PUBLIC LECTURE SERIES

Ashes to Ashes, Dust to Dust: The Fate of Stars like the Sun

Featuring Guest Speaker:

Greg Sloan

1
00:00:11,629 --> 00:00:08,179
good evening ladies and gentlemen and

2
00:00:13,820 --> 00:00:11,639
welcome to the Space Telescope public

3
00:00:15,650 --> 00:00:13,830
lecture series I'm dr. Frank summers of

4
00:00:17,540 --> 00:00:15,660
the ha office of public outreach and is

5
00:00:20,450 --> 00:00:17,550
my pleasure to welcome you each and

6
00:00:22,070 --> 00:00:20,460
every month when you came in if you saw

7
00:00:23,960 --> 00:00:22,080
them on the tables we have our

8
00:00:26,210 --> 00:00:23,970
lithographs our pretty big Hubble

9
00:00:28,609 --> 00:00:26,220
pictures but they're more than just

10
00:00:32,240 --> 00:00:28,619
pretty pictures because on the back we

11
00:00:33,920 --> 00:00:32,250
describe the science behind these images

12
00:00:36,350 --> 00:00:33,930
and give you some of the details of

13
00:00:38,479 --> 00:00:36,360

what's going on ok you didn't grab one

14
00:00:42,500 --> 00:00:38,489
on the way in please catch one on the

15
00:00:45,440 --> 00:00:42,510
way out our speaker tonight

16
00:00:47,119 --> 00:00:45,450
Greg Sloan will be talking on ashes to

17
00:00:51,470 --> 00:00:47,129
ashes dust to dust

18
00:00:53,630 --> 00:00:51,480
the fate of stars like the Sun and when

19
00:00:55,880 --> 00:00:53,640
he scheduled this talk he told me that

20
00:00:57,619 --> 00:00:55,890
you know all these supernovae and

21
00:01:01,010 --> 00:00:57,629
neutron stars and black holes they all

22
00:01:03,049 --> 00:01:01,020
the press but what the real action is

23
00:01:05,780 --> 00:01:03,059
going on is in stars like the Sun and

24
00:01:10,179 --> 00:01:05,790
you'll find that out tonight next month

25
00:01:18,260 --> 00:01:14,060
Katie a lot alow is going to talk on 100

26
00:01:19,520 --> 00:01:18,270
ways to die in the universe ok I'm sure

27
00:01:22,539 --> 00:01:19,530
you're all gonna be interested in that

28
00:01:26,060 --> 00:01:22,549
because hey if it bleeds it leads right

29
00:01:28,969 --> 00:01:26,070
October Gotham Narayan will be speaking

30
00:01:30,740 --> 00:01:28,979
on chasing supernovae with Kepler a

31
00:01:33,890 --> 00:01:30,750
Kepler satellite that was designed to

32
00:01:35,929 --> 00:01:33,900
find extrasolar planets actually can

33
00:01:39,590 --> 00:01:35,939
also be repurposed in its second mission

34
00:01:43,429 --> 00:01:39,600
as k2 mission to finding supernovae out

35
00:01:44,719 --> 00:01:43,439
there and in November which I note will

36
00:01:46,850 --> 00:01:44,729
be on the second Tuesday because

37
00:01:50,270 --> 00:01:46,860
Election Day is the first Tuesday every

38
00:01:51,080 --> 00:01:50,280

other year we push it back so November

39
00:01:53,830 --> 00:01:51,090
13th

40
00:01:57,560 --> 00:01:53,840
Giovanni Bruno will be speaking on

41
00:01:59,749 --> 00:01:57,570
exoplanet atmospheres studying the

42
00:02:02,749 --> 00:01:59,759
atmospheres of planets around other

43
00:02:05,060 --> 00:02:02,759
stars and this is just one of the

44
00:02:07,399 --> 00:02:05,070
coolest ideas we have we actually can

45
00:02:11,330 --> 00:02:07,409
study yeah I miss fears of other planets

46
00:02:12,970 --> 00:02:11,340
yeah details are on our website take

47
00:02:15,040 --> 00:02:12,980
your favorite search engine and put it

48
00:02:17,380 --> 00:02:15,050
public talks or Space Telescope public

49
00:02:20,170 --> 00:02:17,390
lecture series and you'll find this page

50
00:02:23,050 --> 00:02:20,180
where we have our upcoming lectures on

51
00:02:26,619 --> 00:02:23,060
the right side are links to watching it

52
00:02:28,960 --> 00:02:26,629
on live when it's when it's when it is

53
00:02:31,180 --> 00:02:28,970
live or the past lectures all the way

54
00:02:33,370 --> 00:02:31,190
back to 2005

55
00:02:37,020 --> 00:02:33,380
so lots and lots of astronomy on our

56
00:02:40,900 --> 00:02:37,030
page you can also sign up for our

57
00:02:43,479 --> 00:02:40,910
announcement email list the

58
00:02:45,550 --> 00:02:43,489
announcements if you cannot don't like

59
00:02:47,170 --> 00:02:45,560
signing up on the website just give me

60
00:02:50,710 --> 00:02:47,180
your email address and I'll make sure

61
00:02:52,360 --> 00:02:50,720
you are adding to the list if you have

62
00:02:56,979 --> 00:02:52,370
comments or questions you can send email

63
00:03:00,039 --> 00:02:56,989

to public lecture at SSCI you you can

64
00:03:02,440 --> 00:03:00,049
also follow us on social media we have

65
00:03:05,680 --> 00:03:02,450
social media channels for hubble for web

66
00:03:08,259 --> 00:03:05,690
and for the Institute on Facebook

67
00:03:12,819 --> 00:03:08,269
Twitter YouTube and Instagram I do a

68
00:03:19,569 --> 00:03:12,829
tiny amount of social media on Facebook

69
00:03:23,460 --> 00:03:19,579
Google+ and Twitter sometimes I don't

70
00:03:25,960 --> 00:03:23,470
get on air for a week or two anyways

71
00:03:28,240 --> 00:03:25,970
unfortunately if you look at the clouds

72
00:03:30,819 --> 00:03:28,250
on your way in you said hey there's a

73
00:03:33,610 --> 00:03:30,829
lot of them and that means you can't use

74
00:03:35,349 --> 00:03:33,620
the observatory tonight so I talked to

75
00:03:36,910 --> 00:03:35,359
the Maryland space folks and they said

76
00:03:39,039 --> 00:03:36,920
sorry they're not gonna open the

77
00:03:41,319 --> 00:03:39,049
observatory tonight it's a while since

78
00:03:43,629 --> 00:03:41,329
we've actually had a good weather on

79
00:03:46,240 --> 00:03:43,639
these public lecture series hopefully

80
00:03:48,670 --> 00:03:46,250
that will change next month but you

81
00:03:51,460 --> 00:03:48,680
don't have to wait for this you can go

82
00:03:55,210 --> 00:03:51,470
to their web page and the space Margie

83
00:03:57,430 --> 00:03:55,220
and every Friday night they also to look

84
00:04:00,069 --> 00:03:57,440
to open it so if you check their webpage

85
00:04:02,289 --> 00:04:00,079
on Fridays they will tell you whether or

86
00:04:04,180 --> 00:04:02,299
not they're opening it on Fridays now is

87
00:04:07,569 --> 00:04:04,190
a really good time to look at it because

88
00:04:09,789 --> 00:04:07,579

there are several planets that are nice

89
00:04:12,339 --> 00:04:09,799
big and bright in the sky and I'll tell

90
00:04:14,770 --> 00:04:12,349
you about them in just a second all

91
00:04:19,960 --> 00:04:14,780
right because it's now time for news

92
00:04:21,880 --> 00:04:19,970
from the universe August 2018 our only

93
00:04:24,550 --> 00:04:21,890
story for tonight because there's just a

94
00:04:25,750 --> 00:04:24,560
lot of pieces to it is this opposition

95
00:04:29,290 --> 00:04:25,760
up or

96
00:04:30,040 --> 00:04:29,300
tunity now what does opposition mean in

97
00:04:34,090 --> 00:04:30,050
astronomy

98
00:04:37,240 --> 00:04:34,100
well it actually refers to the positions

99
00:04:39,310 --> 00:04:37,250
of the earth and other planets in this

100
00:04:41,920 --> 00:04:39,320
case specifically outer planets planets

101
00:04:45,040 --> 00:04:41,930
outside so if this is where earth is

102
00:04:47,320 --> 00:04:45,050
relative to the Sun when a planet is on

103
00:04:49,450 --> 00:04:47,330
the other side of the Sun in a direct

104
00:04:51,640 --> 00:04:49,460
line that's called conjunction okay

105
00:04:54,250 --> 00:04:51,650
because the planet and the Sun are on

106
00:04:56,890 --> 00:04:54,260
the same point in the sky area in the

107
00:04:59,530 --> 00:04:56,900
sky when it's east directly

108
00:05:02,530 --> 00:04:59,540
perpendicular to the Sun that's called

109
00:05:06,310 --> 00:05:02,540
quadrature but the most exciting point

110
00:05:09,850 --> 00:05:06,320
is when it is directly on line with the

111
00:05:12,280 --> 00:05:09,860
Sun and that's called opposition why is

112
00:05:16,870 --> 00:05:12,290
that exciting because that's what it is

113
00:05:18,970 --> 00:05:16,880

closest to Earth in its orbit okay and

114
00:05:22,060 --> 00:05:18,980
that's when it's closest we're going to

115
00:05:23,710 --> 00:05:22,070
get our best music now if I were

116
00:05:25,600 --> 00:05:23,720
actually teaching a class about this I'd

117
00:05:27,490 --> 00:05:25,610
actually have these things moving around

118
00:05:29,800 --> 00:05:27,500
too because you doesn't stand still

119
00:05:32,050 --> 00:05:29,810
right okay the earth is actually

120
00:05:34,600 --> 00:05:32,060
orbiting and such so it doesn't happen

121
00:05:36,700 --> 00:05:34,610
really uh once per orbit it takes

122
00:05:40,480 --> 00:05:36,710
sometimes a little bit more than an

123
00:05:44,040 --> 00:05:40,490
orbit for this to happen right but the

124
00:05:48,310 --> 00:05:44,050
opportunity this year in 2018 is that

125
00:05:52,420 --> 00:05:48,320
Saturn hit opposition on June 27th 2018

126
00:05:56,800 --> 00:05:52,430
and Mars hit opposition on July 27th

127
00:06:00,160 --> 00:05:56,810
2018 so both Saturn and Mars are really

128
00:06:03,160 --> 00:06:00,170
good viewing this summer okay so of

129
00:06:06,420 --> 00:06:03,170
course who's gonna look at it Oh

130
00:06:10,750 --> 00:06:06,430
Hubble is gonna take a good look and so

131
00:06:14,230 --> 00:06:10,760
Saturn and June I think we took this

132
00:06:20,290 --> 00:06:14,240
picture in late May and we got a great

133
00:06:25,860 --> 00:06:20,300
picture of Saturn here and this folks

134
00:06:31,059 --> 00:06:28,960
this is one of the best pictures Hubble

135
00:06:33,219 --> 00:06:31,069
has ever gotten of Saturn

136
00:06:35,409 --> 00:06:33,229
you know the detectors are better but

137
00:06:37,059 --> 00:06:35,419
it's also one it's one of the cool

138
00:06:39,279 --> 00:06:37,069

things about it is the first time I

139
00:06:42,010 --> 00:06:39,289
remember seeing a very particular

140
00:06:44,170 --> 00:06:42,020
feature on Saturn that Hubble has never

141
00:06:47,499 --> 00:06:44,180
observed before am i in my recollection

142
00:06:50,760 --> 00:06:47,509
right in here in the North Pole you see

143
00:06:55,330 --> 00:06:50,770
this strange storm system it actually

144
00:06:57,339 --> 00:06:55,340
forms a hexagon okay let me take that

145
00:07:00,969 --> 00:06:57,349
graphic off can you see the hexagon

146
00:07:04,270 --> 00:07:00,979
there this hexagon was observed by

147
00:07:08,260 --> 00:07:04,280
Voyager okay like four years ago and

148
00:07:12,339 --> 00:07:08,270
it's still there this is a stable system

149
00:07:16,240 --> 00:07:12,349
on the North Pole of Saturn and you want

150
00:07:18,129 --> 00:07:16,250
to know what we don't truly know how it

151
00:07:19,959 --> 00:07:18,139
forms okay we understand that there's

152
00:07:23,559 --> 00:07:19,969
some resonances in the winds and

153
00:07:25,179 --> 00:07:23,569
everything a hexagon we can do sort of

154
00:07:28,089 --> 00:07:25,189
things we'll have to explain it but it

155
00:07:29,619 --> 00:07:28,099
doesn't we don't quite have everything

156
00:07:33,070 --> 00:07:29,629
we need to know to fully understand this

157
00:07:34,570 --> 00:07:33,080
this is a really cool pattern and this

158
00:07:38,559 --> 00:07:34,580
is the first time I remember seeing it

159
00:07:43,420 --> 00:07:38,569
in any Hubble image one of the so here

160
00:07:45,969 --> 00:07:43,430
is a movie zooming into Saturn we took

161
00:07:48,790 --> 00:07:45,979
several shots of Saturn and you can see

162
00:07:53,559 --> 00:07:48,800
the cloud orbiting around the North Pole

163
00:07:57,550 --> 00:07:53,569

there in that ring so I think there's

164
00:07:59,140 --> 00:07:57,560
like six or eight images here and you

165
00:08:02,529 --> 00:07:59,150
can see that that cloud just at the edge

166
00:08:05,800 --> 00:08:02,539
of the North Pole it repeats this is not

167
00:08:09,990 --> 00:08:05,810
it's not walking those loops so we added

168
00:08:14,079 --> 00:08:10,000
some details of Saturn's North Pole so

169
00:08:16,899 --> 00:08:14,089
Mars also reached opposition there sorry

170
00:08:19,329 --> 00:08:16,909
I forgot this one of the reasons why we

171
00:08:21,459 --> 00:08:19,339
can see more detail in this image then

172
00:08:24,070 --> 00:08:21,469
we can see in other ones is that these

173
00:08:26,589 --> 00:08:24,080
were done with an arrow ban images okay

174
00:08:27,459 --> 00:08:26,599
so the narrow band filters here are

175
00:08:33,219 --> 00:08:27,469
listed up here

176
00:08:36,670 --> 00:08:33,229
the blue is f3 95n the green is 502 N

177
00:08:40,329 --> 00:08:36,680
and the red is 631 n that entity

178
00:08:42,159 --> 00:08:40,339
it stands for narrowband okay so it's a

179
00:08:44,920 --> 00:08:42,169
narrow band of wavelengths so it's

180
00:08:47,500 --> 00:08:44,930
looking at very specific emission from

181
00:08:49,690 --> 00:08:47,510
Saturn which allows us to see more

182
00:08:51,940 --> 00:08:49,700
detail if we just took broadband

183
00:08:53,860 --> 00:08:51,950
wideband filters of red green and blue

184
00:08:54,370 --> 00:08:53,870
we really wouldn't see this kind of

185
00:08:56,850 --> 00:08:54,380
detail

186
00:08:59,710 --> 00:08:56,860
I mean Saturn is actually kind of boring

187
00:09:14,500 --> 00:08:59,720
when you look at with just RGB features

188
00:09:17,860 --> 00:09:14,510

but the Opel program so I'm told that

189
00:09:25,079 --> 00:09:17,870
the microphone is not doing wonders and

190
00:09:33,220 --> 00:09:30,100
okay all right so we're talking about

191
00:09:35,829 --> 00:09:33,230
the Opel program and using these narrow

192
00:09:39,400 --> 00:09:35,839
band filters you're able to see more

193
00:09:41,980 --> 00:09:39,410
detail on Saturn and what Hubble

194
00:09:46,360 --> 00:09:41,990
provides that other missions don't is

195
00:09:48,160 --> 00:09:46,370
this 20-year 30-year lifespan in terms

196
00:09:49,329 --> 00:09:48,170
of taking look at Saturn and seeing

197
00:09:51,400 --> 00:09:49,339
things over time

198
00:09:54,020 --> 00:09:51,410
so this Opel program is this better

199
00:10:00,660 --> 00:09:54,030
system up is that it getting in the way

200
00:10:11,350 --> 00:10:07,239
okay maybe that was the problem

201
00:10:14,109 --> 00:10:11,360
he had multiple yes he does not votes by

202
00:10:16,210 --> 00:10:14,119
the way was grant justice okay who

203
00:10:17,859 --> 00:10:16,220
obviously was monitoring the sound and

204
00:10:21,039 --> 00:10:17,869
saying hey something's wrong with the

205
00:10:25,650 --> 00:10:21,049
sound and having multiple things no it

206
00:10:33,609 --> 00:10:31,900
totally lost track all right so we got

207
00:10:36,009 --> 00:10:33,619
these pictures we can see all sorts of

208
00:10:40,119 --> 00:10:36,019
cool detail plus as you can see in this

209
00:10:42,030 --> 00:10:40,129
we have six of Saturn's moons in this

210
00:10:44,410 --> 00:10:42,040
image and if you go to our website

211
00:10:46,809 --> 00:10:44,420
there's actually a small animation that

212
00:10:49,660 --> 00:10:46,819
takes those six or eight images and

213
00:10:51,609 --> 00:10:49,670

follows the moons as they orbit around -

214
00:10:52,660 --> 00:10:51,619
alright so that's something you can find

215
00:10:58,269 --> 00:10:52,670
on our website

216
00:11:00,639 --> 00:10:58,279
ah let's go to Mars okay now Mars has a

217
00:11:03,639 --> 00:11:00,649
somewhat elliptical orbit okay

218
00:11:06,460 --> 00:11:03,649
Saturn's orbit is relatively circular

219
00:11:09,189 --> 00:11:06,470
Mars is somewhat elliptical so that the

220
00:11:11,350 --> 00:11:09,199
distance between Earth and Mars changes

221
00:11:13,689 --> 00:11:11,360
at different opposition's and you can

222
00:11:17,769 --> 00:11:13,699
see it in this illustration from 1995

223
00:11:19,989 --> 00:11:17,779
through to 2005 this shows the apparent

224
00:11:22,720 --> 00:11:19,999
size of Mars the relative apparent size

225
00:11:24,309 --> 00:11:22,730
of Mars at these opposition's which you

226
00:11:26,229 --> 00:11:24,319
can see occur roughly every two years

227
00:11:30,460 --> 00:11:26,239
okay

228
00:11:33,819 --> 00:11:30,470
and this year's opposition 2018 is the

229
00:11:36,699 --> 00:11:33,829
largest appearance of Mars since this

230
00:11:38,639 --> 00:11:36,709
really big one in 2003 the one in 2003

231
00:11:41,590 --> 00:11:38,649
they tell me was the largest in like

232
00:11:44,049 --> 00:11:41,600
60,000 years okay so that was a really

233
00:11:45,280 --> 00:11:44,059
big one this one isn't quite as big but

234
00:11:47,850 --> 00:11:45,290
it's larger one so we're really looking

235
00:11:50,650 --> 00:11:47,860
forward to it

236
00:11:55,090 --> 00:11:50,660
unfortunately Mars didn't really

237
00:11:57,699 --> 00:11:55,100
cooperate it looks kind of fuzzy right

238
00:12:00,850 --> 00:11:57,709

well that's what happens on Mars

239
00:12:02,259 --> 00:12:00,860
sometimes you get global dust storms on

240
00:12:04,779 --> 00:12:02,269
Mars

241
00:12:07,419 --> 00:12:04,789
and about a month before opposition

242
00:12:09,819 --> 00:12:07,429
there was a serious global dust storm

243
00:12:10,120 --> 00:12:09,829
and actually pictures from about a month

244
00:12:12,190 --> 00:12:10,130
before

245
00:12:14,140 --> 00:12:12,200
opposition were much fuzzier than this

246
00:12:16,900 --> 00:12:14,150
it actually cleared up a little bit by

247
00:12:18,640 --> 00:12:16,910
the time Hubble took their images so in

248
00:12:22,000 --> 00:12:18,650
order to understand features on Mars we

249
00:12:24,880 --> 00:12:22,010
have to give you the annotation notice

250
00:12:28,060 --> 00:12:24,890
we also got Phobos and Deimos Mars two

251
00:12:30,190 --> 00:12:28,070
little moons in there but here's the

252
00:12:31,780 --> 00:12:30,200
helis basin in which you can see the

253
00:12:33,490 --> 00:12:31,790
dust storm is totally filling the hell

254
00:12:35,140 --> 00:12:33,500
of space and that's a giant impact

255
00:12:37,960 --> 00:12:35,150
crater one of the largest impact craters

256
00:12:40,750 --> 00:12:37,970
in the solar system and you've got

257
00:12:42,430 --> 00:12:40,760
Arabia Terra this by the way is they

258
00:12:44,320 --> 00:12:42,440
they marked where the oppertunity lander

259
00:12:47,220 --> 00:12:44,330
is and of course you have the north

260
00:12:50,920 --> 00:12:47,230
polar cap and the southern polar cap

261
00:12:54,730 --> 00:12:50,930
here so unfortunately Mars didn't

262
00:12:58,660 --> 00:12:54,740
cooperate you can sort of see the same

263
00:13:00,790 --> 00:12:58,670

features in the 2016 opposition image

264
00:13:04,810 --> 00:13:00,800
all right you can see this region here

265
00:13:07,180 --> 00:13:04,820
in the middle of 2016 and over on the

266
00:13:10,510 --> 00:13:07,190
left over here but you can't quite make

267
00:13:13,750 --> 00:13:10,520
it out so we created a little video to

268
00:13:16,510 --> 00:13:13,760
show you so here's the 2016 opposition

269
00:13:19,260 --> 00:13:16,520
alright and now we're gonna crossfade to

270
00:13:22,300 --> 00:13:19,270
a computer model from the Viking images

271
00:13:25,960 --> 00:13:22,310
alright we're gonna rotate that Viking

272
00:13:28,560 --> 00:13:25,970
model image just to show you all right

273
00:13:32,170 --> 00:13:28,570
there's the orientation for the 2018

274
00:13:34,360 --> 00:13:32,180
opposition and there's the image we got

275
00:13:36,160 --> 00:13:34,370
from it alright so that helps you

276
00:13:40,810 --> 00:13:36,170
understand yeah the features are there

277
00:13:46,290 --> 00:13:40,820
they're just sort of buried okay however

278
00:13:48,460 --> 00:13:46,300
it could be worse Hey just to show you

279
00:13:51,070 --> 00:13:48,470
testing this and a comparison is the

280
00:13:54,490 --> 00:13:51,080
same size on the right I've added in the

281
00:13:56,530 --> 00:13:54,500
2001 global dust storm actually during

282
00:13:59,500 --> 00:13:56,540
opposition Mars was relatively clear

283
00:14:01,450 --> 00:13:59,510
during 2001 but three months later in

284
00:14:03,130 --> 00:14:01,460
2001 we got a picture of a real global

285
00:14:05,710 --> 00:14:03,140
dust storm which shows you just how

286
00:14:08,050 --> 00:14:05,720
fuzzy Mars can get so we didn't get the

287
00:14:10,290 --> 00:14:08,060
clearest view of Mars but we didn't get

288
00:14:12,370 --> 00:14:10,300

the fuzziest view view of Mars alright

289
00:14:14,920 --> 00:14:12,380
and if you go to our website you

290
00:14:17,710 --> 00:14:14,930
actually we also have another video of

291
00:14:19,300 --> 00:14:17,720
Mars where you see Phobos and Deimos do

292
00:14:22,150 --> 00:14:19,310
a little bit of their dance around Mars

293
00:14:23,860 --> 00:14:22,160
yeah and that is our opposition

294
00:14:28,930 --> 00:14:23,870
opportunity and our new

295
00:14:43,200 --> 00:14:28,940
for August 2008 II any questions that I

296
00:14:47,320 --> 00:14:43,210
can answer yes the I'm not an expert on

297
00:14:50,019 --> 00:14:47,330
atmospheric circulation of Mars but I

298
00:14:52,540 --> 00:14:50,029
believe that if you look at the center

299
00:14:54,490 --> 00:14:52,550
image here versus the right image you

300
00:14:56,530 --> 00:14:54,500
can see that it is somewhat fuzzy over

301
00:14:59,440 --> 00:14:56,540
the poles but you've got a lot of

302
00:15:01,840 --> 00:14:59,450
reflectivity in the ices which makes

303
00:15:04,660 --> 00:15:01,850
them shine through okay Mars's

304
00:15:07,090 --> 00:15:04,670
atmosphere is 1/100 the thickness of

305
00:15:08,980 --> 00:15:07,100
Earth's atmosphere so it's not like a

306
00:15:10,810 --> 00:15:08,990
Venusian atmosphere where you know when

307
00:15:12,760 --> 00:15:10,820
it gets when it gets dusty you can't see

308
00:15:16,060 --> 00:15:12,770
through it or the haze layer on

309
00:15:18,220 --> 00:15:16,070
untighten it's even though it's fully

310
00:15:21,040 --> 00:15:18,230
hazy you can still see through it it's

311
00:15:22,840 --> 00:15:21,050
still a bit transparent so basically it

312
00:15:24,700 --> 00:15:22,850
adds a tinge to the color on the poles

313
00:15:26,400 --> 00:15:24,710

but it doesn't completely block out the

314
00:15:40,540 --> 00:15:26,410
poles good question

315
00:15:44,260 --> 00:15:40,550
alright one more the return of the

316
00:15:45,640 --> 00:15:44,270
microphone I'm gonna put that just to

317
00:15:45,910 --> 00:15:45,650
the side just so it doesn't get all

318
00:15:48,250 --> 00:15:45,920
right

319
00:15:52,150 --> 00:15:48,260
so you are correct yes the Rovers on

320
00:15:55,329 --> 00:15:52,160
Mars when a global dust storm they use

321
00:15:57,940 --> 00:15:55,339
solar energy right and they when a

322
00:16:01,180 --> 00:15:57,950
global dust storm hits they have to shut

323
00:16:02,860 --> 00:16:01,190
down okay and then in order to restart

324
00:16:05,710 --> 00:16:02,870
them they actually have to shake the

325
00:16:07,570 --> 00:16:05,720
dust off of it so if you can think of

326
00:16:10,240 --> 00:16:07,580
those little Rovers sort of shaking like

327
00:16:11,650 --> 00:16:10,250
a dog getting water off of it right they

328
00:16:13,360 --> 00:16:11,660
actually had to had to program the

329
00:16:15,520 --> 00:16:13,370
wheels to go forward and back forward

330
00:16:16,900 --> 00:16:15,530
and back to try and shake it to get the

331
00:16:19,480 --> 00:16:16,910
dust off so they could recharge the

332
00:16:20,980 --> 00:16:19,490
batteries obviously they were they've

333
00:16:23,050 --> 00:16:20,990
been successful because there have been

334
00:16:25,660 --> 00:16:23,060
several of those global dust storms

335
00:16:28,900 --> 00:16:25,670
while we've had Rovers on Mars and they

336
00:16:30,100 --> 00:16:28,910
all seem to have come back and worked so

337
00:16:32,050 --> 00:16:30,110
yeah that's a good point

338
00:16:35,260 --> 00:16:32,060

all right okay

339
00:16:39,160 --> 00:16:35,270
let's move to our featured speaker

340
00:16:42,280 --> 00:16:39,170
tonight I'm excited to hear from our

341
00:16:47,590 --> 00:16:42,290
speaker tonight well hold on I have to

342
00:16:50,560 --> 00:16:47,600
figure out this there we go our speaker

343
00:16:52,690 --> 00:16:50,570
tonight is Greg Sloan

344
00:16:55,480 --> 00:16:52,700
he has been here at the Space Telescope

345
00:16:57,580 --> 00:16:55,490
Science Institute for two years well

346
00:16:59,620 --> 00:16:57,590
he's sort of half here he also has an

347
00:17:02,560 --> 00:16:59,630
adjunct position at UNC Chapel Hill

348
00:17:04,720 --> 00:17:02,570
right so half of his time is spent down

349
00:17:08,260 --> 00:17:04,730
there he teaches down at UNC Chapel Hill

350
00:17:12,190 --> 00:17:08,270
he comes to us from Cornell University

351
00:17:14,440 --> 00:17:12,200
where he worked for 15 years on the

352
00:17:17,860 --> 00:17:14,450
infrared instruments for the Spitzer

353
00:17:20,440 --> 00:17:17,870
Space Telescope so I have a very hard

354
00:17:23,050 --> 00:17:20,450
time imagining anyone more qualified to

355
00:17:25,300 --> 00:17:23,060
come here and work on the mid-infrared

356
00:17:27,370 --> 00:17:25,310
instrument the Miri instrument of James

357
00:17:30,190 --> 00:17:27,380
Webb Space Telescope than someone who's

358
00:17:32,500 --> 00:17:30,200
been working on Spitzer for 15 years it

359
00:17:35,110 --> 00:17:32,510
is one of these great things within NASA

360
00:17:38,470 --> 00:17:35,120
that we can take the infrared knowledge

361
00:17:40,900 --> 00:17:38,480
get learned in the Spitzer mission and

362
00:17:44,290 --> 00:17:40,910
bring it and apply it to the James Webb

363
00:17:45,880 --> 00:17:44,300

mission and I'm sure that the folks here

364
00:17:49,570 --> 00:17:45,890
are just absolutely ecstatic to have you

365
00:17:50,570 --> 00:17:49,580
on board ladies and gentlemen mr. Greg

366
00:17:59,520 --> 00:17:50,580
Sloan

367
00:18:25,990 --> 00:17:59,530
[Applause]

368
00:18:27,100 --> 00:18:26,000
come on I think it wants my password all

369
00:18:29,500 --> 00:18:27,110
right well those are very flattering

370
00:18:31,930 --> 00:18:29,510
comments I have to point out that

371
00:18:34,030 --> 00:18:31,940
there's a lot of people from Spitzer

372
00:18:36,250 --> 00:18:34,040
mission here now working on the

373
00:18:39,490 --> 00:18:36,260
mid-infrared instrument so it's kind of

374
00:18:42,970 --> 00:18:39,500
nice to be back amongst fellow combat

375
00:18:46,330 --> 00:18:42,980
veterans from a previous mission I'm

376
00:18:48,159 --> 00:18:46,340
just one of many I actually I haven't

377
00:18:50,500 --> 00:18:48,169
been teaching too much at UNC Chapel

378
00:18:54,520 --> 00:18:50,510
Hill I just go down there to get a rest

379
00:18:56,260 --> 00:18:54,530
from the intense work here which follows

380
00:19:00,010 --> 00:18:56,270
me down I might add so I'm pretty much

381
00:19:01,680 --> 00:19:00,020
working full full on doing J abuse t

382
00:19:04,360 --> 00:19:01,690
stuff down there when I'm when I'm there

383
00:19:06,549 --> 00:19:04,370
alright so tonight I'm going to talk a

384
00:19:10,360 --> 00:19:06,559
little bit about the the fate of stars

385
00:19:14,650 --> 00:19:10,370
like the Sun I have this poetic Prelude

386
00:19:15,970 --> 00:19:14,660
here so I think that people that do this

387
00:19:17,919 --> 00:19:15,980
kind of research have a little bit of an

388
00:19:20,370 --> 00:19:17,929

inferiority complex because astronomy to

389
00:19:23,130 --> 00:19:20,380
a lot of people consists of three things

390
00:19:25,180 --> 00:19:23,140
exoplanets high redshift universe and

391
00:19:27,760 --> 00:19:25,190
supernovae and this is none of those

392
00:19:29,500 --> 00:19:27,770
things so I'm really flattered to see

393
00:19:30,669 --> 00:19:29,510
such a great turnout tonight and people

394
00:19:32,950 --> 00:19:30,679
decided to brave leaving their

395
00:19:35,320 --> 00:19:32,960
air-conditioning behind to come here and

396
00:19:36,870 --> 00:19:35,330
it's cloudy to boots so anyway let's get

397
00:19:40,180 --> 00:19:36,880
on with it

398
00:19:43,480 --> 00:19:40,190
also if you look at your handout you'll

399
00:19:45,190 --> 00:19:43,490
see that in order to add nice pictures

400
00:19:46,690 --> 00:19:45,200
to otherwise boring words on my slides

401
00:19:47,830 --> 00:19:46,700
I've tried to steal as many Hubble

402
00:19:49,659 --> 00:19:47,840
images as I can so you could follow

403
00:19:55,900 --> 00:19:49,669
along and you can see if I got the

404
00:19:58,870 --> 00:19:55,910
captions right on the back all right so

405
00:20:00,580 --> 00:19:58,880
the talk starts with a periodic table of

406
00:20:02,530 --> 00:20:00,590
elements so you can see this is a really

407
00:20:05,080 --> 00:20:02,540
nice table I pulled off of the Internet

408
00:20:08,180 --> 00:20:05,090
I didn't I forgot to put the source down

409
00:20:09,889 --> 00:20:08,190
here which is very bad of me

410
00:20:11,810 --> 00:20:09,899
but what I want to say this is really

411
00:20:13,580 --> 00:20:11,820
nice it's very complex to an astronomer

412
00:20:19,299 --> 00:20:13,590
there's a simpler version of this

413
00:20:24,440 --> 00:20:19,309

periodic table it looks like this okay

414
00:20:26,240 --> 00:20:24,450
so we have in one corner we have

415
00:20:28,100 --> 00:20:26,250
hydrogen and then in the other corner we

416
00:20:31,970 --> 00:20:28,110
have helium and everything else to an

417
00:20:33,379 --> 00:20:31,980
astronomer is just a metal but there's a

418
00:20:34,820 --> 00:20:33,389
bit more to it than that because when

419
00:20:36,590 --> 00:20:34,830
the universe formed except for a little

420
00:20:38,480 --> 00:20:36,600
bit of lithium to just confuse the story

421
00:20:40,700 --> 00:20:38,490
the universe was just hydrogen and

422
00:20:43,879 --> 00:20:40,710
helium and everything else all these

423
00:20:46,879 --> 00:20:43,889
metals come from stars so I think we've

424
00:20:48,200 --> 00:20:46,889
all heard the the great Carl Sagan quote

425
00:20:50,600 --> 00:20:48,210
that we're all just made of star stuff

426
00:20:53,060 --> 00:20:50,610
well this is this is not poetic it's

427
00:20:56,090 --> 00:20:53,070
absolutely true and so what I have here

428
00:20:59,539 --> 00:20:56,100
is a graph of abundances this is a log

429
00:21:01,490 --> 00:20:59,549
plot so every from here from six to

430
00:21:03,080 --> 00:21:01,500
eight is a factor of 100 those are the

431
00:21:04,639 --> 00:21:03,090
abundances in the order of the atomic

432
00:21:06,470 --> 00:21:04,649
number of the elements you can see

433
00:21:08,450 --> 00:21:06,480
there's a nice zig-zag pattern here

434
00:21:09,980 --> 00:21:08,460
where every all the even numbers have a

435
00:21:11,450 --> 00:21:09,990
bit more abundance compared to the odd

436
00:21:13,220 --> 00:21:11,460
one so I'll explain that in just a sec

437
00:21:15,320 --> 00:21:13,230
and then over here for people that

438
00:21:17,360 --> 00:21:15,330

really can't stand figures like this I

439
00:21:18,830 --> 00:21:17,370
just sort of laid it out as a table so

440
00:21:20,810 --> 00:21:18,840
you can see that very quickly hydrogen

441
00:21:22,909 --> 00:21:20,820
is 90% of the universe this is by number

442
00:21:25,279 --> 00:21:22,919
I think that Frank had put a slide up a

443
00:21:26,509 --> 00:21:25,289
couple of months ago that was by mass so

444
00:21:29,360 --> 00:21:26,519
the number is a little bit different but

445
00:21:30,889 --> 00:21:29,370
it's about 91 percent hydrogen most

446
00:21:34,070 --> 00:21:30,899
everything else that's left is helium

447
00:21:37,070 --> 00:21:34,080
oxygen weighs in at a hefty 1/2 a

448
00:21:39,049 --> 00:21:37,080
percent and then it's just downhill from

449
00:21:41,060 --> 00:21:39,059
there carbon is next and then you know

450
00:21:43,730 --> 00:21:41,070
at one tenth of a percent nitrogen is

451
00:21:45,320 --> 00:21:43,740
just ahead of Neil neon and then from

452
00:21:47,389 --> 00:21:45,330
there it just plummets quickly and then

453
00:21:50,029 --> 00:21:47,399
you can see this so basically in green

454
00:21:51,649 --> 00:21:50,039
right here that's what the primordial

455
00:21:54,590 --> 00:21:51,659
abundance is a universe looked like

456
00:21:57,049 --> 00:21:54,600
right after the Big Bang and this is the

457
00:21:58,669 --> 00:21:57,059
plot now so all of this all this blue

458
00:22:04,549 --> 00:21:58,679
stuff here everything above the the

459
00:22:06,350 --> 00:22:04,559
green that's all made by stars so

460
00:22:08,419 --> 00:22:06,360
farmers since since everything

461
00:22:10,720 --> 00:22:08,429
University of hydrogen helium is a metal

462
00:22:12,799 --> 00:22:10,730
we'd like to talk about metallicity

463
00:22:14,180 --> 00:22:12,809

which is just the abundance of

464
00:22:15,980 --> 00:22:14,190
everything that isn't hydrogen and

465
00:22:19,039 --> 00:22:15,990
helium or the abundance of everything

466
00:22:20,749 --> 00:22:19,049
it's made by stars so I'll be using that

467
00:22:22,000 --> 00:22:20,759
word a lot metallicity I'm just I have

468
00:22:26,980 --> 00:22:22,010
to that that piece of

469
00:22:29,800 --> 00:22:26,990
jargon I cannot drop I apologize okay

470
00:22:32,050 --> 00:22:29,810
so our first pop quiz question for the

471
00:22:36,120 --> 00:22:32,060
day and I because we don't have car talk

472
00:22:39,310 --> 00:22:36,130
anymore I adopted their enumeration so

473
00:22:41,050 --> 00:22:39,320
what is a star so how many people whole

474
00:22:43,150 --> 00:22:41,060
Justin will go through this and so one

475
00:22:45,250 --> 00:22:43,160
if you agree with one raise your hand

476
00:22:47,050 --> 00:22:45,260
something that shines which means it

477
00:22:48,490 --> 00:22:47,060
emits more energy than it then it

478
00:22:52,120 --> 00:22:48,500
absorbs let's see some hands here and

479
00:22:54,070 --> 00:22:52,130
people go for one okay definition of the

480
00:22:57,520 --> 00:22:54,080
star that's a few Pele it's like what a

481
00:22:59,980 --> 00:22:57,530
quarter of us let's go for be something

482
00:23:04,030 --> 00:22:59,990
undergoing nuclear fusion reactions in

483
00:23:05,680 --> 00:23:04,040
its core there we go so that seems to be

484
00:23:08,520 --> 00:23:05,690
I think that's already the winner and

485
00:23:16,170 --> 00:23:08,530
then and then Roman numeral three and

486
00:23:22,240 --> 00:23:18,400
but I see that I'm not on the winning

487
00:23:25,210 --> 00:23:22,250
side so one is not so good because

488
00:23:28,030 --> 00:23:25,220

actually Jupiter emits in the radio

489
00:23:28,990 --> 00:23:28,040
quite a bit of energy oh yeah and I

490
00:23:31,000 --> 00:23:29,000
actually had an answer for the question

491
00:23:33,610 --> 00:23:31,010
that they were gonna come back to on the

492
00:23:35,890 --> 00:23:33,620
rogue planet that's 20 light years away

493
00:23:38,200 --> 00:23:35,900
it's in the news because they picked it

494
00:23:39,730 --> 00:23:38,210
up it was discovered in 2016 I think and

495
00:23:43,480 --> 00:23:39,740
I forget by who I don't know that story

496
00:23:45,850 --> 00:23:43,490
but they picked it up with the VLA The

497
00:23:47,590 --> 00:23:45,860
Very Large Array radio they picked up

498
00:23:50,590 --> 00:23:47,600
the irori that it must be given a really

499
00:23:52,090 --> 00:23:50,600
strong magnetic field yeah so Jupiter

500
00:23:54,850 --> 00:23:52,100
doesn't send Jupiter emits a lot in the

501
00:23:57,280 --> 00:23:54,860
radio and in midst in the foreign for

502
00:24:00,040 --> 00:23:57,290
red so Jupiter would qualify as a planet

503
00:24:02,200 --> 00:24:00,050
by number one but it isn't a star by

504
00:24:05,290 --> 00:24:02,210
number one but it isn't so B is

505
00:24:08,250 --> 00:24:05,300
certainly good I like three because the

506
00:24:11,260 --> 00:24:08,260
the real point is that the moment that a

507
00:24:13,650 --> 00:24:11,270
star starts to form which means the

508
00:24:15,580 --> 00:24:13,660
moment that an interstellar cloud is

509
00:24:19,150 --> 00:24:15,590
compressed just enough to be

510
00:24:22,690 --> 00:24:19,160
self-gravitating from that point on that

511
00:24:25,330 --> 00:24:22,700
poor object is doomed it is eventually

512
00:24:28,210 --> 00:24:25,340
going to wind up as a degenerate object

513
00:24:30,220 --> 00:24:28,220

either a white dwarf imagine half the

514
00:24:33,100 --> 00:24:30,230
mass the Sun packed into an object the

515
00:24:35,860 --> 00:24:33,110
size of the earth that's a white dwarf

516
00:24:38,799 --> 00:24:35,870
or a neutron star I'm at

517
00:24:40,659 --> 00:24:38,809
an object the size of the mass of the

518
00:24:43,419 --> 00:24:40,669
Sun packed into something the size of

519
00:24:47,680 --> 00:24:43,429
Baltimore you know or a black hole

520
00:24:48,940 --> 00:24:47,690
imagine something smaller right so

521
00:24:50,799 --> 00:24:48,950
that's what's gonna happen so basically

522
00:24:52,810 --> 00:24:50,809
all these things all these stars that we

523
00:24:58,720 --> 00:24:52,820
see they're just at some stage of that

524
00:25:00,970 --> 00:24:58,730
battle and they're gonna lose so here's

525
00:25:02,350 --> 00:25:00,980
their fates I apologize in advance I

526
00:25:07,779 --> 00:25:02,360
realized I was going through this today

527
00:25:09,279 --> 00:25:07,789
this is my busiest slide anyway so we

528
00:25:13,180 --> 00:25:09,289
have this broken up into three masked

529
00:25:15,460 --> 00:25:13,190
categories if it's 25 solar masses are

530
00:25:18,789 --> 00:25:15,470
up so 25 times the mass of the Sun or up

531
00:25:20,919 --> 00:25:18,799
and that's a really rough number because

532
00:25:23,860 --> 00:25:20,929
we don't really know it might be 30 it

533
00:25:27,970 --> 00:25:23,870
might be 40 if it's really Hawking big

534
00:25:31,060 --> 00:25:27,980
to use the technical term it will become

535
00:25:32,799 --> 00:25:31,070
a black hole but I shouldn't say it the

536
00:25:33,480 --> 00:25:32,809
core of that star will become a black

537
00:25:36,279 --> 00:25:33,490
hole

538
00:25:37,630 --> 00:25:36,289

90% of the star will be dispersed back

539
00:25:39,730 --> 00:25:37,640
out into space back into the

540
00:25:41,950 --> 00:25:39,740
interstellar medium but the core of the

541
00:25:43,360 --> 00:25:41,960
star would become a black hole I think

542
00:25:45,490 --> 00:25:43,370
the core has to be about three solar

543
00:25:48,279 --> 00:25:45,500
masses or so and then it's it's it's

544
00:25:49,600 --> 00:25:48,289
that's enough mass to overcome any force

545
00:25:51,730 --> 00:25:49,610
that we can think of that would that

546
00:25:53,769 --> 00:25:51,740
would hold this object up if it's

547
00:25:56,080 --> 00:25:53,779
between some number we don't really know

548
00:25:58,600 --> 00:25:56,090
8 to 10 solar masses it's kind of the

549
00:26:01,090 --> 00:25:58,610
bottom into the range and up to 25 where

550
00:26:03,279 --> 00:26:01,100
I said 30 if it's in that range it will

551
00:26:05,560 --> 00:26:03,289
go supernova got all the headlines get

552
00:26:09,760 --> 00:26:05,570
all the attention make me very envious

553
00:26:11,740 --> 00:26:09,770
and it will become a neutron star so I'm

554
00:26:13,690 --> 00:26:11,750
focused on the objects that are less

555
00:26:15,220 --> 00:26:13,700
than 8 to 10 solar masses those are the

556
00:26:17,529 --> 00:26:15,230
oh yeah here's a picture of a supernova

557
00:26:19,210 --> 00:26:17,539
this is supernova 1987a there's a

558
00:26:20,740 --> 00:26:19,220
picture of some fun things happening

559
00:26:22,810 --> 00:26:20,750
around a black hole please don't ask me

560
00:26:24,130 --> 00:26:22,820
what they were because I just thought

561
00:26:29,169 --> 00:26:24,140
that was a pretty picture that's about

562
00:26:32,080 --> 00:26:29,179
all I know sorry but if it's 8 to 10

563
00:26:35,560 --> 00:26:32,090

solar masses or less or less than that

564
00:26:37,029 --> 00:26:35,570
it will become a planetary nebula lots

565
00:26:40,720 --> 00:26:37,039
of good planetary neighborhood pictures

566
00:26:41,950 --> 00:26:40,730
on the handout and a white and the core

567
00:26:45,970 --> 00:26:41,960
of that star will become a white dwarf

568
00:26:47,649 --> 00:26:45,980
in the case of the Sun the the white

569
00:26:49,000 --> 00:26:47,659
dwarf will about have about half of the

570
00:26:49,379 --> 00:26:49,010
mass of the Sun and the other half of

571
00:26:51,329 --> 00:26:49,389
the Sun

572
00:26:55,229 --> 00:26:51,339
maths will be ejected back into space

573
00:26:56,639 --> 00:26:55,239
and at the upper end of this range 90%

574
00:26:59,789 --> 00:26:56,649
of the mass of the star will get ejected

575
00:27:01,739 --> 00:26:59,799
back into space but it's not just the

576
00:27:02,869 --> 00:27:01,749
well we'll get to that so let me let me

577
00:27:05,519 --> 00:27:02,879
just keep going

578
00:27:06,509 --> 00:27:05,529
so how does stars hold themselves up

579
00:27:09,239 --> 00:27:06,519
while they're doing it

580
00:27:11,940 --> 00:27:09,249
well they do it by nuclear reactions by

581
00:27:13,499 --> 00:27:11,950
fusion reactions I just sort of I know

582
00:27:15,599 --> 00:27:13,509
you guys didn't really come here for a

583
00:27:17,729 --> 00:27:15,609
lesson in nuclear physics so it's just

584
00:27:20,249 --> 00:27:17,739
the one slide but I just want to sort of

585
00:27:22,529 --> 00:27:20,259
review this just really quickly the

586
00:27:24,180 --> 00:27:22,539
basic reaction is hydrogen fusion now

587
00:27:26,339 --> 00:27:24,190
there's a lot more to it than just this

588
00:27:29,399 --> 00:27:26,349

you basically take four protons four

589
00:27:31,379 --> 00:27:29,409
hydrogen nuclei and through a few

590
00:27:32,940 --> 00:27:31,389
backflips and contortions and a few

591
00:27:36,749 --> 00:27:32,950
other reactions you wind up with a

592
00:27:38,459 --> 00:27:36,759
helium nucleus this guy right it's it's

593
00:27:41,089 --> 00:27:38,469
ionized so there's no electrons just

594
00:27:43,469 --> 00:27:41,099
just this alpha particle two positrons

595
00:27:45,839 --> 00:27:43,479
some neutrinos I don't remember how many

596
00:27:47,549 --> 00:27:45,849
think two but yeah because of the

597
00:27:49,229 --> 00:27:47,559
positrons and then a whole bunch of

598
00:27:52,560 --> 00:27:49,239
energy which is the point to the

599
00:27:55,440 --> 00:27:52,570
reaction and so the Sun is fusing

600
00:27:56,849 --> 00:27:55,450
hydrogen to helium in its core and it

601
00:27:59,129 --> 00:27:56,859
can keep doing that until it starts to

602
00:28:00,409 --> 00:27:59,139
run out of hydrogen and then things get

603
00:28:03,149 --> 00:28:00,419
interesting

604
00:28:04,739 --> 00:28:03,159
the next reaction that's going to happen

605
00:28:07,379 --> 00:28:04,749
is called the triple alpha reaction

606
00:28:09,869 --> 00:28:07,389
three helium nuclei three alpha

607
00:28:10,979 --> 00:28:09,879
particles hits the name and that will

608
00:28:12,839 --> 00:28:10,989
produce you put three of these guys

609
00:28:17,369 --> 00:28:12,849
together you get carbon and again a lot

610
00:28:20,069 --> 00:28:17,379
of energy and these stars are kicking to

611
00:28:21,659 --> 00:28:20,079
keep you know trying to find new sources

612
00:28:22,829 --> 00:28:21,669
of energy in their core to hold

613
00:28:24,869 --> 00:28:22,839

themselves up otherwise they keep

614
00:28:27,089 --> 00:28:24,879
collapsing and so the next one up is

615
00:28:29,219 --> 00:28:27,099
alpha capture so if you take a carbon

616
00:28:31,649 --> 00:28:29,229
atom you add two more protons and two

617
00:28:35,009 --> 00:28:31,659
more neutrons you get oxygen do it again

618
00:28:36,569 --> 00:28:35,019
you get neon etc and you can also do

619
00:28:39,149 --> 00:28:36,579
proton capture which is how you get to

620
00:28:40,739 --> 00:28:39,159
the odd numbers now you can start to see

621
00:28:42,239 --> 00:28:40,749
why that corrugation and the abundance

622
00:28:44,369 --> 00:28:42,249
exists there's more of the even numbers

623
00:28:47,249 --> 00:28:44,379
because alpha capture happens a lot more

624
00:28:49,199 --> 00:28:47,259
than the proton capture but those only

625
00:28:51,779 --> 00:28:49,209
happen in the really massive stars for

626
00:28:56,539 --> 00:28:51,789
the Sun the last Harrah is a triple

627
00:28:58,469 --> 00:28:56,549
alpha sequence and this is a really cool

628
00:29:00,629 --> 00:28:58,479
diagram there's a really cool periodic

629
00:29:02,680 --> 00:29:00,639
table done by Jennifer Johnson at Ohio

630
00:29:06,340 --> 00:29:02,690
State and this is

631
00:29:09,130 --> 00:29:06,350
our best attempt to explain where all of

632
00:29:11,710 --> 00:29:09,140
these elements come from so yellow is

633
00:29:13,450 --> 00:29:11,720
the one I'm interested in because those

634
00:29:15,100 --> 00:29:13,460
are dyeing low-mass this should be

635
00:29:17,980 --> 00:29:15,110
dyeing low and intermediate-mass stars

636
00:29:20,500 --> 00:29:17,990
bracele everything that doesn't go

637
00:29:22,840 --> 00:29:20,510
supernova and you can see that carbon

638
00:29:25,180 --> 00:29:22,850

and nitrogen which are the two of the

639
00:29:28,120 --> 00:29:25,190
top five are primarily made by these

640
00:29:29,470 --> 00:29:28,130
kinds of stars so without these kinds of

641
00:29:31,200 --> 00:29:29,480
stars is not to be a lot of carbon and

642
00:29:34,390 --> 00:29:31,210
nitrogen out there and you'll remember

643
00:29:37,750 --> 00:29:34,400
we're we're prime it you know carbon is

644
00:29:38,830 --> 00:29:37,760
the element of life so none of those you

645
00:29:40,300 --> 00:29:38,840
know you gotta wait a bit after the

646
00:29:41,560 --> 00:29:40,310
universe forms a supernova you ain't

647
00:29:43,420 --> 00:29:41,570
gonna do it for you you got to wait for

648
00:29:47,670 --> 00:29:43,430
these lower mass stars to evolve and

649
00:29:55,090 --> 00:29:50,860
okay change gears switch gears here

650
00:29:59,710 --> 00:29:55,100
I like this plot probably because I made

651
00:30:01,180 --> 00:29:59,720
it but so basically I've got some black

652
00:30:02,980 --> 00:30:01,190
bodies the black body is just a

653
00:30:04,000 --> 00:30:02,990
theoretical object of a certain

654
00:30:05,890 --> 00:30:04,010
temperature so it's like a perfect

655
00:30:08,980 --> 00:30:05,900
spectrum you can see in a minute I'll

656
00:30:10,480 --> 00:30:08,990
just show you now those are stars those

657
00:30:12,640 --> 00:30:10,490
are black bodies so this you know it's

658
00:30:15,040 --> 00:30:12,650
closed for physicists this works pretty

659
00:30:16,480 --> 00:30:15,050
well so what I want to point out here so

660
00:30:17,800 --> 00:30:16,490
we have wavelength from this axis I'm

661
00:30:21,220 --> 00:30:17,810
gonna do this a lot because I'm actually

662
00:30:22,420 --> 00:30:21,230
a spectroscopy so I love spectra and I

663
00:30:23,650 --> 00:30:22,430

have to tell you that whenever we're

664
00:30:25,780 --> 00:30:23,660
dealing with the PR people for a

665
00:30:28,210 --> 00:30:25,790
telescope we drove the spitzer PR people

666
00:30:29,950 --> 00:30:28,220
crazy because we had all these really we

667
00:30:31,660 --> 00:30:29,960
thought really newsworthy events you

668
00:30:33,490 --> 00:30:31,670
know with we are just findings and

669
00:30:34,960 --> 00:30:33,500
whatnot and we say well there's plot the

670
00:30:36,490 --> 00:30:34,970
spectra the squiggly line and they're

671
00:30:38,650 --> 00:30:36,500
like the people don't want to look at

672
00:30:41,770 --> 00:30:38,660
squiggly lines so i apologize because i

673
00:30:43,660 --> 00:30:41,780
have a lot of squiggly lines so what i

674
00:30:45,010 --> 00:30:43,670
have on the top is a different

675
00:30:48,070 --> 00:30:45,020
temperature black bodies and the point

676
00:30:51,460 --> 00:30:48,080
is that a 38,000 kelvin blackbody peaks

677
00:30:55,600 --> 00:30:51,470
at a wavelength of like point 1 to point

678
00:30:58,030 --> 00:30:55,610
2 microns that's about 1,000 to 2,000

679
00:30:59,800 --> 00:30:58,040
angstroms that's the ultraviolet that's

680
00:31:02,170 --> 00:30:59,810
toasty ultraviolet okay

681
00:31:04,480 --> 00:31:02,180
and then you take a red giant star which

682
00:31:07,180 --> 00:31:04,490
is about 37 50 case something like that

683
00:31:08,790 --> 00:31:07,190
and that Peaks over here at between 1

684
00:31:11,410 --> 00:31:08,800
and 2 microns that's the near-infrared

685
00:31:14,950 --> 00:31:11,420
here in the middle by the way these are

686
00:31:16,259 --> 00:31:14,960
sort of an average response function for

687
00:31:18,239 --> 00:31:16,269
the 3 different types of

688
00:31:20,339 --> 00:31:18,249

detectors in your eye the red green and

689
00:31:23,339 --> 00:31:20,349
blue when I first made this pot it

690
00:31:26,039 --> 00:31:23,349
finally dawned on me I never understood

691
00:31:27,989 --> 00:31:26,049
how people could be colorblind but now I

692
00:31:30,299 --> 00:31:27,999
get it because you can see that the red

693
00:31:33,329 --> 00:31:30,309
and the green responsive "tis in your

694
00:31:35,070 --> 00:31:33,339
eye almost overlap and some people they

695
00:31:37,859 --> 00:31:35,080
do overlap and those people can't

696
00:31:39,779 --> 00:31:37,869
distinguish red and green so probably

697
00:31:41,940 --> 00:31:39,789
not the best design from the get-go but

698
00:31:43,259 --> 00:31:41,950
you know they they eyes work pretty well

699
00:31:45,509 --> 00:31:43,269
so I'm not complaining

700
00:31:48,209 --> 00:31:45,519
astronomers have decided that you know

701
00:31:49,799 --> 00:31:48,219
this is not the ideal filter set so

702
00:31:51,989 --> 00:31:49,809
here's one example is the Johnson

703
00:31:54,930 --> 00:31:51,999
filters how many people here would call

704
00:31:56,609 --> 00:31:54,940
themselves amateur astronomers just to

705
00:32:00,149 --> 00:31:56,619
just a handful do you guys work with

706
00:32:03,539 --> 00:32:00,159
Johnson filters at all not too much okay

707
00:32:05,159 --> 00:32:03,549
well it's probably better a bit so very

708
00:32:06,930 --> 00:32:05,169
standard set so you sort of separate

709
00:32:09,060 --> 00:32:06,940
things out you be the ultra violet blue

710
00:32:11,369 --> 00:32:09,070
and visual and then in this they call

711
00:32:13,829 --> 00:32:11,379
this infrared but this is like near

712
00:32:15,959 --> 00:32:13,839
optical and Fritz over here and then

713
00:32:18,479 --> 00:32:15,969

some near-infrared filters which are

714
00:32:19,560 --> 00:32:18,489
known by their letters jhk you'll notice

715
00:32:20,969 --> 00:32:19,570
they're sort of out of order because

716
00:32:23,699 --> 00:32:20,979
people kind of added these things in

717
00:32:25,109 --> 00:32:23,709
anyway so these are real stars and you

718
00:32:26,609 --> 00:32:25,119
can see that you want to use infrared

719
00:32:28,469 --> 00:32:26,619
filters if you want to look at red

720
00:32:30,569 --> 00:32:28,479
giants you want to be out in the

721
00:32:32,819 --> 00:32:30,579
infrared near-infrared because that's

722
00:32:34,560 --> 00:32:32,829
where all the energy is so you could

723
00:32:37,289 --> 00:32:34,570
much easier to detect them out there and

724
00:32:39,449 --> 00:32:37,299
this is just another filter set um this

725
00:32:46,199 --> 00:32:39,459
is the Sloane filter set not named after

726
00:32:48,299 --> 00:32:46,209
me named after Alfred P Sloan he offered

727
00:32:50,249 --> 00:32:48,309
P sloan Foundation yes there yes named

728
00:32:52,069 --> 00:32:50,259
after that foundation because they

729
00:32:54,149 --> 00:32:52,079
funded the Sloan Digital Sky Survey

730
00:32:57,329 --> 00:32:54,159
which I had never figured out how to

731
00:32:58,889 --> 00:32:57,339
capitalize on but this is a different

732
00:33:01,259 --> 00:32:58,899
filter set and then ii went to show you

733
00:33:04,829 --> 00:33:01,269
some the results of some data taken with

734
00:33:06,180 --> 00:33:04,839
the green the G and the AI filters but

735
00:33:07,319 --> 00:33:06,190
you can see lots of filter sets out

736
00:33:09,509 --> 00:33:07,329
there and people love to argue over

737
00:33:11,029 --> 00:33:09,519
which one's best these are the things

738
00:33:14,849 --> 00:33:11,039

that keep astronomers entertained

739
00:33:17,669 --> 00:33:14,859
alright so here's a picture taken from a

740
00:33:21,349 --> 00:33:17,679
32 inch reflector at Mount Lemmon in

741
00:33:23,789 --> 00:33:21,359
Arizona this is the globular cluster m5

742
00:33:25,769 --> 00:33:23,799
this is the paper which has been hanging

743
00:33:28,049 --> 00:33:25,779
fire for me for a bit we're working that

744
00:33:29,629 --> 00:33:28,059
it's not my data but we have a different

745
00:33:31,099 --> 00:33:29,639
image this one's much prettier

746
00:33:32,239 --> 00:33:31,109
and the one thing I want to point out is

747
00:33:33,409 --> 00:33:32,249
when you look at it you can see there's

748
00:33:35,690 --> 00:33:33,419
some objects some of these stars are

749
00:33:37,219 --> 00:33:35,700
very red and then some of them not so

750
00:33:39,259 --> 00:33:37,229
red and these red ones are also very

751
00:33:42,259 --> 00:33:39,269
bright those are the red giants those

752
00:33:43,819 --> 00:33:42,269
are what we're interested in and so

753
00:33:45,349 --> 00:33:43,829
basically the globular cluster just is

754
00:33:47,539 --> 00:33:45,359
about a million stars all packed

755
00:33:50,749 --> 00:33:47,549
together a nice tight ball okay

756
00:33:53,060 --> 00:33:50,759
and the key points are they're all about

757
00:33:54,499 --> 00:33:53,070
the same distance from the earth so when

758
00:33:56,060 --> 00:33:54,509
I start plotting these things up I don't

759
00:33:57,589 --> 00:33:56,070
have to worry about everything getting

760
00:34:00,289 --> 00:33:57,599
smeared out because some are closer or

761
00:34:00,739 --> 00:34:00,299
further away they're all about the same

762
00:34:02,719 --> 00:34:00,749
age

763
00:34:07,519 --> 00:34:02,729

in this particular case ten point six

764
00:34:08,839 --> 00:34:07,529
billion years roughly thanks to the

765
00:34:10,430 --> 00:34:08,849
hubble space telescope we've actually

766
00:34:11,299 --> 00:34:10,440
learned that they're not all exactly the

767
00:34:14,269 --> 00:34:11,309
same age because there's actually

768
00:34:16,129 --> 00:34:14,279
multiple epochs of star formation early

769
00:34:17,990 --> 00:34:16,139
in the game but about by ten point six

770
00:34:20,389 --> 00:34:18,000
billion years this guy was done making

771
00:34:22,669 --> 00:34:20,399
stars and also the same metallicity

772
00:34:25,940 --> 00:34:22,679
which is very low less than a tenth the

773
00:34:27,889 --> 00:34:25,950
solar metallicity so these things are

774
00:34:31,970 --> 00:34:27,899
these guys are full of metal-poor stars

775
00:34:33,649 --> 00:34:31,980
and very old stars and so this is a

776
00:34:34,999 --> 00:34:33,659
great picture but actually for an

777
00:34:36,139 --> 00:34:35,009
astronomer what you want to do is you

778
00:34:37,940 --> 00:34:36,149
want to actually start plotting how

779
00:34:39,889 --> 00:34:37,950
bright they are versus their color and

780
00:34:42,079 --> 00:34:39,899
that's called a color magnitude diagram

781
00:34:43,609 --> 00:34:42,089
a lot of you guys are veterans of these

782
00:34:45,079 --> 00:34:43,619
talks you've probably seen this before I

783
00:34:47,450 --> 00:34:45,089
just wanted to make sure we had our

784
00:34:49,730 --> 00:34:47,460
bases covered but basically what you do

785
00:34:51,769 --> 00:34:49,740
here is you take the the magnitude and

786
00:34:55,399 --> 00:34:51,779
the G filter and you subtract it from

787
00:34:56,990 --> 00:34:55,409
the I filter and that's a color and the

788
00:34:58,279 --> 00:34:57,000

red or the object the further it's going

789
00:35:00,680 --> 00:34:58,289
to be over to the right the bigger the

790
00:35:02,930 --> 00:35:00,690
the more positive the color that you get

791
00:35:05,089 --> 00:35:02,940
and the blue or the the smaller or even

792
00:35:07,670 --> 00:35:05,099
negative the color so blue blue stuff is

793
00:35:09,259 --> 00:35:07,680
on the left side red stuff is on the

794
00:35:13,190 --> 00:35:09,269
right side and then how bright it is

795
00:35:14,930 --> 00:35:13,200
bright stuffs on the top so I want to

796
00:35:18,019 --> 00:35:14,940
pick this diagram apart cuz all these

797
00:35:20,599 --> 00:35:18,029
stars are the same age if this was a

798
00:35:21,799 --> 00:35:20,609
young cluster you would see a diagonal

799
00:35:23,599 --> 00:35:21,809
stripe that would start here with a

800
00:35:25,579 --> 00:35:23,609
bunch of stars on the bottom and go up

801
00:35:29,150 --> 00:35:25,589
and to the left like this and that would

802
00:35:31,279 --> 00:35:29,160
be called the main-sequence the most

803
00:35:32,809 --> 00:35:31,289
massive stars burn out first and they're

804
00:35:35,059 --> 00:35:32,819
at the top of the main sequence this is

805
00:35:36,319 --> 00:35:35,069
a very old cluster so most of the main

806
00:35:39,589 --> 00:35:36,329
sequence is gone

807
00:35:42,240 --> 00:35:39,599
stars are dead all you have left are the

808
00:35:43,920 --> 00:35:42,250
low mass stars

809
00:35:46,650 --> 00:35:43,930
so we sort of start we have a

810
00:35:48,420 --> 00:35:46,660
main-sequence pointing to it right down

811
00:35:51,359 --> 00:35:48,430
here at the bottom the main-sequence

812
00:35:53,070 --> 00:35:51,369
turnoff is that is this point where the

813
00:35:55,260 --> 00:35:53,080

whole sequence starts to bend a little

814
00:35:57,089 --> 00:35:55,270
bit to the right those are the stars

815
00:36:01,320 --> 00:35:57,099
that are just now running out of

816
00:36:03,599 --> 00:36:01,330
hydrogen fuel in their core so they can

817
00:36:05,820 --> 00:36:03,609
no longer hold themselves up so they

818
00:36:08,240 --> 00:36:05,830
just spent in the case of the Sun ten

819
00:36:10,470 --> 00:36:08,250
billion years happiest clams

820
00:36:14,010 --> 00:36:10,480
burning hydrogen and helium in the core

821
00:36:15,420 --> 00:36:14,020
nice and stable you know the stars nice

822
00:36:16,800 --> 00:36:15,430
astable the planets you know who knows

823
00:36:19,349 --> 00:36:16,810
how many wars and stuff been happening

824
00:36:22,500 --> 00:36:19,359
but the star is pretty stable so when it

825
00:36:24,330 --> 00:36:22,510
runs out of hydrogen in the core the

826
00:36:27,030 --> 00:36:24,340
star will ascend what's called the red

827
00:36:29,160 --> 00:36:27,040
giant branch and that'll take about a

828
00:36:30,480 --> 00:36:29,170
billion years for the Sun and this is

829
00:36:33,180 --> 00:36:30,490
actually things start to get weird

830
00:36:35,400 --> 00:36:33,190
really quick so you have to think of a

831
00:36:38,280 --> 00:36:35,410
star as two parts there's a core and

832
00:36:41,010 --> 00:36:38,290
then there's an envelope all right and

833
00:36:42,390 --> 00:36:41,020
they evolved separately the core is all

834
00:36:45,150 --> 00:36:42,400
the actions in the core the envelope

835
00:36:46,980 --> 00:36:45,160
just responds so what happens is if the

836
00:36:51,510 --> 00:36:46,990
core can't hold itself up anymore what's

837
00:36:53,070 --> 00:36:51,520
it gonna do it's gonna contract collapse

838
00:36:54,990 --> 00:36:53,080

is a little fast because it takes a

839
00:36:56,579 --> 00:36:55,000
billion years but yes it's good to start

840
00:36:59,849 --> 00:36:56,589
collapsing there's nothing to hold it up

841
00:37:02,220 --> 00:36:59,859
anymore gravity is as much to get so as

842
00:37:05,190 --> 00:37:02,230
it collapses as it contracts it's gonna

843
00:37:06,450 --> 00:37:05,200
heat up and as it heats up even though

844
00:37:08,040 --> 00:37:06,460
it doesn't have any hydrogen in the core

845
00:37:10,230 --> 00:37:08,050
it's still burning hydrogen and a shell

846
00:37:11,849 --> 00:37:10,240
around that helium core and the

847
00:37:13,980 --> 00:37:11,859
luminosity actually goes up the star

848
00:37:16,079 --> 00:37:13,990
gets brighter and because the luminosity

849
00:37:17,190 --> 00:37:16,089
goes up the envelope responds because

850
00:37:18,480 --> 00:37:17,200
you get all this radiation pressure

851
00:37:20,790 --> 00:37:18,490
trying to get out it pushes the envelope

852
00:37:22,829 --> 00:37:20,800
out so the core contracts and the

853
00:37:25,349 --> 00:37:22,839
envelope expands at the same time and

854
00:37:30,390 --> 00:37:25,359
you get a red giant a big fat fluffy

855
00:37:31,890 --> 00:37:30,400
star and out of after a billion years

856
00:37:34,230 --> 00:37:31,900
the star gets to the tip of the red

857
00:37:36,500 --> 00:37:34,240
giant branch and now it's hot enough in

858
00:37:38,460 --> 00:37:36,510
the core to ignite the helium reaction

859
00:37:40,320 --> 00:37:38,470
and when that happens a star

860
00:37:43,650 --> 00:37:40,330
reconfigures really quickly it's called

861
00:37:46,650 --> 00:37:43,660
the helium flesh and winds up over here

862
00:37:48,180 --> 00:37:46,660
on the horizontal branch which you could

863
00:37:51,540 --> 00:37:48,190

also call the helium burning main

864
00:37:54,510 --> 00:37:51,550
sequence and so it's nice it's a stable

865
00:37:56,020 --> 00:37:54,520
place again but it's only got about a

866
00:37:58,720 --> 00:37:56,030
hundred million years before

867
00:38:00,190 --> 00:37:58,730
helium in the core and then it does

868
00:38:02,950 --> 00:38:00,200
exactly the same thing it goes back up

869
00:38:04,960 --> 00:38:02,960
the red giant branch a second time this

870
00:38:07,510 --> 00:38:04,970
time with a really complicated structure

871
00:38:11,050 --> 00:38:07,520
because it's got it now has this inert

872
00:38:13,060 --> 00:38:11,060
core of carbon and oxygen surrounded by

873
00:38:15,280 --> 00:38:13,070
a very thin shell of helium which is

874
00:38:17,320 --> 00:38:15,290
being fed by a hydrogen burning shell

875
00:38:19,870 --> 00:38:17,330
outside of that and when you get enough

876
00:38:21,430 --> 00:38:19,880
helium the helium will actually ignite

877
00:38:24,730 --> 00:38:21,440
and you'll get more of that triple alpha

878
00:38:27,880 --> 00:38:24,740
sequence so it's just it's like an onion

879
00:38:29,470 --> 00:38:27,890
and for most stars this is because they

880
00:38:30,850 --> 00:38:29,480
don't have enough mass they don't the

881
00:38:32,950 --> 00:38:30,860
temperatures don't get any higher in the

882
00:38:35,560 --> 00:38:32,960
core this is it there are no more

883
00:38:38,020 --> 00:38:35,570
nuclear fusion sources for them to work

884
00:38:41,320 --> 00:38:38,030
with so when they collapse the next time

885
00:38:43,330 --> 00:38:41,330
they're toast and maybe a million years

886
00:38:45,610 --> 00:38:43,340
for the Sun to basically climb back up

887
00:38:47,890 --> 00:38:45,620
this the second giant branch this is one

888
00:38:50,830 --> 00:38:47,900

of the most so this is called the

889
00:38:52,210 --> 00:38:50,840
asymptotic giant branch because it asked

890
00:38:54,640 --> 00:38:52,220
some Tata cailli approaches the first

891
00:38:58,540 --> 00:38:54,650
giant branch this is the worst possible

892
00:39:00,370 --> 00:38:58,550
name I can imagine in astronomy so what

893
00:39:04,780 --> 00:39:00,380
do you study I study asymptotic giant

894
00:39:08,740 --> 00:39:04,790
branch stars it's like okay well I

895
00:39:10,330 --> 00:39:08,750
better go get some more coffee you know

896
00:39:12,400 --> 00:39:10,340
the only thing you do is call them AGB

897
00:39:13,840 --> 00:39:12,410
stars but I've always been taught you

898
00:39:17,710 --> 00:39:13,850
can't just start using acronyms without

899
00:39:19,990 --> 00:39:17,720
defining them so anyway this is what

900
00:39:23,950 --> 00:39:20,000
this needs a PR rethink in my opinion I

901
00:39:26,440 --> 00:39:23,960
want to call it the death branch we'll

902
00:39:28,210 --> 00:39:26,450
see how that goes so this is just a nice

903
00:39:29,710 --> 00:39:28,220
picture sort of illustrating what the

904
00:39:32,740 --> 00:39:29,720
Sun would look like at different stages

905
00:39:34,690 --> 00:39:32,750
of its life you notice that oh I haven't

906
00:39:40,500 --> 00:39:34,700
cursor let's get that cursor make use of

907
00:39:44,980 --> 00:39:40,510
it and went away it won't come back okay

908
00:39:47,140 --> 00:39:44,990
there is you kids up there there are

909
00:39:52,060 --> 00:39:47,150
four pixels lit up right here that's the

910
00:39:53,560 --> 00:39:52,070
Sun these images are actually 200 pixels

911
00:39:58,000 --> 00:39:53,570
across which is the size of the Earth's

912
00:40:00,970 --> 00:39:58,010
orbit and so you can see that RGB you

913
00:40:02,500 --> 00:40:00,980

know big horizontal branch small again

914
00:40:04,990 --> 00:40:02,510
but not as small as the main sequence

915
00:40:08,020 --> 00:40:05,000
and then early AG be really big this

916
00:40:09,880 --> 00:40:08,030
works out that's about 0.9 au or nine

917
00:40:13,150 --> 00:40:09,890
tenths the radius

918
00:40:16,900 --> 00:40:13,160
Earth's orbit and this is early AGB

919
00:40:18,010 --> 00:40:16,910
things get worse all right but before we

920
00:40:20,170 --> 00:40:18,020
get to that I want to look let's look

921
00:40:22,960 --> 00:40:20,180
inside this guy remember I described to

922
00:40:24,130 --> 00:40:22,970
you this crazy G on this crazy multi

923
00:40:25,170 --> 00:40:24,140
shell geometry well this is what it

924
00:40:29,170 --> 00:40:25,180
looks like

925
00:40:32,080 --> 00:40:29,180
so on the Left we've actually got this

926
00:40:33,520 --> 00:40:32,090
plotted not with radius but with mass to

927
00:40:35,920 --> 00:40:33,530
sort of tell you how far you are along

928
00:40:37,780 --> 00:40:35,930
going from in to out so you can kind of

929
00:40:40,030 --> 00:40:37,790
see all the different parts it halfway

930
00:40:42,910 --> 00:40:40,040
out that's because half the mass of the

931
00:40:44,410 --> 00:40:42,920
star is in the core but if you really

932
00:40:52,900 --> 00:40:44,420
see what it looks like look on the

933
00:40:54,940 --> 00:40:52,910
right-hand side so these are really

934
00:40:58,180 --> 00:40:54,950
interesting creatures these AG be stars

935
00:41:02,410 --> 00:40:58,190
there's these giant puffy tenuous almost

936
00:41:07,800 --> 00:41:02,420
vacuum stars that will expand in the

937
00:41:17,980 --> 00:41:11,560
asymptotic giant branch how about death

938
00:41:20,470 --> 00:41:17,990

branch I'm kind of liking this I mean we

939
00:41:23,320 --> 00:41:20,480
go with this so this core will become a

940
00:41:29,470 --> 00:41:23,330
white dwarf and the envelope will get

941
00:41:31,270 --> 00:41:29,480
ejected so I said that the helium

942
00:41:32,590 --> 00:41:31,280
doesn't burn continuously so the helium

943
00:41:34,270 --> 00:41:32,600
will build up it'll build up and then

944
00:41:36,460 --> 00:41:34,280
they'll be this what they call a thermal

945
00:41:38,350 --> 00:41:36,470
pulse this runaway nuclear reaction

946
00:41:41,170 --> 00:41:38,360
where this triple alpha sequence takes

947
00:41:43,690 --> 00:41:41,180
off so what I did Peter would and his

948
00:41:45,340 --> 00:41:43,700
student somebody I don't remember Vasily

949
00:41:47,410 --> 00:41:45,350
on I've never met Miss Ileana so I don't

950
00:41:48,820 --> 00:41:47,420
know his first name but this is a 25

951
00:41:52,060 --> 00:41:48,830
year old theory paper and it's still

952
00:41:53,530 --> 00:41:52,070
pretty darn good and so what he's done

953
00:41:55,960 --> 00:41:53,540
here is he's basically plotted the

954
00:41:57,340 --> 00:41:55,970
temperature of the star on the top the

955
00:42:00,460 --> 00:41:57,350
log of the temperature the the

956
00:42:01,690 --> 00:42:00,470
luminosity the pulsation period star

957
00:42:04,240 --> 00:42:01,700
we'll get to that in a second that's not

958
00:42:06,880 --> 00:42:04,250
the thermal pulse the expansion velocity

959
00:42:08,260 --> 00:42:06,890
of the star it's mass this is kind of

960
00:42:09,850 --> 00:42:08,270
fun because you'll notice after a few of

961
00:42:11,200 --> 00:42:09,860
these thermal pulses the star hangs in

962
00:42:16,270 --> 00:42:11,210
there hangs in there have been boom it

963
00:42:18,820 --> 00:42:16,280

loses half its mass pretty quickly we

964
00:42:20,470 --> 00:42:18,830
don't actually know how that happens the

965
00:42:22,300 --> 00:42:20,480
way Peter made this work if I remember

966
00:42:22,630 --> 00:42:22,310
right and since 50,000 people can see

967
00:42:24,809 --> 00:42:22,640
this

968
00:42:28,029 --> 00:42:24,819
or something like that 5,000 you said

969
00:42:30,430 --> 00:42:28,039
okay oh that's enough one of them might

970
00:42:31,900 --> 00:42:30,440
be Peter and he's gonna be he's gonna be

971
00:42:33,549 --> 00:42:31,910
mad at me because I think he just turns

972
00:42:35,650 --> 00:42:33,559
on the mass loss dial to make the mass

973
00:42:37,089 --> 00:42:35,660
chaos happen it's not it's a little bit

974
00:42:38,680 --> 00:42:37,099
better than that but basically we don't

975
00:42:41,019 --> 00:42:38,690
really understand that process and

976
00:42:42,370 --> 00:42:41,029
that's pretty important so anyway the

977
00:42:43,749 --> 00:42:42,380
point is every time this thing goes to a

978
00:42:45,940 --> 00:42:43,759
therm through a thermal pulse it

979
00:42:48,910 --> 00:42:45,950
reconfigures itself for a little while

980
00:42:50,589 --> 00:42:48,920
and what happens is the envelope of

981
00:42:52,630 --> 00:42:50,599
these stars is completely convective

982
00:42:54,339 --> 00:42:52,640
that 99% of the star that's just

983
00:42:55,720 --> 00:42:54,349
envelope it's convective you got

984
00:42:58,380 --> 00:42:55,730
convection cells going all the way from

985
00:43:01,690 --> 00:42:58,390
the center out to the Earth's orbit

986
00:43:03,789 --> 00:43:01,700
basically and what happens in the core

987
00:43:05,799 --> 00:43:03,799
when you get learn these helium flashes

988
00:43:09,069 --> 00:43:05,809

there's a little convective layer that

989
00:43:11,140 --> 00:43:09,079
forms there and it overlaps with the

990
00:43:14,440 --> 00:43:11,150
convective envelope so these stars

991
00:43:17,470 --> 00:43:14,450
they're making carbon via this triple

992
00:43:19,720 --> 00:43:17,480
alpha sequence and dredging it right to

993
00:43:22,829 --> 00:43:19,730
the surface of the star so it can be

994
00:43:26,759 --> 00:43:22,839
ejected into the interstellar medium and

995
00:43:29,849 --> 00:43:26,769
that's where the carbon comes from

996
00:43:36,579 --> 00:43:29,859
according to miss Johnson's plot about

997
00:43:38,589 --> 00:43:36,589
75 or 80 percent of it so we have

998
00:43:40,749 --> 00:43:38,599
thermal pulses on the inside happening

999
00:43:45,460 --> 00:43:40,759
for the Sun like every 80,000 years

1000
00:43:46,870 --> 00:43:45,470
something like that the we know this

1001
00:43:49,900 --> 00:43:46,880
happens theoretically we're on really

1002
00:43:51,670 --> 00:43:49,910
solid ground it's not clear to me that

1003
00:43:54,279 --> 00:43:51,680
we have clear that oh that star just had

1004
00:43:56,079 --> 00:43:54,289
a thermal pulse because it's actually

1005
00:43:57,609 --> 00:43:56,089
really hard to see because it takes you

1006
00:44:00,279 --> 00:43:57,619
know thousands of years these stars to

1007
00:44:02,349 --> 00:44:00,289
kind of reconfigure themselves but we do

1008
00:44:03,729 --> 00:44:02,359
see the envelope is as I said this big

1009
00:44:04,900 --> 00:44:03,739
to newest thing stretching all the way

1010
00:44:07,720 --> 00:44:04,910
out to the Earth's orbit it's really

1011
00:44:10,269 --> 00:44:07,730
unstable to just simple pulsations if

1012
00:44:12,180 --> 00:44:10,279
you push out it keeps going and then

1013
00:44:16,690 --> 00:44:12,190

will fall back in so the whole star

1014
00:44:18,819 --> 00:44:16,700
basically is pulsating like this on a

1015
00:44:22,390 --> 00:44:18,829
timescale in this particular case of Chi

1016
00:44:25,150 --> 00:44:22,400
sig with a period of 405 days

1017
00:44:29,170 --> 00:44:25,160
so over the course of a year and 40 days

1018
00:44:31,989 --> 00:44:29,180
it will pulse out and pulse back in so

1019
00:44:36,980 --> 00:44:31,999
Chi sig if you catch it at maximum is a

1020
00:44:41,240 --> 00:44:36,990
naked-eye star does magnitude 3 or 4

1021
00:44:43,160 --> 00:44:41,250
at maximum but when it's at minimum its

1022
00:44:44,630 --> 00:44:43,170
weight it's like a 14th 13th magnitude

1023
00:44:47,240 --> 00:44:44,640
star you just know what you can see that

1024
00:44:52,430 --> 00:44:47,250
with your eye so these are huge major

1025
00:44:55,220 --> 00:44:52,440
pulsations when I put it yes so as I

1026
00:45:00,560 --> 00:44:55,230
said these stars are going crazy inside

1027
00:45:02,510 --> 00:45:00,570
and outside so we were interested in

1028
00:45:04,880 --> 00:45:02,520
digging into this a little bit so we

1029
00:45:06,380 --> 00:45:04,890
took him five and we did our photometry

1030
00:45:08,510 --> 00:45:06,390
but we didn't do it just once we kept

1031
00:45:11,030 --> 00:45:08,520
getting more time over the next couple

1032
00:45:12,650 --> 00:45:11,040
of years to sort of track which stars

1033
00:45:15,829 --> 00:45:12,660
were the variables which stars were

1034
00:45:19,730 --> 00:45:15,839
pulsating and you can see that we got a

1035
00:45:21,470 --> 00:45:19,740
whole bunch of guys on the on the

1036
00:45:24,079 --> 00:45:21,480
horizontal branch those are our Lyra

1037
00:45:25,280 --> 00:45:24,089
stars those are like a standard candle

1038
00:45:27,560 --> 00:45:25,290

they're really you know that's how we

1039
00:45:29,480 --> 00:45:27,570
figured out that the earth was the Sun

1040
00:45:30,890 --> 00:45:29,490
wasn't the center of the Milky Way we

1041
00:45:33,440 --> 00:45:30,900
thought I didn't do it this was like

1042
00:45:36,170 --> 00:45:33,450
what 80 90 years ago now I think

1043
00:45:38,060 --> 00:45:36,180
something like that but you can see out

1044
00:45:39,410 --> 00:45:38,070
here as you climb up the red giant

1045
00:45:42,079 --> 00:45:39,420
branch you can see that the variability

1046
00:45:46,430 --> 00:45:42,089
really does increase all the way to the

1047
00:45:47,690 --> 00:45:46,440
tip and that's pretty cool so we're all

1048
00:45:49,010 --> 00:45:47,700
really proud of our multi epic

1049
00:45:51,560 --> 00:45:49,020
photometry but if you're going to see

1050
00:45:56,810 --> 00:45:51,570
multi epic photometry the Gaia mission

1051
00:45:58,730 --> 00:45:56,820
is stunningly impressive I mean this is

1052
00:46:01,430 --> 00:45:58,740
better than anything this is art as far

1053
00:46:03,710 --> 00:46:01,440
as I'm concerned it so this is their

1054
00:46:06,859 --> 00:46:03,720
color magnitude diagram they've got blue

1055
00:46:11,390 --> 00:46:06,869
and red filters they call them V P and R

1056
00:46:12,859 --> 00:46:11,400
P they didn't ask me and then absolute

1057
00:46:15,290 --> 00:46:12,869
magnitude here so the nice thing about

1058
00:46:16,700 --> 00:46:15,300
Gaia is because it gets parallax's so

1059
00:46:18,740 --> 00:46:16,710
they can correct for distance and put

1060
00:46:22,780 --> 00:46:18,750
all the stars in the solar neighborhood

1061
00:46:25,670 --> 00:46:22,790
all gazillion of them on the same plot

1062
00:46:27,740 --> 00:46:25,680
so here's the main sequence it's like

1063
00:46:29,540 --> 00:46:27,750

right down here here's the giant branch

1064
00:46:32,170 --> 00:46:29,550
and this is basically color-coded by

1065
00:46:34,700 --> 00:46:32,180
variability so way up here here's the

1066
00:46:36,920 --> 00:46:34,710
RGB in the AG beam you can see that

1067
00:46:38,359 --> 00:46:36,930
they're all variables this plot over

1068
00:46:39,589 --> 00:46:38,369
here on the right hand side is kind of

1069
00:46:41,510 --> 00:46:39,599
fun because what they've done here is

1070
00:46:44,060 --> 00:46:41,520
they've mapped known identified

1071
00:46:46,040 --> 00:46:44,070
variables back onto their diagram so

1072
00:46:49,190 --> 00:46:46,050
long period variables is what all these

1073
00:46:50,480 --> 00:46:49,200
guys are these are all AGB stars pulsing

1074
00:46:51,980 --> 00:46:50,490
like mad with

1075
00:46:54,890 --> 00:46:51,990
periods of anywhere between a hundred

1076
00:46:56,900 --> 00:46:54,900
days and a thousand and those are stars

1077
00:46:58,850 --> 00:46:56,910
in the midst of ripping themselves apart

1078
00:47:07,609 --> 00:46:58,860
and blowing their innards back into

1079
00:47:11,210 --> 00:47:07,619
space okay so switch gears again when a

1080
00:47:14,570 --> 00:47:11,220
star it's cool enough molecules can form

1081
00:47:16,370 --> 00:47:14,580
in its atmosphere so here we have a nice

1082
00:47:18,890 --> 00:47:16,380
picture this is the Hyades that's the V

1083
00:47:21,290 --> 00:47:18,900
of the face of the bull on its side that

1084
00:47:24,440 --> 00:47:21,300
star right there is all deber on Alpha

1085
00:47:25,850 --> 00:47:24,450
Tau when I started doing astronomy and

1086
00:47:27,830 --> 00:47:25,860
Fred astronomy at Wyoming where I did my

1087
00:47:29,000 --> 00:47:27,840
PhD I never really appreciated that the

1088
00:47:32,420 --> 00:47:29,010

stars I was gonna be looking at were

1089
00:47:34,670 --> 00:47:32,430
naked eye objects because Alpha Tau was

1090
00:47:38,930 --> 00:47:34,680
what we what what all of our calibration

1091
00:47:40,580 --> 00:47:38,940
hung off of so this is a star in the

1092
00:47:42,500 --> 00:47:40,590
infrared so basically the spectrum is

1093
00:47:44,870 --> 00:47:42,510
dropping off you see there's a couple of

1094
00:47:46,340 --> 00:47:44,880
kinks in the spectrum here this is not

1095
00:47:47,810 --> 00:47:46,350
the best way to plot it because what

1096
00:47:49,400 --> 00:47:47,820
dominates the the fact it's very

1097
00:47:51,440 --> 00:47:49,410
bright at two-and-a-half microns and

1098
00:47:53,090 --> 00:47:51,450
very faint at twenty so what I've done

1099
00:47:54,590 --> 00:47:53,100
is I've got another plot come up here

1100
00:47:57,320 --> 00:47:54,600
where I basically multiplied that

1101
00:47:59,150 --> 00:47:57,330
spectrum by the wavelength squared to

1102
00:48:02,570 --> 00:47:59,160
kind of flatten it out to bring out some

1103
00:48:04,640 --> 00:48:02,580
of the detail so here you go now those

1104
00:48:06,220 --> 00:48:04,650
kinks are these really neat molecular

1105
00:48:08,810 --> 00:48:06,230
absorption bands from carbon monoxide

1106
00:48:11,109 --> 00:48:08,820
and silicon monoxide two of each

1107
00:48:13,220 --> 00:48:11,119
overtone and fundamental here at

1108
00:48:15,440 --> 00:48:13,230
basically four microns and then an

1109
00:48:18,020 --> 00:48:15,450
eighth microns and then here's another

1110
00:48:19,460 --> 00:48:18,030
star - even cooler giant and I've spread

1111
00:48:20,900 --> 00:48:19,470
it out so this just goes from two and a

1112
00:48:23,359 --> 00:48:20,910
half to twelve microns now you can

1113
00:48:27,530 --> 00:48:23,369

really see the carbon monoxide the SiO

1114
00:48:30,230 --> 00:48:27,540
band co water vapor in these coolest

1115
00:48:32,300 --> 00:48:30,240
stars and this is important because

1116
00:48:35,570 --> 00:48:32,310
what's going to happen is when these

1117
00:48:37,010 --> 00:48:35,580
stars start pulsing pulsating remember

1118
00:48:37,910 --> 00:48:37,020
they're getting they're expanding and

1119
00:48:39,260 --> 00:48:37,920
they're getting small and when they're

1120
00:48:43,070 --> 00:48:39,270
expanding there's a bit of a kick and

1121
00:48:44,720 --> 00:48:43,080
velocity outward and if the if this gas

1122
00:48:48,200 --> 00:48:44,730
and these molecules can get far enough

1123
00:48:50,950 --> 00:48:48,210
away from the star they'll actually cool

1124
00:48:55,340 --> 00:48:50,960
enough so that dust can condense out and

1125
00:48:58,390 --> 00:48:55,350
the opacity how opaque dust is compared

1126
00:49:00,290 --> 00:48:58,400
to the same bunch of molecules as a gas

1127
00:49:03,500 --> 00:49:00,300
it's it's sort of like they all just

1128
00:49:04,820 --> 00:49:03,510
dropped their sails you know and

1129
00:49:07,040 --> 00:49:04,830
winds kicked up and they just get

1130
00:49:10,010 --> 00:49:07,050
blasted out so when you start making

1131
00:49:11,570 --> 00:49:10,020
dust from this from these molecules then

1132
00:49:13,820 --> 00:49:11,580
the radiation pressure from the start

1133
00:49:21,440 --> 00:49:13,830
just blows it out into space and that's

1134
00:49:23,090 --> 00:49:21,450
how these stars shed mass so here's a

1135
00:49:28,940 --> 00:49:23,100
really complicated diagram to explain

1136
00:49:31,160 --> 00:49:28,950
everything really simply I'm going to

1137
00:49:32,450 --> 00:49:31,170
see Joseph Peron in Vienna in a couple

1138
00:49:33,800 --> 00:49:32,460

of weeks and I'm not gonna tell him that

1139
00:49:35,810 --> 00:49:33,810
I put it that way because it's actually

1140
00:49:37,190 --> 00:49:35,820
a pretty nice diagram so basically if

1141
00:49:40,520 --> 00:49:37,200
you just draw a line through the middle

1142
00:49:44,300 --> 00:49:40,530
of it cutting it in half vertically the

1143
00:49:45,350 --> 00:49:44,310
upper half is oxygen-rich and the bottom

1144
00:49:46,580 --> 00:49:45,360
half is carbon-rich

1145
00:49:49,280 --> 00:49:46,590
and what it's doing with it and if you

1146
00:49:51,320 --> 00:49:49,290
go from the left side that's the center

1147
00:49:53,570 --> 00:49:51,330
of the star but it's all I can log space

1148
00:49:56,330 --> 00:49:53,580
so you can cram a lot of dynamic range

1149
00:49:57,410 --> 00:49:56,340
into one plot convective envelope you've

1150
00:49:59,480 --> 00:49:57,420
a little further out and now you're out

1151
00:50:01,130 --> 00:49:59,490
in the pulsating atmosphere that's where

1152
00:50:02,990 --> 00:50:01,140
the molecules are and you get further

1153
00:50:04,760 --> 00:50:03,000
out that's where the dust is the whole

1154
00:50:07,580 --> 00:50:04,770
point to this plot is basically to show

1155
00:50:09,670 --> 00:50:07,590
you what happens because the first

1156
00:50:13,940 --> 00:50:09,680
molecule that forms is carbon monoxide

1157
00:50:16,180 --> 00:50:13,950
co and the co will keep forming until it

1158
00:50:19,340 --> 00:50:16,190
runs out of one of them carbon or oxygen

1159
00:50:21,320 --> 00:50:19,350
so remember these stars are they've got

1160
00:50:23,510 --> 00:50:21,330
these thermal pulses in the core they're

1161
00:50:25,610 --> 00:50:23,520
dredging up carbon to the surface they

1162
00:50:26,990 --> 00:50:25,620
started out oxygen-rich but every time

1163
00:50:29,900 --> 00:50:27,000

that they do one of these dredge ups

1164
00:50:31,730 --> 00:50:29,910
there's like an extra Delta in carbon

1165
00:50:35,060 --> 00:50:31,740
and if they do it enough they'll have

1166
00:50:37,760 --> 00:50:35,070
more carbon than oxygen so the co forms

1167
00:50:39,290 --> 00:50:37,770
and it usually it uses up all the carbon

1168
00:50:41,570 --> 00:50:39,300
and just laughs with oxygen is the free

1169
00:50:43,910 --> 00:50:41,580
molecule to make all these molecules and

1170
00:50:47,150 --> 00:50:43,920
to make the dust so you get a lot of

1171
00:50:49,840 --> 00:50:47,160
silicate dust and alumina dust just like

1172
00:50:52,640 --> 00:50:49,850
on the beach just a bunch of silicates

1173
00:50:55,100 --> 00:50:52,650
but if it's a carbon star all the

1174
00:50:57,500 --> 00:50:55,110
oxygens is consumed by the co and you're

1175
00:50:59,750 --> 00:50:57,510
just left with carbon and other you know

1176
00:51:01,670 --> 00:50:59,760
other elements you can make acetylene

1177
00:51:05,840 --> 00:51:01,680
there's a lot of acetylene in these

1178
00:51:07,370 --> 00:51:05,850
stars no smoking but it's okay we can't

1179
00:51:08,890 --> 00:51:07,380
burn anything because the oxygen is all

1180
00:51:11,589 --> 00:51:08,900
gone

1181
00:51:14,349 --> 00:51:11,599
so and the acetylene can make amorphous

1182
00:51:16,089 --> 00:51:14,359
carbon dust so my focus as an infrared

1183
00:51:17,829 --> 00:51:16,099
spectroscopy has always been the dust

1184
00:51:19,299 --> 00:51:17,839
and these are what the spectra of these

1185
00:51:21,640 --> 00:51:19,309
two different kinds of evolved stars

1186
00:51:23,289 --> 00:51:21,650
look like so on the top this is these

1187
00:51:25,210 --> 00:51:23,299
are infrared spectra like the visible

1188
00:51:26,739 --> 00:51:25,220

part of the of wavelength space is over

1189
00:51:28,930 --> 00:51:26,749
here you can't even count even plotted

1190
00:51:31,329 --> 00:51:28,940
so here's the star and now you have

1191
00:51:33,819 --> 00:51:31,339
these emission features from all of this

1192
00:51:36,009 --> 00:51:33,829
hot dust around the star at 10 microns

1193
00:51:37,450 --> 00:51:36,019
and 18 microns so you get those two

1194
00:51:39,099 --> 00:51:37,460
emission features in your spectrum ooh

1195
00:51:43,599 --> 00:51:39,109
I'm looking at silicate dust that was

1196
00:51:45,430 --> 00:51:43,609
easy and then if it's a carbon star you

1197
00:51:46,660 --> 00:51:45,440
can see the silicon carbide dust at 11

1198
00:51:49,509 --> 00:51:46,670
and a half microns but what's actually

1199
00:51:51,670 --> 00:51:49,519
most of the dust so in this spectrum of

1200
00:51:53,349 --> 00:51:51,680
the oxygen star that's actually the star

1201
00:51:56,440 --> 00:51:53,359
that's the photosphere of the star plus

1202
00:52:00,880 --> 00:51:56,450
some dust these carbon stars the dust is

1203
00:52:06,150 --> 00:52:00,890
so opaque you can't see through it what

1204
00:52:18,009 --> 00:52:10,450
and what I really want is reminds me

1205
00:52:20,349 --> 00:52:18,019
never that's crazy I actually my usual

1206
00:52:21,880 --> 00:52:20,359
computer is a Linux system and I feel

1207
00:52:23,710 --> 00:52:21,890
like I have kind of control over it but

1208
00:52:26,769 --> 00:52:23,720
my MacBook thinks for itself and I don't

1209
00:52:29,319 --> 00:52:26,779
like that at all so anyway the amorphous

1210
00:52:31,900 --> 00:52:29,329
so all of the that what looks like the

1211
00:52:33,339 --> 00:52:31,910
star here all this stuff you know

1212
00:52:35,440 --> 00:52:33,349
between the emission and absorption

1213
00:52:38,259 --> 00:52:35,450

features that's actually the amorphous

1214
00:52:40,239 --> 00:52:38,269
carbon dust morphus carbon has no

1215
00:52:42,670 --> 00:52:40,249
features at all it's just except that

1216
00:52:46,989 --> 00:52:42,680
it's just dark it just locks everything

1217
00:52:48,700 --> 00:52:46,999
underneath it so I'm gonna skip this

1218
00:52:50,259 --> 00:52:48,710
this is all about the oxygen rich dust

1219
00:52:51,819 --> 00:52:50,269
and it takes us back a couple of decades

1220
00:52:53,229 --> 00:52:51,829
when I was studying it but lately I've

1221
00:52:54,700 --> 00:52:53,239
been doing the carbon rich to us I feel

1222
00:52:57,249 --> 00:52:54,710
like I'm going on so I'm gonna cut one

1223
00:53:00,039 --> 00:52:57,259
slide out to shorten the talk ever so

1224
00:53:03,430 --> 00:53:00,049
slightly so I want to focus on the ashes

1225
00:53:04,960 --> 00:53:03,440
to ashes part so this is a planetary

1226
00:53:09,670 --> 00:53:04,970
nebula this is a carbon-rich plant

1227
00:53:12,640 --> 00:53:09,680
earnable this is NGC 702 7 so that was a

1228
00:53:15,279 --> 00:53:12,650
carbon star once and the point is is

1229
00:53:17,259 --> 00:53:15,289
that the Sun doesn't have enough mass to

1230
00:53:19,630 --> 00:53:17,269
become a carbon star it to be about

1231
00:53:21,460 --> 00:53:19,640
twice the solar mass up to 5 times in

1232
00:53:22,180 --> 00:53:21,470
that range those guys will all become

1233
00:53:24,190 --> 00:53:22,190
carbons

1234
00:53:25,780 --> 00:53:24,200
one day and as I've already explained

1235
00:53:29,070 --> 00:53:25,790
they're the source of the carbon in the

1236
00:53:31,930 --> 00:53:29,080
universe and if we can understand better

1237
00:53:34,600 --> 00:53:31,940
how these stars died we would have a

1238
00:53:36,100 --> 00:53:34,610

better handle on when in an in in the

1239
00:53:38,920 --> 00:53:36,110
history of a galaxy you'd actually have

1240
00:53:40,660 --> 00:53:38,930
carbon for life to form we actually

1241
00:53:42,850 --> 00:53:40,670
don't understand enough to tell about

1242
00:53:45,070 --> 00:53:42,860
how these things die because basically

1243
00:53:46,750 --> 00:53:45,080
what I think happens is that as soon as

1244
00:53:48,550 --> 00:53:46,760
you dredge up enough carbon and you

1245
00:53:51,040 --> 00:53:48,560
cross some limit the star basically just

1246
00:53:52,240 --> 00:53:51,050
goes into blowout mode and I'm not the

1247
00:53:54,160 --> 00:53:52,250
only one the things this is not my idea

1248
00:53:54,610 --> 00:53:54,170
originally but I've certainly on board

1249
00:53:56,200 --> 00:53:54,620
with it

1250
00:53:58,120 --> 00:53:56,210
but it's really difficult to demonstrate

1251
00:54:02,950 --> 00:53:58,130
that that is true we haven't done that

1252
00:54:04,450 --> 00:54:02,960
yet all right the way we've been

1253
00:54:06,070 --> 00:54:04,460
tackling this problems we've been

1254
00:54:08,560 --> 00:54:06,080
looking at the local groups this is a

1255
00:54:11,560 --> 00:54:08,570
really nice illustration you can see

1256
00:54:13,650 --> 00:54:11,570
this we have Andromeda m31 up here above

1257
00:54:16,150 --> 00:54:13,660
the plane of the local group we've got

1258
00:54:17,530 --> 00:54:16,160
the Milky Way right in the center since

1259
00:54:21,760 --> 00:54:17,540
we drew the plot we're allowed to do

1260
00:54:24,160 --> 00:54:21,770
that but around each of these two big

1261
00:54:27,520 --> 00:54:24,170
spiral galaxies there's a whole swarm of

1262
00:54:30,160 --> 00:54:27,530
dwarf galaxies and most of those dwarf

1263
00:54:31,810 --> 00:54:30,170

galaxies are very metal-poor they

1264
00:54:35,320 --> 00:54:31,820
haven't formed a lot of stars in a long

1265
00:54:37,390 --> 00:54:35,330
time and so they're sort of like they're

1266
00:54:39,130 --> 00:54:37,400
kind of a proxy for what galaxies would

1267
00:54:41,830 --> 00:54:39,140
have looked like at very high redshift

1268
00:54:44,440 --> 00:54:41,840
early in the universe metal-poor

1269
00:54:46,480 --> 00:54:44,450
galaxies the only problem is that most

1270
00:54:48,160 --> 00:54:46,490
of these dwarf galaxies they stopped

1271
00:54:50,800 --> 00:54:48,170
forming stars a long time ago

1272
00:54:52,990 --> 00:54:50,810
the Holy Grail would be to have a metal

1273
00:54:55,060 --> 00:54:53,000
core galaxy that just forms some high

1274
00:54:56,260 --> 00:54:55,070
mass stars because those the ones that

1275
00:54:58,330 --> 00:54:56,270
we would be more interested in but we

1276
00:55:01,570 --> 00:54:58,340
take what you can get so we've been

1277
00:55:04,720 --> 00:55:01,580
looking primarily in the Magellanic

1278
00:55:06,730 --> 00:55:04,730
Clouds the largest small Magellanic

1279
00:55:11,050 --> 00:55:06,740
Clouds Large Magellanic Cloud has a

1280
00:55:12,220 --> 00:55:11,060
metallicity about half solar which is

1281
00:55:14,470 --> 00:55:12,230
sort of like the outer parts of the

1282
00:55:16,420 --> 00:55:14,480
galaxy but still a lot less than most of

1283
00:55:18,750 --> 00:55:16,430
the stars in the galaxy and the small

1284
00:55:21,010 --> 00:55:18,760
Magellanic Cloud is about 1/5 solar

1285
00:55:23,200 --> 00:55:21,020
let's focus on the Large Magellanic

1286
00:55:25,780 --> 00:55:23,210
Cloud here because that's the one I got

1287
00:55:27,580 --> 00:55:25,790
slides on so again I've got a really

1288
00:55:30,160 --> 00:55:27,590

nice snazzy picture I pulled this off

1289
00:55:32,290 --> 00:55:30,170
the web thank you John Gleeson I should

1290
00:55:34,160 --> 00:55:32,300
have asked for permission he's ok good

1291
00:55:36,230 --> 00:55:34,170
advertising great

1292
00:55:39,080 --> 00:55:36,240
and then I have a color-magnitude

1293
00:55:40,640 --> 00:55:39,090
diagram like what I put up before except

1294
00:55:43,100 --> 00:55:40,650
this time it's a near-infrared color

1295
00:55:45,770 --> 00:55:43,110
magnitude diagram and there's so many

1296
00:55:48,410 --> 00:55:45,780
stars to plot that they chose to make it

1297
00:55:49,790 --> 00:55:48,420
a contour plot so here's the peak right

1298
00:55:51,410 --> 00:55:49,800
and those are the next con - all the way

1299
00:55:54,890 --> 00:55:51,420
down I really like this block because

1300
00:55:56,510 --> 00:55:54,900
it's sort of like this giant hand with

1301
00:55:57,260 --> 00:55:56,520
this thumb sticking out and this thumb

1302
00:56:01,040 --> 00:55:57,270
over here

1303
00:56:05,210 --> 00:56:01,050
that's the AGB that's where all the

1304
00:56:07,730 --> 00:56:05,220
dying stars are Dave rebo who got his

1305
00:56:11,480 --> 00:56:07,740
PhD here at Johns Hopkins a few years

1306
00:56:13,220 --> 00:56:11,490
ago took a closer look at the LMC and he

1307
00:56:15,109 --> 00:56:13,230
actually he took all of the AGB stars

1308
00:56:17,510 --> 00:56:15,119
and he plotted them up on this diagram

1309
00:56:21,670 --> 00:56:17,520
so here's the old diagram and here's his

1310
00:56:25,700 --> 00:56:21,680
diagram so basically red is carbon star

1311
00:56:27,680 --> 00:56:25,710
so you can see that that thumb that's

1312
00:56:29,930 --> 00:56:27,690
the carbon stars so these stars are

1313
00:56:31,490 --> 00:56:29,940

incredibly red and they're so red

1314
00:56:34,190 --> 00:56:31,500
they're actually you know like they're

1315
00:56:35,840 --> 00:56:34,200
absorbing infrared light and so these

1316
00:56:38,090 --> 00:56:35,850
stars look like they're getting fainter

1317
00:56:39,710 --> 00:56:38,100
without here at the reddest winds but

1318
00:56:41,690 --> 00:56:39,720
they're not they're just the light can't

1319
00:56:48,560 --> 00:56:41,700
get out at 2 microns it has to get out

1320
00:56:50,330 --> 00:56:48,570
at longer wavelengths so of course I do

1321
00:56:52,430 --> 00:56:50,340
spectroscopy so here's some spectra of

1322
00:56:54,140 --> 00:56:52,440
what these guys look like plotted from

1323
00:56:56,420 --> 00:56:54,150
top to bottom this is the bluest carbon

1324
00:56:59,030 --> 00:56:56,430
star and then every color is sort of

1325
00:57:00,470 --> 00:56:59,040
like a degree of redder all the way down

1326
00:57:02,510 --> 00:57:00,480
to the point that the dust is so thick

1327
00:57:04,520 --> 00:57:02,520
that even the silicon carbide feature

1328
00:57:06,830 --> 00:57:04,530
has gone into absorption it's not

1329
00:57:10,790 --> 00:57:06,840
admitting anymore it's absorbing that's

1330
00:57:12,349 --> 00:57:10,800
that's a lot of dust and yeah and then

1331
00:57:15,349 --> 00:57:12,359
also you can see there's an absorption

1332
00:57:19,010 --> 00:57:15,359
band from acetylene molecules that's the

1333
00:57:21,260 --> 00:57:19,020
stuff that makes the dust and we spit it

1334
00:57:23,330 --> 00:57:21,270
yeah a lot of a lot of a work of these

1335
00:57:24,620 --> 00:57:23,340
on these kinds of spectra but I'm not

1336
00:57:27,050 --> 00:57:24,630
going to show you too much I'm going to

1337
00:57:29,150 --> 00:57:27,060
show you some photometry we're almost to

1338
00:57:32,359 --> 00:57:29,160

the end and it was like 39 or something

1339
00:57:34,220 --> 00:57:32,369
so this is this is a this is not a color

1340
00:57:36,800 --> 00:57:34,230
magnitude plot this is a color color

1341
00:57:39,890 --> 00:57:36,810
plot so what we have here is what color

1342
00:57:42,320 --> 00:57:39,900
it is between 3.6 and 4 point 5 microns

1343
00:57:45,349 --> 00:57:42,330
on this axis and on this axis between

1344
00:57:47,210 --> 00:57:45,359
5.8 and 8 microns and then it's could

1345
00:57:49,460 --> 00:57:47,220
have colored by the color I got from

1346
00:57:51,440 --> 00:57:49,470
Specter I just showed you and the whole

1347
00:57:53,210 --> 00:57:51,450
point here is that for most carbon stars

1348
00:57:56,480 --> 00:57:53,220
if it gets red in one color it gets red

1349
00:57:59,180 --> 00:57:56,490
in another and this it's a pretty tight

1350
00:58:02,660 --> 00:57:59,190
relationship all the way up here except

1351
00:58:05,060 --> 00:58:02,670
for at the very end the reddest stars at

1352
00:58:06,980 --> 00:58:05,070
the longest wavelength there's actually

1353
00:58:08,870 --> 00:58:06,990
they're a little bit too blue at shorter

1354
00:58:13,609 --> 00:58:08,880
wavelengths like some kind of some light

1355
00:58:15,859 --> 00:58:13,619
is escaping from this system and if you

1356
00:58:17,870 --> 00:58:15,869
look at this is a plot of how variable

1357
00:58:20,660 --> 00:58:17,880
they are that Sigma that's a basically

1358
00:58:22,849 --> 00:58:20,670
the the you know you keep taking data at

1359
00:58:23,870 --> 00:58:22,859
different times and if the numbers are

1360
00:58:25,790 --> 00:58:23,880
bounced around all over the place that's

1361
00:58:27,920 --> 00:58:25,800
because it's a variable star so you can

1362
00:58:30,620 --> 00:58:27,930
see for the most of the population the

1363
00:58:33,170 --> 00:58:30,630

the dustier they get from from 0 to

1364
00:58:35,750 --> 00:58:33,180
about 1.5 the stronger they're pulsating

1365
00:58:37,940 --> 00:58:35,760
all makes sense right lots of pulsations

1366
00:58:40,370 --> 00:58:37,950
lots of dust but then all of a sudden

1367
00:58:43,640 --> 00:58:40,380
the reddest winds are hardly pulsating

1368
00:58:44,750 --> 00:58:43,650
at all the hypothesis that we've put out

1369
00:58:46,310 --> 00:58:44,760
there is that's because they've already

1370
00:58:49,400 --> 00:58:46,320
they've stripped their envelope there's

1371
00:58:51,620 --> 00:58:49,410
nothing left to pulsate so basically

1372
00:58:53,810 --> 00:58:51,630
it's just a white dwarf core almost

1373
00:58:56,120 --> 00:58:53,820
inside this really thick dust shell

1374
00:58:58,010 --> 00:58:56,130
except the dust shell is moving outwards

1375
00:58:59,510 --> 00:58:58,020
and it's darting to the asymmetries are

1376
00:59:00,770 --> 00:58:59,520
starting to show so blue light is

1377
00:59:02,839 --> 00:59:00,780
starting to escape the scattered

1378
00:59:04,790 --> 00:59:02,849
emission we think we're looking at

1379
00:59:06,410 --> 00:59:04,800
systems like this in the Large

1380
00:59:09,890 --> 00:59:06,420
Magellanic Cloud this is in the galaxy

1381
00:59:11,120 --> 00:59:09,900
this is a FGL 2688 or the Cygnus egg so

1382
00:59:12,440 --> 00:59:11,130
there's a really thick dust line here

1383
00:59:14,540 --> 00:59:12,450
but there's all this light that's

1384
00:59:16,990 --> 00:59:14,550
getting out the poles of the system and

1385
00:59:20,660 --> 00:59:17,000
then scattering into our line of sight

1386
00:59:22,460 --> 00:59:20,670
so basically my point is is that these

1387
00:59:25,040 --> 00:59:22,470
guys up here that have moved off the

1388
00:59:29,900 --> 00:59:25,050

carbon sequence we think we're catching

1389
00:59:32,120 --> 00:59:29,910
them in the very act of dying the

1390
00:59:34,040 --> 00:59:32,130
problem is that this is a spectroscopic

1391
00:59:35,510 --> 00:59:34,050
sample like we chose to look at these

1392
00:59:38,000 --> 00:59:35,520
guys because they were interesting so

1393
00:59:40,070 --> 00:59:38,010
this is a biased sample so I can't make

1394
00:59:41,750 --> 00:59:40,080
any statistical conclusions from this

1395
00:59:43,790 --> 00:59:41,760
sample so we have to go back and look at

1396
00:59:45,380 --> 00:59:43,800
the larger photometric sample there's a

1397
00:59:48,260 --> 00:59:45,390
spectroscopy I hate that but that's

1398
00:59:50,000 --> 00:59:48,270
that's the way it is all right so this

1399
00:59:52,880 --> 00:59:50,010
is this is basically how the stars die

1400
00:59:54,829 --> 00:59:52,890
and then I just wanted to add this

1401
00:59:57,290 --> 00:59:54,839
amorphous carbon that they're spewing

1402
00:59:59,720 --> 00:59:57,300
into space is made up of little pieces

1403
01:00:00,859 --> 00:59:59,730
of other types of hydrocarbons and you

1404
01:00:02,450 --> 01:00:00,869
can see that when the star

1405
01:00:04,309 --> 01:00:02,460
actually when the when the white dwarf

1406
01:00:08,569 --> 01:00:04,319
or the sinner is exposed enough you can

1407
01:00:10,489 --> 01:00:08,579
see it cooking the dust from the inside

1408
01:00:15,380 --> 01:00:10,499
out and then you can see this is the

1409
01:00:18,499 --> 01:00:15,390
discovery spectrum taken 20 35 45 years

1410
01:00:19,940 --> 01:00:18,509
ago now Fred Gillette and company the

1411
01:00:22,519 --> 01:00:19,950
infrared spectrum they have all these

1412
01:00:24,710 --> 01:00:22,529
bizarre emission features from this

1413
01:00:27,259 --> 01:00:24,720

planetary nebula and then in g7 o27

1414
01:00:29,569 --> 01:00:27,269
which I showed you earlier and this is

1415
01:00:30,950 --> 01:00:29,579
another spectrum from another source but

1416
01:00:33,710 --> 01:00:30,960
basically we're looking at these things

1417
01:00:37,549 --> 01:00:33,720
called polycyclic aromatic hydrocarbons

1418
01:00:39,440 --> 01:00:37,559
which are very small pieces of carbon so

1419
01:00:41,029 --> 01:00:39,450
I put one up here they they don't put

1420
01:00:42,890 --> 01:00:41,039
the little seeds at all the vertices of

1421
01:00:46,029 --> 01:00:42,900
these hexagons but these are basically

1422
01:00:49,460 --> 01:00:46,039
hexagons made of carbon there are little

1423
01:00:51,109 --> 01:00:49,470
molecules there big molecules or small

1424
01:00:53,950 --> 01:00:51,119
dust grains depend on how you think of

1425
01:00:56,329 --> 01:00:53,960
it and we see these things everywhere

1426
01:00:58,579 --> 01:00:56,339
and when you start looking at molecules

1427
01:01:01,519 --> 01:00:58,589
like this my last slide is the next one

1428
01:01:08,059 --> 01:01:01,529
look up here right those are two the

1429
01:01:09,710 --> 01:01:08,069
base pairs for DNA so let's just go back

1430
01:01:12,799 --> 01:01:09,720
for a second there's some differences

1431
01:01:15,019 --> 01:01:12,809
these are just carbon so technically

1432
01:01:17,739 --> 01:01:15,029
this is organic chemistry by definition

1433
01:01:20,749 --> 01:01:17,749
right but that doesn't mean there's life

1434
01:01:22,430 --> 01:01:20,759
because the key point to the DNA base

1435
01:01:24,499 --> 01:01:22,440
pairs is that a lot of nitrogen

1436
01:01:26,150 --> 01:01:24,509
substitutions have happened and there's

1437
01:01:28,849 --> 01:01:26,160
also some oxygen and you'll notice that

1438
01:01:30,049 --> 01:01:28,859

this is a five membered ring not a six

1439
01:01:32,269 --> 01:01:30,059
membered ring you get the idea but the

1440
01:01:33,890 --> 01:01:32,279
point is my point is this carbon rich

1441
01:01:36,079 --> 01:01:33,900
chemistry that we see in the outflows

1442
01:01:38,599 --> 01:01:36,089
from these carbon stars is incredibly

1443
01:01:40,870 --> 01:01:38,609
complex and we haven't detected the

1444
01:01:44,180 --> 01:01:40,880
spectroscopic signature of the nitrogen

1445
01:01:45,710 --> 01:01:44,190
substitutions but that you know that

1446
01:01:47,630 --> 01:01:45,720
certainly is something to keep looking

1447
01:01:49,339 --> 01:01:47,640
for anyway

1448
01:01:50,420 --> 01:01:49,349
that is all I had thanks for putting up

1449
01:01:56,890 --> 01:01:50,430
with me for

1450
01:02:13,079 --> 01:02:04,520
[Applause]

1451
01:02:16,650 --> 01:02:13,089
okay now what I get to be microphone

1452
01:02:19,710 --> 01:02:16,660
delivery guy oh is the microphone is on

1453
01:02:21,809 --> 01:02:19,720
okay good I wonder if anybody can speak

1454
01:02:24,420 --> 01:02:21,819
like in a in an alto voice with that

1455
01:02:30,059 --> 01:02:24,430
thing all right I see a question way in

1456
01:02:32,549 --> 01:02:30,069
the back so you work it out all the way

1457
01:02:45,450 --> 01:02:32,559
back there all right we have to pass

1458
01:02:49,049 --> 01:02:45,460
this but I think you quoted a figure of

1459
01:02:51,660 --> 01:02:49,059
80,000 years for pulsations one for the

1460
01:02:54,299 --> 01:02:51,670
thermal pulses the time between two

1461
01:02:55,980 --> 01:02:54,309
consecutive ignitions of the of the

1462
01:02:58,529 --> 01:02:55,990
layer of helium and the core of the star

1463
01:03:01,319 --> 01:02:58,539

yes but then the long period variables

1464
01:03:03,779 --> 01:03:01,329
their pulsations are you know a year

1465
01:03:05,370 --> 01:03:03,789
maybe right what's the how does one get

1466
01:03:06,750 --> 01:03:05,380
to the other you don't they're

1467
01:03:08,220 --> 01:03:06,760
completely separate one of them

1468
01:03:11,970 --> 01:03:08,230
something going on in the core of the

1469
01:03:14,279 --> 01:03:11,980
star and the other is just basically

1470
01:03:16,950 --> 01:03:14,289
just a dynamic pulsation going on in the

1471
01:03:18,450 --> 01:03:16,960
atmosphere it's unfortunate that they

1472
01:03:20,910 --> 01:03:18,460
decided to call these things thermal

1473
01:03:22,019 --> 01:03:20,920
pulses I mean what else could we call

1474
01:03:24,839 --> 01:03:22,029
them because it's basically it's a

1475
01:03:26,490 --> 01:03:24,849
runaway nuclear fusion event in this

1476
01:03:28,200 --> 01:03:26,500
thin layer of helium in the center of

1477
01:03:30,120 --> 01:03:28,210
the star so it takes about 80,000 years

1478
01:03:32,880 --> 01:03:30,130
for one solar mass star to build up

1479
01:03:34,319 --> 01:03:32,890
enough helium to do this but the point

1480
01:03:37,170 --> 01:03:34,329
is whatever they're doing on the inside

1481
01:03:40,319 --> 01:03:37,180
these stars are also like breathing on

1482
01:03:41,359 --> 01:03:40,329
the outside okay thank you sorry about

1483
01:03:43,170 --> 01:03:41,369
that

1484
01:03:46,859 --> 01:03:43,180
astronomers are really bad at naming

1485
01:03:51,960 --> 01:03:46,869
things you might have noticed over here

1486
01:03:56,970 --> 01:03:51,970
what we hang on we have to we'll get it

1487
01:04:09,999 --> 01:03:56,980
we'll get there I'm sorry can I can

1488
01:04:21,529 --> 01:04:18,440

yeah oh that was early boom

1489
01:04:23,210 --> 01:04:21,539
that one yes okay question you had a

1490
01:04:25,700 --> 01:04:23,220
question oh yeah I just wanted to ask

1491
01:04:32,870 --> 01:04:25,710
can-can you planet secrete around white

1492
01:04:36,400 --> 01:04:32,880
dwarf stars from that ejecta that's a

1493
01:04:40,160 --> 01:04:36,410
good question I don't know the answer I

1494
01:04:42,200 --> 01:04:40,170
my instinct is no but you know I my

1495
01:04:45,680 --> 01:04:42,210
batting record on instinct is not so

1496
01:04:47,150 --> 01:04:45,690
good I do know that Mike Jorah was one

1497
01:04:49,190 --> 01:04:47,160
of the people sort of got this field

1498
01:04:52,309 --> 01:04:49,200
starting started of looking at the

1499
01:04:53,989 --> 01:04:52,319
accretion of material from plants that

1500
01:04:55,309 --> 01:04:53,999
have been ripped apart onto white dwarfs

1501
01:04:59,120 --> 01:04:55,319
but that's not the process you're

1502
01:05:00,920 --> 01:04:59,130
talking about if you had enough mass

1503
01:05:02,269 --> 01:05:00,930
then you could do it but my question is

1504
01:05:05,180 --> 01:05:02,279
where would that mature will be created

1505
01:05:07,789 --> 01:05:05,190
from probably another planet so it'd be

1506
01:05:13,420 --> 01:05:07,799
hard to remake one bit yeah this is I'm

1507
01:05:16,819 --> 01:05:13,430
not the expert on this so my apologies I

1508
01:05:18,890 --> 01:05:16,829
had to follow the path of Mike yes I'm a

1509
01:05:22,880 --> 01:05:18,900
little confused perhaps about the

1510
01:05:26,720 --> 01:05:22,890
relationship between the development of

1511
01:05:31,489 --> 01:05:26,730
these heavy metals and molecules from

1512
01:05:35,690 --> 01:05:31,499
the individual complex molecules from

1513
01:05:40,299 --> 01:05:35,700

smaller molecules and and also what you

1514
01:05:43,339 --> 01:05:40,309
referred to as dust it's just just

1515
01:05:49,069 --> 01:05:43,349
collaborations of these heavy metals in

1516
01:05:51,109 --> 01:05:49,079
various yeah so if you think of the Sun

1517
01:05:53,720 --> 01:05:51,119
so the Sun was was already born with

1518
01:05:56,630 --> 01:05:53,730
lots of oxygen and silicon right so it

1519
01:05:57,950 --> 01:05:56,640
it added some carbon but it already had

1520
01:06:00,499 --> 01:05:57,960
a lot of oxygen and silicon to start

1521
01:06:01,849 --> 01:06:00,509
with and so as it ages out yeah it

1522
01:06:03,559 --> 01:06:01,859
pushes this these it pushes these

1523
01:06:05,690 --> 01:06:03,569
elements out they bind into molecules

1524
01:06:08,390 --> 01:06:05,700
and then those molecules will bind

1525
01:06:14,660 --> 01:06:08,400
together in the dust grains provided

1526
01:06:17,420 --> 01:06:14,670
it's cool enough all the interstellar

1527
01:06:19,630 --> 01:06:17,430
dust that's floating around is related

1528
01:06:23,020 --> 01:06:19,640
to the manufacturer

1529
01:06:25,660 --> 01:06:23,030
this store is made into its death spiral

1530
01:06:28,900 --> 01:06:25,670
so you just put your finger on a really

1531
01:06:31,720 --> 01:06:28,910
difficult question to answer the

1532
01:06:33,340 --> 01:06:31,730
question was so just if we make dust

1533
01:06:35,080 --> 01:06:33,350
around stars and we have dust in the

1534
01:06:41,830 --> 01:06:35,090
interstellar medium is it the same dust

1535
01:06:44,500 --> 01:06:41,840
and the answer is apparently not that

1536
01:06:46,570 --> 01:06:44,510
apparently this this is a there's a

1537
01:06:48,610 --> 01:06:46,580
there's a lot of controversy about this

1538
01:06:50,680 --> 01:06:48,620

right now but the idea is that supernova

1539
01:06:53,140 --> 01:06:50,690
explosions are really efficient at

1540
01:06:55,390 --> 01:06:53,150
destroying dust and so if you act start

1541
01:06:57,520 --> 01:06:55,400
adding up how much dust supernova have

1542
01:06:59,440 --> 01:06:57,530
to destroy it's like all of it so there

1543
01:07:01,330 --> 01:06:59,450
must be another source of dust formation

1544
01:07:05,830 --> 01:07:01,340
out there like maybe the dust is being

1545
01:07:07,630 --> 01:07:05,840
formed in these clouds I I'm a bit of a

1546
01:07:10,450 --> 01:07:07,640
skeptic about the fact that supernova

1547
01:07:13,330 --> 01:07:10,460
destroying all the dusts but I do not

1548
01:07:15,220 --> 01:07:13,340
have a good quantitative really well

1549
01:07:18,880 --> 01:07:15,230
grounded theoretical argument against it

1550
01:07:21,490 --> 01:07:18,890
I just don't like it and that's not good

1551
01:07:23,590 --> 01:07:21,500
enough but there's it's this there's a

1552
01:07:26,680 --> 01:07:23,600
bit of a debate about this so it's not

1553
01:07:37,060 --> 01:07:26,690
the answer to that is not clear and that

1554
01:07:39,010 --> 01:07:37,070
is unfortunate all the ones all of the

1555
01:07:41,080 --> 01:07:39,020
ones that can form into dust yes but

1556
01:07:42,490 --> 01:07:41,090
like the neon is just a noble gas right

1557
01:07:44,950 --> 01:07:42,500
so the neon just has to get dragged

1558
01:07:48,250 --> 01:07:44,960
along with the process as a gas for

1559
01:07:49,750 --> 01:07:48,260
example which does happen because of

1560
01:07:51,880 --> 01:07:49,760
these dust grains get accelerated they

1561
01:07:54,040 --> 01:07:51,890
start slamming into gas molecules and

1562
01:07:57,940 --> 01:07:54,050
dragging their gas atoms and dragging

1563
01:07:58,450 --> 01:07:57,950

them with them - okay who's next who is

1564
01:08:04,090 --> 01:07:58,460
next

1565
01:08:07,140 --> 01:08:04,100
alright right here yes wait to receive

1566
01:08:10,060 --> 01:08:07,150
[Laughter]

1567
01:08:14,620 --> 01:08:10,070
what happens to the dust can the dust

1568
01:08:16,570 --> 01:08:14,630
form planets yes in fact it see the dust

1569
01:08:19,990 --> 01:08:16,580
appears to be a key part of planetary

1570
01:08:22,030 --> 01:08:20,000
formation but not necessarily the you

1571
01:08:23,710 --> 01:08:22,040
know as I said we're having a bit of a

1572
01:08:26,110 --> 01:08:23,720
difficulty understanding the path of the

1573
01:08:29,170 --> 01:08:26,120
dust in the interstellar medium but once

1574
01:08:30,880 --> 01:08:29,180
you have a star starting to form you

1575
01:08:32,290 --> 01:08:30,890
know it's at the cloud that it's in has

1576
01:08:33,550 --> 01:08:32,300
a lot of dust with it so the dust will

1577
01:08:35,440 --> 01:08:33,560
form into a disc

1578
01:08:37,650 --> 01:08:35,450
and then the planets will start to

1579
01:08:39,849 --> 01:08:37,660
basically form you know you'll get

1580
01:08:41,410 --> 01:08:39,859
planetesimals and you'll get planets

1581
01:08:43,630 --> 01:08:41,420
forming and the dust appears to be a key

1582
01:08:45,910 --> 01:08:43,640
part of that process there's some debate

1583
01:08:47,559 --> 01:08:45,920
about like is Jupiter

1584
01:08:49,380 --> 01:08:47,569
there's been some debate whether the

1585
01:08:52,000 --> 01:08:49,390
jovian planets are actually just

1586
01:08:53,320 --> 01:08:52,010
gravitational collapses of gas whether

1587
01:08:55,930 --> 01:08:53,330
you have to first have a terrestrial

1588
01:08:58,780 --> 01:08:55,940

core formed from accumulating a lot of

1589
01:09:00,309 --> 01:08:58,790
dust particles I think that's that was

1590
01:09:05,200 --> 01:09:00,319
an open question the last time I looked

1591
01:09:08,230 --> 01:09:05,210
carefully so the short answer is yet

1592
01:09:09,730 --> 01:09:08,240
dust you need us to make planets all

1593
01:09:13,480 --> 01:09:09,740
right just to make my life easier I'm

1594
01:09:16,240 --> 01:09:13,490
gonna go to someone nearby you in one of

1595
01:09:20,640 --> 01:09:16,250
the last slides water is being formed

1596
01:09:32,920 --> 01:09:20,650
yes is that evaporated it's water vapor

1597
01:09:34,780 --> 01:09:32,930
so it's it's gaseous red giants yeah so

1598
01:09:35,680 --> 01:09:34,790
yeah in a really cool red giant you can

1599
01:09:39,040 --> 01:09:35,690
see this water vapor

1600
01:09:41,710 --> 01:09:39,050
we actually a colleague of mine Kathleen

1601
01:09:44,470 --> 01:09:41,720
Cramer at Boston College and then some

1602
01:09:46,599 --> 01:09:44,480
colleagues at UC Davis Matt ripped it we

1603
01:09:47,950 --> 01:09:46,609
have a proposal in and we just found I

1604
01:09:50,650 --> 01:09:47,960
found out today that we're scheduled

1605
01:09:52,540 --> 01:09:50,660
we're going to be looking at very high

1606
01:09:57,160 --> 01:09:52,550
spectral resolution at some of these

1607
01:09:59,200 --> 01:09:57,170
water vapor lines in some of these these

1608
01:10:00,910 --> 01:09:59,210
these red giants using Sofia which is

1609
01:10:04,180 --> 01:10:00,920
the airborne telescope that flies out of

1610
01:10:05,920 --> 01:10:04,190
California and the hope is that we can

1611
01:10:09,160 --> 01:10:05,930
we can get enough information to work

1612
01:10:10,600 --> 01:10:09,170
out how far above the photosphere this

1613
01:10:12,730 --> 01:10:10,610

water vapor is because that there's a

1614
01:10:15,090 --> 01:10:12,740
big debate is it is in clouds that in

1615
01:10:19,930 --> 01:10:15,100
the east so we're hoping to address that

1616
01:10:25,540 --> 01:10:19,940
so yeah so on that last slide there was

1617
01:10:27,220 --> 01:10:25,550
an adenine thymine complex so is there

1618
01:10:29,500 --> 01:10:27,230
actually evidence that would but there

1619
01:10:31,690 --> 01:10:29,510
is that complex coming from stars and

1620
01:10:33,960 --> 01:10:31,700
I'm curious I'm just I'm a I'm not

1621
01:10:36,190 --> 01:10:33,970
familiar with the idea of such complex

1622
01:10:39,400 --> 01:10:36,200
molecules coming right out of stars I

1623
01:10:41,140 --> 01:10:39,410
always thought that I was I'm curious

1624
01:10:42,250 --> 01:10:41,150
what more evidence there is about stuff

1625
01:10:46,290 --> 01:10:42,260
like that that's really interesting

1626
01:10:47,390 --> 01:10:46,300
if I remember correctly an amino acid

1627
01:10:51,919 --> 01:10:47,400
had

1628
01:10:54,530 --> 01:10:51,929
been seen in in rate using using its

1629
01:10:57,229 --> 01:10:54,540
radio emission they've been able to

1630
01:10:58,340 --> 01:10:57,239
identify this as an amino acid but

1631
01:10:59,360 --> 01:10:58,350
something minimum acids are fairly

1632
01:11:01,209 --> 01:10:59,370
simple and you can see some of the

1633
01:11:08,209 --> 01:11:01,219
molecules were seeing are pretty complex

1634
01:11:10,370 --> 01:11:08,219
so hi I'm wondering if you have any

1635
01:11:13,189 --> 01:11:10,380
thoughts on the fact that there was a

1636
01:11:19,490 --> 01:11:13,199
hexagon on top of Saturn and then your

1637
01:11:21,380 --> 01:11:19,500
last two slides I knew these hexagons

1638
01:11:22,610 --> 01:11:21,390

keep popping up so the question energy

1639
01:11:24,500 --> 01:11:22,620
you guys catch the question is there any

1640
01:11:25,790 --> 01:11:24,510
you know just-just we had a hexagon on

1641
01:11:28,669 --> 01:11:25,800
Saturn's North Pole

1642
01:11:30,830 --> 01:11:28,679
we got carbon arranged in hexagons I

1643
01:11:32,510 --> 01:11:30,840
will just say that you know before we

1644
01:11:34,280 --> 01:11:32,520
had PowerPoint presentations and I was

1645
01:11:35,600 --> 01:11:34,290
doing these with with overheads and I

1646
01:11:37,459 --> 01:11:35,610
would take my talk and a big stack of

1647
01:11:39,260 --> 01:11:37,469
overheads I would have a little envelope

1648
01:11:42,229 --> 01:11:39,270
every long I would do little cutouts a

1649
01:11:43,850 --> 01:11:42,239
chicken wire because you know cuz it's a

1650
01:11:45,350 --> 01:11:43,860
hexagonal shape right within it you'd

1651
01:11:47,360 --> 01:11:45,360
cut the links and be like the hydrogen

1652
01:11:48,950 --> 01:11:47,370
bonds and I would pass those out so

1653
01:11:52,729 --> 01:11:48,960
people could kind of hold quarantine and

1654
01:11:56,470 --> 01:11:52,739
other pause yeah so it's it's I think

1655
01:12:03,950 --> 01:12:00,169
and symmetry yeah

1656
01:12:06,770 --> 01:12:03,960
can you describe in graphic detail as

1657
01:12:11,110 --> 01:12:06,780
much as you can what's gonna happen and

1658
01:12:13,189 --> 01:12:11,120
when our our star our Sun starts to die

1659
01:12:15,140 --> 01:12:13,199
well my wife and I have been discussing

1660
01:12:19,340 --> 01:12:15,150
if we should keep investing in real

1661
01:12:22,610 --> 01:12:19,350
estate yes so the process we'll get to

1662
01:12:24,950 --> 01:12:22,620
see we are 4.6 billion years in to a ten

1663
01:12:27,709 --> 01:12:24,960

billion year process right so another

1664
01:12:29,510 --> 01:12:27,719
4.2 million years the problem is 10

1665
01:12:31,459 --> 01:12:29,520
billion years there's an aero bar there

1666
01:12:33,709 --> 01:12:31,469
right now I don't it's it's probably

1667
01:12:36,560 --> 01:12:33,719
plus I'm gonna just wait your guess it's

1668
01:12:38,060 --> 01:12:36,570
half a billion years plus or minus then

1669
01:12:40,640 --> 01:12:38,070
at that point the Sun will start to

1670
01:12:44,120 --> 01:12:40,650
ascend the red giant branch but actually

1671
01:12:45,709 --> 01:12:44,130
the scary part of all of this is that

1672
01:12:48,260 --> 01:12:45,719
you remember the part I said is that as

1673
01:12:50,959 --> 01:12:48,270
the core collapses as the core starts to

1674
01:12:55,820 --> 01:12:50,969
contract then the luminosity of the star

1675
01:12:58,160 --> 01:12:55,830
goes up that's already happening yeah so

1676
01:13:01,089 --> 01:12:58,170
every day the Sun is just slightly

1677
01:13:07,870 --> 01:13:01,099
brighter and hotter than it was before

1678
01:13:11,000 --> 01:13:07,880
right so you know the the the the

1679
01:13:13,060 --> 01:13:11,010
climate change caused by the burning of

1680
01:13:15,620 --> 01:13:13,070
fossil fuels just making an already

1681
01:13:17,660 --> 01:13:15,630
slowly deteriorating situation worse

1682
01:13:19,700 --> 01:13:17,670
right we're just adding to the problem

1683
01:13:21,729 --> 01:13:19,710
so I guess one of the ways to look at is

1684
01:13:24,530 --> 01:13:21,739
that we're since we clearly can't stop

1685
01:13:25,700 --> 01:13:24,540
consuming fossil fuels we're gonna have

1686
01:13:27,799 --> 01:13:25,710
to figure out some other way to mitigate

1687
01:13:30,049 --> 01:13:27,809
for the problem I don't like that

1688
01:13:31,490 --> 01:13:30,059

solution at all just agreements how

1689
01:13:40,790 --> 01:13:31,500
about fewer fossil fuels might be nice

1690
01:13:43,790 --> 01:13:40,800
but the point is yeah we'll be fried

1691
01:13:45,620 --> 01:13:43,800
before we burn that's good yeah but I

1692
01:13:48,200 --> 01:13:45,630
guess what I'm getting at is that we're

1693
01:13:51,319 --> 01:13:48,210
gonna have to figure out how to mitigate

1694
01:13:54,500 --> 01:13:51,329
for the fact that the earth is warming

1695
01:13:57,350 --> 01:13:54,510
up in the long term anyway because the

1696
01:13:59,899 --> 01:13:57,360
Sun is going to get hotter over the you

1697
01:14:02,330 --> 01:13:59,909
know over the next million years so now

1698
01:14:03,530 --> 01:14:02,340
we have him you know that we need to get

1699
01:14:07,609 --> 01:14:03,540
little bit of a head start because we

1700
01:14:10,760 --> 01:14:07,619
can't stop burning fossil fuels so so

1701
01:14:12,410 --> 01:14:10,770
I'm in my experience the estimate is

1702
01:14:15,109 --> 01:14:12,420
that the earth is totally uninhabitable

1703
01:14:17,080 --> 01:14:15,119
by about three billion years from now is

1704
01:14:19,700 --> 01:14:17,090
that the number that you had in your I

1705
01:14:23,419 --> 01:14:19,710
don't know actually I mean no matter

1706
01:14:25,540 --> 01:14:23,429
what humans do they the earth is an

1707
01:14:27,830 --> 01:14:25,550
uninhabitable in three billion years not

1708
01:14:30,080 --> 01:14:27,840
but before it starts going up the red

1709
01:14:31,490 --> 01:14:30,090
giant branch yeah this is something like

1710
01:14:33,859 --> 01:14:31,500
that would be I think they'd be true all

1711
01:14:43,040 --> 01:14:33,869
I know is that Mars does not look

1712
01:14:48,830 --> 01:14:43,050
particularly appealing right now okay

1713
01:14:51,830 --> 01:14:48,840

you had oh yeah get his attention

1714
01:14:56,000 --> 01:14:51,840
yes a quick question about variable

1715
01:15:00,080 --> 01:14:56,010
stars so when you see a variable star is

1716
01:15:03,379 --> 01:15:00,090
it always an Ag B there are many many

1717
01:15:04,970 --> 01:15:03,389
kinds of variable stars for example you

1718
01:15:06,439 --> 01:15:04,980
could have two completely normal non

1719
01:15:08,600 --> 01:15:06,449
variable stars that are in a binary

1720
01:15:09,350 --> 01:15:08,610
system and if they happen to eclipse

1721
01:15:11,839 --> 01:15:09,360
each other

1722
01:15:15,000 --> 01:15:11,849
then that's an eclipsing binary that's a

1723
01:15:16,950 --> 01:15:15,010
kind of variable star

1724
01:15:18,540 --> 01:15:16,960
there's this there are I mean I could

1725
01:15:21,090 --> 01:15:18,550
not if I could start making a list of

1726
01:15:23,490 --> 01:15:21,100
variable stars and I would get one-tenth

1727
01:15:24,740 --> 01:15:23,500
the way for my memories exhausted there

1728
01:15:29,340 --> 01:15:24,750
are so many different kinds of variables

1729
01:15:30,840 --> 01:15:29,350
Vega is a class of air is a class of

1730
01:15:33,060 --> 01:15:30,850
variable stars actually very low

1731
01:15:36,600 --> 01:15:33,070
amplitude but still yeah there's all

1732
01:15:39,240 --> 01:15:36,610
sorts of different kinds that's just one

1733
01:15:46,290 --> 01:15:39,250
of them yes yes stars do not really

1734
01:15:49,260 --> 01:15:46,300
behave themselves give a question so as

1735
01:15:51,660 --> 01:15:49,270
I understand our Sun transports energy

1736
01:15:53,460 --> 01:15:51,670
through convection and then to the

1737
01:15:56,760 --> 01:15:53,470
photosphere and most of the energy goes

1738
01:15:57,960 --> 01:15:56,770

out that way and you said when it went

1739
01:16:00,570 --> 01:15:57,970
into the death branch that the

1740
01:16:02,850 --> 01:16:00,580
convection went all the way out to near

1741
01:16:05,100 --> 01:16:02,860
Earth's orbit that's because the star

1742
01:16:06,900 --> 01:16:05,110
goes out to Earth's orbit so why isn't

1743
01:16:08,340 --> 01:16:06,910
there like a photosphere where is the

1744
01:16:10,140 --> 01:16:08,350
photosphere at that point is there still

1745
01:16:12,120 --> 01:16:10,150
a photosphere at that point is that are

1746
01:16:14,460 --> 01:16:12,130
we seeing something outside of Earth's

1747
01:16:17,370 --> 01:16:14,470
orbit when we look at these it's still

1748
01:16:21,090 --> 01:16:17,380
yes it's still a photosphere sort of but

1749
01:16:23,490 --> 01:16:21,100
I think that it's the idea that we have

1750
01:16:26,190 --> 01:16:23,500
an with the Sun now we have a reasonably

1751
01:16:28,440 --> 01:16:26,200
good boundary and I think as these

1752
01:16:30,000 --> 01:16:28,450
things get bigger and bigger where you

1753
01:16:33,420 --> 01:16:30,010
draw that boundary becomes a little bit

1754
01:16:37,200 --> 01:16:33,430
more challenging it's it's very

1755
01:16:38,700 --> 01:16:37,210
wavelength dependent yeah it's the it

1756
01:16:39,840 --> 01:16:38,710
gets to the question you're asking is

1757
01:16:41,430 --> 01:16:39,850
actually a really good one

1758
01:16:43,800 --> 01:16:41,440
where's the boundary where does the star

1759
01:16:46,860 --> 01:16:43,810
stop and that's that's that's not

1760
01:16:48,870 --> 01:16:46,870
actually a trivial question to answer it

1761
01:16:51,510 --> 01:16:48,880
gives the theorists fits I'll put it

1762
01:16:53,280 --> 01:16:51,520
that way all right is there there's a

1763
01:16:55,650 --> 01:16:53,290

question I think over here by the by the

1764
01:16:59,670 --> 01:16:55,660
exit I think we have to be quick because

1765
01:17:01,920 --> 01:16:59,680
there's an exit involved actually as

1766
01:17:03,510 --> 01:17:01,930
pertains to the slide you just had up

1767
01:17:07,020 --> 01:17:03,520
there before but Oh

1768
01:17:13,050 --> 01:17:07,030
when does this oxygen start to show up

1769
01:17:16,350 --> 01:17:13,060
and in the scheme of things I think it

1770
01:17:21,990 --> 01:17:16,360
went oh there we go for a more massive

1771
01:17:23,370 --> 01:17:22,000
AGB star you could you can make off do

1772
01:17:24,660 --> 01:17:23,380
you make some oxygen when you make the

1773
01:17:28,440 --> 01:17:24,670
carbon it's sort of like you know you

1774
01:17:28,910 --> 01:17:28,450
just just an extra helium atom in the in

1775
01:17:31,400 --> 01:17:28,920
the middle

1776
01:17:32,900 --> 01:17:31,410
process of boom there's an oxygen so

1777
01:17:35,750 --> 01:17:32,910
yeah we get we get some of that but for

1778
01:17:38,360 --> 01:17:35,760
its for more massive stars I think it's

1779
01:17:41,090 --> 01:17:38,370
solar medallist ease on the on the on

1780
01:17:43,459 --> 01:17:41,100
the other side of the carbon limit so

1781
01:17:46,310 --> 01:17:43,469
five six seven solar masses kind of a

1782
01:17:48,050 --> 01:17:46,320
thing there's another process there and

1783
01:17:49,520 --> 01:17:48,060
I didn't talk about which astronomers

1784
01:17:52,030 --> 01:17:49,530
with their love for really bad names

1785
01:17:55,520 --> 01:17:52,040
called it's called hot bottom burning

1786
01:17:57,950 --> 01:17:55,530
which is involves involves protons

1787
01:17:59,510 --> 01:17:57,960
getting captured and what happens in as

1788
01:18:02,110 --> 01:17:59,520

you actually wind up you make carbon but

1789
01:18:05,390 --> 01:18:02,120
then you're converting it into nitrogen

1790
01:18:07,520 --> 01:18:05,400
yeah there's a this quickly gets I'm not

1791
01:18:09,260 --> 01:18:07,530
a nuclear fusion expert and and the more

1792
01:18:10,520 --> 01:18:09,270
I start to keep talking on the subject

1793
01:18:13,790 --> 01:18:10,530
that quickly you're the more quickly you

1794
01:18:16,490 --> 01:18:13,800
will realize that yeah is that that did

1795
01:18:20,209 --> 01:18:16,500
that help though okay okay so we have a

1796
01:18:22,550 --> 01:18:20,219
question from online asking what are you

1797
01:18:26,720 --> 01:18:22,560
most excited to learn about the Sun from

1798
01:18:30,050 --> 01:18:26,730
the Parker Solar Probe mission is that

1799
01:18:35,120 --> 01:18:30,060
the new one that's that's the next the

1800
01:18:36,979 --> 01:18:35,130
mission I'd yeah I don't know enough to

1801
01:18:38,959 --> 01:18:36,989
answer the question except that I know

1802
01:18:43,160 --> 01:18:38,969
that they're there they're getting the

1803
01:18:46,070 --> 01:18:43,170
probe is going into like the corona yep

1804
01:18:47,870 --> 01:18:46,080
and and that's gonna be really

1805
01:18:50,810 --> 01:18:47,880
impressive I sort of am naturally

1806
01:18:54,620 --> 01:18:50,820
curious about the solar wind because

1807
01:18:57,229 --> 01:18:54,630
we're launching JWST and there's this

1808
01:18:59,870 --> 01:18:57,239
thing called space weathering which is

1809
01:19:03,800 --> 01:18:59,880
basically the result of sort of a steady

1810
01:19:06,890 --> 01:19:03,810
cosmic ray bombardment so what happens

1811
01:19:09,050 --> 01:19:06,900
is over time the detectors that we've

1812
01:19:11,600 --> 01:19:09,060
launched will slowly be degraded by

1813
01:19:13,610 --> 01:19:11,610

getting hit by cosmic rays and the

1814
01:19:16,340 --> 01:19:13,620
cosmic rays which are really the problem

1815
01:19:17,720 --> 01:19:16,350
are the ones that come from the Sun so

1816
01:19:21,650 --> 01:19:17,730
I'd be very CUTE anything we can learn

1817
01:19:25,750 --> 01:19:21,660
more about that process so we know when

1818
01:19:37,880 --> 01:19:33,920
okay so our son has about four billion

1819
01:19:41,780 --> 01:19:37,890
years left and change and change can

1820
01:19:44,360 --> 01:19:41,790
anything catastrophic unexpected occur

1821
01:19:46,910 --> 01:19:44,370
that would derail that timeline for the

1822
01:19:49,040 --> 01:19:46,920
son yeah does anything you know like

1823
01:19:50,660 --> 01:19:49,050
humans might live to 80 or 90 but then

1824
01:19:56,300 --> 01:19:50,670
things happen and some humans live the

1825
01:20:02,990 --> 01:19:56,310
30 or 40 can the same happen something

1826
01:20:10,700 --> 01:20:03,000
unexpected occurs I was thinking of a

1827
01:20:15,290 --> 01:20:10,710
stroke there is no process that I'm

1828
01:20:17,840 --> 01:20:15,300
aware of so I'm thinking probably not

1829
01:20:20,420 --> 01:20:17,850
but i I've learned over the years to

1830
01:20:22,490 --> 01:20:20,430
always hedge my bets ever so slightly

1831
01:20:24,590 --> 01:20:22,500
now I don't there's you know we've been

1832
01:20:26,150 --> 01:20:24,600
studying these systems like these

1833
01:20:29,150 --> 01:20:26,160
globular clusters and stuff at different

1834
01:20:32,240 --> 01:20:29,160
metallicity and every the stars are

1835
01:20:33,590 --> 01:20:32,250
behaving more or less as we expect there

1836
01:20:35,020 --> 01:20:33,600
there's certainly a lot of surprises is

1837
01:20:39,410 --> 01:20:35,030
why we study them but there's nothing

1838
01:20:41,300 --> 01:20:39,420

grand on that scale so I think we're

1839
01:20:44,300 --> 01:20:41,310
okay I think the real estate is safe for

1840
01:20:45,980 --> 01:20:44,310
a bit I will say there was that one Star

1841
01:20:47,570 --> 01:20:45,990
Trek film where the villain shot

1842
01:20:49,840 --> 01:20:47,580
something into the star and made it

1843
01:20:52,690 --> 01:20:49,850
explode yeah we don't know about that

1844
01:20:56,290 --> 01:20:52,700
[Laughter]

1845
01:20:58,910 --> 01:20:56,300
other questions oh we had a questions

1846
01:21:03,070 --> 01:20:58,920
one final question oh yes he's been

1847
01:21:08,810 --> 01:21:05,930
I'm actually just kind of curious about

1848
01:21:11,690 --> 01:21:08,820
the fusion reaction in a normal star

1849
01:21:13,790 --> 01:21:11,700
like the Sun aha does the fusion

1850
01:21:16,970 --> 01:21:13,800
reaction begin in the center and move

1851
01:21:19,520 --> 01:21:16,980
outward and if that's true how long does

1852
01:21:21,770 --> 01:21:19,530
it take for the fusion reaction to get

1853
01:21:24,530 --> 01:21:21,780
to the from the core of the Sun of the

1854
01:21:28,220 --> 01:21:24,540
surface okay so the fusion reaction is

1855
01:21:30,500 --> 01:21:28,230
always just in the core I think it's the

1856
01:21:33,050 --> 01:21:30,510
number twenty percent by mass is in my

1857
01:21:38,040 --> 01:21:33,060
head but this is a fact check the

1858
01:21:40,020 --> 01:21:38,050
speaker kind of a thing so the

1859
01:21:41,280 --> 01:21:40,030
is that the the fusion reaction operates

1860
01:21:43,109 --> 01:21:41,290
more efficiently in the center because

1861
01:21:45,030 --> 01:21:43,119
the temperature is higher but there's

1862
01:21:46,560 --> 01:21:45,040
sort of a radius out to which the

1863
01:21:48,750 --> 01:21:46,570

temperatures high enough to sustain some

1864
01:21:50,790 --> 01:21:48,760
fusion right so what happens is since

1865
01:21:52,709 --> 01:21:50,800
the core is radiative which means

1866
01:21:55,229 --> 01:21:52,719
everything just sits there there's no

1867
01:21:57,930 --> 01:21:55,239
convection the the hydrogen gets

1868
01:22:03,660 --> 01:21:57,940
exhausted faster in the center of the

1869
01:22:06,030 --> 01:22:03,670
Sun so I don't I think it's pretty

1870
01:22:09,089 --> 01:22:06,040
stable configuration for the last 4.7

1871
01:22:10,770 --> 01:22:09,099
billion years by and large but what's

1872
01:22:13,350 --> 01:22:10,780
happening is that the the the amount of

1873
01:22:15,270 --> 01:22:13,360
hydrogen in the core is going in the

1874
01:22:17,879 --> 01:22:15,280
center of the core is dropping fastest

1875
01:22:20,040 --> 01:22:17,889
and so it's slowly the core slowly

1876
01:22:21,390 --> 01:22:20,050
gravitationally contracting and the Sun

1877
01:22:23,250 --> 01:22:21,400
sitting up if I remember right then the

1878
01:22:28,799 --> 01:22:23,260
number is the Sun is twice as bright now

1879
01:22:32,959 --> 01:22:28,809
as it was when it first formed when I

1880
01:22:34,319 --> 01:22:32,969
was at Cornell we just before I left we

1881
01:22:36,390 --> 01:22:34,329
inherited

1882
01:22:38,760 --> 01:22:36,400
Lisa Kelton Egger and then her her group

1883
01:22:40,709 --> 01:22:38,770
which is studying questions like the

1884
01:22:42,060 --> 01:22:40,719
habitability of plants one of the stars

1885
01:22:43,799 --> 01:22:42,070
they've been spending a lot of time

1886
01:22:46,470 --> 01:22:43,809
looking into questions like this like as

1887
01:22:50,299 --> 01:22:46,480
the Sun has evolved the habitable zone

1888
01:22:52,319 --> 01:22:50,309

in the solar system has moved outward

1889
01:22:54,180 --> 01:22:52,329
right because it's getting it's too hot

1890
01:22:56,549 --> 01:22:54,190
venus may have been in a habitable

1891
01:22:58,049 --> 01:22:56,559
planet early in the system or early in

1892
01:23:00,209 --> 01:22:58,059
the history of the solar system for

1893
01:23:01,649 --> 01:23:00,219
example there's other reasons it might

1894
01:23:03,660 --> 01:23:01,659
not have been because the atmosphere got

1895
01:23:04,919 --> 01:23:03,670
pretty thick pretty quick but you know

1896
01:23:06,359 --> 01:23:04,929
it's these kinds of things things aren't

1897
01:23:08,609 --> 01:23:06,369
quite as static as we think of them

1898
01:23:09,899 --> 01:23:08,619
being it's a really neat question it

1899
01:23:11,299 --> 01:23:09,909
gets even more intriguing when you start

1900
01:23:13,589 --> 01:23:11,309
talking about exoplanetary systems

1901
01:23:15,720 --> 01:23:13,599
because now going well the handles own

1902
01:23:20,879 --> 01:23:15,730
is between x and y l it's not that

1903
01:23:25,410 --> 01:23:20,889
simple so yeah all right we are getting

1904
01:23:28,879 --> 01:23:25,420
to the end of our time as i have to cut

1905
01:23:32,879 --> 01:23:28,889
off questions we will see you again in

1906
01:23:35,910 --> 01:23:32,889
September for 100 ways to die in the

1907
01:23:38,459 --> 01:23:35,920
universe so you know a little more death

1908
01:23:50,159 --> 01:23:38,469
and destruction let us give one great

1909
01:23:54,989 --> 01:23:52,889
and and thank y'all that was a lot of