round blobs of sorts across the Galactic

1647
01:16:19,240 --> 01:16:16,040
plane okay and this has all been carved

1648
01:16:21,069 --> 01:16:19,250
out by supernova explosions yeah so they

1649
01:16:23,109 --> 01:16:21,079
are there absolutely you just need to

1650
01:16:23,740 --> 01:16:23,119
have the right resolving power and

1651
01:16:26,650 --> 01:16:23,750
wavelength

1652
01:16:29,080 --> 01:16:26,660
see them ok so we have a question on

1653
01:16:31,300 --> 01:16:29,090
from online says what was the toughest

1654
01:16:37,480 --> 01:16:31,310
part of getting the debris-filled into

1655
01:16:40,960 --> 01:16:37,490
your virtual reality oh okay well let's

1656
01:16:43,750 --> 01:16:40,970
see here so the I think the the the most

1657
01:16:48,340 --> 01:16:43,760
difficult part of creating that dataset

1658
01:16:53,500 --> 01:16:48,350
was just the man-hours Dan hours I

1659
01:16:57,520 --> 01:16:53,510
should say yes so I think that I I went

1660
01:17:01,510 --> 01:16:57,530
on observing trips over several years I

1661
01:17:04,150 --> 01:17:01,520
think I must have banked at least four

1662
01:17:06,700 --> 01:17:04,160
weeks of my life at a telescope to make

1663
01:17:09,130 --> 01:17:06,710

those measurements and then you know

1664
01:17:12,690 --> 01:17:09,140
five years of my life in front of a

1665
01:17:14,920 --> 01:17:12,700
computer to reduce them to make them the

1666
01:17:16,750 --> 01:17:14,930
construction that you see and actually

1667
01:17:19,020 --> 01:17:16,760
the measurements were simple enough this

1668
01:17:21,970 --> 01:17:19,030
is just an aside but the visualization

1669
01:17:26,760 --> 01:17:21,980
finding the right way to do the shadings

1670
01:17:31,180 --> 01:17:26,770
and to make that skin representation

1671
01:17:35,970 --> 01:17:31,190
that took a lot of time okay we've got

1672
01:17:39,340 --> 01:17:35,980
it next be when it's supernova explodes

1673
01:17:42,370 --> 01:17:39,350
but almost all the matter is ejected and

1674
01:17:44,650 --> 01:17:42,380
the neutron stars the collapse collapse

1675
01:17:48,010 --> 01:17:44,660
the of matter what is the radiation

1676
01:17:53,050 --> 01:17:48,020
source that generates light from the

1677
01:17:55,240 --> 01:17:53,060
neutron star the the light of the

1678
01:17:59,620 --> 01:17:55,250
neutron star okay where's that coming

1679
01:18:05,800 --> 01:17:59,630
from it all the B elements are found

1680
01:18:07,990 --> 01:18:05,810
through iron ore okay so way so let me

1681
01:18:09,520 --> 01:18:08,000
try and make sure so the neutron star

1682
01:18:12,490 --> 01:18:09,530
itself is something separate from the

1683
01:18:15,040 --> 01:18:12,500
ejecta and the ejecta depending on the

1684
01:18:17,590 --> 01:18:15,050
type of remnant so in the case of the

1685
01:18:21,030 --> 01:18:17,600
crab the ejecta may be illuminated by

1686
01:18:23,560 --> 01:18:21,040
that neutron star which has a rapidly

1687
01:18:25,660 --> 01:18:23,570
which the neutron star itself is rapidly

1688
01:18:28,540 --> 01:18:25,670

rotating and has a strong magnetic field

1689
01:18:30,970 --> 01:18:28,550
and it can accelerate particles nearby

1690
01:18:33,640 --> 01:18:30,980
that can excite the the surrounding

1691
01:18:35,770 --> 01:18:33,650
ejecta the neutron star itself may have

1692
01:18:37,850 --> 01:18:35,780
a temperature associated with it right

1693
01:18:41,439 --> 01:18:37,860
and emit like a blackbody so

1694
01:18:45,830 --> 01:18:41,449
that that would be its energy source

1695
01:18:48,020 --> 01:18:45,840
right there making you work grant there

1696
01:18:51,379 --> 01:18:48,030
next questions or the exact opposite

1697
01:18:53,600 --> 01:18:51,389
corner of the room and then of course

1698
01:18:55,879 --> 01:18:53,610
you've got pulsar emissions from a

1699
01:19:01,070 --> 01:18:55,889
neutron star you want to fill those why

1700
01:19:04,280 --> 01:19:01,080
we well that's associated with the rapid

1701
01:19:08,689 --> 01:19:04,290
rotation the development of an axis and

1702
01:19:11,570 --> 01:19:08,699
you may have beaming of these highly

1703
01:19:16,310 --> 01:19:11,580
accelerated energy towards us depending

1704
01:19:18,439 --> 01:19:16,320
on the orientation earlier you mentioned

1705
01:19:21,320 --> 01:19:18,449
that you gave an example of using your

1706
01:19:23,720 --> 01:19:21,330
two-fifths to think about two stars that

1707
01:19:27,109 --> 01:19:23,730
are similar size and then one consumes

1708
01:19:29,359 --> 01:19:27,119
the other and I'm wondering how if both

1709
01:19:32,180 --> 01:19:29,369
stars start off roughly at the same size

1710
01:19:36,890 --> 01:19:32,190
what determines which star consumes the

1711
01:19:39,230 --> 01:19:36,900
other oh well may I defer to Niharika

1712
01:19:43,840 --> 01:19:39,240
who is the the stellar evolution expert

1713
01:19:53,240 --> 01:19:50,540

although I'd hold on alright that's an

1714
01:19:55,550 --> 01:19:53,250
excellent question and as such you know

1715
01:19:58,240 --> 01:19:55,560
we've only begin to start to understand

1716
01:20:02,270 --> 01:19:58,250
what happens when two stars interact

1717
01:20:04,010 --> 01:20:02,280
it's very complicated so usually you

1718
01:20:06,950 --> 01:20:04,020
would not expect both stars to be off

1719
01:20:08,870 --> 01:20:06,960
with same mass there would be marginal

1720
01:20:11,450 --> 01:20:08,880
differences in which case if you

1721
01:20:13,010 --> 01:20:11,460
remember dance one of these slides in

1722
01:20:14,990 --> 01:20:13,020
which he had said that there is a mass

1723
01:20:18,560 --> 01:20:15,000
you know when you were going down in

1724
01:20:21,709 --> 01:20:18,570
mass that's the longer you live right so

1725
01:20:24,709 --> 01:20:21,719
the lower mass stars lives longer and

1726
01:20:27,770 --> 01:20:24,719
higher mass stars evolves faster and it

1727
01:20:30,109 --> 01:20:27,780
becomes big so because it becomes big it

1728
01:20:33,830 --> 01:20:30,119
has a tendency to transfer mass in one

1729
01:20:35,780 --> 01:20:33,840
direction preferentially so in an ideal

1730
01:20:37,189 --> 01:20:35,790
in a world where both stars are not the

1731
01:20:38,990 --> 01:20:37,199
same they would serve engulf each other

1732
01:20:42,080 --> 01:20:39,000
and that can also happen in complicated

1733
01:20:44,990 --> 01:20:42,090
physics but usually the more massive

1734
01:20:46,310 --> 01:20:45,000
star because it's faster to evolve it

1735
01:20:48,830 --> 01:20:46,320
will be the one that will transfer mass

1736
01:20:51,830 --> 01:20:48,840
but if you want to know more find me

1737
01:20:58,500 --> 01:20:54,600
okay one more question from online it

1738
01:21:01,110 --> 01:20:58,510

says how close to Earth does a supernova

1739
01:21:03,600 --> 01:21:01,120
have to be before we have to worry about

1740
01:21:05,760 --> 01:21:03,610
the dangerous cosmic rays another thing

1741
01:21:08,070 --> 01:21:05,770
in other words you know if they were

1742
01:21:09,960 --> 01:21:08,080
supernovae certain close distance way it

1743
01:21:14,040 --> 01:21:09,970
could cause some problems here yeah in

1744
01:21:16,680 --> 01:21:14,050
its distance and and certainly it has it

1745
01:21:20,040 --> 01:21:16,690
has affected the Earth's evolutionary

1746
01:21:21,900 --> 01:21:20,050
status at some point there's a lot of

1747
01:21:23,520 --> 01:21:21,910
caveats to that which is to say

1748
01:21:27,000 --> 01:21:23,530
depending on the type of supernova

1749
01:21:29,340 --> 01:21:27,010
explosion and whether or not a jet is

1750
01:21:31,680 --> 01:21:29,350
beamed towards us but I can say I used

1751
01:21:35,060 --> 01:21:31,690
the example of Beetlejuice Beetlejuice

1752
01:21:37,440 --> 01:21:35,070
were to explode it would cause

1753
01:21:39,390 --> 01:21:37,450
non-negligible influence on us and I've

1754
01:21:40,410 --> 01:21:39,400
I worked out this number sometime

1755
01:21:43,310 --> 01:21:40,420
because somebody asked me this before

1756
01:21:46,710 --> 01:21:43,320
and I just don't have it prepared but

1757
01:21:48,060 --> 01:21:46,720
there is a there's a great book by Craig

1758
01:21:51,270 --> 01:21:48,070
wheeler who was at the meeting today

1759
01:21:53,580 --> 01:21:51,280
cosmic explosions that goes into detail

1760
01:21:55,080 --> 01:21:53,590
about what happens here on earth nabil

1761
01:21:59,250 --> 01:21:55,090
juice explodes but I know that's a good

1762
01:22:02,010 --> 01:21:59,260
example so we can watch basically safely

1763
01:22:04,500 --> 01:22:02,020

from from Earth's vantage point about

1764
01:22:06,420 --> 01:22:04,510
beale juice but it would cause some kind

1765
01:22:09,180 --> 01:22:06,430
of noticeable changes here all right so

1766
01:22:09,900 --> 01:22:09,190
the internet says baitul juice is 642

1767
01:22:14,370 --> 01:22:09,910
light-years away

1768
01:22:16,350 --> 01:22:14,380
yes it's somewhere 600 or so light if

1769
01:22:18,960 --> 01:22:16,360
it's a if it if you hear that it's 10

1770
01:22:21,630 --> 01:22:18,970
parsecs away you better crawl under any

1771
01:22:24,030 --> 01:22:21,640
hole or any but they won't understand

1772
01:22:27,360 --> 01:22:24,040
parsecs right that's right 30

1773
01:22:32,280 --> 01:22:27,370
light-years we have a question way back

1774
01:22:36,210 --> 01:22:32,290
there so if the neutron star is a as a

1775
01:22:38,670 --> 01:22:36,220
possible result of the core collapse I

1776
01:22:40,200 --> 01:22:38,680
don't even know if quark stars are a

1777
01:22:42,960 --> 01:22:40,210
real thing or science fiction but I've

1778
01:22:45,600 --> 01:22:42,970
heard of them so would that result from

1779
01:22:48,240 --> 01:22:45,610
the same kind of process just a slightly

1780
01:22:49,830 --> 01:22:48,250
larger precursor star yeah we had a

1781
01:22:54,270 --> 01:22:49,840
couple of questions online as well could

1782
01:22:56,960 --> 01:22:54,280
quark stars result from this I I didn't

1783
01:22:59,520 --> 01:22:56,970
know but I should have known right I'm

1784
01:23:02,730 --> 01:22:59,530
unfamiliar with that literature but I do

1785
01:23:03,660 --> 01:23:02,740
know that that has been posited I mean

1786
01:23:05,850 --> 01:23:03,670
if you have new try

1787
01:23:09,270 --> 01:23:05,860
rich matter why couldn't you have some

1788
01:23:11,400 --> 01:23:09,280

strange quark matter as well and I know

1789
01:23:13,790 --> 01:23:11,410
some scientists have have tried to

1790
01:23:16,740 --> 01:23:13,800
explain some of the interesting

1791
01:23:19,970 --> 01:23:16,750
phenomena we observe in supernovae by

1792
01:23:22,290 --> 01:23:19,980
these transitions into quark matter yeah

1793
01:23:23,520 --> 01:23:22,300
okay I've heard other people say that

1794
01:23:25,260 --> 01:23:23,530
they felt that the quark matter would be

1795
01:23:27,780 --> 01:23:25,270
an unstable would go straight down to a

1796
01:23:29,340 --> 01:23:27,790
black hole well I don't want get a

1797
01:23:31,709 --> 01:23:29,350
stable form of matter in there but you

1798
01:23:35,729 --> 01:23:31,719
know I I want to make a judgment call I

1799
01:23:36,750 --> 01:23:35,739
was being neutral but that's not I'm

1800
01:23:40,229 --> 01:23:36,760
okay with speculate

1801
01:23:42,060 --> 01:23:40,239
okay because it's not my field all right

1802
01:23:46,500 --> 01:23:42,070
you're gonna get the last question

1803
01:23:49,890 --> 01:23:46,510
because we're almost at 9:30 so you've

1804
01:23:53,160 --> 01:23:49,900
got a chart out for soup is over 2009 i

1805
01:23:56,910 --> 01:23:53,170
peak have we found similar patterns that

1806
01:24:00,479 --> 01:23:56,920
are enabling this to say we gotta watch

1807
01:24:02,189 --> 01:24:00,489
these guys real soon right excellent

1808
01:24:06,390 --> 01:24:02,199
question and I tried to make that point

1809
01:24:08,250 --> 01:24:06,400
in that we have such scant details at

1810
01:24:11,100 --> 01:24:08,260
the moment this is kind of pointing us

1811
01:24:13,830 --> 01:24:11,110
that direction I was associated with

1812
01:24:16,830 --> 01:24:13,840
another object where it had this

1813
01:24:19,410 --> 01:24:16,840

luminous outburst okay we continued to

1814
01:24:21,810 --> 01:24:19,420
monitor it and nine months later there

1815
01:24:24,180 --> 01:24:21,820
was a supernova explosion so it is

1816
01:24:26,610 --> 01:24:24,190
happening but I mean I could count all

1817
01:24:28,770 --> 01:24:26,620
these events on my hand the fingers on

1818
01:24:30,860 --> 01:24:28,780
my hands as far as how many that's

1819
01:24:33,780 --> 01:24:30,870
happened even just one hand I think yes

1820
01:24:35,729 --> 01:24:33,790
but see but the the the point that I was

1821
01:24:38,280 --> 01:24:35,739
trying to make is with these new

1822
01:24:40,470 --> 01:24:38,290
facilities the hope is that we'll have

1823
01:24:42,990 --> 01:24:40,480
not just know this hand but all the

1824
01:24:45,050 --> 01:24:43,000
hands in the audience as far as examples

1825
01:24:46,919 --> 01:24:45,060
of this to be able to make real

1826
01:24:49,830 --> 01:24:46,929
anticipations maybe there's certain

1827
01:24:53,520 --> 01:24:49,840
patterns related to the explosion that

1828
01:24:55,800 --> 01:24:53,530
we can exploit yeah and this is just and

1829
01:24:58,050 --> 01:24:55,810
this is just one example of how time

1830
01:25:00,120 --> 01:24:58,060
domain astronomy is taking off with

1831
01:25:02,430 --> 01:25:00,130
things like LSST it's going to change a

1832
01:25:04,140 --> 01:25:02,440
lot in the next decade all right you can

1833
01:25:12,250 --> 01:25:04,150
get that one follow-up question in real

1834
01:25:20,569 --> 01:25:15,379
that's the hope yes we have a short

1835
01:25:23,689 --> 01:25:20,579
turnaround that is well triangulation

1836
01:25:25,009 --> 01:25:23,699
amongst the various facilities we put in

1837
01:25:26,659 --> 01:25:25,019
a proposal for the National Science

1838
01:25:28,459 --> 01:25:26,669

Foundation maybe they'll give us some

1839
01:25:30,859 --> 01:25:28,469
funding to do that but I just have to

1840
01:25:33,469 --> 01:25:30,869
comment that the for the online audience

1841
01:25:36,019 --> 01:25:33,479
that the question inside was about

1842
01:25:37,549 --> 01:25:36,029
neutrinos and that not getting a

1843
01:25:39,619 --> 01:25:37,559
directionality but yes

1844
01:25:41,629 --> 01:25:39,629
triangulation can do it okay we've got

1845
01:25:43,489 --> 01:25:41,639
to stop folks I know this was a fence

1846
01:25:50,830 --> 01:25:43,499
fascinating talk give them another big