PUBLIC LECTURE SERIES

The Crab Nebula and Things that Go Kaboom in the Night

Featuring Guest Speaker:
Frank Summers

1
00:00:07,940 --> 00:00:01,699
everything where it needs to be before

2
00:00:09,169 --> 00:00:07,950
we start alright let's begin good

3
00:00:11,299 --> 00:00:09,179
evening ladies and gentlemen and welcome

4
00:00:13,910 --> 00:00:11,309
to the Space Telescope public lecture

5
00:00:15,860 --> 00:00:13,920
series I'm your host dr. Frank summers

6
00:00:19,040 --> 00:00:15,870
of the office of public outreach and it

7
00:00:24,230 --> 00:00:19,050
is my pleasure to be your host each and

8
00:00:26,390 --> 00:00:24,240
every month if you came in you hopefully

9
00:00:28,279 --> 00:00:26,400
grabbed a lithograph over here this

10
00:00:30,320 --> 00:00:28,289
lithograph has special meaning it will

11
00:00:31,189 --> 00:00:30,330
be actually be used as part of the talk

12
00:00:33,889 --> 00:00:31,199
tonight okay

13
00:00:38,569 --> 00:00:33,899

so the lithograph on supernova remnants

14
00:00:40,819 --> 00:00:38,579
n 1006 and if you want to know what that

15
00:00:42,680 --> 00:00:40,829
means you look over on the back and you

16
00:00:45,260 --> 00:00:42,690
can see all this wonderful text here

17
00:00:48,049 --> 00:00:45,270
that we've written as well as a content

18
00:00:50,360 --> 00:00:48,059
context picture of the full supernova

19
00:00:53,510 --> 00:00:50,370
remnant and that will also appear in

20
00:00:56,990 --> 00:00:53,520
tonight's talk all right so make sure

21
00:00:59,110 --> 00:00:57,000
you silence your electronics the modern

22
00:01:01,880 --> 00:00:59,120
age requires that we have things

23
00:01:05,149 --> 00:01:01,890
ringtones text notifications and camera

24
00:01:07,880 --> 00:01:05,159
clicks turned off thank you very much

25
00:01:11,780 --> 00:01:07,890
tonight the Crab Nebula and things that

26
00:01:16,460 --> 00:01:11,790
go kaboom in the night bye yeah this guy

27
00:01:18,830 --> 00:01:16,470
okay upcoming March 3rd we have Nestor

28
00:01:21,859 --> 00:01:18,840
Espinosa talking about exoplanets a

29
00:01:25,310 --> 00:01:21,869
search for new worlds exoplanets are

30
00:01:27,859 --> 00:01:25,320
just massively hot I always recently

31
00:01:29,420 --> 00:01:27,869
informed that Hubble is actually

32
00:01:31,910 --> 00:01:29,430
spending on order ten to twenty percent

33
00:01:33,649 --> 00:01:31,920
of its time looking at exoplanets and

34
00:01:35,740 --> 00:01:33,659
exoplanet atmospheres and things these

35
00:01:38,929 --> 00:01:35,750
days which was kind of cool because

36
00:01:40,490 --> 00:01:38,939
Hubble was never designed to look at

37
00:01:43,700 --> 00:01:40,500
exoplanets we didn't know about

38
00:01:46,490 --> 00:01:43,710

exoplanets until three or four years

39
00:01:48,230 --> 00:01:46,500
after Hubble launched and that shows you

40
00:01:49,850 --> 00:01:48,240
how we can just adapt this wonderful

41
00:01:50,450 --> 00:01:49,860
telescope to look at anything in the

42
00:01:53,420 --> 00:01:50,460
universe

43
00:01:55,310 --> 00:01:53,430
April 7th we will be celebrating the

44
00:01:57,709 --> 00:01:55,320
30th anniversary of Hubble with an

45
00:01:59,240 --> 00:01:57,719
all-star cast which means nobody's

46
00:02:04,910 --> 00:01:59,250
willing to commit exactly who's gonna

47
00:02:08,900 --> 00:02:04,920
talk on April but there will be probably

48
00:02:12,229 --> 00:02:08,910
more than one speaker and in May we have

49
00:02:12,899 --> 00:02:12,239
our perennial favorite TBA who will show

50
00:02:15,869 --> 00:02:12,909
up

51
00:02:19,770 --> 00:02:15,879
I actually filled the June slot today I

52
00:02:21,479 --> 00:02:19,780
still have to feel am a slot reminder

53
00:02:23,339 --> 00:02:21,489
for those of you are here you know about

54
00:02:26,399 --> 00:02:23,349
this the building is under Lobby is

55
00:02:28,349 --> 00:02:26,409
under reconstruction and February and

56
00:02:30,479 --> 00:02:28,359
March they've told me definitely will be

57
00:02:32,640 --> 00:02:30,489
impacted there's still a question as to

58
00:02:34,050 --> 00:02:32,650
whether it will be done by the April

59
00:02:36,630 --> 00:02:34,060
public lecture okay

60
00:02:38,610 --> 00:02:36,640
so most likely there they originally

61
00:02:40,229 --> 00:02:38,620
expect it to be done by April but things

62
00:02:42,259 --> 00:02:40,239
can always slip okay schedules can

63
00:02:44,819 --> 00:02:42,269

always slip with construction all right

64
00:02:46,050 --> 00:02:44,829
using the alternate entrance the signs

65
00:02:49,979 --> 00:02:46,060
were posted the signs were easy to

66
00:02:52,110 --> 00:02:49,989
follow tonight okay good all right and

67
00:02:55,199 --> 00:02:52,120
especially if you need wheelchair access

68
00:02:59,149 --> 00:02:55,209
we can arrange it but we need to have

69
00:03:06,479 --> 00:03:03,659
website if you just go to stsci dot edu

70
00:03:09,420 --> 00:03:06,489
slash public - lectures you'll find our

71
00:03:13,080 --> 00:03:09,430
public lecture series website here is

72
00:03:16,289 --> 00:03:13,090
our webcasts both on our webcast

73
00:03:20,219 --> 00:03:16,299
archives from stsci and a playlist on

74
00:03:23,610 --> 00:03:20,229
youtube ok the playlist on YouTube goes

75
00:03:26,369 --> 00:03:23,620
back like five six seven years maybe

76
00:03:30,059 --> 00:03:26,379
even eight years and the webcast archive

77
00:03:33,000 --> 00:03:30,069
goes all the way back to 2005 so we're

78
00:03:35,580 --> 00:03:33,010
approaching 15 years of webcast on there

79
00:03:38,399 --> 00:03:35,590
you want a binge watch yeah you got a

80
00:03:40,530 --> 00:03:38,409
lot to binge watch okay can see chepa so

81
00:03:44,250 --> 00:03:40,540
at least an hour sometimes an hour and a

82
00:03:47,759 --> 00:03:44,260
half so good luck with that email if you

83
00:03:49,740 --> 00:03:47,769
want to sign up for our monthly emails

84
00:03:53,430 --> 00:03:49,750
telling you about the lectures fill out

85
00:03:55,229 --> 00:03:53,440
there hit the subscribe button also on

86
00:03:58,349 --> 00:03:55,239
the web we have a list of the upcoming

87
00:04:00,689 --> 00:03:58,359
lectures and for each lecture when you

88
00:04:03,240 --> 00:04:00,699

hit that read more button you will find

89
00:04:06,330 --> 00:04:03,250
the description of it above the speaker

90
00:04:09,390 --> 00:04:06,340
and after the web the lecture has gone

91
00:04:12,449 --> 00:04:09,400
you will find links to the STScI webcast

92
00:04:15,479 --> 00:04:12,459
here as well as the YouTube webcast down

93
00:04:18,449 --> 00:04:15,489
here okay alrighty

94
00:04:21,000 --> 00:04:18,459
the email as I said you can sign up at

95
00:04:23,250 --> 00:04:21,010
the website some people don't like to do

96
00:04:25,950 --> 00:04:23,260
that they write it on a piece of paper

97
00:04:28,920 --> 00:04:25,960
and hand it to me that's just fine too

98
00:04:30,809 --> 00:04:28,930
okay we promise you will not get any

99
00:04:32,969 --> 00:04:30,819
spam there hasn't been any yet and we've

100
00:04:35,219 --> 00:04:32,979
been doing it for like five years

101
00:04:39,390 --> 00:04:35,229
comments and questions can go to public

102
00:04:41,820 --> 00:04:39,400
lecture at STScI dot edu if you'd like

103
00:04:43,350 --> 00:04:41,830
to follow us on social media the Hubble

104
00:04:44,939 --> 00:04:43,360
Space Telescope the James Webb Space

105
00:04:47,640 --> 00:04:44,949
Telescope and the Space Telescope

106
00:04:50,700 --> 00:04:47,650
Science Institute have three separate

107
00:04:54,210 --> 00:04:50,710
accounts on Facebook Twitter YouTube and

108
00:04:56,249 --> 00:04:54,220
Instagram so you can follow us maybe

109
00:04:59,939 --> 00:04:56,259
there's some more but I'm not terribly

110
00:05:02,310 --> 00:04:59,949
social media friendly I do some of it on

111
00:05:06,360 --> 00:05:02,320
Facebook and Twitter you can follow me

112
00:05:08,010 --> 00:05:06,370
at dr. Frank's Summers often times after

113
00:05:10,740 --> 00:05:08,020

the lecture we go to the observatory the

114
00:05:13,110 --> 00:05:10,750
Maryland's great Space Grant Observatory

115
00:05:15,960 --> 00:05:13,120
they informed me that the weather

116
00:05:18,810 --> 00:05:15,970
forecast did not look good so that will

117
00:05:21,300 --> 00:05:18,820
not happen tonight but they have open

118
00:05:25,260 --> 00:05:21,310
houses on Friday evenings if you go over

119
00:05:28,469 --> 00:05:25,270
to their website which is Marilyn MD dot

120
00:05:31,230 --> 00:05:28,479
space grant Arg you can find this page

121
00:05:33,779 --> 00:05:31,240
about their open houses and right there

122
00:05:36,899 --> 00:05:33,789
that's the observatory status on Fridays

123
00:05:39,570 --> 00:05:36,909
it will be updated as to whether they

124
00:05:44,070 --> 00:05:39,580
are having an open house that evening

125
00:05:48,360 --> 00:05:44,080
okay all right and now news from the

126
00:05:51,959 --> 00:05:48,370
universe for February 2020 our first

127
00:05:55,560 --> 00:05:51,969
story tonight Goldilocks stars looking

128
00:06:00,120 --> 00:05:55,570
for life in all the right places all

129
00:06:02,459 --> 00:06:00,130
right so we have had a long new history

130
00:06:05,040 --> 00:06:02,469
of these extrasolar planets which I

131
00:06:06,930 --> 00:06:05,050
mentioned earlier that you know Hubble

132
00:06:08,820 --> 00:06:06,940
wasn't designed to look at extrasolar

133
00:06:10,770 --> 00:06:08,830
planets but it's actually doing a good

134
00:06:14,310 --> 00:06:10,780
amount of extrasolar planet science now

135
00:06:16,170 --> 00:06:14,320
so this is the plot of all the stars in

136
00:06:19,379 --> 00:06:16,180
the sky right Ascension and declination

137
00:06:23,399 --> 00:06:19,389
here that we knew of in 1987 that had

138
00:06:27,240 --> 00:06:23,409

planets and you can see that's zero all

139
00:06:29,610 --> 00:06:27,250
right let's put this plot in motion okay

140
00:06:31,529 --> 00:06:29,620
well as the dates change you'll slowly

141
00:06:34,260 --> 00:06:31,539
start to see a few of them and then in

142
00:06:37,350 --> 00:06:34,270
the early 90s and the later 90s it gets

143
00:06:38,850 --> 00:06:37,360
more and more and into the 2000s it

144
00:06:40,679 --> 00:06:38,860
becomes a lot more

145
00:06:42,929 --> 00:06:40,689
and at the end 2010 you start getting

146
00:06:45,420 --> 00:06:42,939
the Keppler group in there and you get a

147
00:06:50,279 --> 00:06:45,430
ton of planets okay

148
00:06:51,779 --> 00:06:50,289
so now we know of over 4000 extrasolar

149
00:06:55,379 --> 00:06:51,789
planets out there okay

150
00:06:59,730 --> 00:06:55,389
we've gone from nine planets to eight

151
00:07:00,839 --> 00:06:59,740
planets to four thousand planets okay so

152
00:07:03,209 --> 00:07:00,849
those are you who are worried about

153
00:07:06,439 --> 00:07:03,219
Pluto being on the planet no no we got

154
00:07:09,360 --> 00:07:06,449
so many more who cares about that okay

155
00:07:12,209 --> 00:07:09,370
so but the point is is that it's now

156
00:07:14,279 --> 00:07:12,219
become a serious piece of science that

157
00:07:16,890 --> 00:07:14,289
we're doing it's not just finding them

158
00:07:19,499 --> 00:07:16,900
but it's also finding them efficiently

159
00:07:21,510 --> 00:07:19,509
and finding the ones we really want so

160
00:07:23,820 --> 00:07:21,520
when you look at this star field here

161
00:07:25,740 --> 00:07:23,830
you've got the red stars the orange

162
00:07:29,070 --> 00:07:25,750
stars and the white stars and the blue

163
00:07:32,749 --> 00:07:29,080

stars etc where are you gonna look okay

164
00:07:35,339 --> 00:07:32,759
what is most likely to have planets and

165
00:07:37,439 --> 00:07:35,349
furthermore because this is what excites

166
00:07:39,510 --> 00:07:37,449
the public imagination and what hey we

167
00:07:42,600 --> 00:07:39,520
as astronomers also want to know which

168
00:07:44,519 --> 00:07:42,610
ones are most likely to have life okay

169
00:07:47,129 --> 00:07:44,529
so what are the arguments you're gonna

170
00:07:48,839 --> 00:07:47,139
have right well the star has to live

171
00:07:51,600 --> 00:07:48,849
long enough okay so all the short-lived

172
00:07:52,950 --> 00:07:51,610
stars the white and the blue stars they

173
00:07:54,869 --> 00:07:52,960
don't live long enough for a planet of

174
00:07:57,029 --> 00:07:54,879
her life to develop because life on our

175
00:08:00,360 --> 00:07:57,039
solar in life in our solar system took 4

176
00:08:02,279 --> 00:08:00,370
billion years to become complex the

177
00:08:04,110 --> 00:08:02,289
Cambrian explosion was about 500 million

178
00:08:06,180 --> 00:08:04,120
years ago 600 million years ago

179
00:08:09,119 --> 00:08:06,190
and we've been around for 4.6 billion

180
00:08:11,219 --> 00:08:09,129
years so that means four billion years

181
00:08:15,200 --> 00:08:11,229
per life to develop you need a long live

182
00:08:18,899 --> 00:08:15,210
star okay you also need a star a planet

183
00:08:21,390 --> 00:08:18,909
in a habitable zone that's going to be

184
00:08:24,899 --> 00:08:21,400
safe and that can't be too much

185
00:08:27,629 --> 00:08:24,909
radiation and other things so using

186
00:08:29,579 --> 00:08:27,639
Hubble they were able to go in and study

187
00:08:32,029 --> 00:08:29,589
a bunch of the stars and try and

188
00:08:34,350 --> 00:08:32,039

understand this high-energy radiation

189
00:08:36,779 --> 00:08:34,360
looking using Hubble's capability for

190
00:08:39,089 --> 00:08:36,789
ultraviolet observation to understand

191
00:08:42,120 --> 00:08:39,099
the high-energy radiation factor in all

192
00:08:44,579 --> 00:08:42,130
of this and this is the diagram they

193
00:08:46,949 --> 00:08:44,589
gave us here so we start with the M

194
00:08:49,740 --> 00:08:46,959
stars those tiniest stars the red star

195
00:08:51,720 --> 00:08:49,750
the red dwarf stars okay they have

196
00:08:52,600 --> 00:08:51,730
because they're faint they have a very

197
00:08:56,079 --> 00:08:52,610
small habitable

198
00:08:58,150 --> 00:08:56,089
zone what really makes them not so great

199
00:09:01,300 --> 00:08:58,160
is that they have a lot of x-ray

200
00:09:03,759 --> 00:09:01,310
irradiance they have these small stars

201
00:09:06,579 --> 00:09:03,769
have a lot of stellar flares they're

202
00:09:08,769 --> 00:09:06,589
very active okay and so even though if

203
00:09:10,420 --> 00:09:08,779
even though there are a ton of them they

204
00:09:13,449 --> 00:09:10,430
are the most numerous stars in the

205
00:09:15,040 --> 00:09:13,459
universe about 74% of the universe of

206
00:09:18,490 --> 00:09:15,050
the stars in the universe are these red

207
00:09:20,740 --> 00:09:18,500
dwarfs they are not really good for life

208
00:09:23,740 --> 00:09:20,750
because of all this x-ray irradiance

209
00:09:26,530 --> 00:09:23,750
okay if you move up to the K stars the

210
00:09:29,199 --> 00:09:26,540
it's depicted here as orange stars they

211
00:09:32,230 --> 00:09:29,209
have a bigger habitable zone they have

212
00:09:35,170 --> 00:09:32,240
some x-ray irradiance etc from the study

213
00:09:38,380 --> 00:09:35,180

not too much but you know some that will

214
00:09:40,480 --> 00:09:38,390
be worrisome they're much less than the

215
00:09:42,490 --> 00:09:40,490
red button three times more than the

216
00:09:46,000 --> 00:09:42,500
yellow and they live for forty billion

217
00:09:48,190 --> 00:09:46,010
years okay that's pretty good if you go

218
00:09:50,110 --> 00:09:48,200
to the sun-like stars the G stars they

219
00:09:52,690 --> 00:09:50,120
have a much bigger habitable zone they

220
00:09:56,650 --> 00:09:52,700
have a very acceptable x-ray irradiance

221
00:10:00,310 --> 00:09:56,660
because hey life developed here also but

222
00:10:01,689 --> 00:10:00,320
their number is considerably fewer and

223
00:10:03,400 --> 00:10:01,699
living for ten billion years you're

224
00:10:05,800 --> 00:10:03,410
starting to get to the the borderline of

225
00:10:08,910 --> 00:10:05,810
well could life develop so the

226
00:10:11,050 --> 00:10:08,920
conclusion of their study was that the

227
00:10:12,639 --> 00:10:11,060
optimal stars to look at if you're

228
00:10:15,430 --> 00:10:12,649
trying to find places where life could

229
00:10:19,269 --> 00:10:15,440
develop would be those K stars all right

230
00:10:21,790 --> 00:10:19,279
the sun-like stars just not not as many

231
00:10:24,490 --> 00:10:21,800
as of them whereas the the K stars the

232
00:10:26,769 --> 00:10:24,500
orange stars would be more favorable and

233
00:10:28,449 --> 00:10:26,779
this will help us design future searches

234
00:10:31,030 --> 00:10:28,459
that are looking for those type of

235
00:10:33,699 --> 00:10:31,040
planets so we have to do this these

236
00:10:36,069 --> 00:10:33,709
observations in this theoretical work to

237
00:10:39,220 --> 00:10:36,079
help design future surveys and make them

238
00:10:42,250 --> 00:10:39,230

as efficient as possible our second

239
00:10:45,880 --> 00:10:42,260
story so long and thanks for all the

240
00:10:48,639 --> 00:10:45,890
PAHs now you may not get this reference

241
00:10:50,650 --> 00:10:48,649
okay but this is a reference to the

242
00:10:53,350 --> 00:10:50,660
title of a book by Douglas Adams called

243
00:10:54,880 --> 00:10:53,360
so long and thanks for all the fish it's

244
00:10:57,430 --> 00:10:54,890
from The Hitchhiker's Guide to the

245
00:11:00,699 --> 00:10:57,440
galaxy trilogy it's actually the fourth

246
00:11:03,250 --> 00:11:00,709
book in the trilogy and when the

247
00:11:05,350 --> 00:11:03,260
Dolphins leave Earth in this book that's

248
00:11:06,160 --> 00:11:05,360
what they say hey so long and thanks for

249
00:11:08,440 --> 00:11:06,170
all the fish

250
00:11:10,450 --> 00:11:08,450
but we're not talking about fish here

251
00:11:14,020 --> 00:11:10,460
we're talking about PA h's which are

252
00:11:16,060 --> 00:11:14,030
polycyclic aromatic hydrocarbons and I

253
00:11:18,190 --> 00:11:16,070
found this plot of these unpronounceable

254
00:11:20,110 --> 00:11:18,200
names etc and you can see that there are

255
00:11:22,840 --> 00:11:20,120
these carbon things all put together and

256
00:11:25,570 --> 00:11:22,850
in the chemistry right well you know

257
00:11:28,960 --> 00:11:25,580
them because PHS are produced when you

258
00:11:30,220 --> 00:11:28,970
burn fuel and so on your grill when

259
00:11:32,070 --> 00:11:30,230
you're cooking your burgers and you get

260
00:11:34,830 --> 00:11:32,080
all those black lines on those things

261
00:11:36,670 --> 00:11:34,840
then B then polycyclic aromatic

262
00:11:40,480 --> 00:11:36,680
hydrocarbons okay they're good eating

263
00:11:42,160 --> 00:11:40,490

you know so we are it's sort of this the

264
00:11:44,440 --> 00:11:42,170
soot from the grill type thing all right

265
00:11:46,990 --> 00:11:44,450
and that's what a parallel cyclic

266
00:11:49,350 --> 00:11:47,000
aromatic hydrocarbon is in your life but

267
00:11:54,330 --> 00:11:49,360
to astronomers polycyclic aromatic

268
00:11:58,360 --> 00:11:54,340
hydrocarbons they can be damn beautiful

269
00:12:01,180 --> 00:11:58,370
that's PAH is in the universe okay all

270
00:12:04,030 --> 00:12:01,190
right they actually emit at several

271
00:12:06,880 --> 00:12:04,040
bands in the in the in the near to the

272
00:12:10,180 --> 00:12:06,890
mid infrared okay and this is a picture

273
00:12:13,360 --> 00:12:10,190
of the nebula gum 29 and you are seeing

274
00:12:15,610 --> 00:12:13,370
emission from a lot of PAHs here alright

275
00:12:18,490 --> 00:12:15,620
and this this picture in the infrared

276
00:12:22,510 --> 00:12:18,500
was of course taken by the Spitzer Space

277
00:12:26,890 --> 00:12:22,520
Telescope alright and Spitzer has had a

278
00:12:31,990 --> 00:12:26,900
16 and 1/2 year career unfortunately it

279
00:12:34,300 --> 00:12:32,000
ended last week okay so the Spitzer was

280
00:12:36,940 --> 00:12:34,310
launched in 2003 and a had its primary

281
00:12:39,400 --> 00:12:36,950
mission for six years this is called the

282
00:12:42,820 --> 00:12:39,410
cold mission in retrospect because it

283
00:12:44,860 --> 00:12:42,830
had the the coolant to keep certain of

284
00:12:46,180 --> 00:12:44,870
its instruments really cold which is

285
00:12:47,560 --> 00:12:46,190
what you need for infrared you're

286
00:12:49,270 --> 00:12:47,570
looking at heat radiation your

287
00:12:51,280 --> 00:12:49,280
instruments need to be cold so that is

288
00:12:54,220 --> 00:12:51,290

not excess heat that interferes with

289
00:12:56,830 --> 00:12:54,230
your observations after the coolant ran

290
00:12:59,590 --> 00:12:56,840
out in 2009 two instruments that needed

291
00:13:01,150 --> 00:12:59,600
coolant were decommissioned and it went

292
00:13:04,000 --> 00:13:01,160
into what's called the warm mission

293
00:13:07,300 --> 00:13:04,010
right and that went on for several years

294
00:13:08,740 --> 00:13:07,310
and it was Excel to end in 2018 but with

295
00:13:11,800 --> 00:13:08,750
delays to the James Webb Space Telescope

296
00:13:15,610 --> 00:13:11,810
they extended it and it now became the

297
00:13:18,450 --> 00:13:15,620
beyond mission an extension to 2020 and

298
00:13:19,930 --> 00:13:18,460
that is what has just expired and so

299
00:13:22,600 --> 00:13:19,940
spitzer as you

300
00:13:25,030 --> 00:13:22,610
see over here had their idea of AI it's

301
00:13:27,670 --> 00:13:25,040
the final voyage right there are a lot

302
00:13:29,830 --> 00:13:27,680
of Star Trek fans out out at the JPL

303
00:13:32,500 --> 00:13:29,840
okay so this is what they came up with

304
00:13:36,730 --> 00:13:32,510
and so in the Spitzer final voyage the

305
00:13:38,740 --> 00:13:36,740
last observation was on January 28th

306
00:13:43,150 --> 00:13:38,750
and then they started turning off the

307
00:13:45,220 --> 00:13:43,160
instruments and at 2:30 last Friday they

308
00:13:45,850 --> 00:13:45,230
or was the last Thursday yeah his last

309
00:13:48,250 --> 00:13:45,860
Thursday

310
00:13:50,560 --> 00:13:48,260
they sent the last command to turn it

311
00:13:52,570 --> 00:13:50,570
and put it in safe mode and so the

312
00:13:54,730 --> 00:13:52,580
Spitzer Space Telescope is still out

313
00:13:57,430 --> 00:13:54,740

there it's on an earth trailing orbits

314
00:14:00,160 --> 00:13:57,440
it's orbiting around the Sun but it is

315
00:14:02,520 --> 00:14:00,170
now in safe mode and will no longer be

316
00:14:05,380 --> 00:14:02,530
producing science so we have had some

317
00:14:07,360 --> 00:14:05,390
amazing images from Spitzer and I just

318
00:14:10,270 --> 00:14:07,370
wanted to pay tribute with some of them

319
00:14:13,120 --> 00:14:10,280
this is the star forming regions in the

320
00:14:15,490 --> 00:14:13,130
constellation of akhiya I mean just look

321
00:14:17,110 --> 00:14:15,500
at the beauty of the dust I mean I

322
00:14:19,930 --> 00:14:17,120
Hubble has some great star forming

323
00:14:21,250 --> 00:14:19,940
region images but Spitzer is able to tie

324
00:14:23,710 --> 00:14:21,260
them all together with all the

325
00:14:25,540 --> 00:14:23,720
background gas that we don't see with

326
00:14:27,370 --> 00:14:25,550
Hubble and you can see that's the

327
00:14:30,190 --> 00:14:27,380
amazing amount of star formation that's

328
00:14:32,620 --> 00:14:30,200
going on in this region and talk about

329
00:14:34,690 --> 00:14:32,630
an even more amazing star formation what

330
00:14:37,690 --> 00:14:34,700
we see in the Large Magellanic Cloud

331
00:14:40,090 --> 00:14:37,700
these are all the star forming regions

332
00:14:42,880 --> 00:14:40,100
in the Large Magellanic Cloud including

333
00:14:45,760 --> 00:14:42,890
the tarantula nebula right here the

334
00:14:49,480 --> 00:14:45,770
largest star forming region not in the

335
00:14:52,420 --> 00:14:49,490
Magellanic Cloud not in the Milky Way

336
00:14:54,610 --> 00:14:52,430
galaxy but in the entire local group

337
00:14:57,820 --> 00:14:54,620
alright there's so much amazing stuff

338
00:15:00,670 --> 00:14:57,830

that Spitzer revealed to us in the Large

339
00:15:04,180 --> 00:15:00,680
Magellanic Cloud with this survey and

340
00:15:07,300 --> 00:15:04,190
finally up on galactic scales this is

341
00:15:09,610 --> 00:15:07,310
the galaxy m81 and what we see in

342
00:15:12,100 --> 00:15:09,620
visible light is generally this dark

343
00:15:14,350 --> 00:15:12,110
dust lanes in the spiral arms and look

344
00:15:17,890 --> 00:15:14,360
how beautiful it is look at all the

345
00:15:20,860 --> 00:15:17,900
detail of the dust inside these galaxies

346
00:15:24,370 --> 00:15:20,870
you can really see the spiral arms just

347
00:15:27,310 --> 00:15:24,380
jump out so Spitzer has had a 16 and 1/2

348
00:15:30,040 --> 00:15:27,320
year history of producing some amazing

349
00:15:32,440 --> 00:15:30,050
science science that is complementary to

350
00:15:33,319 --> 00:15:32,450
the other Great observatories Hubble and

351
00:15:34,729 --> 00:15:33,329
Chandra

352
00:15:38,600 --> 00:15:34,739
and I've had the privilege of working

353
00:15:41,449 --> 00:15:38,610
with some amazing people at iPAQ and JPL

354
00:15:44,509 --> 00:15:41,459
and it will be missed

355
00:15:46,340 --> 00:15:44,519
but you know hopefully these James Webb

356
00:15:48,559 --> 00:15:46,350
Space Telescope will be online soon

357
00:15:50,749 --> 00:15:48,569
enough and we'll be able to surpass

358
00:15:55,039 --> 00:15:50,759
these and bring them even more but we

359
00:15:59,840 --> 00:15:55,049
bid a fond farewell to Spitzer alright

360
00:16:04,999 --> 00:15:59,850
time for our featured speaker and let me

361
00:16:11,019 --> 00:16:05,009
just switch powerpoints oops that's the

362
00:16:16,059 --> 00:16:13,579
speaker tonight is Frank summers from

363
00:16:19,249 --> 00:16:16,069

the Space Telescope Science Institute

364
00:16:22,999 --> 00:16:19,259
he has been an outreach astrophysicist

365
00:16:25,429 --> 00:16:23,009
here at Space Telescope for ah

366
00:16:27,139 --> 00:16:25,439
what year is this nineteen years coming

367
00:16:28,999 --> 00:16:27,149
up okay and he's been your host for the

368
00:16:32,179 --> 00:16:29,009
public lecture series for 18 years of

369
00:16:34,819 --> 00:16:32,189
that I usually try to tell you something

370
00:16:37,609 --> 00:16:34,829
interesting about myself when I give

371
00:16:40,609 --> 00:16:37,619
talks so I will introduce my wife

372
00:16:42,259 --> 00:16:40,619
sitting in the front row here and we met

373
00:16:45,769 --> 00:16:42,269
at the University of California Berkeley

374
00:16:49,280 --> 00:16:45,779
ballroom dance club so Carolyn and I

375
00:16:52,340 --> 00:16:49,290
have met met dancing and we do an

376
00:16:54,109 --> 00:16:52,350
absolutely mean West Coast Swing this

377
00:16:56,659 --> 00:16:54,119
lady really knows how to do a West Coast

378
00:16:59,569 --> 00:16:56,669
Swing and she makes me look good on the

379
00:17:01,369 --> 00:16:59,579
dance floor and sitting next to her is

380
00:17:07,429 --> 00:17:01,379
my mom who taught me how to tap-dance

381
00:17:09,260 --> 00:17:07,439
when I was 10 years old so my two

382
00:17:13,090 --> 00:17:09,270
dancing partners in the front row

383
00:17:18,500 --> 00:17:16,340
alright enough about me let's talk about

384
00:17:20,360 --> 00:17:18,510
some cool things at the universe all

385
00:17:23,779 --> 00:17:20,370
right the Crab Nebula and things that go

386
00:17:25,689 --> 00:17:23,789
boom in the night and we're gonna start

387
00:17:28,069 --> 00:17:25,699
about this by talking about stars and

388
00:17:30,740 --> 00:17:28,079

one way to think of a star is that say

389
00:17:33,529 --> 00:17:30,750
gravitationally confined nuclear fusion

390
00:17:35,029 --> 00:17:33,539
reactor okay now when you think of

391
00:17:36,889 --> 00:17:35,039
nuclear reactors you're probably

392
00:17:39,350 --> 00:17:36,899
thinking of the cooling towers at

393
00:17:42,049 --> 00:17:39,360
nuclear power plants okay but that's

394
00:17:45,130 --> 00:17:42,059
nuclear fission okay these power plants

395
00:17:47,410 --> 00:17:45,140
create energy by nuclear fission

396
00:17:50,140 --> 00:17:47,420
and fishin is when you're breaking atoms

397
00:17:52,930 --> 00:17:50,150
apart and the most popular fuel in

398
00:17:56,440 --> 00:17:52,940
fishing reactors these days are uranium

399
00:18:00,460 --> 00:17:56,450
and plutonium specifically uranium-235

400
00:18:02,830 --> 00:18:00,470
which captures a neutron and then breaks

401
00:18:04,510 --> 00:18:02,840
off into two pieces and the energy that

402
00:18:07,080 --> 00:18:04,520
it breaks off into those two pieces is

403
00:18:10,000 --> 00:18:07,090
used to heat water which then drives

404
00:18:13,000 --> 00:18:10,010
wheels and creates the power and energy

405
00:18:18,220 --> 00:18:13,010
okay so this is fission taking large

406
00:18:20,160 --> 00:18:18,230
atoms of you know 200 and 250 neutrons

407
00:18:22,300 --> 00:18:20,170
and protons breaking them apart okay

408
00:18:24,580 --> 00:18:22,310
that's not what we're talking about

409
00:18:27,550 --> 00:18:24,590
we're talking about nuclear fusion

410
00:18:30,130 --> 00:18:27,560
alright and nuclear fusion reactors do

411
00:18:31,930 --> 00:18:30,140
exist okay but they're still in the

412
00:18:33,010 --> 00:18:31,940
experimental stage and have been for

413
00:18:35,650 --> 00:18:33,020

several decades

414
00:18:38,020 --> 00:18:35,660
alright and the idea is you're fusing

415
00:18:40,360 --> 00:18:38,030
small things together so take hydrogen

416
00:18:42,190 --> 00:18:40,370
smash it together enough and then you

417
00:18:44,290 --> 00:18:42,200
create helium okay

418
00:18:47,440 --> 00:18:44,300
the simplest lightest elements making

419
00:18:50,050 --> 00:18:47,450
slightly slightly heavier light elements

420
00:18:52,060 --> 00:18:50,060
okay and this requires million-degree

421
00:18:53,650 --> 00:18:52,070
temperatures all right and when you

422
00:18:55,600 --> 00:18:53,660
create million-degree temperatures

423
00:18:57,670 --> 00:18:55,610
you're gonna create a huge pressure

424
00:18:59,830 --> 00:18:57,680
pushing out right okay

425
00:19:01,900 --> 00:18:59,840
so how do you keep all this plasma

426
00:19:05,500 --> 00:19:01,910
together all right well this what you're

427
00:19:10,600 --> 00:19:05,510
looking at right here is a tokamak okay

428
00:19:13,060 --> 00:19:10,610
this is a tokamak fusion reactor and it

429
00:19:13,870 --> 00:19:13,070
uses what's called magnetic confinement

430
00:19:15,730 --> 00:19:13,880
okay

431
00:19:19,210 --> 00:19:15,740
so you get these really strong magnetic

432
00:19:20,710 --> 00:19:19,220
fields to confine the plasma so that you

433
00:19:22,780 --> 00:19:20,720
can get it up to these really high

434
00:19:28,510 --> 00:19:22,790
temperatures a matter of fact of this

435
00:19:31,330 --> 00:19:28,520
one in some time in 2018 was the first

436
00:19:34,900 --> 00:19:31,340
one to reach the magic temperature of 15

437
00:19:37,150 --> 00:19:34,910
million degrees all right so they're

438
00:19:39,220 --> 00:19:37,160

making serious progress I mean last time

439
00:19:40,870 --> 00:19:39,230
I looked into fusion reactors they

440
00:19:42,580 --> 00:19:40,880
really hadn't barely gotten to the

441
00:19:45,400 --> 00:19:42,590
million degree temperature they're up to

442
00:19:47,640 --> 00:19:45,410
15 million here they may be even further

443
00:19:51,820 --> 00:19:47,650
because I'm not a pure expert in that

444
00:19:53,260 --> 00:19:51,830
and so the idea is really just make sure

445
00:19:55,510 --> 00:19:53,270
that you recognize that energy is

446
00:19:58,690 --> 00:19:55,520
generated by combining light atoms

447
00:20:00,160 --> 00:19:58,700
together it also is kind of

448
00:20:03,010 --> 00:20:00,170
pressing for those of us who grew up in

449
00:20:05,620 --> 00:20:03,020
the 80s that we are really a long way

450
00:20:08,710 --> 00:20:05,630
from the mr. fusion from the Back to the

451
00:20:10,510 --> 00:20:08,720
Future movies of course I kind of worry

452
00:20:13,090 --> 00:20:10,520
about this because if the temperature

453
00:20:15,250 --> 00:20:13,100
gauge of my car goes up to 15 million

454
00:20:17,830 --> 00:20:15,260
degrees okay I that's a serious

455
00:20:19,450 --> 00:20:17,840
overheating problem you might have all

456
00:20:22,930 --> 00:20:19,460
right so we're not gonna have our mr.

457
00:20:25,570 --> 00:20:22,940
fusion anytime soon but maybe by like

458
00:20:28,300 --> 00:20:25,580
2030 there's a company in England that

459
00:20:30,220 --> 00:20:28,310
predicts by around 2030 they might be

460
00:20:33,220 --> 00:20:30,230
able to make it commercially viable that

461
00:20:35,560 --> 00:20:33,230
fusion reaction I've been told that for

462
00:20:37,180 --> 00:20:35,570
many decades so I'm gonna take that with

463
00:20:39,100 --> 00:20:37,190

a grain of salt but hey cross our

464
00:20:41,980 --> 00:20:39,110
fingers because fusion would be a great

465
00:20:44,260 --> 00:20:41,990
way to produce so if we don't have

466
00:20:46,570 --> 00:20:44,270
fusion reactors that's a sustainable

467
00:20:49,030 --> 00:20:46,580
fusion reactors on earth where are we

468
00:20:53,110 --> 00:20:49,040
gonna go we're gonna go to the stars

469
00:20:56,140 --> 00:20:53,120
because our Sun is hot it's got a

470
00:20:59,140 --> 00:20:56,150
surface temperature of 6,000 Kelvin and

471
00:21:01,120 --> 00:20:59,150
it's very luminous it produces four

472
00:21:03,670 --> 00:21:01,130
times ten to the three herbs per second

473
00:21:05,860 --> 00:21:03,680
and most of you don't know what herbs

474
00:21:07,090 --> 00:21:05,870
per second means but you don't need to

475
00:21:08,980 --> 00:21:07,100
know you just need to know it's a really

476
00:21:11,860 --> 00:21:08,990
big number and I'm gonna use that later

477
00:21:14,230 --> 00:21:11,870
in my talk okay all right if you

478
00:21:17,260 --> 00:21:14,240
translate that luminosity into watts

479
00:21:19,180 --> 00:21:17,270
it's four times ten to the 26 watts

480
00:21:24,430 --> 00:21:19,190
all right you have used a 100 watt light

481
00:21:27,160 --> 00:21:24,440
bulb yeah this is more okay matter of

482
00:21:31,510 --> 00:21:27,170
fact it's so much more it's really more

483
00:21:33,040 --> 00:21:31,520
than the 1.21 jigowatts that that were

484
00:21:34,180 --> 00:21:33,050
used in the Back to the Future movie

485
00:21:36,040 --> 00:21:34,190
okay

486
00:21:38,050 --> 00:21:36,050
matter of fact Barney should reply to

487
00:21:41,820 --> 00:21:38,060
him and say well that's nothing because

488
00:21:45,280 --> 00:21:41,830

the Sun is 400 mega Giga gigawatts okay

489
00:21:47,950 --> 00:21:45,290
so really yes a Billy a million billion

490
00:21:50,140 --> 00:21:47,960
times larger than the gigawatts are

491
00:21:51,730 --> 00:21:50,150
actually he always said gigawatts in the

492
00:21:54,280 --> 00:21:51,740
movie and it always bothered me all

493
00:21:56,650 --> 00:21:54,290
right but you know sort of like gif and

494
00:22:00,820 --> 00:21:56,660
jiff right all right but and we always

495
00:22:05,020 --> 00:22:00,830
say gigawatts these days anyways so with

496
00:22:06,850 --> 00:22:05,030
that energy it's created in the core

497
00:22:09,940 --> 00:22:06,860
where the core temperature is that

498
00:22:12,130 --> 00:22:09,950
magical 15 million degrees Kelvin okay

499
00:22:13,930 --> 00:22:12,140
so that's what makes that tokamak

500
00:22:17,110 --> 00:22:13,940
react are so important that they reached

501
00:22:19,630 --> 00:22:17,120
the magical temperature that is the core

502
00:22:22,930 --> 00:22:19,640
of the Sun and at that temperature and

503
00:22:26,080 --> 00:22:22,940
of course the pressure in there you can

504
00:22:27,730 --> 00:22:26,090
create nuclear fusion okay so the

505
00:22:29,830 --> 00:22:27,740
nuclear fusion is happening in the core

506
00:22:32,590 --> 00:22:29,840
of the Sun and instead of magnetic

507
00:22:35,290 --> 00:22:32,600
fields to keep everything together this

508
00:22:37,470 --> 00:22:35,300
is gravitational confinement so it's the

509
00:22:39,790 --> 00:22:37,480
mass of all the outer lying layers

510
00:22:42,220 --> 00:22:39,800
pressing in that provides the pressure

511
00:22:44,200 --> 00:22:42,230
to keep this all together so you can get

512
00:22:46,450 --> 00:22:44,210
the density and the temperature and the

513
00:22:49,840 --> 00:22:46,460

pressure necessary for nuclear fusion

514
00:22:51,310 --> 00:22:49,850
all right so we're gonna go into a

515
00:22:53,710 --> 00:22:51,320
little bit of detail so that you

516
00:22:58,270 --> 00:22:53,720
understand the process it's not quite as

517
00:23:00,100 --> 00:22:58,280
simple as you might think okay so we're

518
00:23:02,170 --> 00:23:00,110
gonna head take a couple protons up here

519
00:23:05,050 --> 00:23:02,180
right we're gonna smash them together

520
00:23:07,420 --> 00:23:05,060
and create heavy hydrogen which is also

521
00:23:09,370 --> 00:23:07,430
called deuterium and that creates some

522
00:23:11,470 --> 00:23:09,380
energy and a beta particle and a

523
00:23:13,630 --> 00:23:11,480
neutrino going off okay then you add

524
00:23:16,960 --> 00:23:13,640
another proton coming in to hit this

525
00:23:19,540 --> 00:23:16,970
deuterium and you can make light helium

526
00:23:21,850 --> 00:23:19,550
helium three and that gives off a photon

527
00:23:22,900 --> 00:23:21,860
and then you take two of these helium

528
00:23:25,450 --> 00:23:22,910
threes together

529
00:23:27,190 --> 00:23:25,460
smash them you get a helium four which

530
00:23:30,040 --> 00:23:27,200
is your stable nucleus of helium and

531
00:23:32,740 --> 00:23:30,050
then you get two protons coming out so

532
00:23:35,560 --> 00:23:32,750
the total thing is is you get like six

533
00:23:38,140 --> 00:23:35,570
protons going in and then one helium and

534
00:23:40,110 --> 00:23:38,150
two protons coming out all right which

535
00:23:43,240 --> 00:23:40,120
if you just get rid of the extra protons

536
00:23:44,830 --> 00:23:43,250
the simple way to remember it down here

537
00:23:47,530 --> 00:23:44,840
which we usually think of is for

538
00:23:51,940 --> 00:23:47,540

hydrogen go to one helium plus some

539
00:23:54,280 --> 00:23:51,950
energy now what is where does that

540
00:23:55,360 --> 00:23:54,290
energy come from okay and it's really

541
00:23:58,720 --> 00:23:55,370
kind of cool when you think about

542
00:24:02,020 --> 00:23:58,730
hydrogen fusion to look at exactly how

543
00:24:04,690 --> 00:24:02,030
it comes about so you've got the mass of

544
00:24:07,000 --> 00:24:04,700
four hydrogen atoms together is six

545
00:24:10,210 --> 00:24:07,010
point six nine times 10 to the 24th

546
00:24:13,180 --> 00:24:10,220
grams okay the mass of the helium atom

547
00:24:16,300 --> 00:24:13,190
is six point six four times ten to the

548
00:24:18,430 --> 00:24:16,310
minus 24 grams and the difference is

549
00:24:21,250 --> 00:24:18,440
five times ten to the minus twenty six

550
00:24:23,770 --> 00:24:21,260
grams okay now we all know a gram is a

551
00:24:24,970 --> 00:24:23,780
pretty pathetic amount of an of weight

552
00:24:27,640 --> 00:24:24,980
right

553
00:24:31,030 --> 00:24:27,650
of mass and ten to the minus twenty

554
00:24:35,650 --> 00:24:31,040
sixth of a gram is really pathetic than

555
00:24:41,290 --> 00:24:35,660
pathetic right but you're going to turn

556
00:24:43,210 --> 00:24:41,300
that missing mass into energy and you

557
00:24:45,670 --> 00:24:43,220
can do that via the famous equation e

558
00:24:49,150 --> 00:24:45,680
equals MC squared did you ever think

559
00:24:51,700 --> 00:24:49,160
you'd actually have reason to use equals

560
00:24:53,140 --> 00:24:51,710
MC squared most people is like oh yeah

561
00:24:55,990 --> 00:24:53,150
it's a famous equation I have no idea

562
00:24:58,480 --> 00:24:56,000
what it means but yeah but yes this is

563
00:25:02,950 --> 00:24:58,490

where it comes in energy equals mass

564
00:25:06,370 --> 00:25:02,960
times the speed of light squared okay so

565
00:25:08,230 --> 00:25:06,380
that missing mass becomes energy and it

566
00:25:11,020 --> 00:25:08,240
produces five times ten to the minus

567
00:25:14,170 --> 00:25:11,030
five herbs and as I said you probably

568
00:25:16,900 --> 00:25:14,180
don't know what an ERG is I have there a

569
00:25:19,450 --> 00:25:16,910
fun description of what our Giz it's the

570
00:25:25,480 --> 00:25:19,460
amount of energy a flea needs to use to

571
00:25:28,030 --> 00:25:25,490
do a push up so a flea doing a push up

572
00:25:30,880 --> 00:25:28,040
but this is one one hundred thousandth

573
00:25:34,720 --> 00:25:30,890
of a flea doing a push up okay so it's a

574
00:25:36,490 --> 00:25:34,730
pathetic amount of energy okay but when

575
00:25:38,830 --> 00:25:36,500
you do the math that's the pathetic

576
00:25:41,650 --> 00:25:38,840
amount of energy from one nuclear

577
00:25:44,380 --> 00:25:41,660
reaction okay one nuclear fusion

578
00:25:48,250 --> 00:25:44,390
reaction how many of those do you need

579
00:25:52,120 --> 00:25:48,260
to produce four times 10 to the 33 herbs

580
00:25:55,060 --> 00:25:52,130
every second okay you can do the math

581
00:25:58,780 --> 00:25:55,070
there's the math for you the result is

582
00:26:00,940 --> 00:25:58,790
really kind of cool okay so the Sun is

583
00:26:03,880 --> 00:26:00,950
powered by the conversion of mass to

584
00:26:10,510 --> 00:26:03,890
energy at a rate of about five million

585
00:26:13,330 --> 00:26:10,520
tons every second think about that five

586
00:26:17,080 --> 00:26:13,340
million tons of mass is converted to

587
00:26:19,010 --> 00:26:17,090
energy every single second for our Sun

588
00:26:21,170 --> 00:26:19,020

to shine

589
00:26:23,720 --> 00:26:21,180
and the Sun is just one of a billion

590
00:26:26,960 --> 00:26:23,730
stars inside maybe a hundred billion

591
00:26:30,920 --> 00:26:26,970
stars in our galaxy that's an awful lot

592
00:26:34,520 --> 00:26:30,930
of mass converting to energy to power

593
00:26:39,740 --> 00:26:34,530
the stars in the universe that's kind of

594
00:26:42,770 --> 00:26:39,750
cool all right but stars will eat up

595
00:26:44,570 --> 00:26:42,780
their mass in the core if you're burning

596
00:26:48,080 --> 00:26:44,580
it at five million now first of all a

597
00:26:51,920 --> 00:26:48,090
star as many many many more larger than

598
00:26:54,350 --> 00:26:51,930
five million tons okay but after a few

599
00:26:58,070 --> 00:26:54,360
billion years you can start to make a

600
00:27:01,760 --> 00:26:58,080
dent in there okay so stars like the Sun

601
00:27:05,360 --> 00:27:01,770
they will end not with a bang but a

602
00:27:08,690 --> 00:27:05,370
whimper okay so in the core you've got

603
00:27:11,960 --> 00:27:08,700
hydrogen converting to helium okay and

604
00:27:14,420 --> 00:27:11,970
this is the main sequence lifetime of a

605
00:27:16,460 --> 00:27:14,430
star it's the stable one our Sun will be

606
00:27:19,490 --> 00:27:16,470
in this for about ten billion years nine

607
00:27:21,110 --> 00:27:19,500
ten billion years okay this is when

608
00:27:24,230 --> 00:27:21,120
stars are at their most stable hydrogen

609
00:27:26,750 --> 00:27:24,240
converting to helium but eventually

610
00:27:29,830 --> 00:27:26,760
they're going to build up a whole bunch

611
00:27:33,050 --> 00:27:29,840
of helium in their core that will not

612
00:27:35,540 --> 00:27:33,060
undergo fusion at you know ten million

613
00:27:38,230 --> 00:27:35,550

degrees or 15 million degrees it has to

614
00:27:40,700 --> 00:27:38,240
have a much higher temperature so the

615
00:27:42,980 --> 00:27:40,710
hydrogen to helium moves out into what

616
00:27:45,230 --> 00:27:42,990
we call shell fusion okay there's a

617
00:27:48,020 --> 00:27:45,240
shell around an inert core of hydrogen

618
00:27:53,980 --> 00:27:48,030
of helium and that shell is converting

619
00:27:55,970 --> 00:27:53,990
hydrogen to helium okay and then the

620
00:27:59,000 --> 00:27:55,980
when you heat up to about a hundred

621
00:28:02,540 --> 00:27:59,010
million degrees in the core okay they

622
00:28:03,680 --> 00:28:02,550
contract in heats up then helium can use

623
00:28:07,010 --> 00:28:03,690
what's called the triple alpha process

624
00:28:08,810 --> 00:28:07,020
to become carbon so three helium's

625
00:28:11,090 --> 00:28:08,820
together you get one carbon out four

626
00:28:13,750 --> 00:28:11,100
plus four plus four is 12 right to get

627
00:28:16,700 --> 00:28:13,760
the helium to the carbon alright and

628
00:28:18,440 --> 00:28:16,710
that's when the star hits 100 million

629
00:28:21,380 --> 00:28:18,450
degrees and this produces another

630
00:28:24,380 --> 00:28:21,390
semi-stable phase of the star is called

631
00:28:26,780 --> 00:28:24,390
the red giant phase and red giant means

632
00:28:30,050 --> 00:28:26,790
that because of this excess energy and

633
00:28:32,630 --> 00:28:30,060
the heat provided by it we go from the

634
00:28:36,380 --> 00:28:32,640
Sun being this size to the

635
00:28:40,460 --> 00:28:36,390
giant being that size the Sun will bloat

636
00:28:43,130 --> 00:28:40,470
by a factor of 100 okay we'll go from

637
00:28:46,570 --> 00:28:43,140
you know yellow what's yellow star to a

638
00:28:51,170 --> 00:28:46,580

red star that is 100 times larger

639
00:28:53,420 --> 00:28:51,180
Mercury and Venus will be swallowed by

640
00:28:55,480 --> 00:28:53,430
the Sun when this happens this will

641
00:28:58,970 --> 00:28:55,490
happen let's see the Suns about 5

642
00:29:00,710 --> 00:28:58,980
billion years old somewhere between 10

643
00:29:03,440 --> 00:29:00,720
and 12 billion years is when this will

644
00:29:04,790 --> 00:29:03,450
happen so we got 5 to 7 billion years

645
00:29:07,070 --> 00:29:04,800
left ok

646
00:29:09,890 --> 00:29:07,080
now actually the Sun is heating up

647
00:29:11,840 --> 00:29:09,900
during that process and Earth will only

648
00:29:14,660 --> 00:29:11,850
be livable for another 3 billion years

649
00:29:17,870 --> 00:29:14,670
or so ok so you know it's not quite as

650
00:29:20,720 --> 00:29:17,880
long as long as that but the red giant

651
00:29:24,650 --> 00:29:20,730
phase will kick in in five to seven

652
00:29:28,670 --> 00:29:24,660
billion years and then after the red

653
00:29:32,150 --> 00:29:28,680
giant phase you end up with the helium

654
00:29:34,280 --> 00:29:32,160
shell fusion ok you build up carbon in

655
00:29:36,290 --> 00:29:34,290
the core all right the car it's not hot

656
00:29:39,650 --> 00:29:36,300
enough to fuse carbon into into the next

657
00:29:41,810 --> 00:29:39,660
element and you get the helium shell

658
00:29:44,140 --> 00:29:41,820
fusion helium turning to carbon hydrogen

659
00:29:47,990 --> 00:29:44,150
eternity healing you get these shells

660
00:29:50,570 --> 00:29:48,000
that's as far as our Sun will go that's

661
00:29:52,850 --> 00:29:50,580
as far as a medium mass star will go

662
00:29:55,700 --> 00:29:52,860
they do not have enough gravitational

663
00:29:58,010 --> 00:29:55,710

pressure to heat things up to go beyond

664
00:30:00,410 --> 00:29:58,020
100 million degrees into the next stage

665
00:30:02,120 --> 00:30:00,420
where you get carbon fusion so they'll

666
00:30:04,370 --> 00:30:02,130
build up carbon and build up carbon and

667
00:30:07,040 --> 00:30:04,380
billet carbon and they won't get past it

668
00:30:08,480 --> 00:30:07,050
at that time you and suffer what's

669
00:30:10,760 --> 00:30:08,490
called a helium catastrophe when

670
00:30:12,410 --> 00:30:10,770
everything's trying to trying to burn

671
00:30:15,260 --> 00:30:12,420
trying to burn not really not not not

672
00:30:18,290 --> 00:30:15,270
not making the fusion and it blows off

673
00:30:23,450 --> 00:30:18,300
its outer layers and this is what we

674
00:30:26,330 --> 00:30:23,460
call a planetary nebula so this is in

675
00:30:30,590 --> 00:30:26,340
the center right here that's the core of

676
00:30:32,930 --> 00:30:30,600
the star and out here is the material of

677
00:30:35,870 --> 00:30:32,940
the atmosphere of the star blowing off

678
00:30:38,000 --> 00:30:35,880
into outer space why is it called a

679
00:30:39,800 --> 00:30:38,010
planetary nebula because astronomers

680
00:30:41,270 --> 00:30:39,810
were ignorant when they first called it

681
00:30:42,950 --> 00:30:41,280
this ok they didn't know what it was

682
00:30:44,930 --> 00:30:42,960
they said it looks kind of like a planet

683
00:30:46,790 --> 00:30:44,940
right and you can sort of imagine them

684
00:30:49,460 --> 00:30:46,800
thinking this looks like a planet

685
00:30:52,300 --> 00:30:49,470
but this is actually the death of a

686
00:30:55,370 --> 00:30:52,310
medium mass star and they can be

687
00:30:58,130 --> 00:30:55,380
stunningly beautiful okay sometimes we

688
00:31:00,890 --> 00:30:58,140

call them cosmic butterflies here is one

689
00:31:02,740 --> 00:31:00,900
that's got a dust disk around the star

690
00:31:05,990 --> 00:31:02,750
and so it goes off in two directions

691
00:31:07,700 --> 00:31:06,000
this one's called the bug nebula but we

692
00:31:09,590 --> 00:31:07,710
did a press release on it where we said

693
00:31:10,730 --> 00:31:09,600
it looked like a butterfly and so

694
00:31:13,970 --> 00:31:10,740
everybody's calling it the butterfly

695
00:31:16,850 --> 00:31:13,980
nebula now we we renamed this object by

696
00:31:18,880 --> 00:31:16,860
a press release unintentional but hey

697
00:31:21,530 --> 00:31:18,890
that's the power of Hubble for you okay

698
00:31:23,570 --> 00:31:21,540
and here is another one called the ring

699
00:31:26,510 --> 00:31:23,580
nebula okay and you can see it's just

700
00:31:29,330 --> 00:31:26,520
these wonderful beautiful things of

701
00:31:31,580 --> 00:31:29,340
material being thrown off and then right

702
00:31:34,040 --> 00:31:31,590
there at the core alright right there in

703
00:31:37,550 --> 00:31:34,050
the core is that stellar remnant the

704
00:31:39,650 --> 00:31:37,560
remains of the star and that is called a

705
00:31:42,230 --> 00:31:39,660
white dwarf it's the remains of this

706
00:31:45,080 --> 00:31:42,240
medium mass star it's basically that

707
00:31:47,600 --> 00:31:45,090
carbon core okay so in the process that

708
00:31:49,220 --> 00:31:47,610
is trying to you know go up to carbon

709
00:31:51,080 --> 00:31:49,230
fusion and does not quite getting there

710
00:31:53,870 --> 00:31:51,090
it burns everything into carbon and

711
00:31:56,480 --> 00:31:53,880
blows off the outer stuff around it so

712
00:32:00,260 --> 00:31:56,490
it is no longer producing energy it's a

713
00:32:04,040 --> 00:32:00,270

really hot carbon core it's massively

714
00:32:06,440 --> 00:32:04,050
hot it's dense and it slowly cools and

715
00:32:09,920 --> 00:32:06,450
this is a white dwarf this right here

716
00:32:12,110 --> 00:32:09,930
that's the star Sirius that Sirius a it

717
00:32:14,570 --> 00:32:12,120
has a companion star Sirius B that is a

718
00:32:18,830 --> 00:32:14,580
white dwarf so this is a main-sequence

719
00:32:20,510 --> 00:32:18,840
star this is a white dwarf okay and the

720
00:32:24,200 --> 00:32:20,520
easiest way to remember what a white

721
00:32:27,080 --> 00:32:24,210
dwarf is and it's a giant glowing piece

722
00:32:30,290 --> 00:32:27,090
of carbon so it's a cosmic charcoal

723
00:32:32,690 --> 00:32:30,300
briquette all right and you could do an

724
00:32:34,670 --> 00:32:32,700
awful lot of marshmallows off of a white

725
00:32:38,120 --> 00:32:34,680
dwarf star because it will slowly cool

726
00:32:40,760 --> 00:32:38,130
for billions tens of billions of years

727
00:32:42,080 --> 00:32:40,770
okay but these are not the subject of

728
00:32:43,460 --> 00:32:42,090
what I we're talking about tonight well

729
00:32:46,520 --> 00:32:43,470
we're really talking about tonight are

730
00:32:49,760 --> 00:32:46,530
the things that go kaboom in the night

731
00:32:51,560 --> 00:32:49,770
and so how do we get to that kaboom well

732
00:32:54,860 --> 00:32:51,570
we left off here where we've got the

733
00:32:57,440 --> 00:32:54,870
carbon in the core and helium shell

734
00:32:59,190 --> 00:32:57,450
burning shell fusion and hydrogen shell

735
00:33:01,320 --> 00:32:59,200
fusion well if

736
00:33:03,990 --> 00:33:01,330
you will have more mass you can compress

737
00:33:06,600 --> 00:33:04,000
that and then the carbon goes to oxygen

738
00:33:08,940 --> 00:33:06,610

and you can do this over and over and

739
00:33:11,759 --> 00:33:08,950
over again with these really massive

740
00:33:15,120 --> 00:33:11,769
stars so you have carbon going to oxygen

741
00:33:18,629 --> 00:33:15,130
oxygen going to neon neon to magnesium

742
00:33:21,750 --> 00:33:18,639
magnesium to silicon silicon tired and

743
00:33:24,810 --> 00:33:21,760
we get an iron core okay and this causes

744
00:33:28,649 --> 00:33:24,820
the star to swell-up even further to

745
00:33:30,659 --> 00:33:28,659
become a super giant star and the

746
00:33:33,659 --> 00:33:30,669
supergiant star we all love best is

747
00:33:36,649 --> 00:33:33,669
baitul juice this isn't a picture of it

748
00:33:39,779 --> 00:33:36,659
a picture that resolves the pixels of

749
00:33:42,299 --> 00:33:39,789
baitul juice and you can see the size of

750
00:33:45,570 --> 00:33:42,309
the star here right all right the size

751
00:33:48,389 --> 00:33:45,580
of the star here this in comparison is

752
00:33:50,340 --> 00:33:48,399
the size of Earth's orbit and this is

753
00:33:53,580 --> 00:33:50,350
the size of Jupiter's orbit

754
00:33:58,409 --> 00:33:53,590
so if baitul juice were in the place of

755
00:34:02,009 --> 00:33:58,419
the Sun Mercury Venus Earth Mars the

756
00:34:04,710 --> 00:34:02,019
asteroid belt and Jupiter would all be

757
00:34:07,560 --> 00:34:04,720
orbiting inside the star they'd be all

758
00:34:09,780 --> 00:34:07,570
be swallowed by the star okay that's how

759
00:34:12,270 --> 00:34:09,790
big a supergiant star is up to a

760
00:34:15,800 --> 00:34:12,280
thousand or a couple thousand times the

761
00:34:19,050 --> 00:34:15,810
size of our Sun so we get these

762
00:34:23,280 --> 00:34:19,060
supergiant stars but there's a problem

763
00:34:27,240 --> 00:34:23,290

with these stars that you cannot fuse

764
00:34:28,589 --> 00:34:27,250
iron to a heavier element and get out

765
00:34:31,169 --> 00:34:28,599
energy okay

766
00:34:32,250 --> 00:34:31,179
that's exothermic you take things put

767
00:34:36,149 --> 00:34:32,260
them together you get energy out

768
00:34:39,300 --> 00:34:36,159
exothermic combining iron to make

769
00:34:43,109 --> 00:34:39,310
heavier elements is endothermic it eats

770
00:34:45,540 --> 00:34:43,119
up energy so you cannot go beyond here

771
00:34:47,399 --> 00:34:45,550
and you build up iron and you build up

772
00:34:49,950 --> 00:34:47,409
iron and you build up iron in the core

773
00:34:52,260 --> 00:34:49,960
until you reach the Chandrasekhar mass

774
00:34:55,530 --> 00:34:52,270
of iron and what time the nuclear

775
00:34:58,980 --> 00:34:55,540
structure collapses it breaks down on

776
00:35:01,230 --> 00:34:58,990
the nuclear scale electrons combine with

777
00:35:04,410 --> 00:35:01,240
protons to form neutrons releases a

778
00:35:05,700 --> 00:35:04,420
flood of neutrinos and the star blows

779
00:35:10,480 --> 00:35:05,710
itself apart

780
00:35:13,900 --> 00:35:10,490
okay this is the kaboom

781
00:35:17,800 --> 00:35:13,910
all right the star blows itself apart in

782
00:35:20,890 --> 00:35:17,810
a supernova explosion it releases 10 to

783
00:35:22,990 --> 00:35:20,900
the 51 herbs all right we talked about

784
00:35:26,050 --> 00:35:23,000
the Sun producing 10 to the 33 herbs

785
00:35:29,080 --> 00:35:26,060
every second if you integrate that over

786
00:35:32,920 --> 00:35:29,090
the entire lifetime of the Sun you

787
00:35:35,800 --> 00:35:32,930
almost get 10 to the 51 in a millisecond

788
00:35:39,120 --> 00:35:35,810

as much energy as the Sun will ever

789
00:35:43,210 --> 00:35:39,130
produce is released in an explosion

790
00:35:45,730 --> 00:35:43,220
that's a serious explosion okay

791
00:35:48,670 --> 00:35:45,740
they are cosmic beacons here we have a

792
00:35:50,770 --> 00:35:48,680
picture of a galaxy this galaxy over

793
00:35:53,170 --> 00:35:50,780
here is you know a hundred million light

794
00:35:55,000 --> 00:35:53,180
years away but what can we see we can

795
00:35:56,920 --> 00:35:55,010
see what looks like a single star and

796
00:35:59,680 --> 00:35:56,930
normally we'd say oh that's a star in

797
00:36:04,120 --> 00:35:59,690
our own galaxy but that's not that's a

798
00:36:06,880 --> 00:36:04,130
supernova explosion in that galaxy 10 to

799
00:36:11,200 --> 00:36:06,890
51 herbs is as bright as a billion stars

800
00:36:15,010 --> 00:36:11,210
so we can see the supernovae across

801
00:36:18,160 --> 00:36:15,020
billions of light year of space and what

802
00:36:20,859 --> 00:36:18,170
they do is a sort of form of galactic

803
00:36:23,650 --> 00:36:20,869
recycling because the gas collapses to

804
00:36:26,950 --> 00:36:23,660
form stars and the explosions blow that

805
00:36:30,030 --> 00:36:26,960
stass right back out into space but it's

806
00:36:33,190 --> 00:36:30,040
not the same gas because it has been

807
00:36:36,099 --> 00:36:33,200
enriched all those elements that were

808
00:36:38,290 --> 00:36:36,109
formed in the supernova and more that

809
00:36:41,260 --> 00:36:38,300
were formed during the explode during

810
00:36:43,330 --> 00:36:41,270
the explosion so as the main sequence

811
00:36:45,400 --> 00:36:43,340
forms all these elements in the core and

812
00:36:47,020 --> 00:36:45,410
then the supernova blows them out and

813
00:36:49,000 --> 00:36:47,030

actually creates because you've got a

814
00:36:50,680 --> 00:36:49,010
lot of extra energy during the supernova

815
00:36:52,420 --> 00:36:50,690
you can actually use those endothermic

816
00:36:55,660 --> 00:36:52,430
reactions to make larger and larger

817
00:36:58,960 --> 00:36:55,670
elements you blow them out into space so

818
00:37:00,970 --> 00:36:58,970
where are these elements come from this

819
00:37:03,700 --> 00:37:00,980
is a cool chart that shows you the

820
00:37:05,680 --> 00:37:03,710
cosmological source of the astronomical

821
00:37:07,570 --> 00:37:05,690
sources of the elements in the periodic

822
00:37:10,480 --> 00:37:07,580
table and what we're gonna pay attention

823
00:37:12,640 --> 00:37:10,490
to is down here in the lower right the

824
00:37:14,590 --> 00:37:12,650
exploding massive stars and you can also

825
00:37:16,840 --> 00:37:14,600
explode white dwarfs these are your

826
00:37:21,070 --> 00:37:16,850
supernovae your green and your light

827
00:37:23,830 --> 00:37:21,080
blue right and so you can see everyone

828
00:37:26,740 --> 00:37:23,840
take a deep breath you

829
00:37:29,820 --> 00:37:26,750
in oxygen where did that oxygen come

830
00:37:32,290 --> 00:37:29,830
from it did not come from the Big Bang

831
00:37:35,380 --> 00:37:32,300
hydrogen and helium only came from the

832
00:37:39,760 --> 00:37:35,390
Big Bang that oxygen you just broke

833
00:37:42,640 --> 00:37:39,770
breathed in came from a supernova if you

834
00:37:44,950 --> 00:37:42,650
look over here at oxygen right right up

835
00:37:49,060 --> 00:37:44,960
here it's green it comes from the

836
00:37:51,910 --> 00:37:49,070
explosion of massive stars Wow

837
00:37:53,650 --> 00:37:51,920
kind of cool all right all right you can

838
00:37:54,550 --> 00:37:53,660

do more than that you like to put salt

839
00:37:57,030 --> 00:37:54,560
on things

840
00:37:59,890 --> 00:37:57,040
well here's your sodium over here right

841
00:38:02,140 --> 00:37:59,900
and here's your chlorine over here

842
00:38:03,360 --> 00:38:02,150
sodium chloride is salt where did it

843
00:38:06,190 --> 00:38:03,370
come from

844
00:38:07,900 --> 00:38:06,200
supernova explosions okay when you were

845
00:38:10,030 --> 00:38:07,910
watching the Super Bowl eatin those

846
00:38:12,880 --> 00:38:10,040
salty snacks you didn't realize you were

847
00:38:17,020 --> 00:38:12,890
eating supernova dust at that time okay

848
00:38:19,540 --> 00:38:17,030
all right so so many of the elements the

849
00:38:24,220 --> 00:38:19,550
calcium in our teeth the iron in our

850
00:38:27,280 --> 00:38:24,230
blood come from supernovae okay our

851
00:38:30,880 --> 00:38:27,290
connection is not to the stars but

852
00:38:34,450 --> 00:38:30,890
really that we come from the stars which

853
00:38:36,220 --> 00:38:34,460
is kind of cool all right but again

854
00:38:37,360 --> 00:38:36,230
that's not the story that we're trying

855
00:38:39,940 --> 00:38:37,370
to tell here tonight we're gonna trying

856
00:38:42,190 --> 00:38:39,950
to get beyond that um let's talk about

857
00:38:44,770 --> 00:38:42,200
the remnants what's left over after

858
00:38:47,770 --> 00:38:44,780
these supernova explosions in the core

859
00:38:51,220 --> 00:38:47,780
when you have a high mass star 8 to

860
00:38:53,110 --> 00:38:51,230
about 15 solar masses you end up forming

861
00:38:54,640 --> 00:38:53,120
a neutron star at the core remember I

862
00:38:57,190 --> 00:38:54,650
talked about the protons and the

863
00:38:58,360 --> 00:38:57,200

electrons combining to form neutrons all

864
00:39:00,010 --> 00:38:58,370
right and that's what happens when the

865
00:39:02,110 --> 00:39:00,020
nuclear structure collapses

866
00:39:04,780 --> 00:39:02,120
well you build up this huge ball of

867
00:39:07,690 --> 00:39:04,790
neutrons all right and for certain and

868
00:39:10,360 --> 00:39:07,700
for her not to massive stars you create

869
00:39:13,810 --> 00:39:10,370
this giant core that is basically a ball

870
00:39:18,190 --> 00:39:13,820
of neutrons okay neutrons packed at

871
00:39:21,850 --> 00:39:18,200
atomic density so this is a star a mass

872
00:39:24,760 --> 00:39:21,860
of material at basically the saw at the

873
00:39:27,210 --> 00:39:24,770
density of an atomic nucleus do you know

874
00:39:30,310 --> 00:39:27,220
how to get the density of a neutron star

875
00:39:33,340 --> 00:39:30,320
you start with a herd of 50 million

876
00:39:37,360 --> 00:39:33,350
elephants you take all those 50 million

877
00:39:39,250 --> 00:39:37,370
elephants and pack them into a thimble

878
00:39:41,740 --> 00:39:39,260
50 million elephants in the thimble

879
00:39:42,940 --> 00:39:41,750
that's the density of a neutron star

880
00:39:45,040 --> 00:39:42,950
okay

881
00:39:47,200 --> 00:39:45,050
the other thing because you basically

882
00:39:49,960 --> 00:39:47,210
you got the mass of a Sun in a basically

883
00:39:52,600 --> 00:39:49,970
a ten kilometer radius all right and

884
00:39:56,290 --> 00:39:52,610
when you collapse things down they tend

885
00:39:59,020 --> 00:39:56,300
to spin up alright and neutron stars can

886
00:40:00,850 --> 00:39:59,030
create what are called pulsars so this

887
00:40:02,410 --> 00:40:00,860
is a diagram over here on the right this

888
00:40:04,150 --> 00:40:02,420

diagram is of the Pulsar

889
00:40:07,600 --> 00:40:04,160
there's the neutron star in the core

890
00:40:10,270 --> 00:40:07,610
here are the magnetic fields are going

891
00:40:12,820 --> 00:40:10,280
around it and the magnetic fields can

892
00:40:17,230 --> 00:40:12,830
fling off emission basically electrons

893
00:40:19,930 --> 00:40:17,240
and such along a beam and so if you've

894
00:40:21,970 --> 00:40:19,940
got this thing spinning and it goes like

895
00:40:23,500 --> 00:40:21,980
you can see that it's not on axis so

896
00:40:25,690 --> 00:40:23,510
it's gonna spin like this right and

897
00:40:27,460 --> 00:40:25,700
you're gonna see a flash of light and

898
00:40:29,770 --> 00:40:27,470
then it comes back here with a flash of

899
00:40:31,870 --> 00:40:29,780
light and a flash of light and a flash

900
00:40:32,860 --> 00:40:31,880
of light every time it spins you'll get

901
00:40:35,190 --> 00:40:32,870
a flash of light

902
00:40:37,810 --> 00:40:35,200
okay these are cosmic lighthouses

903
00:40:40,540 --> 00:40:37,820
alright and they called pulsars because

904
00:40:44,830 --> 00:40:40,550
we see this pulsed emission all right

905
00:40:47,830 --> 00:40:44,840
they can spin 30 times a second a

906
00:40:50,020 --> 00:40:47,840
hundred times a second sometimes you

907
00:40:52,030 --> 00:40:50,030
know once every three seconds but you've

908
00:40:54,940 --> 00:40:52,040
got these things that are ten kilometers

909
00:40:56,830 --> 00:40:54,950
across spinning at these incredible

910
00:40:59,260 --> 00:40:56,840
rates alright and we've actually watched

911
00:41:01,420 --> 00:40:59,270
them slowed down over the years this is

912
00:41:04,870 --> 00:41:01,430
important it will come back later in the

913
00:41:08,140 --> 00:41:04,880

talk if you have a really high master

914
00:41:11,260 --> 00:41:08,150
star you collapse through the neutron

915
00:41:17,110 --> 00:41:11,270
star phase and you go into becoming a

916
00:41:20,500 --> 00:41:17,120
black hole this is the ultimate density

917
00:41:21,820 --> 00:41:20,510
that we've got okay it's black what does

918
00:41:25,300 --> 00:41:21,830
that really mean it means that there's

919
00:41:27,610 --> 00:41:25,310
no emission from it okay the escape

920
00:41:30,580 --> 00:41:27,620
velocity from the Schwarzschild radius

921
00:41:34,000 --> 00:41:30,590
of a black hole is equal to the speed of

922
00:41:37,270 --> 00:41:34,010
light so light that tries to leave that

923
00:41:40,120 --> 00:41:37,280
black hole comes back onto it okay a

924
00:41:42,520 --> 00:41:40,130
light cannot escape from inside the

925
00:41:47,530 --> 00:41:42,530
Schwarzschild radius okay that's why it

926
00:41:50,110 --> 00:41:47,540
is black okay and that means that the

927
00:41:51,130 --> 00:41:50,120
black hole itself is not directly

928
00:41:52,509 --> 00:41:51,140
observable

929
00:41:54,849 --> 00:41:52,519
because what are you going to observe

930
00:41:56,039 --> 00:41:54,859
there's no emission coming from it now

931
00:42:00,130 --> 00:41:56,049
yes there could be Hawking radiation

932
00:42:02,229 --> 00:42:00,140
that's another talk okay so we have to

933
00:42:05,799 --> 00:42:02,239
do in direct observation all right and

934
00:42:08,019 --> 00:42:05,809
the most the the most common way we see

935
00:42:10,660 --> 00:42:08,029
black holes is by the x-ray binaries so

936
00:42:14,019 --> 00:42:10,670
this is a diagram here of an x-ray

937
00:42:16,569 --> 00:42:14,029
binary this is a black hole in here and

938
00:42:19,269 --> 00:42:16,579

you have a star that's orbiting around

939
00:42:21,880 --> 00:42:19,279
it and the material being pulled off

940
00:42:26,019 --> 00:42:21,890
that star flowing into a disc around

941
00:42:27,849 --> 00:42:26,029
that around the black hole and then some

942
00:42:29,470 --> 00:42:27,859
of the material being thrown off some of

943
00:42:31,509 --> 00:42:29,480
the material goes into the black hole

944
00:42:34,450 --> 00:42:31,519
the magnetic fields again spinning

945
00:42:37,029 --> 00:42:34,460
around throw things off in jets alright

946
00:42:39,999 --> 00:42:37,039
so you can see the jet emission these

947
00:42:43,479 --> 00:42:40,009
are visible in x-rays alright and there

948
00:42:46,089 --> 00:42:43,489
were a tremendous number of x-ray dots

949
00:42:48,789 --> 00:42:46,099
out there x-ray stars until we figured

950
00:42:51,609 --> 00:42:48,799
out ok these must be black holes in

951
00:42:53,950 --> 00:42:51,619
x-ray binary systems they're also called

952
00:42:57,940 --> 00:42:53,960
cataclysmic binaries which I think is a

953
00:43:03,039 --> 00:42:57,950
cool name ok cataclysmic binaries whoops

954
00:43:05,170 --> 00:43:03,049
sorry there we go and so with the x-ray

955
00:43:07,960 --> 00:43:05,180
binaries you got accretion disk and jets

956
00:43:09,759 --> 00:43:07,970
that you can see on the other way to

957
00:43:11,370 --> 00:43:09,769
tell whether the black holes exist are

958
00:43:14,670 --> 00:43:11,380
their gravitational effects

959
00:43:17,289 --> 00:43:14,680
gravitational lensing or the effect on

960
00:43:20,079 --> 00:43:17,299
for supermassive black holes for stellar

961
00:43:21,880 --> 00:43:20,089
orbits around them etc so we cannot see

962
00:43:24,880 --> 00:43:21,890
these directly alright

963
00:43:27,609 --> 00:43:24,890

so now we get to the meat of the subject

964
00:43:31,589 --> 00:43:27,619
for tonight and it is live fast die

965
00:43:35,559 --> 00:43:31,599
young and leave a good-looking corpse

966
00:43:39,220 --> 00:43:35,569
because I didn't talk about the

967
00:43:41,920 --> 00:43:39,230
timescales of those fusion processes now

968
00:43:45,849 --> 00:43:41,930
if you naively think about it we got a

969
00:43:48,910 --> 00:43:45,859
one solar mass star and we've got a ten

970
00:43:52,059 --> 00:43:48,920
solar mass star this has ten times the

971
00:43:54,970 --> 00:43:52,069
amount of nuclear fuel for the processes

972
00:43:57,279 --> 00:43:54,980
going on so which one would you expect

973
00:43:59,200 --> 00:43:57,289
to live longer the one with more fuel

974
00:44:03,410 --> 00:43:59,210
right that's what you would normally

975
00:44:08,120 --> 00:44:03,420
think and you would be totally wrong

976
00:44:11,440 --> 00:44:08,130
because the more massive stars heat up

977
00:44:14,740 --> 00:44:11,450
to higher temperatures and therefore

978
00:44:20,630 --> 00:44:14,750
burn through their nuclear fuel at a

979
00:44:22,849 --> 00:44:20,640
much higher rate so that one solar mass

980
00:44:26,390 --> 00:44:22,859
star according to this chart you can say

981
00:44:29,480 --> 00:44:26,400
okay here one solar mass goes up to

982
00:44:31,910 --> 00:44:29,490
about 10 to the 10th years 10 billion

983
00:44:35,000 --> 00:44:31,920
years for its lifetime all right

984
00:44:39,950 --> 00:44:35,010
whereas that 10 solar mass star right

985
00:44:45,589 --> 00:44:39,960
here goes up to about 20 30 million

986
00:44:49,400 --> 00:44:45,599
years okay it has 10 times the nuclear

987
00:44:53,359 --> 00:44:49,410
fuel but it lives for less than 1% of

988
00:44:56,900 --> 00:44:53,369

the time whoa that's burning that's

989
00:44:58,880 --> 00:44:56,910
living fast and dying young okay

990
00:45:02,120 --> 00:44:58,890
and do they leave a good-looking corpse

991
00:45:05,720 --> 00:45:02,130
oh you betcha they carried some

992
00:45:08,870 --> 00:45:05,730
beautiful nebulae this is one of my

993
00:45:10,700 --> 00:45:08,880
favorites Cassiopeia a and this is

994
00:45:13,249 --> 00:45:10,710
observed in radio light with from the

995
00:45:15,680 --> 00:45:13,259
Very Large Array okay so you're seeing

996
00:45:19,190 --> 00:45:15,690
electrons spiraling around magnetic

997
00:45:21,289 --> 00:45:19,200
field lines emitting in the radio we can

998
00:45:23,180 --> 00:45:21,299
also see it doesn't look just good in

999
00:45:25,819 --> 00:45:23,190
the radio we can also see it in the

1000
00:45:28,339 --> 00:45:25,829
infrared from Spitzer you can see all

1001
00:45:30,559 --> 00:45:28,349
the dust and amendment night that that's

1002
00:45:33,049 --> 00:45:30,569
heated up in here we can see it in

1003
00:45:36,009 --> 00:45:33,059
Hubble invisible light where we can see

1004
00:45:38,210 --> 00:45:36,019
the fine filamentary structure of this

1005
00:45:41,349 --> 00:45:38,220
shell of material that has been blown

1006
00:45:44,660 --> 00:45:41,359
out into space but they look even better

1007
00:45:47,359 --> 00:45:44,670
in x-rays because you have such high

1008
00:45:49,430 --> 00:45:47,369
temperature gas you can see all the

1009
00:45:52,370 --> 00:45:49,440
material inside this bubble that's

1010
00:45:56,900 --> 00:45:52,380
expanding bubble of material that's been

1011
00:46:00,230 --> 00:45:56,910
blown out into space this this is the

1012
00:46:04,009 --> 00:46:00,240
guts of a star bursting across

1013
00:46:05,720 --> 00:46:04,019

interstellar space all right stars blow

1014
00:46:06,200 --> 00:46:05,730
their guts out right at the end of their

1015
00:46:08,809 --> 00:46:06,210
lives

1016
00:46:11,269 --> 00:46:08,819
okay the massive ones at least okay an

1017
00:46:14,990 --> 00:46:11,279
x-ray is the really cool place to see it

1018
00:46:17,059 --> 00:46:15,000
that is Cassiopeia a here's the x-rays

1019
00:46:19,339 --> 00:46:17,069
of Kepler's supernova remnant

1020
00:46:24,650 --> 00:46:19,349
that was observed by Johannes Kepler I

1021
00:46:27,499 --> 00:46:24,660
think 1604 I believe and then also his

1022
00:46:28,849 --> 00:46:27,509
predecessor Tycho Brahe he he also got a

1023
00:46:31,609 --> 00:46:28,859
supernova named after him

1024
00:46:33,859 --> 00:46:31,619
Tico's supernova remnant again in x-rays

1025
00:46:37,189 --> 00:46:33,869
from Chandra all right and you could see

1026
00:46:39,589 --> 00:46:37,199
these big giant bubbles a material

1027
00:46:42,709 --> 00:46:39,599
spewing out into the universe now Hubble

1028
00:46:44,390 --> 00:46:42,719
doesn't quite see these all the details

1029
00:46:46,819 --> 00:46:44,400
but it does have a couple couple pretty

1030
00:46:47,719 --> 00:46:46,829
ones in the Large Magellanic Cloud

1031
00:46:50,659 --> 00:46:47,729
here's one called

1032
00:46:52,640 --> 00:46:50,669
n 49 and you can see that delicate

1033
00:46:54,140 --> 00:46:52,650
filamentary structure okay because

1034
00:46:56,269 --> 00:46:54,150
Hubble's only observing things that

1035
00:46:58,969 --> 00:46:56,279
thousands of degrees not at millions of

1036
00:47:01,370 --> 00:46:58,979
degrees so it only gets the edges of it

1037
00:47:04,729 --> 00:47:01,380
and it really gets the edges of one that

1038
00:47:09,259 --> 00:47:04,739

we call the red bubble a supernova

1039
00:47:11,779 --> 00:47:09,269
remnant Oh 509 - 67.5 needs a better

1040
00:47:15,949 --> 00:47:11,789
name so we call it the red bubble from

1041
00:47:19,039 --> 00:47:15,959
Hubble okay so we look at these

1042
00:47:21,229 --> 00:47:19,049
supernova remnants okay and you can see

1043
00:47:23,449 --> 00:47:21,239
them all have these roughly spherical

1044
00:47:27,349 --> 00:47:23,459
structures well not all of them all of

1045
00:47:29,569 --> 00:47:27,359
them - but this is the blast wave driven

1046
00:47:32,269 --> 00:47:29,579
supernova remnant where you can imagine

1047
00:47:34,279 --> 00:47:32,279
if you have a point explosion and it

1048
00:47:37,459 --> 00:47:34,289
blows off in all directions you're going

1049
00:47:39,949 --> 00:47:37,469
to get this beautiful bubble okay and

1050
00:47:42,140 --> 00:47:39,959
it's just amazing sort of stuff of how

1051
00:47:44,630 --> 00:47:42,150
these stars and their lives and spew

1052
00:47:48,079 --> 00:47:44,640
their spew the elements out into

1053
00:47:51,669 --> 00:47:48,089
interstellar space but I'm here to tell

1054
00:47:57,309 --> 00:47:51,679
you a tale of two supernovae okay and

1055
00:47:58,429 --> 00:47:57,319
this is why I gave out supernova 1001

1056
00:48:01,999 --> 00:47:58,439
1006

1057
00:48:05,899 --> 00:48:02,009
so they lithograph we gave out tonight

1058
00:48:08,269 --> 00:48:05,909
supernova remnant 10 1006 this is the

1059
00:48:09,949 --> 00:48:08,279
visible light from Hubble now it's a

1060
00:48:12,409 --> 00:48:09,959
tiny little filament I talked about

1061
00:48:15,999 --> 00:48:12,419
seeing only the edges of it this is

1062
00:48:19,939 --> 00:48:16,009
actually a tiny piece of the edge of 10

1063
00:48:22,189 --> 00:48:19,949

1006 here is the x-ray view of it okay

1064
00:48:24,679 --> 00:48:22,199
and that yellow square up there is

1065
00:48:26,539 --> 00:48:24,689
approximately what Hubble sees in the

1066
00:48:31,070 --> 00:48:26,549
right-hand image okay so you can see

1067
00:48:35,030 --> 00:48:31,080
this giant bubble here and so we've got

1068
00:48:38,420 --> 00:48:35,040
ten that 1006 and we're gonna contrast

1069
00:48:41,330 --> 00:48:38,430
it I'm against another supernova Roman

1070
00:48:43,610 --> 00:48:41,340
both of these supernovae were observed

1071
00:48:46,160 --> 00:48:43,620
by chinese astronomers that's how we can

1072
00:48:48,320 --> 00:48:46,170
date when they happen okay there wasn't

1073
00:48:51,410 --> 00:48:48,330
European astronomers doing doing stuff

1074
00:48:53,630 --> 00:48:51,420
in the year 1006

1075
00:48:56,660 --> 00:48:53,640
but Chinese astronomers observe this and

1076
00:49:03,380 --> 00:48:56,670
we were able to date it and 50 years

1077
00:49:05,330 --> 00:49:03,390
later they saw supernova 1054 okay some

1078
00:49:11,320 --> 00:49:05,340
of you may recognize this as the Crab

1079
00:49:14,330 --> 00:49:11,330
Nebula okay and so we have 1006 we have

1080
00:49:18,340 --> 00:49:14,340
1054 two supernovae that were observe

1081
00:49:22,640 --> 00:49:18,350
that formed a thousand years ago but

1082
00:49:24,530 --> 00:49:22,650
they don't really look alike do they all

1083
00:49:26,990 --> 00:49:24,540
right this one has this beautiful bubble

1084
00:49:30,110 --> 00:49:27,000
shape and the Crab Nebula sort of has

1085
00:49:32,150 --> 00:49:30,120
like a football shape it's not really

1086
00:49:33,830 --> 00:49:32,160
spherical and this has got you know

1087
00:49:36,290 --> 00:49:33,840
filamentary structure around the edge

1088
00:49:38,810 --> 00:49:36,300

but nothing crossed the center and this

1089
00:49:39,940 --> 00:49:38,820
one has filamentary structure across the

1090
00:49:44,270 --> 00:49:39,950
whole thing

1091
00:49:45,830 --> 00:49:44,280
now that's kind of weird isn't that okay

1092
00:49:47,510 --> 00:49:45,840
well it's not that the filamentary

1093
00:49:49,790 --> 00:49:47,520
structure is weird okay because we do

1094
00:49:51,800 --> 00:49:49,800
see filamentary structure I mean this is

1095
00:49:54,260 --> 00:49:51,810
filamentous structure in Cassiopeia A

1096
00:49:56,030 --> 00:49:54,270
and you see that gorgeous structures

1097
00:49:58,280 --> 00:49:56,040
these are actually Raleigh Taylor

1098
00:50:00,050 --> 00:49:58,290
Raleigh Taylor instabilities okay when

1099
00:50:01,610 --> 00:50:00,060
you get the pressure differential and

1100
00:50:04,310 --> 00:50:01,620
you create these gorgeous filamentary

1101
00:50:06,320 --> 00:50:04,320
things Raleigh Taylor instabilities look

1102
00:50:09,260 --> 00:50:06,330
them up there are a lot of fun

1103
00:50:12,350 --> 00:50:09,270
but this has all this filamentary

1104
00:50:13,640 --> 00:50:12,360
structure as part of this big bubble

1105
00:50:15,650 --> 00:50:13,650
structure okay

1106
00:50:17,350 --> 00:50:15,660
so it has some of that but it really has

1107
00:50:21,730 --> 00:50:17,360
the big bubble structure as its dominant

1108
00:50:24,560 --> 00:50:21,740
so what's going on here that these two

1109
00:50:26,680 --> 00:50:24,570
which are both a thousand years old

1110
00:50:29,180 --> 00:50:26,690
don't look anything alike each other

1111
00:50:32,300 --> 00:50:29,190
well the answer is that I'm hiding

1112
00:50:33,770 --> 00:50:32,310
something from you okay I'm not lying to

1113
00:50:37,610 --> 00:50:33,780

you but I haven't given you the full

1114
00:50:40,060 --> 00:50:37,620
piece of information because these two

1115
00:50:42,890 --> 00:50:40,070
are not being seen at the same scale

1116
00:50:44,270 --> 00:50:42,900
right there it roughly actually at the

1117
00:50:47,150 --> 00:50:44,280
same distance

1118
00:50:51,830 --> 00:50:47,160
but if Hubble can take that image with

1119
00:50:54,080 --> 00:50:51,840
one pointing for the Crab Nebula okay it

1120
00:50:56,990 --> 00:50:54,090
is does this whole thing in one pointing

1121
00:50:59,000 --> 00:50:57,000
and on ten thousand one thousand six it

1122
00:51:02,660 --> 00:50:59,010
only did one pointing of a small region

1123
00:51:06,640 --> 00:51:02,670
up here says something's different so if

1124
00:51:09,320 --> 00:51:06,650
I put these at the same physical scale

1125
00:51:12,290 --> 00:51:09,330
one thousand and six is about sixty

1126
00:51:17,260 --> 00:51:12,300
lightyears across and and the Crab

1127
00:51:21,770 --> 00:51:17,270
Nebula is ten lightyears across well

1128
00:51:23,960 --> 00:51:21,780
okay so this is what smacks you as an

1129
00:51:25,970 --> 00:51:23,970
astronomer that you've been talking

1130
00:51:28,970 --> 00:51:25,980
about the Crab Nebula as a supernova

1131
00:51:31,130 --> 00:51:28,980
explosion and you knew it was not quite

1132
00:51:32,390 --> 00:51:31,140
the same as all the others but you sort

1133
00:51:34,820 --> 00:51:32,400
of said okay well it's got to have

1134
00:51:38,240 --> 00:51:34,830
mostly the characteristics of a blast

1135
00:51:41,090 --> 00:51:38,250
wave supernova but it doesn't this is a

1136
00:51:43,580 --> 00:51:41,100
blot the this one on the left is a blast

1137
00:51:46,820 --> 00:51:43,590
wave dominated supernova remnant the

1138
00:51:49,670 --> 00:51:46,830

Crab Nebula is clearly not a blast waves

1139
00:51:53,960 --> 00:51:49,680
dominated supernova remnant what the

1140
00:51:56,630 --> 00:51:53,970
heck is it it is a pulsar wind nebula

1141
00:52:00,920 --> 00:51:56,640
okay and this is where things get really

1142
00:52:04,130 --> 00:52:00,930
cool okay so here is our view of from

1143
00:52:06,620 --> 00:52:04,140
Hubble of the Crab Nebula right but to

1144
00:52:08,930 --> 00:52:06,630
really understand the Crab Nebula you

1145
00:52:10,460 --> 00:52:08,940
want to use multi wavelength

1146
00:52:12,740 --> 00:52:10,470
you don't want to use just visible light

1147
00:52:14,990 --> 00:52:12,750
you want to use all the wavelengths you

1148
00:52:18,370 --> 00:52:15,000
have at your disposal so here is a

1149
00:52:21,890 --> 00:52:18,380
separation at the same scale of radio

1150
00:52:25,130 --> 00:52:21,900
infrared optical ultraviolet and x-ray

1151
00:52:27,770 --> 00:52:25,140
views of the Crab Nebula including a

1152
00:52:30,050 --> 00:52:27,780
composite image in the lower right okay

1153
00:52:33,170 --> 00:52:30,060
and we're going to work from the inside

1154
00:52:35,090 --> 00:52:33,180
out let's start with the x-ray here is a

1155
00:52:37,180 --> 00:52:35,100
comparison of the Chandra x-ray image

1156
00:52:42,770 --> 00:52:37,190
versus the Hubble visible light image

1157
00:52:44,750 --> 00:52:42,780
and the crab collapsed to form the crab

1158
00:52:47,570 --> 00:52:44,760
supernova collapsed to form a neutron

1159
00:52:51,170 --> 00:52:47,580
star a neutron star that spin spin spin

1160
00:52:54,230 --> 00:52:51,180
spin spin has a pulsar the crab pulsar

1161
00:52:56,600 --> 00:52:54,240
is seen clearly in x-rays right there at

1162
00:52:58,220 --> 00:52:56,610
the center of the Crab Nebula

1163
00:53:02,030 --> 00:52:58,230

it is a

1164
00:53:05,150 --> 00:53:02,040
three millisecond pulsar it spins 30

1165
00:53:08,120 --> 00:53:05,160
times a second alright so take all of

1166
00:53:11,300 --> 00:53:08,130
Baltimore City and spin it 30 times a

1167
00:53:13,730 --> 00:53:11,310
second alright and actually you'd have

1168
00:53:15,950 --> 00:53:13,740
to have Baltimore City the size with the

1169
00:53:18,170 --> 00:53:15,960
mass of the Sun in Baltimore City and

1170
00:53:20,120 --> 00:53:18,180
spin it 30 times that's a tremendous

1171
00:53:22,220 --> 00:53:20,130
amount of energy okay

1172
00:53:23,690 --> 00:53:22,230
and all those magnetic fields are

1173
00:53:26,180 --> 00:53:23,700
spinning around getting wrapped up and

1174
00:53:28,760 --> 00:53:26,190
getting wrapped up and the materials

1175
00:53:32,870 --> 00:53:28,770
shooting out as Jets and here's the jet

1176
00:53:35,000 --> 00:53:32,880
that you see in x-rays spewing out from

1177
00:53:37,820 --> 00:53:35,010
that pulsar and there would of course be

1178
00:53:39,440 --> 00:53:37,830
another jet coming off across here if

1179
00:53:40,760 --> 00:53:39,450
you really process it you might be able

1180
00:53:44,930 --> 00:53:40,770
to see a little bit of that jet but it's

1181
00:53:46,670 --> 00:53:44,940
not easily visible plus there is a disk

1182
00:53:49,460 --> 00:53:46,680
of material a ringed disc of material

1183
00:53:51,380 --> 00:53:49,470
see that ring here and see that ring

1184
00:53:53,900 --> 00:53:51,390
here some more of a tourist type thing

1185
00:53:56,180 --> 00:53:53,910
you've got a disc of material around it

1186
00:53:59,180 --> 00:53:56,190
and if we take time lapse things we can

1187
00:54:01,130 --> 00:53:59,190
actually see energy propagating out so

1188
00:54:04,640 --> 00:54:01,140

with these magnetic fields getting all

1189
00:54:08,480 --> 00:54:04,650
wrapped up alright and forming up it's

1190
00:54:11,870 --> 00:54:08,490
an efficient energy distribution system

1191
00:54:14,780 --> 00:54:11,880
energy flows away from that pulsar the

1192
00:54:17,240 --> 00:54:14,790
Pulsar is creating huge energy that's

1193
00:54:20,330 --> 00:54:17,250
falling out into the system what's it

1194
00:54:22,190 --> 00:54:20,340
gonna heat well it's gonna hit the gas

1195
00:54:25,070 --> 00:54:22,200
around it alright and so here we have

1196
00:54:27,680 --> 00:54:25,080
two images this is Spitzer infrared

1197
00:54:32,410 --> 00:54:27,690
image here alright and over here is

1198
00:54:34,580 --> 00:54:32,420
Hubble and visible light in a medium and

1199
00:54:37,220 --> 00:54:34,590
visible agreed okay

1200
00:54:41,300 --> 00:54:37,230
and you see all this blue gas on the

1201
00:54:45,620 --> 00:54:41,310
left that blue gas is the gas that has

1202
00:54:47,660 --> 00:54:45,630
been heated by this pulsar emission and

1203
00:54:50,050 --> 00:54:47,670
is now emitting what's called

1204
00:54:52,970 --> 00:54:50,060
synchrotron radiation all right

1205
00:54:55,490 --> 00:54:52,980
synchrotron radiation is when electrons

1206
00:54:58,670 --> 00:54:55,500
spiral around magnetic field lines and

1207
00:55:00,770 --> 00:54:58,680
emit radiation okay and the tighter they

1208
00:55:03,560 --> 00:55:00,780
they they spin around it the higher

1209
00:55:06,650 --> 00:55:03,570
energy radiation they hit synchrotron

1210
00:55:09,830 --> 00:55:06,660
radiation from the crab is seen in radio

1211
00:55:11,350 --> 00:55:09,840
it's seen in infrared it's seen

1212
00:55:13,390 --> 00:55:11,360
invisible it's see

1213
00:55:16,420 --> 00:55:13,400

ultraviolet it's even seen a little bit

1214
00:55:18,790 --> 00:55:16,430
in x-rays we've got tremendous amounts

1215
00:55:20,320 --> 00:55:18,800
of synchrotron radiation and you want to

1216
00:55:22,180 --> 00:55:20,330
convince yourself that it's coming from

1217
00:55:25,090 --> 00:55:22,190
the magnetic field lines you look at

1218
00:55:27,340 --> 00:55:25,100
this Hubble image and you can see the

1219
00:55:30,220 --> 00:55:27,350
linear features look at this structure

1220
00:55:34,270 --> 00:55:30,230
here and get the emission following all

1221
00:55:36,180 --> 00:55:34,280
of these very striated lines in here so

1222
00:55:39,010 --> 00:55:36,190
you've got this synchrotron radiation

1223
00:55:41,110 --> 00:55:39,020
from the material and it's at many

1224
00:55:44,250 --> 00:55:41,120
different energies from low energy radio

1225
00:55:49,030 --> 00:55:44,260
to high-energy ultraviolet and x-ray

1226
00:55:53,020 --> 00:55:49,040
that energy then goes out and hits the

1227
00:55:55,780 --> 00:55:53,030
blast wave okay so this is what we see

1228
00:55:58,540 --> 00:55:55,790
in visible light with Hubble we see the

1229
00:56:02,530 --> 00:55:58,550
elements that are spewed out from the

1230
00:56:05,080 --> 00:56:02,540
supernova being energized by that

1231
00:56:09,520 --> 00:56:05,090
synchrotron radiation okay

1232
00:56:12,310 --> 00:56:09,530
the energy here is not due to the energy

1233
00:56:14,440 --> 00:56:12,320
of the blast wave it's the energy that's

1234
00:56:17,380 --> 00:56:14,450
coming from the synchrotron radiation

1235
00:56:21,940 --> 00:56:17,390
that heats it up and that's what we see

1236
00:56:25,690 --> 00:56:21,950
with Hubble and oxygen and in sulfur so

1237
00:56:29,710 --> 00:56:25,700
we have this Russian doll structure in

1238
00:56:31,530 --> 00:56:29,720

the Crab Nebula you have the Pulsar

1239
00:56:34,270 --> 00:56:31,540
which you can see beautifully an x-ray

1240
00:56:37,210 --> 00:56:34,280
creating all this energy which then

1241
00:56:38,620 --> 00:56:37,220
heats up the gas with that that emits in

1242
00:56:41,170 --> 00:56:38,630
synchrotron radiation and that

1243
00:56:44,050 --> 00:56:41,180
synchrotron that radiation then hitting

1244
00:56:47,410 --> 00:56:44,060
the filthy elements that glow in visible

1245
00:56:51,460 --> 00:56:47,420
light one of the experts I worked with

1246
00:56:53,440 --> 00:56:51,470
on this project says to me well look you

1247
00:56:56,200 --> 00:56:53,450
know we think of these supernova

1248
00:56:59,110 --> 00:56:56,210
remnants as glowing on their own but

1249
00:57:02,770 --> 00:56:59,120
without the crab pulsar we probably

1250
00:57:06,700 --> 00:57:02,780
wouldn't even see the Crab Nebula this

1251
00:57:09,700 --> 00:57:06,710
is a pulsar wind nebula the energy the

1252
00:57:12,430 --> 00:57:09,710
wind from the Pulsar driving all of the

1253
00:57:15,500 --> 00:57:12,440
emission that you see in x-ray infrared

1254
00:57:22,040 --> 00:57:18,770
that's a cool story and that's the story

1255
00:57:25,040 --> 00:57:22,050
we wanted to tell in our latest 3d

1256
00:57:26,990 --> 00:57:25,050
visualization so our visualization is

1257
00:57:30,380 --> 00:57:27,000
Crab Nebula the multi-wavelength

1258
00:57:35,030 --> 00:57:30,390
structure of a pulsar wind nebula when I

1259
00:57:39,020 --> 00:57:35,040
say we who are we we are NASA's universe

1260
00:57:42,980 --> 00:57:39,030
of learning this is the educate the

1261
00:57:44,750 --> 00:57:42,990
outreach funding from NASA that used to

1262
00:57:46,310 --> 00:57:44,760
be on a mission specific it used to be

1263
00:57:48,170 --> 00:57:46,320

just Hubble did its outreach and then

1264
00:57:50,690 --> 00:57:48,180
Spitzer did its outreach and Chandra did

1265
00:57:54,950 --> 00:57:50,700
its outreach and so on they combined it

1266
00:57:57,200 --> 00:57:54,960
into a in a program that works across

1267
00:57:59,599 --> 00:57:57,210
wavelength and it's all about getting

1268
00:58:01,730 --> 00:57:59,609
the stories out regardless of the

1269
00:58:03,380 --> 00:58:01,740
wavelength so we combine the Space

1270
00:58:06,260 --> 00:58:03,390
Telescope Science Institute we're the

1271
00:58:08,330 --> 00:58:06,270
home of Hubble with Caltech I pack the

1272
00:58:10,400 --> 00:58:08,340
home of Spitzer with the center for

1273
00:58:12,560 --> 00:58:10,410
astrophysics Harvard and Smithsonian the

1274
00:58:17,000 --> 00:58:12,570
home of the Spitz of the Chandra x-ray

1275
00:58:18,950 --> 00:58:17,010
Observatory JPL NASA JPL and Sonoma

1276
00:58:21,650 --> 00:58:18,960
State University all of these groups

1277
00:58:23,060 --> 00:58:21,660
working together so we've got Hubble

1278
00:58:25,640 --> 00:58:23,070
Chandra and spitz are all working

1279
00:58:28,160 --> 00:58:25,650
together to do this project okay and

1280
00:58:30,859 --> 00:58:28,170
this is the combined image that we

1281
00:58:33,710 --> 00:58:30,869
released as part of this project it has

1282
00:58:37,070 --> 00:58:33,720
you can see the x-ray pulsar in the core

1283
00:58:39,290 --> 00:58:37,080
it has the red of the infrared from

1284
00:58:41,180 --> 00:58:39,300
Spitzer around that and then it has the

1285
00:58:43,520 --> 00:58:41,190
yellow of Hubble in the oxygen emission

1286
00:58:45,140 --> 00:58:43,530
around that so I'm going to talk a

1287
00:58:47,420 --> 00:58:45,150
little bit about how we did the

1288
00:58:50,570 --> 00:58:47,430

visualization because hey that's my

1289
00:58:52,460 --> 00:58:50,580
specialty if you remember from last year

1290
00:58:54,859 --> 00:58:52,470
I called my I gave a talk where I talked

1291
00:58:56,990 --> 00:58:54,869
about an astrophysicist that's me that's

1292
00:58:59,200 --> 00:58:57,000
that's my moniker for myself as an

1293
00:59:00,530 --> 00:58:59,210
astronomer who does visualizations an

1294
00:59:04,940 --> 00:59:00,540
astrophysicist

1295
00:59:06,680 --> 00:59:04,950
so the x-ray in for the Crab Nebula what

1296
00:59:08,930 --> 00:59:06,690
we just want to get across the idea that

1297
00:59:12,050 --> 00:59:08,940
there's the pulsar the disc and the Jets

1298
00:59:14,690 --> 00:59:12,060
and these are relatively straightforward

1299
00:59:16,430 --> 00:59:14,700
geometries to do in 3d ok when you're

1300
00:59:17,480 --> 00:59:16,440
thinking of 3d modeling all right

1301
00:59:18,500 --> 00:59:17,490
creating a disc

1302
00:59:21,740 --> 00:59:18,510
yeah that's pretty straightforward

1303
00:59:24,320 --> 00:59:21,750
creating a sphere for the pulsar great

1304
00:59:26,210 --> 00:59:24,330
making the Jets was a little more work

1305
00:59:28,700 --> 00:59:26,220
on this but we have some really good

1306
00:59:30,620 --> 00:59:28,710
artists here who go out and we're

1307
00:59:33,560 --> 00:59:30,630
to create the jet and then we got this

1308
00:59:36,290 --> 00:59:33,570
nice fuzzy haze around it to work in the

1309
00:59:38,660 --> 00:59:36,300
x-ray so I don't want to diminish the

1310
00:59:40,970 --> 00:59:38,670
work that Joe did on this but this is

1311
00:59:44,000 --> 00:59:40,980
this is more standard 3d stuff because

1312
00:59:46,609 --> 00:59:44,010
you can actually have physical stuff but

1313
00:59:49,040 --> 00:59:46,619

then you go to the synchrotron radiation

1314
00:59:52,310 --> 00:59:49,050
which we're representing with Spitzer's

1315
00:59:55,070 --> 00:59:52,320
observations in the infrared and this is

1316
00:59:57,380 --> 00:59:55,080
much more of an amorphous cloud plus we

1317
00:59:59,750 --> 00:59:57,390
have to get across the idea that it's

1318
01:00:04,130 --> 00:59:59,760
the magnetic field lines from which this

1319
01:00:07,160 --> 01:00:04,140
in this radiation is emitting so he Joe

1320
01:00:10,030 --> 01:00:07,170
also did this one um and he chose to do

1321
01:00:12,320 --> 01:00:10,040
it via something called fluids and

1322
01:00:14,390 --> 01:00:12,330
basically as you can see here this is

1323
01:00:18,380 --> 01:00:14,400
just drawing lots of squiggly lines in

1324
01:00:20,270 --> 01:00:18,390
3d okay now this is the later version of

1325
01:00:22,099 --> 01:00:20,280
the model the first version of the model

1326
01:00:24,200 --> 01:00:22,109
was just to try and create the

1327
01:00:25,790 --> 01:00:24,210
three-dimensional structure and then it

1328
01:00:27,650 --> 01:00:25,800
looked like a layer cake type thing and

1329
01:00:29,480 --> 01:00:27,660
you're trying to get the rough shape of

1330
01:00:30,380 --> 01:00:29,490
it now do we know what it looks like

1331
01:00:34,460 --> 01:00:30,390
when we spin it

1332
01:00:37,010 --> 01:00:34,470
no but that's why you have me on the

1333
01:00:38,089 --> 01:00:37,020
project who as the astronomer who's able

1334
01:00:40,339 --> 01:00:38,099
to sit there and say all right well it's

1335
01:00:43,220 --> 01:00:40,349
roughly going to look like this and you

1336
01:00:46,040 --> 01:00:43,230
can see for example this gap right here

1337
01:00:48,530 --> 01:00:46,050
see that gap right there that's actually

1338
01:00:50,810 --> 01:00:48,540

a magnetic torus it's a belt that's

1339
01:00:52,970 --> 01:00:50,820
squeezing in all right and there's no

1340
01:00:55,579 --> 01:00:52,980
synchrotron radiation for this belt

1341
01:00:57,410 --> 01:00:55,589
around there all right now I'm around to

1342
01:00:58,609 --> 01:00:57,420
sit there and talk to the experts and

1343
01:01:00,640 --> 01:00:58,619
make sure that we put as many

1344
01:01:02,839 --> 01:01:00,650
Astrophysical features into this

1345
01:01:05,660 --> 01:01:02,849
3-dimensional model this approximation

1346
01:01:07,910 --> 01:01:05,670
of what's going on and then when you

1347
01:01:10,730 --> 01:01:07,920
take all these squiggly lines and then

1348
01:01:14,390 --> 01:01:10,740
emit fluids from it and visualize it you

1349
01:01:15,980 --> 01:01:14,400
can get that all right and you would

1350
01:01:17,329 --> 01:01:15,990
it's hard to believe that that could

1351
01:01:19,250 --> 01:01:17,339
come from that and that's not the final

1352
01:01:23,359 --> 01:01:19,260
version of it that's still you know one

1353
01:01:25,609 --> 01:01:23,369
of the medium halfway through to create

1354
01:01:27,500 --> 01:01:25,619
this but you also see that by doing it

1355
01:01:29,089 --> 01:01:27,510
with these squiggly lines we get the

1356
01:01:33,500 --> 01:01:29,099
feeling that it's the magnetic field

1357
01:01:35,450 --> 01:01:33,510
lines that are creating the emission now

1358
01:01:38,180 --> 01:01:35,460
the hard part came when we tried to do

1359
01:01:40,010 --> 01:01:38,190
the visible light and this I thought was

1360
01:01:42,170 --> 01:01:40,020
actually going to be easy because we

1361
01:01:44,540 --> 01:01:42,180
have some observations right

1362
01:01:47,300 --> 01:01:44,550
we can we have observations and these

1363
01:01:50,390 --> 01:01:47,310

are come in the form of velocity slices

1364
01:01:53,840 --> 01:01:50,400
of the nebula alright so these images

1365
01:01:56,150 --> 01:01:53,850
are oxygen three observations and you

1366
01:01:59,480 --> 01:01:56,160
use a very narrow band filter that you

1367
01:02:03,080 --> 01:01:59,490
can adjust back and forth to pull out

1368
01:02:04,670 --> 01:02:03,090
the Doppler shifted emission okay so at

1369
01:02:07,010 --> 01:02:04,680
the distance of the Crab Nebula there is

1370
01:02:09,260 --> 01:02:07,020
a certain emission line of oxygen oxygen

1371
01:02:12,140 --> 01:02:09,270
three that occurs at a certain

1372
01:02:14,390 --> 01:02:12,150
wavelength but if it's moving toward you

1373
01:02:17,480 --> 01:02:14,400
then that addition is going to be blue

1374
01:02:19,280 --> 01:02:17,490
shifted to shorter wavelengths and it's

1375
01:02:23,000 --> 01:02:19,290
moving away from you it's going to be

1376
01:02:25,670 --> 01:02:23,010
red shifted to longer wavelengths so the

1377
01:02:28,850 --> 01:02:25,680
stuff on the front of the nebula that's

1378
01:02:30,710 --> 01:02:28,860
moving toward you blue shifted should be

1379
01:02:31,880 --> 01:02:30,720
at shorter wavelengths and the stuff on

1380
01:02:34,100 --> 01:02:31,890
the back of the nebula that's moving

1381
01:02:35,930 --> 01:02:34,110
away from you should be red shifted to

1382
01:02:38,660 --> 01:02:35,940
longer wavelengths and if you use a

1383
01:02:42,470 --> 01:02:38,670
filter to pull out those different

1384
01:02:45,230 --> 01:02:42,480
Doppler shifted velocity slices you get

1385
01:02:47,660 --> 01:02:45,240
this and so working from the back to the

1386
01:02:51,050 --> 01:02:47,670
front you can see the top left working

1387
01:02:52,730 --> 01:02:51,060
through to the bottom right which is the

1388
01:02:54,500 --> 01:02:52,740

stuff in the front and you sort of get

1389
01:02:57,080 --> 01:02:54,510
these velocity slices through the nebula

1390
01:03:00,100 --> 01:02:57,090
which from which we had expected we'd be

1391
01:03:06,410 --> 01:03:00,110
able to create an interesting 3d model

1392
01:03:08,780 --> 01:03:06,420
we were wrong okay that the translating

1393
01:03:12,080 --> 01:03:08,790
from velocity space to real space

1394
01:03:14,200 --> 01:03:12,090
doesn't have a really good solution all

1395
01:03:18,560 --> 01:03:14,210
right you've got velocity stuff moving

1396
01:03:21,260 --> 01:03:18,570
outward that is gets very fuzzy so the

1397
01:03:24,440 --> 01:03:21,270
paper for that this came from did their

1398
01:03:27,080 --> 01:03:24,450
own version of it and this is sort of

1399
01:03:28,760 --> 01:03:27,090
the rotation of the their-their model

1400
01:03:31,970 --> 01:03:28,770
and you can see it particularly here

1401
01:03:33,940 --> 01:03:31,980
look at the blob enos of that okay all

1402
01:03:36,790 --> 01:03:33,950
right and we thought that there was some

1403
01:03:41,660 --> 01:03:36,800
new data that would be able to help us

1404
01:03:43,040 --> 01:03:41,670
and yeah no it didn't help us matter of

1405
01:03:45,190 --> 01:03:43,050
fact there is some new data that won't

1406
01:03:47,240 --> 01:03:45,200
be coming out till this year that I

1407
01:03:49,130 --> 01:03:47,250
still don't think it will help actually

1408
01:03:51,380 --> 01:03:49,140
help us okay

1409
01:03:53,090 --> 01:03:51,390
the translation from velocity space to

1410
01:03:54,770 --> 01:03:53,100
real space was much more difficult than

1411
01:03:58,279 --> 01:03:54,780
we thought it would be

1412
01:04:01,490 --> 01:03:58,289
so what are we gonna do well we're gonna

1413
01:04:03,529 --> 01:04:01,500

go back to Copernicus okay so we invoked

1414
01:04:04,880 --> 01:04:03,539
the Copernican principle all right what

1415
01:04:07,069 --> 01:04:04,890
is the Copernican principle

1416
01:04:10,549 --> 01:04:07,079
well Copernicus as you know was the one

1417
01:04:12,020 --> 01:04:10,559
who promulgated the sun-centered solar

1418
01:04:13,609 --> 01:04:12,030
system instead of the Earth's center

1419
01:04:15,890 --> 01:04:13,619
solar system the heliocentric model

1420
01:04:19,819 --> 01:04:15,900
versus the geocentric model okay and

1421
01:04:21,890 --> 01:04:19,829
what Copernicus did is he said hey we're

1422
01:04:24,410 --> 01:04:21,900
here on earth we're not at the center of

1423
01:04:25,700 --> 01:04:24,420
the solar system and we astronomers have

1424
01:04:29,059 --> 01:04:25,710
called this into a Copernican principle

1425
01:04:32,059 --> 01:04:29,069
because we learned you know later that

1426
01:04:34,819 --> 01:04:32,069
hey you know what the Sun is not the

1427
01:04:37,430 --> 01:04:34,829
center of the galaxy and we can go even

1428
01:04:40,430 --> 01:04:37,440
further to say that our galaxy is not at

1429
01:04:43,480 --> 01:04:40,440
the center of the universe we are not at

1430
01:04:47,299 --> 01:04:43,490
the center of anything okay

1431
01:04:51,200 --> 01:04:47,309
that's the Copernican principle we exist

1432
01:04:54,049 --> 01:04:51,210
at no special point in the universe all

1433
01:04:57,200 --> 01:04:54,059
right and so therefore the Krabi

1434
01:05:00,220 --> 01:04:57,210
Copernican principle is to say that we

1435
01:05:03,260 --> 01:05:00,230
have no special view of the Crab Nebula

1436
01:05:05,750 --> 01:05:03,270
right so we see all these filamentary

1437
01:05:08,150 --> 01:05:05,760
structures across the face and we see

1438
01:05:11,120 --> 01:05:08,160

all this play of material around the

1439
01:05:12,740 --> 01:05:11,130
edges but if I looked at that's because

1440
01:05:14,930 --> 01:05:12,750
we're looking at it from here but if I

1441
01:05:17,450 --> 01:05:14,940
look at it from the side I should

1442
01:05:19,789 --> 01:05:17,460
probably see the same thing filaments

1443
01:05:24,680 --> 01:05:19,799
across the face splays a material around

1444
01:05:27,769 --> 01:05:24,690
the edges so using the fabry-perot data

1445
01:05:29,539 --> 01:05:27,779
I was able to pick out which filaments

1446
01:05:31,430 --> 01:05:29,549
we thought were on the front of the

1447
01:05:34,099 --> 01:05:31,440
nebula and which filaments were on the

1448
01:05:35,930 --> 01:05:34,109
back we could then go into the Hubble

1449
01:05:36,470 --> 01:05:35,940
data which is much higher resolution

1450
01:05:39,079 --> 01:05:36,480
than this

1451
01:05:42,529 --> 01:05:39,089
pick out those filaments and paint them

1452
01:05:43,849 --> 01:05:42,539
on to basically a potato okay that had

1453
01:05:45,319 --> 01:05:43,859
the the filaments on the front and

1454
01:05:47,299 --> 01:05:45,329
filaments in the back and we can connect

1455
01:05:49,849 --> 01:05:47,309
them across the edges so that we had

1456
01:05:53,240 --> 01:05:49,859
filaments from every direction okay so

1457
01:05:55,069 --> 01:05:53,250
we got the image on the right is the

1458
01:05:56,960 --> 01:05:55,079
filament potato that has filaments and

1459
01:05:59,269 --> 01:05:56,970
as you spin it you'll see filaments from

1460
01:06:01,339 --> 01:05:59,279
every direction so what are we gonna do

1461
01:06:04,069 --> 01:06:01,349
about the splays now that we have those

1462
01:06:05,740 --> 01:06:04,079
filaments we have to add in some splays

1463
01:06:09,190 --> 01:06:05,750

around it okay

1464
01:06:11,440 --> 01:06:09,200
and to do this right

1465
01:06:14,080 --> 01:06:11,450
took a long well actually it's

1466
01:06:17,190 --> 01:06:14,090
impossible okay according to according

1467
01:06:19,690 --> 01:06:17,200
to my team to do it really really right

1468
01:06:22,750 --> 01:06:19,700
because you don't know how thick those

1469
01:06:24,790 --> 01:06:22,760
plays are and everything so we cheated

1470
01:06:27,339 --> 01:06:24,800
okay

1471
01:06:31,180 --> 01:06:27,349
we did not do a full 3d model of these

1472
01:06:34,359 --> 01:06:31,190
plays we actually did 18 2d models of

1473
01:06:36,550 --> 01:06:34,369
these plays so we've got a plane of

1474
01:06:39,310 --> 01:06:36,560
material here that creates this plays

1475
01:06:41,470 --> 01:06:39,320
and then you rotate that ten degrees and

1476
01:06:43,900 --> 01:06:41,480
do another splay material and ten

1477
01:06:47,290 --> 01:06:43,910
degrees another set of plays and you do

1478
01:06:52,180 --> 01:06:47,300
18 of these and you fill out a full

1479
01:06:54,190 --> 01:06:52,190
rotation of displays so that as you're

1480
01:06:55,720 --> 01:06:54,200
watching that potatoes spin here and

1481
01:06:57,730 --> 01:06:55,730
you're seeing all the filaments from

1482
01:07:01,480 --> 01:06:57,740
every direction you're seeing splays

1483
01:07:03,940 --> 01:07:01,490
around it okay so this isn't a full 3d

1484
01:07:06,190 --> 01:07:03,950
model it's a two and a half D model all

1485
01:07:08,680 --> 01:07:06,200
right and if I were trying to chief are

1486
01:07:10,870 --> 01:07:08,690
trying to fool you I wouldn't admit to

1487
01:07:13,599 --> 01:07:10,880
what we're doing what we had to do to

1488
01:07:15,010 --> 01:07:13,609

get this to work but this is what we had

1489
01:07:16,930 --> 01:07:15,020
to do in order to get that

1490
01:07:19,000 --> 01:07:16,940
three-dimensional structure so this

1491
01:07:20,589 --> 01:07:19,010
model only works from that one camera

1492
01:07:23,620 --> 01:07:20,599
path that we have in the movie that

1493
01:07:25,680 --> 01:07:23,630
you're about to see all right and it

1494
01:07:28,829 --> 01:07:25,690
shows you that really getting that

1495
01:07:30,609 --> 01:07:28,839
filamentary beautiful structure is

1496
01:07:31,750 --> 01:07:30,619
really difficult

1497
01:07:33,730 --> 01:07:31,760
all right matter of fact I was talking

1498
01:07:36,880 --> 01:07:33,740
to my visualization friends out of JPL

1499
01:07:39,940 --> 01:07:36,890
alright and he was like I knew you

1500
01:07:43,690 --> 01:07:39,950
couldn't do that alright it was like

1501
01:07:45,940 --> 01:07:43,700
yeah I sort of thought I could but you

1502
01:07:47,740 --> 01:07:45,950
know we have not figured it out maybe

1503
01:07:49,510 --> 01:07:47,750
we'll be able to figure it out the only

1504
01:07:51,460 --> 01:07:49,520
way to do this and make it self

1505
01:07:53,890 --> 01:07:51,470
consistent and enjoy and and really look

1506
01:07:55,990 --> 01:07:53,900
good is actually to do a simulation of

1507
01:07:58,870 --> 01:07:56,000
this type of stuff but then it wouldn't

1508
01:08:01,300 --> 01:07:58,880
match the Hubble image very well alright

1509
01:08:03,070 --> 01:08:01,310
and so the it was the tearing back and

1510
01:08:04,780 --> 01:08:03,080
forth between wanting to make it look

1511
01:08:07,210 --> 01:08:04,790
like the Hubble image and wanting to

1512
01:08:10,630 --> 01:08:07,220
make it have this beautiful structure

1513
01:08:12,880 --> 01:08:10,640

and this was our approximation so can we

1514
01:08:16,319 --> 01:08:12,890
take the lights down they got this big

1515
01:08:20,519 --> 01:08:16,329
light here because I'm much of the movie

1516
01:08:22,410 --> 01:08:20,529
Thank You Calvin all right so here we go

1517
01:08:25,950 --> 01:08:22,420
Crab Nebula the multi-wavelength

1518
01:08:29,380 --> 01:08:25,960
structure of a pulsar wind nebula

1519
01:08:31,480 --> 01:08:29,390
where's my cursor oats

1520
01:08:35,809 --> 01:08:31,490
I have to pull my cursor back onto my

1521
01:08:35,819 --> 01:12:19,240
[Music]

1522
01:12:25,880 --> 01:12:23,420
all right so some final thoughts for you

1523
01:12:28,850 --> 01:12:25,890
what you might take away from this talk

1524
01:12:32,780 --> 01:12:28,860
tonight the universe is powered by

1525
01:12:34,790 --> 01:12:32,790
nuclear fusion the elements including

1526
01:12:38,240 --> 01:12:34,800
what you're made of were forged in the

1527
01:12:40,940 --> 01:12:38,250
stars but those stars they do not last

1528
01:12:42,830 --> 01:12:40,950
forever and the stellar graveyard of the

1529
01:12:45,020 --> 01:12:42,840
universe is filled with these white

1530
01:12:48,920 --> 01:12:45,030
dwarfs these neutron stars and these

1531
01:12:50,840 --> 01:12:48,930
black holes but before they go ungentle

1532
01:12:53,180 --> 01:12:50,850
into that good night

1533
01:12:56,140 --> 01:12:53,190
they rage against the dying of light by

1534
01:12:59,540 --> 01:12:56,150
putting off these gaseous dust masks of

1535
01:13:02,690 --> 01:12:59,550
planetary nebulae and supernova remnants

1536
01:13:05,450 --> 01:13:02,700
and finally that Crab Nebula pictured on

1537
01:13:07,640 --> 01:13:05,460
the right there is not the prototypical

1538
01:13:11,390 --> 01:13:07,650

supernova remnant we once thought it was

1539
01:13:14,450 --> 01:13:11,400
it is a pulsar wind nebula it is unusual

1540
01:13:16,010 --> 01:13:14,460
and if you enjoyed the visualization you

1541
01:13:19,040 --> 01:13:16,020
can watch it on the Hubble Space

1542
01:13:20,690 --> 01:13:19,050
Telescope channel on YouTube and if you

1543
01:13:23,150 --> 01:13:20,700
would like to download it and you know

1544
01:13:26,090 --> 01:13:23,160
show it to your friends or colleagues or

1545
01:13:29,510 --> 01:13:26,100
your dog you can download it on Hubble

1546
01:13:38,729 --> 01:13:29,520
site dot o-r-g thank you very much for

1547
01:13:45,760 --> 01:13:42,100
okay if you have to leave please go on

1548
01:13:48,609 --> 01:13:45,770
ahead but as always we have grant with

1549
01:13:51,609 --> 01:13:48,619
the throwing microphone all right dude

1550
01:13:52,810 --> 01:13:51,619
so he needs his energy so please have a

1551
01:13:54,760 --> 01:13:52,820
question so grant can throw the

1552
01:13:57,490 --> 01:13:54,770
microphone over there couple good ones

1553
01:14:01,529 --> 01:13:57,500
online is there a couple I can't monitor

1554
01:14:03,549 --> 01:14:01,539
this chat while I'm talking okay

1555
01:14:05,649 --> 01:14:03,559
interesting

1556
01:14:07,870 --> 01:14:05,659
so you talked about modeling the

1557
01:14:09,580 --> 01:14:07,880
philippi in the visible wavelength when

1558
01:14:12,640 --> 01:14:09,590
you did the 3d model you talk about

1559
01:14:15,189 --> 01:14:12,650
modeling the filaments and the display

1560
01:14:17,020 --> 01:14:15,199
this I called them splays because their

1561
01:14:21,790 --> 01:14:17,030
displays of material but are they

1562
01:14:24,100 --> 01:14:21,800
actually different now physical what

1563
01:14:27,760 --> 01:14:24,110

makes it really difficult is that the

1564
01:14:31,270 --> 01:14:27,770
splays seen edge-on are the filaments

1565
01:14:33,339 --> 01:14:31,280
okay and to get a proper 3-dimensional

1566
01:14:35,640 --> 01:14:33,349
structure the three-dimensional depth to

1567
01:14:37,750 --> 01:14:35,650
a splay and make it look like a filament

1568
01:14:39,910 --> 01:14:37,760
was what the problem that I couldn't

1569
01:14:42,760 --> 01:14:39,920
solve that's when we went to the two and

1570
01:14:44,979 --> 01:14:42,770
a half D solution of it and what we were

1571
01:14:46,839 --> 01:14:44,989
doing and that's what my colleague said

1572
01:14:49,779 --> 01:14:46,849
yeah you weren't gonna be able to do

1573
01:14:53,830 --> 01:14:49,789
that dude what do you think you are like

1574
01:14:57,279 --> 01:14:53,840
well I hoped so yeah that day so really

1575
01:14:58,540 --> 01:14:57,289
when you see the the and you see the

1576
01:15:00,609 --> 01:14:58,550
filaments across the face

1577
01:15:02,470 --> 01:15:00,619
they're probably projected out into you

1578
01:15:05,350 --> 01:15:02,480
and they are these displays with their

1579
01:15:11,470 --> 01:15:05,360
various filaments there's various with

1580
01:15:13,839 --> 01:15:11,480
to them yes behind you it seems like a

1581
01:15:17,379 --> 01:15:13,849
supernova is a pretty dangerous thing to

1582
01:15:21,129 --> 01:15:17,389
have yeah I wouldn't want to have one in

1583
01:15:25,060 --> 01:15:21,139
my back yard yeah what's like a safe

1584
01:15:27,069 --> 01:15:25,070
distance so if you're me so if you're

1585
01:15:32,850 --> 01:15:27,079
mr. fusion to blows up how far away do

1586
01:15:34,689 --> 01:15:32,860
you need to be right so interesting

1587
01:15:37,029 --> 01:15:34,699
thing is is that there have been

1588
01:15:39,540 --> 01:15:37,039

supernovae in our galaxy that probably

1589
01:15:43,000 --> 01:15:39,550
have affected the solar system right

1590
01:15:45,700 --> 01:15:43,010
Crab Nebula well it was a thousand years

1591
01:15:49,149 --> 01:15:45,710
ago okay and it's about seven thousand

1592
01:15:50,290 --> 01:15:49,159
light years away so I think we were kind

1593
01:15:52,500 --> 01:15:50,300
of safe from that but

1594
01:15:55,360 --> 01:15:52,510
if it were a thousand light-years away

1595
01:15:58,600 --> 01:15:55,370
the the high-energy radiation could do

1596
01:16:01,360 --> 01:15:58,610
some some damage and there have been

1597
01:16:04,450 --> 01:16:01,370
papers written on this what is the safe

1598
01:16:06,880 --> 01:16:04,460
zone away from away from it I seven

1599
01:16:11,110 --> 01:16:06,890
thousand light-years sounds like that's

1600
01:16:15,010 --> 01:16:11,120
enough distance baitul juice is about

1601
01:16:16,810 --> 01:16:15,020
sixteen hundred if I remember I can't I

1602
01:16:18,460 --> 01:16:16,820
mean I don't keep all these things in my

1603
01:16:21,340 --> 01:16:18,470
head but I mean it's it's it's much

1604
01:16:24,850 --> 01:16:21,350
closer so baitul juice when it goes

1605
01:16:28,180 --> 01:16:24,860
supernova might might be problematic but

1606
01:16:31,620 --> 01:16:28,190
it might not that answered two of the

1607
01:16:34,750 --> 01:16:31,630
questions online but another is yes the

1608
01:16:36,820 --> 01:16:34,760
distance to fatal juice we're not quite

1609
01:16:39,070 --> 01:16:36,830
sure of there's a plus or minus of

1610
01:16:43,930 --> 01:16:39,080
course using the case how can we tell

1611
01:16:47,350 --> 01:16:43,940
how old it is okay so a red supergiant

1612
01:16:49,720 --> 01:16:47,360
of that mass looking at the spectral

1613
01:16:53,320 --> 01:16:49,730

type of it and everything is only gonna

1614
01:16:55,030 --> 01:16:53,330
live for at most 20 30 million years do

1615
01:16:59,320 --> 01:16:55,040
we know how many million years it has

1616
01:17:01,630 --> 01:16:59,330
left no but we know how long from the

1617
01:17:04,450 --> 01:17:01,640
modelling how long it takes to progress

1618
01:17:07,360 --> 01:17:04,460
from the main sequence massive star to

1619
01:17:09,910 --> 01:17:07,370
the red giant to the red supergiant on

1620
01:17:11,680 --> 01:17:09,920
that so this is why we can't tell with

1621
01:17:14,740 --> 01:17:11,690
any certainty when bail juice will

1622
01:17:16,450 --> 01:17:14,750
explode and so the next few million

1623
01:17:21,130 --> 01:17:16,460
years is the best approximation we can

1624
01:17:23,410 --> 01:17:21,140
come up with yeah my question is what

1625
01:17:25,000 --> 01:17:23,420
about the magnetized I can't um they're

1626
01:17:27,190 --> 01:17:25,010
not listed there in the stellar

1627
01:17:29,560 --> 01:17:27,200
graveyard magnet ours are not included

1628
01:17:31,450 --> 01:17:29,570
in this talk as getting a little too

1629
01:17:33,820 --> 01:17:31,460
detailed of the neutron stars that end

1630
01:17:36,190 --> 01:17:33,830
up becoming magnet magnet chars I'm not

1631
01:17:40,720 --> 01:17:36,200
an expert on those as well

1632
01:17:43,300 --> 01:17:40,730
I did almost an hour ahead just using

1633
01:17:45,280 --> 01:17:43,310
this stuff so I'll try and pull in an

1634
01:17:53,080 --> 01:17:45,290
expert who can talk about this those

1635
01:17:55,590 --> 01:17:53,090
things as well okay yes yep

1636
01:17:58,000 --> 01:17:55,600
isn't that by the way a cool diagram as

1637
01:17:59,500 --> 01:17:58,010
some astronomers created that over the

1638
01:18:04,120 --> 01:17:59,510

last two years and it was like this is

1639
01:18:04,450 --> 01:18:04,130
really a lot of fun yes go ahead two of

1640
01:18:07,570 --> 01:18:04,460
them were

1641
01:18:10,330 --> 01:18:07,580
gray because they're radioactive sources

1642
01:18:13,870 --> 01:18:10,340
that don't exist for very long and don't

1643
01:18:15,610 --> 01:18:13,880
therefore come from astronomy you'll

1644
01:18:17,830 --> 01:18:15,620
also notice that periodic table didn't

1645
01:18:21,670 --> 01:18:17,840
include all of the ones that were only

1646
01:18:24,970 --> 01:18:21,680
created in particle physics experiments

1647
01:18:27,400 --> 01:18:24,980
here on earth okay so basically to

1648
01:18:29,020 --> 01:18:27,410
complete that they did to make it

1649
01:18:30,880 --> 01:18:29,030
complete they did all of the up tupters

1650
01:18:33,490 --> 01:18:30,890
of the the highest element that's

1651
01:18:35,530 --> 01:18:33,500
created an astronomical source and two

1652
01:18:36,729 --> 01:18:35,540
of the ones they're smaller didn't are

1653
01:18:41,780 --> 01:18:36,739
not created by astronomical sources

1654
01:19:03,120 --> 01:18:48,330
alright this is gonna be fun I believe

1655
01:19:05,390 --> 01:19:03,130
in you oh is that a mic drop yeah Crab

1656
01:19:11,010 --> 01:19:05,400
Nebula is in the constellation Taurus

1657
01:19:13,680 --> 01:19:11,020
yes and it's labeled m1 Messier one yes

1658
01:19:15,479 --> 01:19:13,690
and if it were clear tonight you could

1659
01:19:16,830 --> 01:19:15,489
see it with the telescope across the

1660
01:19:19,560 --> 01:19:16,840
street quite easily

1661
01:19:25,110 --> 01:19:19,570
absolutely it would look kind of like a

1662
01:19:26,610 --> 01:19:25,120
cotton ball you know and it wouldn't be

1663
01:19:28,200 --> 01:19:26,620

as colorful as the Hubble image because

1664
01:19:29,820 --> 01:19:28,210
the Hubble images are narrow band

1665
01:19:32,040 --> 01:19:29,830
filters designed to pull out those

1666
01:19:35,750 --> 01:19:32,050
sulfur and oxygen and then given colors

1667
01:19:38,479 --> 01:19:35,760
yes we have a what we call a white light

1668
01:19:40,740 --> 01:19:38,489
image through the telescope yeah

1669
01:19:42,740 --> 01:19:40,750
actually that's a really important thing

1670
01:19:46,740 --> 01:19:42,750
this is this being what February

1671
01:19:49,380 --> 01:19:46,750
February Oh Ryan is nice and high in the

1672
01:19:51,500 --> 01:19:49,390
evening okay so you get C baitul juice

1673
01:19:54,840 --> 01:19:51,510
dimming catch it while you still can

1674
01:19:57,350 --> 01:19:54,850
rigel Orion's belt the Orion Nebula and

1675
01:20:00,180 --> 01:19:57,360
then up to the right Oh from that is

1676
01:20:02,700 --> 01:20:00,190
where the Crab Nebula is in the

1677
01:20:07,400 --> 01:20:02,710
constellation of Taurus okay so thank

1678
01:20:11,390 --> 01:20:07,410
you Herman any other questions

1679
01:20:14,330 --> 01:20:11,400
check online okay let me actually

1680
01:20:17,490 --> 01:20:14,340
extrasolar planets next month right yeah

1681
01:20:20,430 --> 01:20:17,500
what is the lower mass limit for a star

1682
01:20:23,160 --> 01:20:20,440
that can go supernova and what class of

1683
01:20:26,250 --> 01:20:23,170
star is it with that lower mass limit

1684
01:20:28,110 --> 01:20:26,260
okay so the mass limit for going

1685
01:20:31,770 --> 01:20:28,120
supernova to form a neutron star is

1686
01:20:33,540 --> 01:20:31,780
eight solar masses and then it's

1687
01:20:36,930 --> 01:20:33,550
somewhere between 15 and 20 to form a

1688
01:20:39,270 --> 01:20:36,940

black hole it used to be 20 but I

1689
01:20:42,390 --> 01:20:39,280
thought they lowered it and I'm never

1690
01:20:43,440 --> 01:20:42,400
didn't keep up with that and these would

1691
01:20:45,780 --> 01:20:43,450
be O&B stars

1692
01:20:48,420 --> 01:20:45,790
basically Oh stars the most massive

1693
01:20:50,760 --> 01:20:48,430
stars and the brightest stars that we

1694
01:20:52,770 --> 01:20:50,770
have when we think of massive stars we

1695
01:20:53,990 --> 01:20:52,780
think of O&B stars but the ones that are

1696
01:20:56,390 --> 01:20:54,000
going to supernova are

1697
01:21:00,260 --> 01:20:56,400
Oh stars and the massive Oh stars okay

1698
01:21:02,870 --> 01:21:00,270
anything more yes one more and we have a

1699
01:21:05,120 --> 01:21:02,880
question from the audience here - when a

1700
01:21:06,440 --> 01:21:05,130
massive star tries to fuse its iron into

1701
01:21:11,390 --> 01:21:06,450
a heavier element does it actually

1702
01:21:14,210 --> 01:21:11,400
succeed in producing it it doesn't well

1703
01:21:16,010 --> 01:21:14,220
I mean it can go a little bit but then

1704
01:21:17,990 --> 01:21:16,020
it eats up the energy so it then then it

1705
01:21:20,420 --> 01:21:18,000
that cools that by eating up the energy

1706
01:21:22,490 --> 01:21:20,430
that cools it off so if that fusion

1707
01:21:24,170 --> 01:21:22,500
reaction goes it only goes for a short

1708
01:21:25,760 --> 01:21:24,180
amount of time and then pulls back and

1709
01:21:27,470 --> 01:21:25,770
goes from can go for a short amount of

1710
01:21:29,810 --> 01:21:27,480
time and pull back so you could you know

1711
01:21:31,910 --> 01:21:29,820
the excess energy could be could could

1712
01:21:32,870 --> 01:21:31,920
be provide that fusion but it wouldn't

1713
01:21:35,300 --> 01:21:32,880

last very long

1714
01:21:38,390 --> 01:21:35,310
so a negligible amount of that happens

1715
01:21:41,480 --> 01:21:38,400
but when the star explodes as a

1716
01:21:44,240 --> 01:21:41,490
supernova there's plenty of extra energy

1717
01:21:46,790 --> 01:21:44,250
and you can then actually power those

1718
01:21:49,070 --> 01:21:46,800
react those fusion reactions alright

1719
01:21:51,650 --> 01:21:49,080
last question because we're getting

1720
01:21:54,620 --> 01:21:51,660
towards 9:30 you know I always have to

1721
01:21:57,440 --> 01:21:54,630
cut off cut myself off related to the

1722
01:21:58,910 --> 01:21:57,450
previous question is the all the extra

1723
01:22:02,900 --> 01:21:58,920
energy that comes out of it is

1724
01:22:07,820 --> 01:22:02,910
essentially still the conversion of of

1725
01:22:10,640 --> 01:22:07,830
matter to energy is that essentially I'm

1726
01:22:12,820 --> 01:22:10,650
not exact when you combine protons and

1727
01:22:15,590 --> 01:22:12,830
neutrons and electrons to make neutrons

1728
01:22:17,390 --> 01:22:15,600
they're probably something but it's also

1729
01:22:21,140 --> 01:22:17,400
the flood of neutrinos that that's

1730
01:22:22,430 --> 01:22:21,150
released as well at that time in that so

1731
01:22:24,710 --> 01:22:22,440
there's going to be some of that and

1732
01:22:26,660 --> 01:22:24,720
there's going to be some of them just

1733
01:22:30,080 --> 01:22:26,670
the amazing number of neutrinos you

1734
01:22:32,750 --> 01:22:30,090
create with that I'm not a particle

1735
01:22:35,600 --> 01:22:32,760
physicist so I know it enough to explain

1736
01:22:37,220 --> 01:22:35,610
the basics but I'm happy to admit my

1737
01:22:39,880 --> 01:22:37,230
ignorant on all the on some of the

1738
01:22:43,220 --> 01:22:39,890

details objective

1739
01:22:47,480 --> 01:22:43,230
yes good particle physicist to do all

1740
01:22:48,350 --> 01:22:47,490
those diagrams for an hour yeah all

1741
01:22:52,010 --> 01:22:48,360
right

1742
01:22:54,470 --> 01:22:52,020
next month mr. Espinoza will be talking

1743
01:22:56,090 --> 01:22:54,480
about exoplanets you know you're not

1744
01:22:59,150 --> 01:22:56,100
gonna want to me jet that's the first

1745
01:23:02,120 --> 01:22:59,160
Tuesday in March the construction will

1746
01:23:03,950 --> 01:23:02,130
still be going on thank everybody for