

1
00:00:05,899 --> 00:00:11,638
good evening ladies and gentlemen and

2
00:00:08,189 --> 00:00:13,830
welcome to the Space Telescope public

3
00:00:11,638 --> 00:00:15,660
lecture series I'm dr. Frank summers of

4
00:00:13,830 --> 00:00:17,550
the ha office of public outreach and is

5
00:00:15,660 --> 00:00:20,460
my pleasure to welcome you each and

6
00:00:17,550 --> 00:00:22,080
every month when you came in if you saw

7
00:00:20,460 --> 00:00:23,969
them on the tables we have our

8
00:00:22,079 --> 00:00:26,219
lithographs our pretty big Hubble

9
00:00:23,969 --> 00:00:28,618
pictures but they're more than just

10
00:00:26,219 --> 00:00:32,250
pretty pictures because on the back we

11
00:00:28,618 --> 00:00:33,929
describe the science behind these images

12
00:00:32,250 --> 00:00:36,359
and give you some of the details of

13
00:00:33,929 --> 00:00:38,488
what's going on ok you didn't grab one

14
00:00:36,359 --> 00:00:42,509
on the way in please catch one on the

15
00:00:38,488 --> 00:00:45,449
way out our speaker tonight

16
00:00:42,509 --> 00:00:47,128
Greg Sloan will be talking on ashes to

17
00:00:45,450 --> 00:00:51,480
ashes dust to dust

18
00:00:47,128 --> 00:00:53,640
the fate of stars like the Sun and when

19
00:00:51,479 --> 00:00:55,890
he scheduled this talk he told me that

20
00:00:53,640 --> 00:00:57,628
you know all these supernovae and

21
00:00:55,890 --> 00:01:01,020
neutron stars and black holes they all

22
00:00:57,628 --> 00:01:03,058
the press but what the real action is

23
00:01:01,020 --> 00:01:05,790
going on is in stars like the Sun and

24
00:01:03,058 --> 00:01:09,739
you'll find that out tonight next month

25
00:01:05,790 --> 00:01:09,740
we're gonna have some more death for you

26
00:01:10,188 --> 00:01:18,269
Katie a lot alow is going to talk on 100

27
00:01:14,069 --> 00:01:19,529
ways to die in the universe ok I'm sure

28
00:01:18,269 --> 00:01:22,548
you're all gonna be interested in that

29

00:01:19,530 --> 00:01:26,070
because hey if it bleeds it leads right

30
00:01:22,549 --> 00:01:28,979
October Gotham Narayan will be speaking

31
00:01:26,069 --> 00:01:30,750
on chasing supernovae with Kepler a

32
00:01:28,978 --> 00:01:33,900
Kepler satellite that was designed to

33
00:01:30,750 --> 00:01:35,938
find extrasolar planets actually can

34
00:01:33,900 --> 00:01:39,600
also be repurposed in its second mission

35
00:01:35,938 --> 00:01:43,438
as k2 mission to finding supernovae out

36
00:01:39,599 --> 00:01:44,728
there and in November which I note will

37
00:01:43,438 --> 00:01:46,859
be on the second Tuesday because

38
00:01:44,728 --> 00:01:50,280
Election Day is the first Tuesday every

39
00:01:46,859 --> 00:01:51,090
other year we push it back so November

40
00:01:50,280 --> 00:01:53,840
13th

41
00:01:51,090 --> 00:01:57,570
Giovanni Bruno will be speaking on

42
00:01:53,840 --> 00:01:59,759
exoplanet atmospheres studying the

43
00:01:57,569 --> 00:02:02,758

atmospheres of planets around other

44

00:01:59,759 --> 00:02:05,069

stars and this is just one of the

45

00:02:02,759 --> 00:02:07,409

coolest ideas we have we actually can

46

00:02:05,069 --> 00:02:11,340

study yeah I miss fears of other planets

47

00:02:07,409 --> 00:02:12,980

yeah details are on our website take

48

00:02:11,340 --> 00:02:15,050

your favorite search engine and put it

49

00:02:12,979 --> 00:02:17,389

public talks or Space Telescope public

50

00:02:15,050 --> 00:02:20,180

lecture series and you'll find this page

51

00:02:17,389 --> 00:02:23,059

where we have our upcoming lectures on

52

00:02:20,180 --> 00:02:26,629

the right side are links to watching it

53

00:02:23,060 --> 00:02:28,969

on live when it's when it's when it is

54

00:02:26,628 --> 00:02:31,189

live or the past lectures all the way

55

00:02:28,969 --> 00:02:33,379

back to 2005

56

00:02:31,189 --> 00:02:37,030

so lots and lots of astronomy on our

57

00:02:33,379 --> 00:02:40,909

page you can also sign up for our

58
00:02:37,030 --> 00:02:43,489
announcement email list the

59
00:02:40,909 --> 00:02:45,560
announcements if you cannot don't like

60
00:02:43,489 --> 00:02:47,180
signing up on the website just give me

61
00:02:45,560 --> 00:02:50,719
your email address and I'll make sure

62
00:02:47,180 --> 00:02:52,370
you are adding to the list if you have

63
00:02:50,719 --> 00:02:56,989
comments or questions you can send email

64
00:02:52,370 --> 00:03:00,049
to public lecture at SSCI you you can

65
00:02:56,989 --> 00:03:02,450
also follow us on social media we have

66
00:03:00,049 --> 00:03:05,689
social media channels for hubble for web

67
00:03:02,449 --> 00:03:08,268
and for the Institute on Facebook

68
00:03:05,689 --> 00:03:12,829
Twitter YouTube and Instagram I do a

69
00:03:08,269 --> 00:03:19,579
tiny amount of social media on Facebook

70
00:03:12,829 --> 00:03:23,469
Google+ and Twitter sometimes I don't

71
00:03:19,579 --> 00:03:25,969
get on air for a week or two anyways

72
00:03:23,469 --> 00:03:28,250
unfortunately if you look at the clouds

73
00:03:25,969 --> 00:03:30,829
on your way in you said hey there's a

74
00:03:28,250 --> 00:03:33,620
lot of them and that means you can't use

75
00:03:30,829 --> 00:03:35,359
the observatory tonight so I talked to

76
00:03:33,620 --> 00:03:36,920
the Maryland space folks and they said

77
00:03:35,359 --> 00:03:39,049
sorry they're not gonna open the

78
00:03:36,919 --> 00:03:41,328
observatory tonight it's a while since

79
00:03:39,049 --> 00:03:43,639
we've actually had a good weather on

80
00:03:41,329 --> 00:03:46,250
these public lecture series hopefully

81
00:03:43,639 --> 00:03:48,680
that will change next month but you

82
00:03:46,250 --> 00:03:51,469
don't have to wait for this you can go

83
00:03:48,680 --> 00:03:55,219
to their web page and the space Margie

84
00:03:51,469 --> 00:03:57,439
and every Friday night they also to look

85
00:03:55,219 --> 00:04:00,079
to open it so if you check their webpage

86

00:03:57,439 --> 00:04:02,299
on Fridays they will tell you whether or

87
00:04:00,079 --> 00:04:04,189
not they're opening it on Fridays now is

88
00:04:02,299 --> 00:04:07,579
a really good time to look at it because

89
00:04:04,189 --> 00:04:09,799
there are several planets that are nice

90
00:04:07,579 --> 00:04:12,349
big and bright in the sky and I'll tell

91
00:04:09,799 --> 00:04:14,780
you about them in just a second all

92
00:04:12,348 --> 00:04:19,969
right because it's now time for news

93
00:04:14,780 --> 00:04:21,889
from the universe August 2018 our only

94
00:04:19,970 --> 00:04:24,560
story for tonight because there's just a

95
00:04:21,889 --> 00:04:25,759
lot of pieces to it is this opposition

96
00:04:24,560 --> 00:04:29,300
up or

97
00:04:25,759 --> 00:04:30,050
tunity now what does opposition mean in

98
00:04:29,300 --> 00:04:34,100
astronomy

99
00:04:30,050 --> 00:04:37,250
well it actually refers to the positions

100
00:04:34,100 --> 00:04:39,320

of the earth and other planets in this

101

00:04:37,250 --> 00:04:41,930

case specifically outer planets planets

102

00:04:39,319 --> 00:04:45,050

outside so if this is where earth is

103

00:04:41,930 --> 00:04:47,329

relative to the Sun when a planet is on

104

00:04:45,050 --> 00:04:49,460

the other side of the Sun in a direct

105

00:04:47,329 --> 00:04:51,649

line that's called conjunction okay

106

00:04:49,459 --> 00:04:54,259

because the planet and the Sun are on

107

00:04:51,649 --> 00:04:56,899

the same point in the sky area in the

108

00:04:54,259 --> 00:04:59,539

sky when it's east directly

109

00:04:56,899 --> 00:05:02,539

perpendicular to the Sun that's called

110

00:04:59,540 --> 00:05:06,319

quadrature but the most exciting point

111

00:05:02,540 --> 00:05:09,860

is when it is directly on line with the

112

00:05:06,319 --> 00:05:12,290

Sun and that's called opposition why is

113

00:05:09,860 --> 00:05:16,879

that exciting because that's what it is

114

00:05:12,290 --> 00:05:18,980

closest to Earth in its orbit okay and

115
00:05:16,879 --> 00:05:22,069
that's when it's closest we're going to

116
00:05:18,980 --> 00:05:23,720
get our best music now if I were

117
00:05:22,069 --> 00:05:25,610
actually teaching a class about this I'd

118
00:05:23,720 --> 00:05:27,500
actually have these things moving around

119
00:05:25,610 --> 00:05:29,810
too because you doesn't stand still

120
00:05:27,500 --> 00:05:32,060
right okay the earth is actually

121
00:05:29,810 --> 00:05:34,610
orbiting and such so it doesn't happen

122
00:05:32,060 --> 00:05:36,709
really uh once per orbit it takes

123
00:05:34,610 --> 00:05:40,490
sometimes a little bit more than an

124
00:05:36,709 --> 00:05:44,049
orbit for this to happen right but the

125
00:05:40,490 --> 00:05:48,319
opportunity this year in 2018 is that

126
00:05:44,050 --> 00:05:52,430
Saturn hit opposition on June 27th 2018

127
00:05:48,319 --> 00:05:56,810
and Mars hit opposition on July 27th

128
00:05:52,430 --> 00:06:00,170
2018 so both Saturn and Mars are really

129
00:05:56,810 --> 00:06:03,170
good viewing this summer okay so of

130
00:06:00,170 --> 00:06:06,430
course who's gonna look at it Oh

131
00:06:03,170 --> 00:06:10,759
Hubble is gonna take a good look and so

132
00:06:06,430 --> 00:06:14,240
Saturn and June I think we took this

133
00:06:10,759 --> 00:06:20,300
picture in late May and we got a great

134
00:06:14,240 --> 00:06:24,519
picture of Saturn here and this folks

135
00:06:20,300 --> 00:06:24,520
you saw him

136
00:06:25,870 --> 00:06:31,069
this is one of the best pictures Hubble

137
00:06:28,970 --> 00:06:33,229
has ever gotten of Saturn

138
00:06:31,069 --> 00:06:35,419
you know the detectors are better but

139
00:06:33,228 --> 00:06:37,068
it's also one it's one of the cool

140
00:06:35,418 --> 00:06:39,288
things about it is the first time I

141
00:06:37,069 --> 00:06:42,020
remember seeing a very particular

142
00:06:39,288 --> 00:06:44,180
feature on Saturn that Hubble has never

143

00:06:42,019 --> 00:06:47,508
observed before am i in my recollection

144
00:06:44,180 --> 00:06:50,769
right in here in the North Pole you see

145
00:06:47,509 --> 00:06:55,340
this strange storm system it actually

146
00:06:50,769 --> 00:06:57,348
forms a hexagon okay let me take that

147
00:06:55,339 --> 00:07:00,978
graphic off can you see the hexagon

148
00:06:57,348 --> 00:07:04,279
there this hexagon was observed by

149
00:07:00,978 --> 00:07:08,269
Voyager okay like four years ago and

150
00:07:04,279 --> 00:07:12,348
it's still there this is a stable system

151
00:07:08,269 --> 00:07:16,250
on the North Pole of Saturn and you want

152
00:07:12,348 --> 00:07:18,139
to know what we don't truly know how it

153
00:07:16,250 --> 00:07:19,968
forms okay we understand that there's

154
00:07:18,139 --> 00:07:23,569
some resonances in the winds and

155
00:07:19,968 --> 00:07:25,189
everything a hexagon we can do sort of

156
00:07:23,569 --> 00:07:28,098
things we'll have to explain it but it

157
00:07:25,189 --> 00:07:29,629

doesn't we don't quite have everything

158

00:07:28,098 --> 00:07:33,079

we need to know to fully understand this

159

00:07:29,629 --> 00:07:34,580

this is a really cool pattern and this

160

00:07:33,079 --> 00:07:38,568

is the first time I remember seeing it

161

00:07:34,579 --> 00:07:43,430

in any Hubble image one of the so here

162

00:07:38,569 --> 00:07:45,979

is a movie zooming into Saturn we took

163

00:07:43,430 --> 00:07:48,800

several shots of Saturn and you can see

164

00:07:45,978 --> 00:07:53,568

the cloud orbiting around the North Pole

165

00:07:48,800 --> 00:07:57,560

there in that ring so I think there's

166

00:07:53,569 --> 00:07:59,150

like six or eight images here and you

167

00:07:57,560 --> 00:08:02,538

can see that that cloud just at the edge

168

00:07:59,149 --> 00:08:05,810

of the North Pole it repeats this is not

169

00:08:02,538 --> 00:08:10,000

it's not walking those loops so we added

170

00:08:05,810 --> 00:08:14,088

some details of Saturn's North Pole so

171

00:08:10,000 --> 00:08:16,908

Mars also reached opposition there sorry

172
00:08:14,088 --> 00:08:19,338
I forgot this one of the reasons why we

173
00:08:16,908 --> 00:08:21,468
can see more detail in this image then

174
00:08:19,338 --> 00:08:24,079
we can see in other ones is that these

175
00:08:21,468 --> 00:08:26,598
were done with an arrow ban images okay

176
00:08:24,079 --> 00:08:27,468
so the narrow band filters here are

177
00:08:26,598 --> 00:08:33,229
listed up here

178
00:08:27,468 --> 00:08:36,679
the blue is f3 95n the green is 502 N

179
00:08:33,229 --> 00:08:40,339
and the red is 631 n that entity

180
00:08:36,679 --> 00:08:42,168
it stands for narrowband okay so it's a

181
00:08:40,339 --> 00:08:44,930
narrow band of wavelengths so it's

182
00:08:42,168 --> 00:08:47,509
looking at very specific emission from

183
00:08:44,929 --> 00:08:49,699
Saturn which allows us to see more

184
00:08:47,509 --> 00:08:51,950
detail if we just took broadband

185
00:08:49,700 --> 00:08:53,870
wideband filters of red green and blue

186
00:08:51,950 --> 00:08:54,379
we really wouldn't see this kind of

187
00:08:53,870 --> 00:08:56,860
detail

188
00:08:54,379 --> 00:08:59,720
I mean Saturn is actually kind of boring

189
00:08:56,860 --> 00:09:14,509
when you look at with just RGB features

190
00:08:59,720 --> 00:09:17,870
but the Opel program so I'm told that

191
00:09:14,509 --> 00:09:22,299
the microphone is not doing wonders and

192
00:09:17,870 --> 00:09:22,299
I need to switch to the lavalier hold on

193
00:09:25,089 --> 00:09:33,230
okay all right so we're talking about

194
00:09:30,110 --> 00:09:35,839
the Opel program and using these narrow

195
00:09:33,230 --> 00:09:39,409
band filters you're able to see more

196
00:09:35,839 --> 00:09:41,990
detail on Saturn and what Hubble

197
00:09:39,409 --> 00:09:46,370
provides that other missions don't is

198
00:09:41,990 --> 00:09:48,169
this 20-year 30-year lifespan in terms

199
00:09:46,370 --> 00:09:49,339
of taking look at Saturn and seeing

200

00:09:48,169 --> 00:09:51,409
things over time

201
00:09:49,339 --> 00:09:54,030
so this Opel program is this better

202
00:09:51,409 --> 00:09:59,500
system up is that it getting in the way

203
00:09:54,029 --> 00:09:59,500
[Laughter]

204
00:10:00,669 --> 00:10:11,360
okay maybe that was the problem

205
00:10:07,249 --> 00:10:14,119
he had multiple yes he does not votes by

206
00:10:11,360 --> 00:10:16,220
the way was grant justice okay who

207
00:10:14,119 --> 00:10:17,869
obviously was monitoring the sound and

208
00:10:16,220 --> 00:10:21,048
saying hey something's wrong with the

209
00:10:17,869 --> 00:10:25,569
sound and having multiple things no it

210
00:10:21,048 --> 00:10:25,568
was just a random microphone steal I

211
00:10:25,659 --> 00:10:33,618
totally lost track all right so we got

212
00:10:31,909 --> 00:10:36,019
these pictures we can see all sorts of

213
00:10:33,619 --> 00:10:40,129
cool detail plus as you can see in this

214
00:10:36,019 --> 00:10:42,039

we have six of Saturn's moons in this

215

00:10:40,129 --> 00:10:44,420

image and if you go to our website

216

00:10:42,039 --> 00:10:46,818

there's actually a small animation that

217

00:10:44,419 --> 00:10:49,669

takes those six or eight images and

218

00:10:46,818 --> 00:10:51,618

follows the moons as they orbit around -

219

00:10:49,669 --> 00:10:52,669

alright so that's something you can find

220

00:10:51,619 --> 00:10:58,278

on our website

221

00:10:52,669 --> 00:11:00,649

ah let's go to Mars okay now Mars has a

222

00:10:58,278 --> 00:11:03,649

somewhat elliptical orbit okay

223

00:11:00,649 --> 00:11:06,470

Saturn's orbit is relatively circular

224

00:11:03,649 --> 00:11:09,198

Mars is somewhat elliptical so that the

225

00:11:06,470 --> 00:11:11,360

distance between Earth and Mars changes

226

00:11:09,198 --> 00:11:13,698

at different opposition's and you can

227

00:11:11,360 --> 00:11:17,778

see it in this illustration from 1995

228

00:11:13,698 --> 00:11:19,998

through to 2005 this shows the apparent

229
00:11:17,778 --> 00:11:22,730
size of Mars the relative apparent size

230
00:11:19,999 --> 00:11:24,319
of Mars at these opposition's which you

231
00:11:22,730 --> 00:11:26,239
can see occur roughly every two years

232
00:11:24,318 --> 00:11:30,469
okay

233
00:11:26,239 --> 00:11:33,829
and this year's opposition 2018 is the

234
00:11:30,470 --> 00:11:36,709
largest appearance of Mars since this

235
00:11:33,828 --> 00:11:38,649
really big one in 2003 the one in 2003

236
00:11:36,708 --> 00:11:41,599
they tell me was the largest in like

237
00:11:38,649 --> 00:11:44,058
60,000 years okay so that was a really

238
00:11:41,600 --> 00:11:45,290
big one this one isn't quite as big but

239
00:11:44,058 --> 00:11:47,860
it's larger one so we're really looking

240
00:11:45,289 --> 00:11:50,659
forward to it

241
00:11:47,860 --> 00:11:55,100
unfortunately Mars didn't really

242
00:11:50,659 --> 00:11:57,708
cooperate it looks kind of fuzzy right

243
00:11:55,100 --> 00:12:00,860
well that's what happens on Mars

244
00:11:57,708 --> 00:12:02,268
sometimes you get global dust storms on

245
00:12:00,860 --> 00:12:04,788
Mars

246
00:12:02,269 --> 00:12:07,428
and about a month before opposition

247
00:12:04,788 --> 00:12:09,828
there was a serious global dust storm

248
00:12:07,428 --> 00:12:10,129
and actually pictures from about a month

249
00:12:09,828 --> 00:12:12,199
before

250
00:12:10,129 --> 00:12:14,149
opposition were much fuzzier than this

251
00:12:12,200 --> 00:12:16,910
it actually cleared up a little bit by

252
00:12:14,149 --> 00:12:18,649
the time Hubble took their images so in

253
00:12:16,909 --> 00:12:22,009
order to understand features on Mars we

254
00:12:18,649 --> 00:12:24,889
have to give you the annotation notice

255
00:12:22,009 --> 00:12:28,069
we also got Phobos and Deimos Mars two

256
00:12:24,889 --> 00:12:30,199
little moons in there but here's the

257

00:12:28,070 --> 00:12:31,790
helis basin in which you can see the

258
00:12:30,200 --> 00:12:33,500
dust storm is totally filling the hell

259
00:12:31,789 --> 00:12:35,149
of space and that's a giant impact

260
00:12:33,500 --> 00:12:37,970
crater one of the largest impact craters

261
00:12:35,149 --> 00:12:40,759
in the solar system and you've got

262
00:12:37,970 --> 00:12:42,440
Arabia Terra this by the way is they

263
00:12:40,759 --> 00:12:44,330
they marked where the oppertunity lander

264
00:12:42,440 --> 00:12:47,230
is and of course you have the north

265
00:12:44,330 --> 00:12:50,930
polar cap and the southern polar cap

266
00:12:47,230 --> 00:12:54,740
here so unfortunately Mars didn't

267
00:12:50,929 --> 00:12:58,669
cooperate you can sort of see the same

268
00:12:54,740 --> 00:13:00,799
features in the 2016 opposition image

269
00:12:58,669 --> 00:13:04,819
all right you can see this region here

270
00:13:00,799 --> 00:13:07,189
in the middle of 2016 and over on the

271
00:13:04,820 --> 00:13:10,520

left over here but you can't quite make

272

00:13:07,190 --> 00:13:13,760

it out so we created a little video to

273

00:13:10,519 --> 00:13:16,519

show you so here's the 2016 opposition

274

00:13:13,759 --> 00:13:19,269

alright and now we're gonna crossfade to

275

00:13:16,519 --> 00:13:22,309

a computer model from the Viking images

276

00:13:19,269 --> 00:13:25,970

alright we're gonna rotate that Viking

277

00:13:22,309 --> 00:13:28,569

model image just to show you all right

278

00:13:25,970 --> 00:13:32,180

there's the orientation for the 2018

279

00:13:28,570 --> 00:13:34,370

opposition and there's the image we got

280

00:13:32,179 --> 00:13:36,169

from it alright so that helps you

281

00:13:34,370 --> 00:13:40,820

understand yeah the features are there

282

00:13:36,169 --> 00:13:46,299

they're just sort of buried okay however

283

00:13:40,820 --> 00:13:48,470

it could be worse Hey just to show you

284

00:13:46,299 --> 00:13:51,079

testing this and a comparison is the

285

00:13:48,470 --> 00:13:54,500

same size on the right I've added in the

286
00:13:51,080 --> 00:13:56,540
2001 global dust storm actually during

287
00:13:54,500 --> 00:13:59,509
opposition Mars was relatively clear

288
00:13:56,539 --> 00:14:01,459
during 2001 but three months later in

289
00:13:59,509 --> 00:14:03,139
2001 we got a picture of a real global

290
00:14:01,460 --> 00:14:05,720
dust storm which shows you just how

291
00:14:03,139 --> 00:14:08,059
fuzzy Mars can get so we didn't get the

292
00:14:05,720 --> 00:14:10,300
clearest view of Mars but we didn't get

293
00:14:08,059 --> 00:14:12,379
the fuzziest view view of Mars alright

294
00:14:10,299 --> 00:14:14,929
and if you go to our website you

295
00:14:12,379 --> 00:14:17,720
actually we also have another video of

296
00:14:14,929 --> 00:14:19,309
Mars where you see Phobos and Deimos do

297
00:14:17,720 --> 00:14:22,160
a little bit of their dance around Mars

298
00:14:19,309 --> 00:14:23,869
yeah and that is our opposition

299
00:14:22,159 --> 00:14:28,939
opportunity and our new

300
00:14:23,870 --> 00:14:43,210
for August 2008 II any questions that I

301
00:14:28,940 --> 00:14:47,330
can answer yes the I'm not an expert on

302
00:14:43,210 --> 00:14:50,028
atmospheric circulation of Mars but I

303
00:14:47,330 --> 00:14:52,550
believe that if you look at the center

304
00:14:50,028 --> 00:14:54,500
image here versus the right image you

305
00:14:52,549 --> 00:14:56,539
can see that it is somewhat fuzzy over

306
00:14:54,500 --> 00:14:59,450
the poles but you've got a lot of

307
00:14:56,539 --> 00:15:01,849
reflectivity in the ices which makes

308
00:14:59,450 --> 00:15:04,670
them shine through okay Mars's

309
00:15:01,850 --> 00:15:07,100
atmosphere is 1/100 the thickness of

310
00:15:04,669 --> 00:15:08,990
Earth's atmosphere so it's not like a

311
00:15:07,100 --> 00:15:10,820
Venusian atmosphere where you know when

312
00:15:08,990 --> 00:15:12,769
it gets when it gets dusty you can't see

313
00:15:10,820 --> 00:15:16,070
through it or the haze layer on

314

00:15:12,769 --> 00:15:18,230
untighten it's even though it's fully

315
00:15:16,070 --> 00:15:21,050
hazy you can still see through it it's

316
00:15:18,230 --> 00:15:22,850
still a bit transparent so basically it

317
00:15:21,049 --> 00:15:24,709
adds a tinge to the color on the poles

318
00:15:22,850 --> 00:15:26,409
but it doesn't completely block out the

319
00:15:24,710 --> 00:15:40,550
poles good question

320
00:15:26,409 --> 00:15:44,269
alright one more the return of the

321
00:15:40,549 --> 00:15:45,649
microphone I'm gonna put that just to

322
00:15:44,269 --> 00:15:45,919
the side just so it doesn't get all

323
00:15:45,649 --> 00:15:48,259
right

324
00:15:45,919 --> 00:15:52,159
so you are correct yes the Rovers on

325
00:15:48,259 --> 00:15:55,338
Mars when a global dust storm they use

326
00:15:52,159 --> 00:15:57,949
solar energy right and they when a

327
00:15:55,339 --> 00:16:01,190
global dust storm hits they have to shut

328
00:15:57,950 --> 00:16:02,870

down okay and then in order to restart

329

00:16:01,190 --> 00:16:05,720

them they actually have to shake the

330

00:16:02,870 --> 00:16:07,580

dust off of it so if you can think of

331

00:16:05,720 --> 00:16:10,250

those little Rovers sort of shaking like

332

00:16:07,580 --> 00:16:11,660

a dog getting water off of it right they

333

00:16:10,250 --> 00:16:13,370

actually had to had to program the

334

00:16:11,659 --> 00:16:15,529

wheels to go forward and back forward

335

00:16:13,370 --> 00:16:16,909

and back to try and shake it to get the

336

00:16:15,529 --> 00:16:19,490

dust off so they could recharge the

337

00:16:16,909 --> 00:16:20,990

batteries obviously they were they've

338

00:16:19,490 --> 00:16:23,060

been successful because there have been

339

00:16:20,990 --> 00:16:25,669

several of those global dust storms

340

00:16:23,059 --> 00:16:28,909

while we've had Rovers on Mars and they

341

00:16:25,669 --> 00:16:30,110

all seem to have come back and worked so

342

00:16:28,909 --> 00:16:32,059

yeah that's a good point

343

00:16:30,110 --> 00:16:35,269

all right okay

344

00:16:32,059 --> 00:16:39,169

let's move to our featured speaker

345

00:16:35,269 --> 00:16:42,289

tonight I'm excited to hear from our

346

00:16:39,169 --> 00:16:47,599

speaker tonight well hold on I have to

347

00:16:42,289 --> 00:16:50,569

figure out this there we go our speaker

348

00:16:47,600 --> 00:16:52,700

tonight is Greg Sloan

349

00:16:50,570 --> 00:16:55,490

he has been here at the Space Telescope

350

00:16:52,700 --> 00:16:57,590

Science Institute for two years well

351

00:16:55,490 --> 00:16:59,629

he's sort of half here he also has an

352

00:16:57,590 --> 00:17:02,570

adjunct position at UNC Chapel Hill

353

00:16:59,629 --> 00:17:04,730

right so half of his time is spent down

354

00:17:02,570 --> 00:17:08,269

there he teaches down at UNC Chapel Hill

355

00:17:04,730 --> 00:17:12,200

he comes to us from Cornell University

356

00:17:08,269 --> 00:17:14,450

where he worked for 15 years on the

357
00:17:12,200 --> 00:17:17,870
infrared instruments for the Spitzer

358
00:17:14,450 --> 00:17:20,450
Space Telescope so I have a very hard

359
00:17:17,869 --> 00:17:23,059
time imagining anyone more qualified to

360
00:17:20,450 --> 00:17:25,309
come here and work on the mid-infrared

361
00:17:23,059 --> 00:17:27,379
instrument the Miri instrument of James

362
00:17:25,309 --> 00:17:30,200
Webb Space Telescope than someone who's

363
00:17:27,380 --> 00:17:32,510
been working on Spitzer for 15 years it

364
00:17:30,200 --> 00:17:35,120
is one of these great things within NASA

365
00:17:32,509 --> 00:17:38,480
that we can take the infrared knowledge

366
00:17:35,119 --> 00:17:40,909
get learned in the Spitzer mission and

367
00:17:38,480 --> 00:17:44,299
bring it and apply it to the James Webb

368
00:17:40,910 --> 00:17:45,890
mission and I'm sure that the folks here

369
00:17:44,299 --> 00:17:49,579
are just absolutely ecstatic to have you

370
00:17:45,890 --> 00:17:50,580
on board ladies and gentlemen mr. Greg

371

00:17:49,579 --> 00:17:59,529
Sloan

372
00:17:50,579 --> 00:18:26,000
[Applause]

373
00:17:59,529 --> 00:18:27,109
come on I think it wants my password all

374
00:18:26,000 --> 00:18:29,509
right well those are very flattering

375
00:18:27,109 --> 00:18:31,939
comments I have to point out that

376
00:18:29,509 --> 00:18:34,039
there's a lot of people from Spitzer

377
00:18:31,940 --> 00:18:36,259
mission here now working on the

378
00:18:34,039 --> 00:18:39,500
mid-infrared instrument so it's kind of

379
00:18:36,259 --> 00:18:42,980
nice to be back amongst fellow combat

380
00:18:39,500 --> 00:18:46,339
veterans from a previous mission I'm

381
00:18:42,980 --> 00:18:48,169
just one of many I actually I haven't

382
00:18:46,339 --> 00:18:50,509
been teaching too much at UNC Chapel

383
00:18:48,169 --> 00:18:54,530
Hill I just go down there to get a rest

384
00:18:50,509 --> 00:18:56,269
from the intense work here which follows

385
00:18:54,529 --> 00:19:00,019

me down I might add so I'm pretty much

386

00:18:56,269 --> 00:19:01,690

working full full on doing J abuse t

387

00:19:00,019 --> 00:19:04,369

stuff down there when I'm when I'm there

388

00:19:01,690 --> 00:19:06,558

alright so tonight I'm going to talk a

389

00:19:04,369 --> 00:19:10,369

little bit about the the fate of stars

390

00:19:06,558 --> 00:19:14,660

like the Sun I have this poetic Prelude

391

00:19:10,369 --> 00:19:15,979

here so I think that people that do this

392

00:19:14,660 --> 00:19:17,929

kind of research have a little bit of an

393

00:19:15,980 --> 00:19:20,380

inferiority complex because astronomy to

394

00:19:17,929 --> 00:19:23,140

a lot of people consists of three things

395

00:19:20,380 --> 00:19:25,190

exoplanets high redshift universe and

396

00:19:23,140 --> 00:19:27,770

supernovae and this is none of those

397

00:19:25,190 --> 00:19:29,509

things so I'm really flattered to see

398

00:19:27,769 --> 00:19:30,679

such a great turnout tonight and people

399

00:19:29,509 --> 00:19:32,960

decided to brave leaving their

400
00:19:30,679 --> 00:19:35,330
air-conditioning behind to come here and

401
00:19:32,960 --> 00:19:36,880
it's cloudy to boots so anyway let's get

402
00:19:35,329 --> 00:19:40,189
on with it

403
00:19:36,880 --> 00:19:43,490
also if you look at your handout you'll

404
00:19:40,190 --> 00:19:45,200
see that in order to add nice pictures

405
00:19:43,490 --> 00:19:46,700
to otherwise boring words on my slides

406
00:19:45,200 --> 00:19:47,840
I've tried to steal as many Hubble

407
00:19:46,700 --> 00:19:49,669
images as I can so you could follow

408
00:19:47,839 --> 00:19:55,909
along and you can see if I got the

409
00:19:49,669 --> 00:19:58,880
captions right on the back all right so

410
00:19:55,910 --> 00:20:00,590
the talk starts with a periodic table of

411
00:19:58,880 --> 00:20:02,540
elements so you can see this is a really

412
00:20:00,589 --> 00:20:05,089
nice table I pulled off of the Internet

413
00:20:02,539 --> 00:20:08,190
I didn't I forgot to put the source down

414
00:20:05,089 --> 00:20:09,898
here which is very bad of me

415
00:20:08,190 --> 00:20:11,820
but what I want to say this is really

416
00:20:09,898 --> 00:20:13,589
nice it's very complex to an astronomer

417
00:20:11,819 --> 00:20:19,308
there's a simpler version of this

418
00:20:13,589 --> 00:20:24,449
periodic table it looks like this okay

419
00:20:19,308 --> 00:20:26,250
so we have in one corner we have

420
00:20:24,450 --> 00:20:28,110
hydrogen and then in the other corner we

421
00:20:26,250 --> 00:20:31,980
have helium and everything else to an

422
00:20:28,109 --> 00:20:33,388
astronomer is just a metal but there's a

423
00:20:31,980 --> 00:20:34,829
bit more to it than that because when

424
00:20:33,388 --> 00:20:36,599
the universe formed except for a little

425
00:20:34,829 --> 00:20:38,490
bit of lithium to just confuse the story

426
00:20:36,599 --> 00:20:40,709
the universe was just hydrogen and

427
00:20:38,490 --> 00:20:43,888
helium and everything else all these

428

00:20:40,710 --> 00:20:46,889
metals come from stars so I think we've

429
00:20:43,888 --> 00:20:48,209
all heard the the great Carl Sagan quote

430
00:20:46,888 --> 00:20:50,609
that we're all just made of star stuff

431
00:20:48,210 --> 00:20:53,069
well this is this is not poetic it's

432
00:20:50,609 --> 00:20:56,099
absolutely true and so what I have here

433
00:20:53,069 --> 00:20:59,548
is a graph of abundances this is a log

434
00:20:56,099 --> 00:21:01,500
plot so every from here from six to

435
00:20:59,548 --> 00:21:03,089
eight is a factor of 100 those are the

436
00:21:01,500 --> 00:21:04,648
abundances in the order of the atomic

437
00:21:03,089 --> 00:21:06,480
number of the elements you can see

438
00:21:04,648 --> 00:21:08,459
there's a nice zig-zag pattern here

439
00:21:06,480 --> 00:21:09,990
where every all the even numbers have a

440
00:21:08,460 --> 00:21:11,460
bit more abundance compared to the odd

441
00:21:09,990 --> 00:21:13,230
one so I'll explain that in just a sec

442
00:21:11,460 --> 00:21:15,329

and then over here for people that

443

00:21:13,230 --> 00:21:17,370

really can't stand figures like this I

444

00:21:15,329 --> 00:21:18,839

just sort of laid it out as a table so

445

00:21:17,369 --> 00:21:20,819

you can see that very quickly hydrogen

446

00:21:18,839 --> 00:21:22,918

is 90% of the universe this is by number

447

00:21:20,819 --> 00:21:25,288

I think that Frank had put a slide up a

448

00:21:22,919 --> 00:21:26,519

couple of months ago that was by mass so

449

00:21:25,288 --> 00:21:29,369

the number is a little bit different but

450

00:21:26,519 --> 00:21:30,899

it's about 91 percent hydrogen most

451

00:21:29,369 --> 00:21:34,079

everything else that's left is helium

452

00:21:30,898 --> 00:21:37,079

oxygen weighs in at a hefty 1/2 a

453

00:21:34,079 --> 00:21:39,058

percent and then it's just downhill from

454

00:21:37,079 --> 00:21:41,069

there carbon is next and then you know

455

00:21:39,058 --> 00:21:43,740

at one tenth of a percent nitrogen is

456

00:21:41,069 --> 00:21:45,329

just ahead of Neil neon and then from

457
00:21:43,740 --> 00:21:47,399
there it just plummets quickly and then

458
00:21:45,329 --> 00:21:50,038
you can see this so basically in green

459
00:21:47,398 --> 00:21:51,658
right here that's what the primordial

460
00:21:50,038 --> 00:21:54,599
abundance is a universe looked like

461
00:21:51,659 --> 00:21:57,059
right after the Big Bang and this is the

462
00:21:54,599 --> 00:21:58,678
plot now so all of this all this blue

463
00:21:57,058 --> 00:22:04,558
stuff here everything above the the

464
00:21:58,679 --> 00:22:06,360
green that's all made by stars so

465
00:22:04,558 --> 00:22:08,428
farmers since since everything

466
00:22:06,359 --> 00:22:10,729
University of hydrogen helium is a metal

467
00:22:08,429 --> 00:22:12,809
we'd like to talk about metallicity

468
00:22:10,730 --> 00:22:14,190
which is just the abundance of

469
00:22:12,808 --> 00:22:15,990
everything that isn't hydrogen and

470
00:22:14,190 --> 00:22:19,048
helium or the abundance of everything

471
00:22:15,990 --> 00:22:20,759
it's made by stars so I'll be using that

472
00:22:19,048 --> 00:22:22,009
word a lot metallicity I'm just I have

473
00:22:20,759 --> 00:22:26,990
to that that piece of

474
00:22:22,009 --> 00:22:29,809
jargon I cannot drop I apologize okay

475
00:22:26,990 --> 00:22:32,059
so our first pop quiz question for the

476
00:22:29,809 --> 00:22:36,129
day and I because we don't have car talk

477
00:22:32,059 --> 00:22:39,319
anymore I adopted their enumeration so

478
00:22:36,130 --> 00:22:41,060
what is a star so how many people whole

479
00:22:39,319 --> 00:22:43,159
Justin will go through this and so one

480
00:22:41,059 --> 00:22:45,259
if you agree with one raise your hand

481
00:22:43,160 --> 00:22:47,060
something that shines which means it

482
00:22:45,259 --> 00:22:48,500
emits more energy than it then it

483
00:22:47,059 --> 00:22:52,129
absorbs let's see some hands here and

484
00:22:48,500 --> 00:22:54,079
people go for one okay definition of the

485

00:22:52,130 --> 00:22:57,530
star that's a few Pele it's like what a

486
00:22:54,079 --> 00:22:59,990
quarter of us let's go for be something

487
00:22:57,529 --> 00:23:04,039
undergoing nuclear fusion reactions in

488
00:22:59,990 --> 00:23:05,690
its core there we go so that seems to be

489
00:23:04,039 --> 00:23:08,529
I think that's already the winner and

490
00:23:05,690 --> 00:23:13,210
then and then Roman numeral three and

491
00:23:08,529 --> 00:23:13,210
ultimately doomed battle with gravity

492
00:23:16,180 --> 00:23:22,250
but I see that I'm not on the winning

493
00:23:18,410 --> 00:23:25,220
side so one is not so good because

494
00:23:22,250 --> 00:23:28,039
actually Jupiter emits in the radio

495
00:23:25,220 --> 00:23:29,000
quite a bit of energy oh yeah and I

496
00:23:28,039 --> 00:23:31,009
actually had an answer for the question

497
00:23:29,000 --> 00:23:33,619
that they were gonna come back to on the

498
00:23:31,009 --> 00:23:35,900
rogue planet that's 20 light years away

499
00:23:33,619 --> 00:23:38,209

it's in the news because they picked it

500

00:23:35,900 --> 00:23:39,740

up it was discovered in 2016 I think and

501

00:23:38,210 --> 00:23:43,490

I forget by who I don't know that story

502

00:23:39,740 --> 00:23:45,859

but they picked it up with the VLA The

503

00:23:43,490 --> 00:23:47,599

Very Large Array radio they picked up

504

00:23:45,859 --> 00:23:50,599

the irori that it must be given a really

505

00:23:47,599 --> 00:23:52,099

strong magnetic field yeah so Jupiter

506

00:23:50,599 --> 00:23:54,859

doesn't send Jupiter emits a lot in the

507

00:23:52,099 --> 00:23:57,289

radio and in midst in the foreign for

508

00:23:54,859 --> 00:24:00,049

red so Jupiter would qualify as a planet

509

00:23:57,289 --> 00:24:02,210

by number one but it isn't a star by

510

00:24:00,049 --> 00:24:05,299

number one but it isn't so B is

511

00:24:02,210 --> 00:24:08,259

certainly good I like three because the

512

00:24:05,299 --> 00:24:11,269

the real point is that the moment that a

513

00:24:08,259 --> 00:24:13,660

star starts to form which means the

514
00:24:11,269 --> 00:24:15,589
moment that an interstellar cloud is

515
00:24:13,660 --> 00:24:19,160
compressed just enough to be

516
00:24:15,589 --> 00:24:22,699
self-gravitating from that point on that

517
00:24:19,160 --> 00:24:25,340
poor object is doomed it is eventually

518
00:24:22,700 --> 00:24:28,220
going to wind up as a degenerate object

519
00:24:25,339 --> 00:24:30,230
either a white dwarf imagine half the

520
00:24:28,220 --> 00:24:33,110
mass the Sun packed into an object the

521
00:24:30,230 --> 00:24:35,870
size of the earth that's a white dwarf

522
00:24:33,109 --> 00:24:38,808
or a neutron star I'm at

523
00:24:35,869 --> 00:24:40,668
an object the size of the mass of the

524
00:24:38,808 --> 00:24:43,428
Sun packed into something the size of

525
00:24:40,669 --> 00:24:47,690
Baltimore you know or a black hole

526
00:24:43,429 --> 00:24:48,950
imagine something smaller right so

527
00:24:47,690 --> 00:24:50,808
that's what's gonna happen so basically

528
00:24:48,950 --> 00:24:52,819
all these things all these stars that we

529
00:24:50,808 --> 00:24:58,730
see they're just at some stage of that

530
00:24:52,819 --> 00:25:00,980
battle and they're gonna lose so here's

531
00:24:58,730 --> 00:25:02,360
their fates I apologize in advance I

532
00:25:00,980 --> 00:25:07,788
realized I was going through this today

533
00:25:02,359 --> 00:25:09,288
this is my busiest slide anyway so we

534
00:25:07,788 --> 00:25:13,190
have this broken up into three masked

535
00:25:09,288 --> 00:25:15,470
categories if it's 25 solar masses are

536
00:25:13,190 --> 00:25:18,798
up so 25 times the mass of the Sun or up

537
00:25:15,470 --> 00:25:20,929
and that's a really rough number because

538
00:25:18,798 --> 00:25:23,869
we don't really know it might be 30 it

539
00:25:20,929 --> 00:25:27,980
might be 40 if it's really Hawking big

540
00:25:23,869 --> 00:25:31,069
to use the technical term it will become

541
00:25:27,980 --> 00:25:32,808
a black hole but I shouldn't say it the

542

00:25:31,069 --> 00:25:33,490
core of that star will become a black

543
00:25:32,808 --> 00:25:36,288
hole

544
00:25:33,490 --> 00:25:37,640
90% of the star will be dispersed back

545
00:25:36,288 --> 00:25:39,740
out into space back into the

546
00:25:37,640 --> 00:25:41,960
interstellar medium but the core of the

547
00:25:39,740 --> 00:25:43,370
star would become a black hole I think

548
00:25:41,960 --> 00:25:45,500
the core has to be about three solar

549
00:25:43,369 --> 00:25:48,288
masses or so and then it's it's it's

550
00:25:45,500 --> 00:25:49,609
that's enough mass to overcome any force

551
00:25:48,288 --> 00:25:51,740
that we can think of that would that

552
00:25:49,609 --> 00:25:53,778
would hold this object up if it's

553
00:25:51,740 --> 00:25:56,089
between some number we don't really know

554
00:25:53,778 --> 00:25:58,609
8 to 10 solar masses it's kind of the

555
00:25:56,089 --> 00:26:01,099
bottom into the range and up to 25 where

556
00:25:58,609 --> 00:26:03,288

I said 30 if it's in that range it will

557

00:26:01,099 --> 00:26:05,569

go supernova got all the headlines get

558

00:26:03,288 --> 00:26:09,769

all the attention make me very envious

559

00:26:05,569 --> 00:26:11,750

and it will become a neutron star so I'm

560

00:26:09,769 --> 00:26:13,700

focused on the objects that are less

561

00:26:11,750 --> 00:26:15,230

than 8 to 10 solar masses those are the

562

00:26:13,700 --> 00:26:17,538

oh yeah here's a picture of a supernova

563

00:26:15,230 --> 00:26:19,220

this is supernova 1987a there's a

564

00:26:17,538 --> 00:26:20,750

picture of some fun things happening

565

00:26:19,220 --> 00:26:22,819

around a black hole please don't ask me

566

00:26:20,750 --> 00:26:24,140

what they were because I just thought

567

00:26:22,819 --> 00:26:29,178

that was a pretty picture that's about

568

00:26:24,140 --> 00:26:32,090

all I know sorry but if it's 8 to 10

569

00:26:29,179 --> 00:26:35,570

solar masses or less or less than that

570

00:26:32,089 --> 00:26:37,038

it will become a planetary nebula lots

571
00:26:35,569 --> 00:26:40,730
of good planetary neighborhood pictures

572
00:26:37,038 --> 00:26:41,960
on the handout and a white and the core

573
00:26:40,730 --> 00:26:45,980
of that star will become a white dwarf

574
00:26:41,960 --> 00:26:47,659
in the case of the Sun the the white

575
00:26:45,980 --> 00:26:49,009
dwarf will about have about half of the

576
00:26:47,659 --> 00:26:49,389
mass of the Sun and the other half of

577
00:26:49,009 --> 00:26:51,338
the Sun

578
00:26:49,388 --> 00:26:55,238
maths will be ejected back into space

579
00:26:51,338 --> 00:26:56,648
and at the upper end of this range 90%

580
00:26:55,239 --> 00:26:59,798
of the mass of the star will get ejected

581
00:26:56,648 --> 00:27:01,748
back into space but it's not just the

582
00:26:59,798 --> 00:27:02,878
well we'll get to that so let me let me

583
00:27:01,749 --> 00:27:05,528
just keep going

584
00:27:02,878 --> 00:27:06,519
so how does stars hold themselves up

585
00:27:05,528 --> 00:27:09,249
while they're doing it

586
00:27:06,519 --> 00:27:11,950
well they do it by nuclear reactions by

587
00:27:09,249 --> 00:27:13,509
fusion reactions I just sort of I know

588
00:27:11,950 --> 00:27:15,609
you guys didn't really come here for a

589
00:27:13,509 --> 00:27:17,739
lesson in nuclear physics so it's just

590
00:27:15,608 --> 00:27:20,259
the one slide but I just want to sort of

591
00:27:17,739 --> 00:27:22,538
review this just really quickly the

592
00:27:20,259 --> 00:27:24,190
basic reaction is hydrogen fusion now

593
00:27:22,538 --> 00:27:26,348
there's a lot more to it than just this

594
00:27:24,190 --> 00:27:29,409
you basically take four protons four

595
00:27:26,348 --> 00:27:31,388
hydrogen nuclei and through a few

596
00:27:29,409 --> 00:27:32,950
backflips and contortions and a few

597
00:27:31,388 --> 00:27:36,758
other reactions you wind up with a

598
00:27:32,950 --> 00:27:38,469
helium nucleus this guy right it's it's

599

00:27:36,759 --> 00:27:41,098
ionized so there's no electrons just

600
00:27:38,469 --> 00:27:43,479
just this alpha particle two positrons

601
00:27:41,098 --> 00:27:45,848
some neutrinos I don't remember how many

602
00:27:43,479 --> 00:27:47,558
think two but yeah because of the

603
00:27:45,848 --> 00:27:49,239
positrons and then a whole bunch of

604
00:27:47,558 --> 00:27:52,569
energy which is the point to the

605
00:27:49,239 --> 00:27:55,450
reaction and so the Sun is fusing

606
00:27:52,569 --> 00:27:56,858
hydrogen to helium in its core and it

607
00:27:55,450 --> 00:27:59,139
can keep doing that until it starts to

608
00:27:56,858 --> 00:28:00,418
run out of hydrogen and then things get

609
00:27:59,138 --> 00:28:03,158
interesting

610
00:28:00,419 --> 00:28:04,749
the next reaction that's going to happen

611
00:28:03,159 --> 00:28:07,389
is called the triple alpha reaction

612
00:28:04,749 --> 00:28:09,879
three helium nuclei three alpha

613
00:28:07,388 --> 00:28:10,988

particles hits the name and that will

614

00:28:09,878 --> 00:28:12,848

produce you put three of these guys

615

00:28:10,989 --> 00:28:17,379

together you get carbon and again a lot

616

00:28:12,848 --> 00:28:20,078

of energy and these stars are kicking to

617

00:28:17,378 --> 00:28:21,668

keep you know trying to find new sources

618

00:28:20,078 --> 00:28:22,838

of energy in their core to hold

619

00:28:21,669 --> 00:28:24,879

themselves up otherwise they keep

620

00:28:22,838 --> 00:28:27,098

collapsing and so the next one up is

621

00:28:24,878 --> 00:28:29,228

alpha capture so if you take a carbon

622

00:28:27,098 --> 00:28:31,658

atom you add two more protons and two

623

00:28:29,229 --> 00:28:35,019

more neutrons you get oxygen do it again

624

00:28:31,659 --> 00:28:36,579

you get neon etc and you can also do

625

00:28:35,019 --> 00:28:39,159

proton capture which is how you get to

626

00:28:36,578 --> 00:28:40,749

the odd numbers now you can start to see

627

00:28:39,159 --> 00:28:42,249

why that corrugation and the abundance

628
00:28:40,749 --> 00:28:44,379
exists there's more of the even numbers

629
00:28:42,249 --> 00:28:47,259
because alpha capture happens a lot more

630
00:28:44,378 --> 00:28:49,208
than the proton capture but those only

631
00:28:47,259 --> 00:28:51,788
happen in the really massive stars for

632
00:28:49,209 --> 00:28:56,548
the Sun the last Harrah is a triple

633
00:28:51,788 --> 00:28:58,479
alpha sequence and this is a really cool

634
00:28:56,548 --> 00:29:00,638
diagram there's a really cool periodic

635
00:28:58,479 --> 00:29:02,690
table done by Jennifer Johnson at Ohio

636
00:29:00,638 --> 00:29:06,349
State and this is

637
00:29:02,690 --> 00:29:09,140
our best attempt to explain where all of

638
00:29:06,349 --> 00:29:11,719
these elements come from so yellow is

639
00:29:09,140 --> 00:29:13,460
the one I'm interested in because those

640
00:29:11,720 --> 00:29:15,110
are dyeing low-mass this should be

641
00:29:13,460 --> 00:29:17,990
dyeing low and intermediate-mass stars

642
00:29:15,109 --> 00:29:20,509
bracele everything that doesn't go

643
00:29:17,990 --> 00:29:22,849
supernova and you can see that carbon

644
00:29:20,509 --> 00:29:25,190
and nitrogen which are the two of the

645
00:29:22,849 --> 00:29:28,129
top five are primarily made by these

646
00:29:25,190 --> 00:29:29,480
kinds of stars so without these kinds of

647
00:29:28,130 --> 00:29:31,210
stars is not to be a lot of carbon and

648
00:29:29,480 --> 00:29:34,400
nitrogen out there and you'll remember

649
00:29:31,210 --> 00:29:37,759
we're we're prime it you know carbon is

650
00:29:34,400 --> 00:29:38,840
the element of life so none of those you

651
00:29:37,759 --> 00:29:40,309
know you gotta wait a bit after the

652
00:29:38,839 --> 00:29:41,569
universe forms a supernova you ain't

653
00:29:40,309 --> 00:29:43,429
gonna do it for you you got to wait for

654
00:29:41,569 --> 00:29:47,049
these lower mass stars to evolve and

655
00:29:43,430 --> 00:29:47,049
start seeding the interstellar medium

656

00:29:47,680 --> 00:29:55,100
okay change gears switch gears here

657
00:29:50,869 --> 00:29:59,719
I like this plot probably because I made

658
00:29:55,099 --> 00:30:01,189
it but so basically I've got some black

659
00:29:59,720 --> 00:30:02,990
bodies the black body is just a

660
00:30:01,190 --> 00:30:04,009
theoretical object of a certain

661
00:30:02,990 --> 00:30:05,900
temperature so it's like a perfect

662
00:30:04,009 --> 00:30:08,990
spectrum you can see in a minute I'll

663
00:30:05,900 --> 00:30:10,490
just show you now those are stars those

664
00:30:08,990 --> 00:30:12,650
are black bodies so this you know it's

665
00:30:10,490 --> 00:30:15,049
closed for physicists this works pretty

666
00:30:12,650 --> 00:30:16,490
well so what I want to point out here so

667
00:30:15,049 --> 00:30:17,809
we have wavelength from this axis I'm

668
00:30:16,490 --> 00:30:21,230
gonna do this a lot because I'm actually

669
00:30:17,809 --> 00:30:22,429
a spectroscopy so I love spectra and I

670
00:30:21,230 --> 00:30:23,660

have to tell you that whenever we're

671

00:30:22,430 --> 00:30:25,789
dealing with the PR people for a

672

00:30:23,660 --> 00:30:28,220
telescope we drove the spitzer PR people

673

00:30:25,789 --> 00:30:29,960
crazy because we had all these really we

674

00:30:28,220 --> 00:30:31,670
thought really newsworthy events you

675

00:30:29,960 --> 00:30:33,500
know with we are just findings and

676

00:30:31,670 --> 00:30:34,970
whatnot and we say well there's plot the

677

00:30:33,500 --> 00:30:36,500
spectra the squiggly line and they're

678

00:30:34,970 --> 00:30:38,660
like the people don't want to look at

679

00:30:36,500 --> 00:30:41,779
squiggly lines so i apologize because i

680

00:30:38,660 --> 00:30:43,670
have a lot of squiggly lines so what i

681

00:30:41,779 --> 00:30:45,019
have on the top is a different

682

00:30:43,670 --> 00:30:48,080
temperature black bodies and the point

683

00:30:45,019 --> 00:30:51,470
is that a 38,000 kelvin blackbody peaks

684

00:30:48,079 --> 00:30:55,609
at a wavelength of like point 1 to point

685
00:30:51,470 --> 00:30:58,039
2 microns that's about 1,000 to 2,000

686
00:30:55,609 --> 00:30:59,809
angstroms that's the ultraviolet that's

687
00:30:58,039 --> 00:31:02,180
toasty ultraviolet okay

688
00:30:59,809 --> 00:31:04,490
and then you take a red giant star which

689
00:31:02,180 --> 00:31:07,190
is about 37 50 case something like that

690
00:31:04,490 --> 00:31:08,799
and that Peaks over here at between 1

691
00:31:07,190 --> 00:31:11,420
and 2 microns that's the near-infrared

692
00:31:08,799 --> 00:31:14,960
here in the middle by the way these are

693
00:31:11,420 --> 00:31:16,269
sort of an average response function for

694
00:31:14,960 --> 00:31:18,249
the 3 different types of

695
00:31:16,269 --> 00:31:20,348
detectors in your eye the red green and

696
00:31:18,249 --> 00:31:23,348
blue when I first made this pot it

697
00:31:20,348 --> 00:31:26,048
finally dawned on me I never understood

698
00:31:23,348 --> 00:31:27,999
how people could be colorblind but now I

699
00:31:26,048 --> 00:31:30,308
get it because you can see that the red

700
00:31:27,999 --> 00:31:33,338
and the green responsive 'tis in your

701
00:31:30,308 --> 00:31:35,079
eye almost overlap and some people they

702
00:31:33,338 --> 00:31:37,868
do overlap and those people can't

703
00:31:35,079 --> 00:31:39,788
distinguish red and green so probably

704
00:31:37,868 --> 00:31:41,949
not the best design from the get-go but

705
00:31:39,788 --> 00:31:43,269
you know they they eyes work pretty well

706
00:31:41,950 --> 00:31:45,519
so I'm not complaining

707
00:31:43,269 --> 00:31:48,219
astronomers have decided that you know

708
00:31:45,519 --> 00:31:49,808
this is not the ideal filter set so

709
00:31:48,219 --> 00:31:51,999
here's one example is the Johnson

710
00:31:49,808 --> 00:31:54,940
filters how many people here would call

711
00:31:51,999 --> 00:31:56,618
themselves amateur astronomers just to

712
00:31:54,940 --> 00:32:00,159
just a handful do you guys work with

713

00:31:56,618 --> 00:32:03,548
Johnson filters at all not too much okay

714
00:32:00,159 --> 00:32:05,169
well it's probably better a bit so very

715
00:32:03,548 --> 00:32:06,940
standard set so you sort of separate

716
00:32:05,169 --> 00:32:09,070
things out you be the ultra violet blue

717
00:32:06,940 --> 00:32:11,379
and visual and then in this they call

718
00:32:09,069 --> 00:32:13,838
this infrared but this is like near

719
00:32:11,378 --> 00:32:15,968
optical and Fritz over here and then

720
00:32:13,838 --> 00:32:18,489
some near-infrared filters which are

721
00:32:15,969 --> 00:32:19,570
known by their letters jhk you'll notice

722
00:32:18,489 --> 00:32:20,979
they're sort of out of order because

723
00:32:19,569 --> 00:32:23,708
people kind of added these things in

724
00:32:20,979 --> 00:32:25,119
anyway so these are real stars and you

725
00:32:23,709 --> 00:32:26,619
can see that you want to use infrared

726
00:32:25,118 --> 00:32:28,478
filters if you want to look at red

727
00:32:26,618 --> 00:32:30,578

giants you want to be out in the

728

00:32:28,479 --> 00:32:32,828

infrared near-infrared because that's

729

00:32:30,578 --> 00:32:34,569

where all the energy is so you could

730

00:32:32,828 --> 00:32:37,298

much easier to detect them out there and

731

00:32:34,569 --> 00:32:39,458

this is just another filter set um this

732

00:32:37,298 --> 00:32:46,209

is the Sloan filter set not named after

733

00:32:39,459 --> 00:32:48,308

me named after Alfred P Sloan he offered

734

00:32:46,209 --> 00:32:50,259

P sloan Foundation yes there yes named

735

00:32:48,308 --> 00:32:52,078

after that foundation because they

736

00:32:50,259 --> 00:32:54,159

funded the Sloan Digital Sky Survey

737

00:32:52,078 --> 00:32:57,338

which I had never figured out how to

738

00:32:54,159 --> 00:32:58,899

capitalize on but this is a different

739

00:32:57,338 --> 00:33:01,269

filter set and then ii went to show you

740

00:32:58,898 --> 00:33:04,838

some the results of some data taken with

741

00:33:01,269 --> 00:33:06,190

the green the G and the AI filters but

742
00:33:04,838 --> 00:33:07,328
you can see lots of filter sets out

743
00:33:06,190 --> 00:33:09,519
there and people love to argue over

744
00:33:07,328 --> 00:33:11,038
which one's best these are the things

745
00:33:09,519 --> 00:33:14,858
that keep astronomers entertained

746
00:33:11,038 --> 00:33:17,679
alright so here's a picture taken from a

747
00:33:14,858 --> 00:33:21,358
32 inch reflector at Mount Lemmon in

748
00:33:17,679 --> 00:33:23,798
Arizona this is the globular cluster m5

749
00:33:21,358 --> 00:33:25,778
this is the paper which has been hanging

750
00:33:23,798 --> 00:33:28,058
fire for me for a bit we're working that

751
00:33:25,778 --> 00:33:29,638
it's not my data but we have a different

752
00:33:28,058 --> 00:33:31,108
image this one's much prettier

753
00:33:29,638 --> 00:33:32,248
and the one thing I want to point out is

754
00:33:31,108 --> 00:33:33,418
when you look at it you can see there's

755
00:33:32,249 --> 00:33:35,700
some objects some of these stars are

756
00:33:33,419 --> 00:33:37,229
very red and then some of them not so

757
00:33:35,700 --> 00:33:39,269
red and these red ones are also very

758
00:33:37,229 --> 00:33:42,269
bright those are the red giants those

759
00:33:39,269 --> 00:33:43,828
are what we're interested in and so

760
00:33:42,269 --> 00:33:45,358
basically the globular cluster just is

761
00:33:43,828 --> 00:33:47,548
about a million stars all packed

762
00:33:45,358 --> 00:33:50,759
together a nice tight ball okay

763
00:33:47,548 --> 00:33:53,069
and the key points are they're all about

764
00:33:50,759 --> 00:33:54,509
the same distance from the earth so when

765
00:33:53,069 --> 00:33:56,069
I start plotting these things up I don't

766
00:33:54,509 --> 00:33:57,598
have to worry about everything getting

767
00:33:56,069 --> 00:34:00,298
smeared out because some are closer or

768
00:33:57,598 --> 00:34:00,749
further away they're all about the same

769
00:34:00,298 --> 00:34:02,729
age

770

00:34:00,749 --> 00:34:07,528
in this particular case ten point six

771
00:34:02,729 --> 00:34:08,849
billion years roughly thanks to the

772
00:34:07,528 --> 00:34:10,440
hubble space telescope we've actually

773
00:34:08,849 --> 00:34:11,309
learned that they're not all exactly the

774
00:34:10,440 --> 00:34:14,278
same age because there's actually

775
00:34:11,309 --> 00:34:16,139
multiple epochs of star formation early

776
00:34:14,278 --> 00:34:18,000
in the game but about by ten point six

777
00:34:16,139 --> 00:34:20,399
billion years this guy was done making

778
00:34:18,000 --> 00:34:22,679
stars and also the same metallicity

779
00:34:20,398 --> 00:34:25,949
which is very low less than a tenth the

780
00:34:22,679 --> 00:34:27,898
solar metallicity so these things are

781
00:34:25,949 --> 00:34:31,980
these guys are full of metal-poor stars

782
00:34:27,898 --> 00:34:33,659
and very old stars and so this is a

783
00:34:31,980 --> 00:34:35,009
great picture but actually for an

784
00:34:33,659 --> 00:34:36,148

astronomer what you want to do is you

785

00:34:35,009 --> 00:34:37,949

want to actually start plotting how

786

00:34:36,148 --> 00:34:39,898

bright they are versus their color and

787

00:34:37,949 --> 00:34:42,088

that's called a color magnitude diagram

788

00:34:39,898 --> 00:34:43,618

a lot of you guys are veterans of these

789

00:34:42,088 --> 00:34:45,088

talks you've probably seen this before I

790

00:34:43,619 --> 00:34:47,460

just wanted to make sure we had our

791

00:34:45,088 --> 00:34:49,739

bases covered but basically what you do

792

00:34:47,460 --> 00:34:51,778

here is you take the the magnitude and

793

00:34:49,739 --> 00:34:55,408

the G filter and you subtract it from

794

00:34:51,778 --> 00:34:57,000

the I filter and that's a color and the

795

00:34:55,409 --> 00:34:58,289

red or the object the further it's going

796

00:34:57,000 --> 00:35:00,690

to be over to the right the bigger the

797

00:34:58,289 --> 00:35:02,940

the more positive the color that you get

798

00:35:00,690 --> 00:35:05,099

and the blue or the the smaller or even

799
00:35:02,940 --> 00:35:07,679
negative the color so blue blue stuff is

800
00:35:05,099 --> 00:35:09,269
on the left side red stuff is on the

801
00:35:07,679 --> 00:35:13,199
right side and then how bright it is

802
00:35:09,268 --> 00:35:14,939
bright stuffs on the top so I want to

803
00:35:13,199 --> 00:35:18,028
pick this diagram apart cuz all these

804
00:35:14,940 --> 00:35:20,608
stars are the same age if this was a

805
00:35:18,028 --> 00:35:21,809
young cluster you would see a diagonal

806
00:35:20,608 --> 00:35:23,608
stripe that would start here with a

807
00:35:21,809 --> 00:35:25,589
bunch of stars on the bottom and go up

808
00:35:23,608 --> 00:35:29,159
and to the left like this and that would

809
00:35:25,588 --> 00:35:31,288
be called the main-sequence the most

810
00:35:29,159 --> 00:35:32,818
massive stars burn out first and they're

811
00:35:31,289 --> 00:35:35,069
at the top of the main sequence this is

812
00:35:32,818 --> 00:35:36,329
a very old cluster so most of the main

813
00:35:35,068 --> 00:35:39,599
sequence is gone

814
00:35:36,329 --> 00:35:42,250
stars are dead all you have left are the

815
00:35:39,599 --> 00:35:43,930
low mass stars

816
00:35:42,250 --> 00:35:46,659
so we sort of start we have a

817
00:35:43,929 --> 00:35:48,429
main-sequence pointing to it right down

818
00:35:46,659 --> 00:35:51,368
here at the bottom the main-sequence

819
00:35:48,429 --> 00:35:53,079
turnoff is that is this point where the

820
00:35:51,369 --> 00:35:55,269
whole sequence starts to bend a little

821
00:35:53,079 --> 00:35:57,098
bit to the right those are the stars

822
00:35:55,269 --> 00:36:01,329
that are just now running out of

823
00:35:57,099 --> 00:36:03,609
hydrogen fuel in their core so they can

824
00:36:01,329 --> 00:36:05,829
no longer hold themselves up so they

825
00:36:03,608 --> 00:36:08,250
just spent in the case of the Sun ten

826
00:36:05,829 --> 00:36:10,480
billion years happiest clams

827

00:36:08,250 --> 00:36:14,019
burning hydrogen and helium in the core

828
00:36:10,480 --> 00:36:15,429
nice and stable you know the stars nice

829
00:36:14,019 --> 00:36:16,809
astable the planets you know who knows

830
00:36:15,429 --> 00:36:19,358
how many wars and stuff been happening

831
00:36:16,809 --> 00:36:22,509
but the star is pretty stable so when it

832
00:36:19,358 --> 00:36:24,340
runs out of hydrogen in the core the

833
00:36:22,510 --> 00:36:27,040
star will ascend what's called the red

834
00:36:24,340 --> 00:36:29,170
giant branch and that'll take about a

835
00:36:27,039 --> 00:36:30,489
billion years for the Sun and this is

836
00:36:29,170 --> 00:36:33,190
actually things start to get weird

837
00:36:30,489 --> 00:36:35,409
really quick so you have to think of a

838
00:36:33,190 --> 00:36:38,289
star as two parts there's a core and

839
00:36:35,409 --> 00:36:41,019
then there's an envelope all right and

840
00:36:38,289 --> 00:36:42,400
they evolved separately the core is all

841
00:36:41,019 --> 00:36:45,159

the actions in the core the envelope

842

00:36:42,400 --> 00:36:46,990

just responds so what happens is if the

843

00:36:45,159 --> 00:36:51,519

core can't hold itself up anymore what's

844

00:36:46,989 --> 00:36:53,079

it gonna do it's gonna contract collapse

845

00:36:51,519 --> 00:36:55,000

is a little fast because it takes a

846

00:36:53,079 --> 00:36:56,588

billion years but yes it's good to start

847

00:36:55,000 --> 00:36:59,858

collapsing there's nothing to hold it up

848

00:36:56,588 --> 00:37:02,230

anymore gravity is as much to get so as

849

00:36:59,858 --> 00:37:05,199

it collapses as it contracts it's gonna

850

00:37:02,230 --> 00:37:06,460

heat up and as it heats up even though

851

00:37:05,199 --> 00:37:08,049

it doesn't have any hydrogen in the core

852

00:37:06,460 --> 00:37:10,240

it's still burning hydrogen and a shell

853

00:37:08,050 --> 00:37:11,859

around that helium core and the

854

00:37:10,239 --> 00:37:13,989

luminosity actually goes up the star

855

00:37:11,858 --> 00:37:16,088

gets brighter and because the luminosity

856
00:37:13,989 --> 00:37:17,199
goes up the envelope responds because

857
00:37:16,088 --> 00:37:18,489
you get all this radiation pressure

858
00:37:17,199 --> 00:37:20,799
trying to get out it pushes the envelope

859
00:37:18,489 --> 00:37:22,838
out so the core contracts and the

860
00:37:20,800 --> 00:37:25,359
envelope expands at the same time and

861
00:37:22,838 --> 00:37:30,400
you get a red giant a big fat fluffy

862
00:37:25,358 --> 00:37:31,900
star and out of after a billion years

863
00:37:30,400 --> 00:37:34,240
the star gets to the tip of the red

864
00:37:31,900 --> 00:37:36,510
giant branch and now it's hot enough in

865
00:37:34,239 --> 00:37:38,469
the core to ignite the helium reaction

866
00:37:36,510 --> 00:37:40,330
and when that happens a star

867
00:37:38,469 --> 00:37:43,659
reconfigures really quickly it's called

868
00:37:40,329 --> 00:37:46,659
the helium flash and winds up over here

869
00:37:43,659 --> 00:37:48,190
on the horizontal branch which you could

870
00:37:46,659 --> 00:37:51,549
also call the helium burning main

871
00:37:48,190 --> 00:37:54,519
sequence and so it's nice it's a stable

872
00:37:51,550 --> 00:37:56,030
place again but it's only got about a

873
00:37:54,519 --> 00:37:58,730
hundred million years before

874
00:37:56,030 --> 00:38:00,200
helium in the core and then it does

875
00:37:58,730 --> 00:38:02,960
exactly the same thing it goes back up

876
00:38:00,199 --> 00:38:04,969
the red giant branch a second time this

877
00:38:02,960 --> 00:38:07,519
time with a really complicated structure

878
00:38:04,969 --> 00:38:11,059
because it's got it now has this inert

879
00:38:07,519 --> 00:38:13,070
core of carbon and oxygen surrounded by

880
00:38:11,059 --> 00:38:15,289
a very thin shell of helium which is

881
00:38:13,070 --> 00:38:17,330
being fed by a hydrogen burning shell

882
00:38:15,289 --> 00:38:19,880
outside of that and when you get enough

883
00:38:17,329 --> 00:38:21,440
helium the helium will actually ignite

884

00:38:19,880 --> 00:38:24,740
and you'll get more of that triple alpha

885
00:38:21,440 --> 00:38:27,889
sequence so it's just it's like an onion

886
00:38:24,739 --> 00:38:29,479
and for most stars this is because they

887
00:38:27,889 --> 00:38:30,859
don't have enough mass they don't the

888
00:38:29,480 --> 00:38:32,960
temperatures don't get any higher in the

889
00:38:30,860 --> 00:38:35,570
core this is it there are no more

890
00:38:32,960 --> 00:38:38,030
nuclear fusion sources for them to work

891
00:38:35,570 --> 00:38:41,330
with so when they collapse the next time

892
00:38:38,030 --> 00:38:43,340
they're toast and maybe a million years

893
00:38:41,329 --> 00:38:45,619
for the Sun to basically climb back up

894
00:38:43,340 --> 00:38:47,900
this the second giant branch this is one

895
00:38:45,619 --> 00:38:50,839
of the most so this is called the

896
00:38:47,900 --> 00:38:52,220
asymptotic giant branch because it asked

897
00:38:50,840 --> 00:38:54,650
some Tata cailli approaches the first

898
00:38:52,219 --> 00:38:58,549

giant branch this is the worst possible

899

00:38:54,650 --> 00:39:00,380

name I can imagine in astronomy so what

900

00:38:58,550 --> 00:39:04,789

do you study I study asymptotic giant

901

00:39:00,380 --> 00:39:08,750

branch stars it's like okay well I

902

00:39:04,789 --> 00:39:10,340

better go get some more coffee you know

903

00:39:08,750 --> 00:39:12,409

the only thing you do is call them AGB

904

00:39:10,340 --> 00:39:13,850

stars but I've always been taught you

905

00:39:12,409 --> 00:39:17,719

can't just start using acronyms without

906

00:39:13,849 --> 00:39:20,000

defining them so anyway this is what

907

00:39:17,719 --> 00:39:23,959

this needs a PR rethink in my opinion I

908

00:39:20,000 --> 00:39:26,449

want to call it the death branch we'll

909

00:39:23,960 --> 00:39:28,220

see how that goes so this is just a nice

910

00:39:26,449 --> 00:39:29,719

picture sort of illustrating what the

911

00:39:28,219 --> 00:39:32,750

Sun would look like at different stages

912

00:39:29,719 --> 00:39:34,699

of its life you notice that oh I haven't

913
00:39:32,750 --> 00:39:40,510
cursor let's get that cursor make use of

914
00:39:34,699 --> 00:39:44,989
it and went away it won't come back okay

915
00:39:40,510 --> 00:39:47,150
there is you kids up there there are

916
00:39:44,989 --> 00:39:52,069
four pixels lit up right here that's the

917
00:39:47,150 --> 00:39:53,570
Sun these images are actually 200 pixels

918
00:39:52,070 --> 00:39:58,010
across which is the size of the Earth's

919
00:39:53,570 --> 00:40:00,980
orbit and so you can see that RGB you

920
00:39:58,010 --> 00:40:02,510
know big horizontal branch small again

921
00:40:00,980 --> 00:40:05,000
but not as small as the main sequence

922
00:40:02,510 --> 00:40:08,030
and then early AG be really big this

923
00:40:05,000 --> 00:40:09,889
works out that's about 0.9 au or nine

924
00:40:08,030 --> 00:40:13,160
tenths the radius

925
00:40:09,889 --> 00:40:16,909
Earth's orbit and this is early AGB

926
00:40:13,159 --> 00:40:18,019
things get worse all right but before we

927
00:40:16,909 --> 00:40:20,179
get to that I want to look let's look

928
00:40:18,019 --> 00:40:22,969
inside this guy remember I described to

929
00:40:20,179 --> 00:40:24,139
you this crazy G on this crazy multi

930
00:40:22,969 --> 00:40:25,179
shell geometry well this is what it

931
00:40:24,139 --> 00:40:29,179
looks like

932
00:40:25,179 --> 00:40:32,089
so on the Left we've actually got this

933
00:40:29,179 --> 00:40:33,529
plotted not with radius but with mass to

934
00:40:32,090 --> 00:40:35,930
sort of tell you how far you are along

935
00:40:33,530 --> 00:40:37,790
going from in to out so you can kind of

936
00:40:35,929 --> 00:40:40,039
see all the different parts it halfway

937
00:40:37,789 --> 00:40:42,920
out that's because half the mass of the

938
00:40:40,039 --> 00:40:44,420
star is in the core but if you really

939
00:40:42,920 --> 00:40:52,909
see what it looks like look on the

940
00:40:44,420 --> 00:40:54,950
right-hand side so these are really

941

00:40:52,909 --> 00:40:58,190
interesting creatures these AG be stars

942
00:40:54,949 --> 00:41:02,419
there's these giant puffy tenuous almost

943
00:40:58,190 --> 00:41:05,980
vacuum stars that will expand in the

944
00:41:02,420 --> 00:41:05,980
case of the Sun to engulf the earth

945
00:41:07,809 --> 00:41:17,989
asymptotic giant branch how about death

946
00:41:11,570 --> 00:41:20,480
branch I'm kind of liking this I mean we

947
00:41:17,989 --> 00:41:23,329
go with this so this core will become a

948
00:41:20,480 --> 00:41:29,480
white dwarf and the envelope will get

949
00:41:23,329 --> 00:41:31,279
ejected so I said that the helium

950
00:41:29,480 --> 00:41:32,599
doesn't burn continuously so the helium

951
00:41:31,280 --> 00:41:34,280
will build up it'll build up and then

952
00:41:32,599 --> 00:41:36,469
they'll be this what they call a thermal

953
00:41:34,280 --> 00:41:38,360
pulse this runaway nuclear reaction

954
00:41:36,469 --> 00:41:41,179
where this triple alpha sequence takes

955
00:41:38,360 --> 00:41:43,700

off so what I did Peter would and his

956

00:41:41,179 --> 00:41:45,349

student somebody I don't remember Vasily

957

00:41:43,699 --> 00:41:47,419

on I've never met Miss Ileana so I don't

958

00:41:45,349 --> 00:41:48,829

know his first name but this is a 25

959

00:41:47,420 --> 00:41:52,070

year old theory paper and it's still

960

00:41:48,829 --> 00:41:53,539

pretty darn good and so what he's done

961

00:41:52,070 --> 00:41:55,970

here is he's basically plotted the

962

00:41:53,539 --> 00:41:57,349

temperature of the star on the top the

963

00:41:55,969 --> 00:42:00,469

log of the temperature the the

964

00:41:57,349 --> 00:42:01,699

luminosity the pulsation period star

965

00:42:00,469 --> 00:42:04,250

we'll get to that in a second that's not

966

00:42:01,699 --> 00:42:06,889

the thermal pulse the expansion velocity

967

00:42:04,250 --> 00:42:08,269

of the star it's mass this is kind of

968

00:42:06,889 --> 00:42:09,859

fun because you'll notice after a few of

969

00:42:08,269 --> 00:42:11,210

these thermal pulses the star hangs in

970
00:42:09,860 --> 00:42:16,280
there hangs in there have been boom it

971
00:42:11,210 --> 00:42:18,829
loses half its mass pretty quickly we

972
00:42:16,280 --> 00:42:20,480
don't actually know how that happens the

973
00:42:18,829 --> 00:42:22,309
way Peter made this work if I remember

974
00:42:20,480 --> 00:42:22,639
right and since 50,000 people can see

975
00:42:22,309 --> 00:42:24,818
this

976
00:42:22,639 --> 00:42:28,038
or something like that 5,000 you said

977
00:42:24,818 --> 00:42:30,440
okay oh that's enough one of them might

978
00:42:28,039 --> 00:42:31,910
be Peter and he's gonna be he's gonna be

979
00:42:30,440 --> 00:42:33,559
mad at me because I think he just turns

980
00:42:31,909 --> 00:42:35,659
on the mass loss dial to make the mass

981
00:42:33,559 --> 00:42:37,099
chaos happen it's not it's a little bit

982
00:42:35,659 --> 00:42:38,690
better than that but basically we don't

983
00:42:37,099 --> 00:42:41,028
really understand that process and

984
00:42:38,690 --> 00:42:42,380
that's pretty important so anyway the

985
00:42:41,028 --> 00:42:43,759
point is every time this thing goes to a

986
00:42:42,380 --> 00:42:45,950
therm through a thermal pulse it

987
00:42:43,759 --> 00:42:48,920
reconfigures itself for a little while

988
00:42:45,949 --> 00:42:50,598
and what happens is the envelope of

989
00:42:48,920 --> 00:42:52,639
these stars is completely convective

990
00:42:50,599 --> 00:42:54,349
that 99% of the star that's just

991
00:42:52,639 --> 00:42:55,730
envelope it's convective you got

992
00:42:54,349 --> 00:42:58,390
convection cells going all the way from

993
00:42:55,730 --> 00:43:01,699
the center out to the Earth's orbit

994
00:42:58,389 --> 00:43:03,798
basically and what happens in the core

995
00:43:01,699 --> 00:43:05,808
when you get learn these helium flashes

996
00:43:03,798 --> 00:43:09,079
there's a little convective layer that

997
00:43:05,809 --> 00:43:11,150
forms there and it overlaps with the

998

00:43:09,079 --> 00:43:14,450
convective envelope so these stars

999
00:43:11,150 --> 00:43:17,480
they're making carbon via this triple

1000
00:43:14,449 --> 00:43:19,730
alpha sequence and dredging it right to

1001
00:43:17,480 --> 00:43:22,838
the surface of the star so it can be

1002
00:43:19,730 --> 00:43:26,769
ejected into the interstellar medium and

1003
00:43:22,838 --> 00:43:29,858
that's where the carbon comes from

1004
00:43:26,768 --> 00:43:36,588
according to miss Johnson's plot about

1005
00:43:29,858 --> 00:43:38,598
75 or 80 percent of it so we have

1006
00:43:36,588 --> 00:43:40,759
thermal pulses on the inside happening

1007
00:43:38,599 --> 00:43:45,470
for the Sun like every 80,000 years

1008
00:43:40,759 --> 00:43:46,880
something like that the we know this

1009
00:43:45,469 --> 00:43:49,909
happens theoretically we're on really

1010
00:43:46,880 --> 00:43:51,680
solid ground it's not clear to me that

1011
00:43:49,909 --> 00:43:54,288
we have clear that oh that star just had

1012
00:43:51,679 --> 00:43:56,088

a thermal pulse because it's actually

1013

00:43:54,289 --> 00:43:57,619

really hard to see because it takes you

1014

00:43:56,088 --> 00:44:00,288

know thousands of years these stars to

1015

00:43:57,619 --> 00:44:02,358

kind of reconfigure themselves but we do

1016

00:44:00,289 --> 00:44:03,739

see the envelope is as I said this big

1017

00:44:02,358 --> 00:44:04,909

to newest thing stretching all the way

1018

00:44:03,739 --> 00:44:07,730

out to the Earth's orbit it's really

1019

00:44:04,909 --> 00:44:10,278

unstable to just simple pulsations if

1020

00:44:07,730 --> 00:44:12,190

you push out it keeps going and then

1021

00:44:10,278 --> 00:44:16,699

will fall back in so the whole star

1022

00:44:12,190 --> 00:44:18,829

basically is pulsating like this on a

1023

00:44:16,699 --> 00:44:22,399

timescale in this particular case of Chi

1024

00:44:18,829 --> 00:44:25,160

sig with a period of 405 days

1025

00:44:22,400 --> 00:44:29,180

so over the course of a year and 40 days

1026

00:44:25,159 --> 00:44:31,998

it will pulse out and pulse back in so

1027
00:44:29,179 --> 00:44:36,989
Chi sig if you catch it at maximum is a

1028
00:44:31,998 --> 00:44:41,250
naked-eye star does magnitude 3 or 4

1029
00:44:36,989 --> 00:44:43,169
at maximum but when it's at minimum its

1030
00:44:41,250 --> 00:44:44,639
weight it's like a 14th 13th magnitude

1031
00:44:43,170 --> 00:44:47,250
star you just know what you can see that

1032
00:44:44,639 --> 00:44:52,440
with your eye so these are huge major

1033
00:44:47,250 --> 00:44:55,230
pulsations when I put it yes so as I

1034
00:44:52,440 --> 00:45:00,570
said these stars are going crazy inside

1035
00:44:55,230 --> 00:45:02,519
and outside so we were interested in

1036
00:45:00,570 --> 00:45:04,890
digging into this a little bit so we

1037
00:45:02,519 --> 00:45:06,389
took him five and we did our photometry

1038
00:45:04,889 --> 00:45:08,519
but we didn't do it just once we kept

1039
00:45:06,389 --> 00:45:11,039
getting more time over the next couple

1040
00:45:08,519 --> 00:45:12,659
of years to sort of track which stars

1041
00:45:11,039 --> 00:45:15,838
were the variables which stars were

1042
00:45:12,659 --> 00:45:19,739
pulsating and you can see that we got a

1043
00:45:15,838 --> 00:45:21,480
whole bunch of guys on the on the

1044
00:45:19,739 --> 00:45:24,088
horizontal branch those are our Lyra

1045
00:45:21,480 --> 00:45:25,289
stars those are like a standard candle

1046
00:45:24,088 --> 00:45:27,570
they're really you know that's how we

1047
00:45:25,289 --> 00:45:29,489
figured out that the earth was the Sun

1048
00:45:27,570 --> 00:45:30,900
wasn't the center of the Milky Way we

1049
00:45:29,489 --> 00:45:33,449
thought I didn't do it this was like

1050
00:45:30,900 --> 00:45:36,180
what 80 90 years ago now I think

1051
00:45:33,449 --> 00:45:38,069
something like that but you can see out

1052
00:45:36,179 --> 00:45:39,419
here as you climb up the red giant

1053
00:45:38,070 --> 00:45:42,088
branch you can see that the variability

1054
00:45:39,420 --> 00:45:46,440
really does increase all the way to the

1055

00:45:42,088 --> 00:45:47,699
tip and that's pretty cool so we're all

1056
00:45:46,440 --> 00:45:49,019
really proud of our multi epic

1057
00:45:47,699 --> 00:45:51,569
photometry but if you're going to see

1058
00:45:49,019 --> 00:45:56,820
multi epic photometry the Gaia mission

1059
00:45:51,570 --> 00:45:58,740
is stunningly impressive I mean this is

1060
00:45:56,820 --> 00:46:01,440
better than anything this is art as far

1061
00:45:58,739 --> 00:46:03,719
as I'm concerned it so this is their

1062
00:46:01,440 --> 00:46:06,869
color magnitude diagram they've got blue

1063
00:46:03,719 --> 00:46:11,399
and red filters they call them V P and R

1064
00:46:06,869 --> 00:46:12,869
P they didn't ask me and then absolute

1065
00:46:11,400 --> 00:46:15,300
magnitude here so the nice thing about

1066
00:46:12,869 --> 00:46:16,710
Gaia is because it gets parallax's so

1067
00:46:15,300 --> 00:46:18,750
they can correct for distance and put

1068
00:46:16,710 --> 00:46:22,789
all the stars in the solar neighborhood

1069
00:46:18,750 --> 00:46:25,679

all gazillion of them on the same plot

1070

00:46:22,789 --> 00:46:27,750

so here's the main sequence it's like

1071

00:46:25,679 --> 00:46:29,549

right down here here's the giant branch

1072

00:46:27,750 --> 00:46:32,179

and this is basically color-coded by

1073

00:46:29,550 --> 00:46:34,710

variability so way up here here's the

1074

00:46:32,179 --> 00:46:36,929

RGB in the AG beam you can see that

1075

00:46:34,710 --> 00:46:38,369

they're all variables this plot over

1076

00:46:36,929 --> 00:46:39,598

here on the right hand side is kind of

1077

00:46:38,369 --> 00:46:41,519

fun because what they've done here is

1078

00:46:39,599 --> 00:46:44,070

they've mapped known identified

1079

00:46:41,519 --> 00:46:46,050

variables back onto their diagram so

1080

00:46:44,070 --> 00:46:49,200

long period variables is what all these

1081

00:46:46,050 --> 00:46:50,490

guys are these are all AGB stars pulsing

1082

00:46:49,199 --> 00:46:51,989

like mad with

1083

00:46:50,489 --> 00:46:54,899

periods of anywhere between a hundred

1084
00:46:51,989 --> 00:46:56,909
days and a thousand and those are stars

1085
00:46:54,900 --> 00:46:58,860
in the midst of ripping themselves apart

1086
00:46:56,909 --> 00:47:07,618
and blowing their innards back into

1087
00:46:58,860 --> 00:47:11,220
space okay so switch gears again when a

1088
00:47:07,619 --> 00:47:14,579
star it's cool enough molecules can form

1089
00:47:11,219 --> 00:47:16,379
in its atmosphere so here we have a nice

1090
00:47:14,579 --> 00:47:18,900
picture this is the Hyades that's the V

1091
00:47:16,380 --> 00:47:21,300
of the face of the bull on its side that

1092
00:47:18,900 --> 00:47:24,450
star right there is all deber on Alpha

1093
00:47:21,300 --> 00:47:25,860
Tau when I started doing astronomy and

1094
00:47:24,449 --> 00:47:27,839
Fred astronomy at Wyoming where I did my

1095
00:47:25,860 --> 00:47:29,010
PhD I never really appreciated that the

1096
00:47:27,840 --> 00:47:32,430
stars I was gonna be looking at were

1097
00:47:29,010 --> 00:47:34,680
naked eye objects because Alpha Tau was

1098
00:47:32,429 --> 00:47:38,940
what we what what all of our calibration

1099
00:47:34,679 --> 00:47:40,589
hung off of so this is a star in the

1100
00:47:38,940 --> 00:47:42,510
infrared so basically the spectrum is

1101
00:47:40,590 --> 00:47:44,880
dropping off you see there's a couple of

1102
00:47:42,510 --> 00:47:46,350
kinks in the spectrum here this is not

1103
00:47:44,880 --> 00:47:47,820
the best way to plot it because what

1104
00:47:46,349 --> 00:47:49,409
dominates the the fact it's very

1105
00:47:47,820 --> 00:47:51,450
bright at two-and-a-half microns and

1106
00:47:49,409 --> 00:47:53,099
very faint at twenty so what I've done

1107
00:47:51,449 --> 00:47:54,599
is I've got another plot come up here

1108
00:47:53,099 --> 00:47:57,329
where I basically multiplied that

1109
00:47:54,599 --> 00:47:59,159
spectrum by the wavelength squared to

1110
00:47:57,329 --> 00:48:02,579
kind of flatten it out to bring out some

1111
00:47:59,159 --> 00:48:04,649
of the detail so here you go now those

1112

00:48:02,579 --> 00:48:06,230
kinks are these really neat molecular

1113
00:48:04,650 --> 00:48:08,820
absorption bands from carbon monoxide

1114
00:48:06,230 --> 00:48:11,119
and silicon monoxide two of each

1115
00:48:08,820 --> 00:48:13,230
overtone and fundamental here at

1116
00:48:11,119 --> 00:48:15,450
basically four microns and then an

1117
00:48:13,230 --> 00:48:18,030
eighth microns and then here's another

1118
00:48:15,449 --> 00:48:19,469
star - even cooler giant and I've spread

1119
00:48:18,030 --> 00:48:20,910
it out so this just goes from two and a

1120
00:48:19,469 --> 00:48:23,368
half to twelve microns now you can

1121
00:48:20,909 --> 00:48:27,539
really see the carbon monoxide the SiO

1122
00:48:23,369 --> 00:48:30,240
band co water vapor in these coolest

1123
00:48:27,539 --> 00:48:32,309
stars and this is important because

1124
00:48:30,239 --> 00:48:35,579
what's going to happen is when these

1125
00:48:32,309 --> 00:48:37,019
stars start pulsing pulsating remember

1126
00:48:35,579 --> 00:48:37,920

they're getting they're expanding and

1127

00:48:37,019 --> 00:48:39,269

they're getting small and when they're

1128

00:48:37,920 --> 00:48:43,079

expanding there's a bit of a kick and

1129

00:48:39,269 --> 00:48:44,730

velocity outward and if the if this gas

1130

00:48:43,079 --> 00:48:48,210

and these molecules can get far enough

1131

00:48:44,730 --> 00:48:50,960

away from the star they'll actually cool

1132

00:48:48,210 --> 00:48:55,349

enough so that dust can condense out and

1133

00:48:50,960 --> 00:48:58,400

the opacity how opaque dust is compared

1134

00:48:55,349 --> 00:49:00,299

to the same bunch of molecules as a gas

1135

00:48:58,400 --> 00:49:03,510

it's it's sort of like they all just

1136

00:49:00,300 --> 00:49:04,830

dropped their sails you know and

1137

00:49:03,510 --> 00:49:07,050

winds kicked up and they just get

1138

00:49:04,829 --> 00:49:10,019

blasted out so when you start making

1139

00:49:07,050 --> 00:49:11,580

dust from this from these molecules then

1140

00:49:10,019 --> 00:49:13,829

the radiation pressure from the start

1141
00:49:11,579 --> 00:49:21,449
just blows it out into space and that's

1142
00:49:13,829 --> 00:49:23,099
how these stars shed mass so here's a

1143
00:49:21,449 --> 00:49:28,949
really complicated diagram to explain

1144
00:49:23,099 --> 00:49:31,170
everything really simply I'm going to

1145
00:49:28,949 --> 00:49:32,460
see Joseph Peron in Vienna in a couple

1146
00:49:31,170 --> 00:49:33,809
of weeks and I'm not gonna tell him that

1147
00:49:32,460 --> 00:49:35,820
I put it that way because it's actually

1148
00:49:33,809 --> 00:49:37,199
a pretty nice diagram so basically if

1149
00:49:35,820 --> 00:49:40,530
you just draw a line through the middle

1150
00:49:37,199 --> 00:49:44,309
of it cutting it in half vertically the

1151
00:49:40,530 --> 00:49:45,360
upper half is oxygen-rich and the bottom

1152
00:49:44,309 --> 00:49:46,590
half is carbon-rich

1153
00:49:45,360 --> 00:49:49,289
and what it's doing with it and if you

1154
00:49:46,590 --> 00:49:51,329
go from the left side that's the center

1155
00:49:49,289 --> 00:49:53,579
of the star but it's all I can log space

1156
00:49:51,329 --> 00:49:56,340
so you can cram a lot of dynamic range

1157
00:49:53,579 --> 00:49:57,420
into one plot convective envelope you've

1158
00:49:56,340 --> 00:49:59,490
a little further out and now you're out

1159
00:49:57,420 --> 00:50:01,139
in the pulsating atmosphere that's where

1160
00:49:59,489 --> 00:50:03,000
the molecules are and you get further

1161
00:50:01,139 --> 00:50:04,769
out that's where the dust is the whole

1162
00:50:03,000 --> 00:50:07,590
point to this plot is basically to show

1163
00:50:04,769 --> 00:50:09,679
you what happens because the first

1164
00:50:07,590 --> 00:50:13,950
molecule that forms is carbon monoxide

1165
00:50:09,679 --> 00:50:16,190
co and the co will keep forming until it

1166
00:50:13,949 --> 00:50:19,349
runs out of one of them carbon or oxygen

1167
00:50:16,190 --> 00:50:21,329
so remember these stars are they've got

1168
00:50:19,349 --> 00:50:23,519
these thermal pulses in the core they're

1169

00:50:21,329 --> 00:50:25,619
dredging up carbon to the surface they

1170
00:50:23,519 --> 00:50:27,000
started out oxygen-rich but every time

1171
00:50:25,619 --> 00:50:29,909
that they do one of these dredge ups

1172
00:50:27,000 --> 00:50:31,739
there's like an extra Delta in carbon

1173
00:50:29,909 --> 00:50:35,069
and if they do it enough they'll have

1174
00:50:31,739 --> 00:50:37,769
more carbon than oxygen so the co forms

1175
00:50:35,070 --> 00:50:39,300
and it usually it uses up all the carbon

1176
00:50:37,769 --> 00:50:41,579
and just laughs with oxygen is the free

1177
00:50:39,300 --> 00:50:43,920
molecule to make all these molecules and

1178
00:50:41,579 --> 00:50:47,159
to make the dust so you get a lot of

1179
00:50:43,920 --> 00:50:49,849
silicate dust and alumina dust just like

1180
00:50:47,159 --> 00:50:52,649
on the beach just a bunch of silicates

1181
00:50:49,849 --> 00:50:55,110
but if it's a carbon star all the

1182
00:50:52,650 --> 00:50:57,510
oxygens is consumed by the co and you're

1183
00:50:55,110 --> 00:50:59,760

just left with carbon and other you know

1184

00:50:57,510 --> 00:51:01,680

other elements you can make acetylene

1185

00:50:59,760 --> 00:51:05,850

there's a lot of acetylene in these

1186

00:51:01,679 --> 00:51:07,379

stars no smoking but it's okay we can't

1187

00:51:05,849 --> 00:51:08,900

burn anything because the oxygen is all

1188

00:51:07,380 --> 00:51:11,599

gone

1189

00:51:08,900 --> 00:51:14,358

so and the acetylene can make amorphous

1190

00:51:11,599 --> 00:51:16,099

carbon dust so my focus as an infrared

1191

00:51:14,358 --> 00:51:17,838

spectroscopy has always been the dust

1192

00:51:16,099 --> 00:51:19,309

and these are what the spectra of these

1193

00:51:17,838 --> 00:51:21,650

two different kinds of evolved stars

1194

00:51:19,309 --> 00:51:23,298

look like so on the top this is these

1195

00:51:21,650 --> 00:51:25,220

are infrared spectra like the visible

1196

00:51:23,298 --> 00:51:26,748

part of the of wavelength space is over

1197

00:51:25,219 --> 00:51:28,939

here you can't even count even plotted

1198
00:51:26,748 --> 00:51:31,338
so here's the star and now you have

1199
00:51:28,940 --> 00:51:33,829
these emission features from all of this

1200
00:51:31,338 --> 00:51:36,018
hot dust around the star at 10 microns

1201
00:51:33,829 --> 00:51:37,460
and 18 microns so you get those two

1202
00:51:36,018 --> 00:51:39,108
emission features in your spectrum ooh

1203
00:51:37,460 --> 00:51:43,608
I'm looking at silicate dust that was

1204
00:51:39,108 --> 00:51:45,440
easy and then if it's a carbon star you

1205
00:51:43,608 --> 00:51:46,670
can see the silicon carbide dust at 11

1206
00:51:45,440 --> 00:51:49,519
and a half microns but what's actually

1207
00:51:46,670 --> 00:51:51,680
most of the dust so in this spectrum of

1208
00:51:49,518 --> 00:51:53,358
the oxygen star that's actually the star

1209
00:51:51,679 --> 00:51:56,449
that's the photosphere of the star plus

1210
00:51:53,358 --> 00:52:00,889
some dust these carbon stars the dust is

1211
00:51:56,449 --> 00:52:05,980
so opaque you can't see through it what

1212
00:52:00,889 --> 00:52:05,980
I do oh man

1213
00:52:06,159 --> 00:52:18,018
and what I really want is reminds me

1214
00:52:10,460 --> 00:52:20,358
never that's crazy I actually my usual

1215
00:52:18,018 --> 00:52:21,889
computer is a Linux system and I feel

1216
00:52:20,358 --> 00:52:23,719
like I have kind of control over it but

1217
00:52:21,889 --> 00:52:26,778
my MacBook thinks for itself and I don't

1218
00:52:23,719 --> 00:52:29,328
like that at all so anyway the amorphous

1219
00:52:26,778 --> 00:52:31,909
so all of the that what looks like the

1220
00:52:29,329 --> 00:52:33,349
star here all this stuff you know

1221
00:52:31,909 --> 00:52:35,449
between the emission and absorption

1222
00:52:33,349 --> 00:52:38,269
features that's actually the amorphous

1223
00:52:35,449 --> 00:52:40,248
carbon dust morphus carbon has no

1224
00:52:38,268 --> 00:52:42,679
features at all it's just except that

1225
00:52:40,248 --> 00:52:46,998
it's just dark it just locks everything

1226

00:52:42,679 --> 00:52:48,710
underneath it so I'm gonna skip this

1227
00:52:46,998 --> 00:52:50,268
this is all about the oxygen rich dust

1228
00:52:48,710 --> 00:52:51,829
and it takes us back a couple of decades

1229
00:52:50,268 --> 00:52:53,238
when I was studying it but lately I've

1230
00:52:51,829 --> 00:52:54,710
been doing the carbon rich to us I feel

1231
00:52:53,239 --> 00:52:57,259
like I'm going on so I'm gonna cut one

1232
00:52:54,710 --> 00:53:00,048
slide out to shorten the talk ever so

1233
00:52:57,259 --> 00:53:03,440
slightly so I want to focus on the ashes

1234
00:53:00,048 --> 00:53:04,969
to ashes part so this is a planetary

1235
00:53:03,440 --> 00:53:09,679
nebula this is a carbon-rich plant

1236
00:53:04,969 --> 00:53:12,649
earnable this is NGC 702 7 so that was a

1237
00:53:09,679 --> 00:53:15,288
carbon star once and the point is is

1238
00:53:12,650 --> 00:53:17,269
that the Sun doesn't have enough mass to

1239
00:53:15,289 --> 00:53:19,640
become a carbon star it to be about

1240
00:53:17,268 --> 00:53:21,469

twice the solar mass up to 5 times in

1241
00:53:19,639 --> 00:53:22,190
that range those guys will all become

1242
00:53:21,469 --> 00:53:24,199
carbons

1243
00:53:22,190 --> 00:53:25,789
one day and as I've already explained

1244
00:53:24,199 --> 00:53:29,079
they're the source of the carbon in the

1245
00:53:25,789 --> 00:53:31,940
universe and if we can understand better

1246
00:53:29,079 --> 00:53:34,610
how these stars died we would have a

1247
00:53:31,940 --> 00:53:36,110
better handle on when in an in in the

1248
00:53:34,610 --> 00:53:38,930
history of a galaxy you'd actually have

1249
00:53:36,110 --> 00:53:40,670
carbon for life to form we actually

1250
00:53:38,929 --> 00:53:42,859
don't understand enough to tell about

1251
00:53:40,670 --> 00:53:45,079
how these things die because basically

1252
00:53:42,860 --> 00:53:46,760
what I think happens is that as soon as

1253
00:53:45,079 --> 00:53:48,559
you dredge up enough carbon and you

1254
00:53:46,760 --> 00:53:51,050
cross some limit the star basically just

1255
00:53:48,559 --> 00:53:52,250
goes into blowout mode and I'm not the

1256
00:53:51,050 --> 00:53:54,170
only one the things this is not my idea

1257
00:53:52,250 --> 00:53:54,619
originally but I've certainly on board

1258
00:53:54,170 --> 00:53:56,210
with it

1259
00:53:54,619 --> 00:53:58,130
but it's really difficult to demonstrate

1260
00:53:56,210 --> 00:54:02,960
that that is true we haven't done that

1261
00:53:58,130 --> 00:54:04,460
yet all right the way we've been

1262
00:54:02,960 --> 00:54:06,079
tackling this problems we've been

1263
00:54:04,460 --> 00:54:08,570
looking at the local groups this is a

1264
00:54:06,079 --> 00:54:11,569
really nice illustration you can see

1265
00:54:08,570 --> 00:54:13,660
this we have Andromeda m31 up here above

1266
00:54:11,570 --> 00:54:16,160
the plane of the local group we've got

1267
00:54:13,659 --> 00:54:17,539
the Milky Way right in the center since

1268
00:54:16,159 --> 00:54:21,769
we drew the plot we're allowed to do

1269
00:54:17,539 --> 00:54:24,170
that but around each of these two big

1270
00:54:21,769 --> 00:54:27,530
spiral galaxies there's a whole swarm of

1271
00:54:24,170 --> 00:54:30,170
dwarf galaxies and most of those dwarf

1272
00:54:27,530 --> 00:54:31,820
galaxies are very metal-poor they

1273
00:54:30,170 --> 00:54:35,329
haven't formed a lot of stars in a long

1274
00:54:31,820 --> 00:54:37,400
time and so they're sort of like they're

1275
00:54:35,329 --> 00:54:39,139
kind of a proxy for what galaxies would

1276
00:54:37,400 --> 00:54:41,840
have looked like at very high redshift

1277
00:54:39,139 --> 00:54:44,449
early in the universe metal-poor

1278
00:54:41,840 --> 00:54:46,490
galaxies the only problem is that most

1279
00:54:44,449 --> 00:54:48,169
of these dwarf galaxies they stopped

1280
00:54:46,489 --> 00:54:50,809
forming stars a long time ago

1281
00:54:48,170 --> 00:54:53,000
the Holy Grail would be to have a metal

1282
00:54:50,809 --> 00:54:55,070
core galaxy that just forms some high

1283

00:54:53,000 --> 00:54:56,269
mass stars because those the ones that

1284
00:54:55,070 --> 00:54:58,340
we would be more interested in but we

1285
00:54:56,269 --> 00:55:01,579
take what you can get so we've been

1286
00:54:58,340 --> 00:55:04,730
looking primarily in the Magellanic

1287
00:55:01,579 --> 00:55:06,739
Clouds the largest small Magellanic

1288
00:55:04,730 --> 00:55:11,059
Clouds Large Magellanic Cloud has a

1289
00:55:06,739 --> 00:55:12,229
metallicity about half solar which is

1290
00:55:11,059 --> 00:55:14,480
sort of like the outer parts of the

1291
00:55:12,230 --> 00:55:16,429
galaxy but still a lot less than most of

1292
00:55:14,480 --> 00:55:18,760
the stars in the galaxy and the small

1293
00:55:16,429 --> 00:55:21,019
Magellanic Cloud is about 1/5 solar

1294
00:55:18,760 --> 00:55:23,210
let's focus on the Large Magellanic

1295
00:55:21,019 --> 00:55:25,789
Cloud here because that's the one I got

1296
00:55:23,210 --> 00:55:27,590
slides on so again I've got a really

1297
00:55:25,789 --> 00:55:30,170

nice snazzy picture I pulled this off

1298

00:55:27,590 --> 00:55:32,300

the web thank you John Gleeson I should

1299

00:55:30,170 --> 00:55:34,170

have asked for permission he's ok good

1300

00:55:32,300 --> 00:55:36,240

advertising great

1301

00:55:34,170 --> 00:55:39,090

and then I have a color-magnitude

1302

00:55:36,239 --> 00:55:40,649

diagram like what I put up before except

1303

00:55:39,090 --> 00:55:43,110

this time it's a near-infrared color

1304

00:55:40,650 --> 00:55:45,780

magnitude diagram and there's so many

1305

00:55:43,110 --> 00:55:48,420

stars to plot that they chose to make it

1306

00:55:45,780 --> 00:55:49,800

a contour plot so here's the peak right

1307

00:55:48,420 --> 00:55:51,420

and those are the next con - all the way

1308

00:55:49,800 --> 00:55:54,900

down I really like this block because

1309

00:55:51,420 --> 00:55:56,519

it's sort of like this giant hand with

1310

00:55:54,900 --> 00:55:57,269

this thumb sticking out and this thumb

1311

00:55:56,519 --> 00:56:01,050

over here

1312
00:55:57,269 --> 00:56:05,219
that's the AGB that's where all the

1313
00:56:01,050 --> 00:56:07,740
dying stars are Dave rebo who got his

1314
00:56:05,219 --> 00:56:11,489
PhD here at Johns Hopkins a few years

1315
00:56:07,739 --> 00:56:13,229
ago took a closer look at the LMC and he

1316
00:56:11,489 --> 00:56:15,118
actually he took all of the AGB stars

1317
00:56:13,230 --> 00:56:17,519
and he plotted them up on this diagram

1318
00:56:15,119 --> 00:56:21,680
so here's the old diagram and here's his

1319
00:56:17,519 --> 00:56:25,710
diagram so basically red is carbon star

1320
00:56:21,679 --> 00:56:27,690
so you can see that that thumb that's

1321
00:56:25,710 --> 00:56:29,940
the carbon stars so these stars are

1322
00:56:27,690 --> 00:56:31,500
incredibly red and they're so red

1323
00:56:29,940 --> 00:56:34,200
they're actually you know like they're

1324
00:56:31,500 --> 00:56:35,849
absorbing infrared light and so these

1325
00:56:34,199 --> 00:56:38,099
stars look like they're getting fainter

1326
00:56:35,849 --> 00:56:39,719
without here at the reddest winds but

1327
00:56:38,099 --> 00:56:41,699
they're not they're just the light can't

1328
00:56:39,719 --> 00:56:48,569
get out at 2 microns it has to get out

1329
00:56:41,699 --> 00:56:50,339
at longer wavelengths so of course I do

1330
00:56:48,570 --> 00:56:52,440
spectroscopy so here's some spectra of

1331
00:56:50,340 --> 00:56:54,150
what these guys look like plotted from

1332
00:56:52,440 --> 00:56:56,429
top to bottom this is the bluest carbon

1333
00:56:54,150 --> 00:56:59,039
star and then every color is sort of

1334
00:56:56,429 --> 00:57:00,480
like a degree of redder all the way down

1335
00:56:59,039 --> 00:57:02,519
to the point that the dust is so thick

1336
00:57:00,480 --> 00:57:04,530
that even the silicon carbide feature

1337
00:57:02,519 --> 00:57:06,840
has gone into absorption it's not

1338
00:57:04,530 --> 00:57:10,800
admitting anymore it's absorbing that's

1339
00:57:06,840 --> 00:57:12,358
that's a lot of dust and yeah and then

1340

00:57:10,800 --> 00:57:15,359
also you can see there's an absorption

1341
00:57:12,358 --> 00:57:19,019
band from acetylene molecules that's the

1342
00:57:15,358 --> 00:57:21,269
stuff that makes the dust and we spit it

1343
00:57:19,019 --> 00:57:23,340
yeah a lot of a lot of a work of these

1344
00:57:21,269 --> 00:57:24,630
on these kinds of spectra but I'm not

1345
00:57:23,340 --> 00:57:27,059
going to show you too much I'm going to

1346
00:57:24,630 --> 00:57:29,160
show you some photometry we're almost to

1347
00:57:27,059 --> 00:57:32,369
the end and it was like 39 or something

1348
00:57:29,159 --> 00:57:34,230
so this is this is a this is not a color

1349
00:57:32,369 --> 00:57:36,809
magnitude plot this is a color color

1350
00:57:34,230 --> 00:57:39,900
plot so what we have here is what color

1351
00:57:36,809 --> 00:57:42,329
it is between 3.6 and 4 point 5 microns

1352
00:57:39,900 --> 00:57:45,358
on this axis and on this axis between

1353
00:57:42,329 --> 00:57:47,219
5.8 and 8 microns and then it's could

1354
00:57:45,358 --> 00:57:49,469

have colored by the color I got from

1355

00:57:47,219 --> 00:57:51,449

Specter I just showed you and the whole

1356

00:57:49,469 --> 00:57:53,219

point here is that for most carbon stars

1357

00:57:51,449 --> 00:57:56,489

if it gets red in one color it gets red

1358

00:57:53,219 --> 00:57:59,189

in another and this it's a pretty tight

1359

00:57:56,489 --> 00:58:02,669

relationship all the way up here except

1360

00:57:59,190 --> 00:58:05,070

for at the very end the reddest stars at

1361

00:58:02,670 --> 00:58:06,990

the longest wavelength there's actually

1362

00:58:05,070 --> 00:58:08,880

they're a little bit too blue at shorter

1363

00:58:06,989 --> 00:58:13,618

wavelengths like some kind of some light

1364

00:58:08,880 --> 00:58:15,869

is escaping from this system and if you

1365

00:58:13,619 --> 00:58:17,880

look at this is a plot of how variable

1366

00:58:15,869 --> 00:58:20,670

they are that Sigma that's a basically

1367

00:58:17,880 --> 00:58:22,858

the the you know you keep taking data at

1368

00:58:20,670 --> 00:58:23,880

different times and if the numbers are

1369
00:58:22,858 --> 00:58:25,799
bounced around all over the place that's

1370
00:58:23,880 --> 00:58:27,930
because it's a variable star so you can

1371
00:58:25,800 --> 00:58:30,630
see for the most of the population the

1372
00:58:27,929 --> 00:58:33,179
the dustier they get from from 0 to

1373
00:58:30,630 --> 00:58:35,760
about 1.5 the stronger they're pulsating

1374
00:58:33,179 --> 00:58:37,949
all makes sense right lots of pulsations

1375
00:58:35,760 --> 00:58:40,380
lots of dust but then all of a sudden

1376
00:58:37,949 --> 00:58:43,649
the reddest winds are hardly pulsating

1377
00:58:40,380 --> 00:58:44,760
at all the hypothesis that we've put out

1378
00:58:43,650 --> 00:58:46,320
there is that's because they've already

1379
00:58:44,760 --> 00:58:49,410
they've stripped their envelope there's

1380
00:58:46,320 --> 00:58:51,630
nothing left to pulsate so basically

1381
00:58:49,409 --> 00:58:53,819
it's just a white dwarf core almost

1382
00:58:51,630 --> 00:58:56,130
inside this really thick dust shell

1383
00:58:53,820 --> 00:58:58,019
except the dust shell is moving outwards

1384
00:58:56,130 --> 00:58:59,519
and it's darting to the asymmetries are

1385
00:58:58,019 --> 00:59:00,780
starting to show so blue light is

1386
00:58:59,519 --> 00:59:02,849
starting to escape the scattered

1387
00:59:00,780 --> 00:59:04,800
emission we think we're looking at

1388
00:59:02,849 --> 00:59:06,420
systems like this in the Large

1389
00:59:04,800 --> 00:59:09,900
Magellanic Cloud this is in the galaxy

1390
00:59:06,420 --> 00:59:11,130
this is a FGL 2688 or the Cygnus egg so

1391
00:59:09,900 --> 00:59:12,450
there's a really thick dust line here

1392
00:59:11,130 --> 00:59:14,550
but there's all this light that's

1393
00:59:12,449 --> 00:59:17,000
getting out the poles of the system and

1394
00:59:14,550 --> 00:59:20,670
then scattering into our line of sight

1395
00:59:17,000 --> 00:59:22,469
so basically my point is is that these

1396
00:59:20,670 --> 00:59:25,050
guys up here that have moved off the

1397

00:59:22,469 --> 00:59:29,909
carbon sequence we think we're catching

1398
00:59:25,050 --> 00:59:32,130
them in the very act of dying the

1399
00:59:29,909 --> 00:59:34,049
problem is that this is a spectroscopic

1400
00:59:32,130 --> 00:59:35,519
sample like we chose to look at these

1401
00:59:34,050 --> 00:59:38,010
guys because they were interesting so

1402
00:59:35,519 --> 00:59:40,079
this is a biased sample so I can't make

1403
00:59:38,010 --> 00:59:41,760
any statistical conclusions from this

1404
00:59:40,079 --> 00:59:43,799
sample so we have to go back and look at

1405
00:59:41,760 --> 00:59:45,390
the larger photometric sample there's a

1406
00:59:43,800 --> 00:59:48,269
spectroscopy I hate that but that's

1407
00:59:45,389 --> 00:59:50,009
that's the way it is all right so this

1408
00:59:48,269 --> 00:59:52,889
is this is basically how the stars die

1409
00:59:50,010 --> 00:59:54,839
and then I just wanted to add this

1410
00:59:52,889 --> 00:59:57,299
amorphous carbon that they're spewing

1411
00:59:54,838 --> 00:59:59,730

into space is made up of little pieces

1412
00:59:57,300 --> 01:00:00,869
of other types of hydrocarbons and you

1413
00:59:59,730 --> 01:00:02,460
can see that when the star

1414
01:00:00,869 --> 01:00:04,318
actually when the when the white dwarf

1415
01:00:02,460 --> 01:00:08,579
or the sinner is exposed enough you can

1416
01:00:04,318 --> 01:00:10,498
see it cooking the dust from the inside

1417
01:00:08,579 --> 01:00:15,390
out and then you can see this is the

1418
01:00:10,498 --> 01:00:18,509
discovery spectrum taken 20 35 45 years

1419
01:00:15,389 --> 01:00:19,949
ago now Fred Gillette and company the

1420
01:00:18,509 --> 01:00:22,528
infrared spectrum they have all these

1421
01:00:19,949 --> 01:00:24,719
bizarre emission features from this

1422
01:00:22,528 --> 01:00:27,268
planetary nebula and then in g7 o27

1423
01:00:24,719 --> 01:00:29,578
which I showed you earlier and this is

1424
01:00:27,268 --> 01:00:30,959
another spectrum from another source but

1425
01:00:29,579 --> 01:00:33,720
basically we're looking at these things

1426
01:00:30,960 --> 01:00:37,559
called polycyclic aromatic hydrocarbons

1427
01:00:33,719 --> 01:00:39,449
which are very small pieces of carbon so

1428
01:00:37,559 --> 01:00:41,039
I put one up here they they don't put

1429
01:00:39,449 --> 01:00:42,899
the little seeds at all the vertices of

1430
01:00:41,039 --> 01:00:46,039
these hexagons but these are basically

1431
01:00:42,900 --> 01:00:49,470
hexagons made of carbon there are little

1432
01:00:46,039 --> 01:00:51,119
molecules there big molecules or small

1433
01:00:49,469 --> 01:00:53,959
dust grains depend on how you think of

1434
01:00:51,119 --> 01:00:56,338
it and we see these things everywhere

1435
01:00:53,960 --> 01:00:58,588
and when you start looking at molecules

1436
01:00:56,338 --> 01:01:01,528
like this my last slide is the next one

1437
01:00:58,588 --> 01:01:08,068
look up here right those are two the

1438
01:01:01,528 --> 01:01:09,719
base pairs for DNA so let's just go back

1439
01:01:08,068 --> 01:01:12,808
for a second there's some differences

1440
01:01:09,719 --> 01:01:15,028
these are just carbon so technically

1441
01:01:12,809 --> 01:01:17,749
this is organic chemistry by definition

1442
01:01:15,028 --> 01:01:20,759
right but that doesn't mean there's life

1443
01:01:17,748 --> 01:01:22,439
because the key point to the DNA base

1444
01:01:20,759 --> 01:01:24,509
pairs is that a lot of nitrogen

1445
01:01:22,440 --> 01:01:26,159
substitutions have happened and there's

1446
01:01:24,509 --> 01:01:28,858
also some oxygen and you'll notice that

1447
01:01:26,159 --> 01:01:30,058
this is a five membered ring not a six

1448
01:01:28,858 --> 01:01:32,278
membered ring you get the idea but the

1449
01:01:30,059 --> 01:01:33,900
point is my point is this carbon rich

1450
01:01:32,278 --> 01:01:36,088
chemistry that we see in the outflows

1451
01:01:33,900 --> 01:01:38,608
from these carbon stars is incredibly

1452
01:01:36,088 --> 01:01:40,880
complex and we haven't detected the

1453
01:01:38,608 --> 01:01:44,190
spectroscopic signature of the nitrogen

1454

01:01:40,880 --> 01:01:45,720
substitutions but that you know that

1455
01:01:44,190 --> 01:01:47,639
certainly is something to keep looking

1456
01:01:45,719 --> 01:01:49,348
for anyway

1457
01:01:47,639 --> 01:01:50,429
that is all I had thanks for putting up

1458
01:01:49,349 --> 01:01:53,620
with me for

1459
01:01:50,429 --> 01:01:53,619
[Applause]

1460
01:01:56,900 --> 01:02:13,088
[Applause]

1461
01:02:04,530 --> 01:02:16,660
okay now what I get to be microphone

1462
01:02:13,088 --> 01:02:19,719
delivery guy oh is the microphone is on

1463
01:02:16,659 --> 01:02:21,818
okay good I wonder if anybody can speak

1464
01:02:19,719 --> 01:02:24,429
like in a in an alto voice with that

1465
01:02:21,818 --> 01:02:30,068
thing all right I see a question way in

1466
01:02:24,429 --> 01:02:32,558
the back so you work it out all the way

1467
01:02:30,068 --> 01:02:45,460
back there all right we have to pass

1468
01:02:32,559 --> 01:02:49,059

this but I think you quoted a figure of

1469

01:02:45,460 --> 01:02:51,670

80,000 years for pulsations one for the

1470

01:02:49,059 --> 01:02:54,309

thermal pulses the time between two

1471

01:02:51,670 --> 01:02:55,990

consecutive ignitions of the of the

1472

01:02:54,309 --> 01:02:58,539

layer of helium and the core of the star

1473

01:02:55,989 --> 01:03:01,328

yes but then the long period variables

1474

01:02:58,539 --> 01:03:03,789

their pulsations are you know a year

1475

01:03:01,329 --> 01:03:05,380

maybe right what's the how does one get

1476

01:03:03,789 --> 01:03:06,760

to the other you don't they're

1477

01:03:05,380 --> 01:03:08,230

completely separate one of them

1478

01:03:06,760 --> 01:03:11,980

something going on in the core of the

1479

01:03:08,230 --> 01:03:14,289

star and the other is just basically

1480

01:03:11,980 --> 01:03:16,960

just a dynamic pulsation going on in the

1481

01:03:14,289 --> 01:03:18,460

atmosphere it's unfortunate that they

1482

01:03:16,960 --> 01:03:20,920

decided to call these things thermal

1483
01:03:18,460 --> 01:03:22,028
pulses I mean what else could we call

1484
01:03:20,920 --> 01:03:24,849
them because it's basically it's a

1485
01:03:22,028 --> 01:03:26,500
runaway nuclear fusion event in this

1486
01:03:24,849 --> 01:03:28,210
thin layer of helium in the center of

1487
01:03:26,500 --> 01:03:30,130
the star so it takes about 80,000 years

1488
01:03:28,210 --> 01:03:32,889
for one solar mass star to build up

1489
01:03:30,130 --> 01:03:34,329
enough helium to do this but the point

1490
01:03:32,889 --> 01:03:37,179
is whatever they're doing on the inside

1491
01:03:34,329 --> 01:03:40,329
these stars are also like breathing on

1492
01:03:37,179 --> 01:03:41,368
the outside okay thank you sorry about

1493
01:03:40,329 --> 01:03:43,180
that

1494
01:03:41,369 --> 01:03:46,869
astronomers are really bad at naming

1495
01:03:43,179 --> 01:03:51,969
things you might have noticed over here

1496
01:03:46,869 --> 01:03:56,980
what we hang on we have to we'll get it

1497
01:03:51,969 --> 01:04:09,149
we'll get there I'm sorry can I can

1498
01:03:56,980 --> 01:04:09,150
commute the progression of what

1499
01:04:10,009 --> 01:04:21,539
yeah oh that was early boom

1500
01:04:18,449 --> 01:04:23,219
that one yes okay question you had a

1501
01:04:21,539 --> 01:04:25,710
question oh yeah I just wanted to ask

1502
01:04:23,219 --> 01:04:32,879
can-can you planet secrete around white

1503
01:04:25,710 --> 01:04:36,409
dwarf stars from that ejecta that's a

1504
01:04:32,880 --> 01:04:40,170
good question I don't know the answer I

1505
01:04:36,409 --> 01:04:42,210
my instinct is no but you know I my

1506
01:04:40,170 --> 01:04:45,690
batting record on instinct is not so

1507
01:04:42,210 --> 01:04:47,159
good I do know that Mike Jorah was one

1508
01:04:45,690 --> 01:04:49,200
of the people sort of got this field

1509
01:04:47,159 --> 01:04:52,318
starting started of looking at the

1510
01:04:49,199 --> 01:04:53,998
accretion of material from planets that

1511

01:04:52,318 --> 01:04:55,318
have been ripped apart onto white dwarfs

1512
01:04:53,998 --> 01:04:59,129
but that's not the process you're

1513
01:04:55,318 --> 01:05:00,929
talking about if you had enough mass

1514
01:04:59,130 --> 01:05:02,278
then you could do it but my question is

1515
01:05:00,929 --> 01:05:05,190
where would that mature will be created

1516
01:05:02,278 --> 01:05:07,798
from probably another planet so it'd be

1517
01:05:05,190 --> 01:05:13,429
hard to remake one bit yeah this is I'm

1518
01:05:07,798 --> 01:05:16,829
not the expert on this so my apologies I

1519
01:05:13,429 --> 01:05:18,899
had to follow the path of Mike yes I'm a

1520
01:05:16,829 --> 01:05:22,890
little confused perhaps about the

1521
01:05:18,900 --> 01:05:26,730
relationship between the development of

1522
01:05:22,889 --> 01:05:31,498
these heavy metals and molecules from

1523
01:05:26,730 --> 01:05:35,699
the individual complex molecules from

1524
01:05:31,498 --> 01:05:40,308
smaller molecules and and also what you

1525
01:05:35,699 --> 01:05:43,348

referred to as dust it's just just

1526

01:05:40,309 --> 01:05:49,079

collaborations of these heavy metals in

1527

01:05:43,349 --> 01:05:51,119

various yeah so if you think of the Sun

1528

01:05:49,079 --> 01:05:53,730

so the Sun was was already born with

1529

01:05:51,119 --> 01:05:56,640

lots of oxygen and silicon right so it

1530

01:05:53,730 --> 01:05:57,960

it added some carbon but it already had

1531

01:05:56,639 --> 01:06:00,509

a lot of oxygen and silicon to start

1532

01:05:57,960 --> 01:06:01,858

with and so as it ages out yeah it

1533

01:06:00,509 --> 01:06:03,568

pushes this these it pushes these

1534

01:06:01,858 --> 01:06:05,699

elements out they bind into molecules

1535

01:06:03,568 --> 01:06:08,400

and then those molecules will bind

1536

01:06:05,699 --> 01:06:14,669

together in the dust grains provided

1537

01:06:08,400 --> 01:06:17,430

it's cool enough all the interstellar

1538

01:06:14,670 --> 01:06:19,639

dust that's floating around is related

1539

01:06:17,429 --> 01:06:23,029

to the manufacturer

1540
01:06:19,639 --> 01:06:25,670
this store is made into its death spiral

1541
01:06:23,030 --> 01:06:28,910
so you just put your finger on a really

1542
01:06:25,670 --> 01:06:31,730
difficult question to answer the

1543
01:06:28,909 --> 01:06:33,349
question was so just if we make dust

1544
01:06:31,730 --> 01:06:35,090
around stars and we have dust in the

1545
01:06:33,349 --> 01:06:41,839
interstellar medium is it the same dust

1546
01:06:35,090 --> 01:06:44,510
and the answer is apparently not that

1547
01:06:41,840 --> 01:06:46,579
apparently this this is a there's a

1548
01:06:44,510 --> 01:06:48,620
there's a lot of controversy about this

1549
01:06:46,579 --> 01:06:50,690
right now but the idea is that supernova

1550
01:06:48,619 --> 01:06:53,150
explosions are really efficient at

1551
01:06:50,690 --> 01:06:55,400
destroying dust and so if you act start

1552
01:06:53,150 --> 01:06:57,530
adding up how much dust supernova have

1553
01:06:55,400 --> 01:06:59,450
to destroy it's like all of it so there

1554
01:06:57,530 --> 01:07:01,340
must be another source of dust formation

1555
01:06:59,449 --> 01:07:05,839
out there like maybe the dust is being

1556
01:07:01,340 --> 01:07:07,640
formed in these clouds I I'm a bit of a

1557
01:07:05,840 --> 01:07:10,460
skeptical about the fact that supernova

1558
01:07:07,639 --> 01:07:13,339
destroying all the dusts but I do not

1559
01:07:10,460 --> 01:07:15,230
have a good quantitative really well

1560
01:07:13,340 --> 01:07:18,890
grounded theoretical argument against it

1561
01:07:15,230 --> 01:07:21,500
I just don't like it and that's not good

1562
01:07:18,889 --> 01:07:23,599
enough but there's it's this there's a

1563
01:07:21,500 --> 01:07:26,690
bit of a debate about this so it's not

1564
01:07:23,599 --> 01:07:37,069
the answer to that is not clear and that

1565
01:07:26,690 --> 01:07:39,019
is unfortunate all the ones all of the

1566
01:07:37,070 --> 01:07:41,090
ones that can form into dust yes but

1567
01:07:39,019 --> 01:07:42,500
like the neon is just a noble gas right

1568

01:07:41,090 --> 01:07:44,960
so the neon just has to get dragged

1569
01:07:42,500 --> 01:07:48,260
along with the process as a gas for

1570
01:07:44,960 --> 01:07:49,760
example which does happen because of

1571
01:07:48,260 --> 01:07:51,890
these dust grains get accelerated they

1572
01:07:49,760 --> 01:07:54,050
start slamming into gas molecules and

1573
01:07:51,889 --> 01:07:57,949
dragging their gas atoms and dragging

1574
01:07:54,050 --> 01:07:58,460
them with them - okay who's next who is

1575
01:07:57,949 --> 01:08:04,099
next

1576
01:07:58,460 --> 01:08:07,150
alright right here yes wait to receive

1577
01:08:04,099 --> 01:08:10,069
[Laughter]

1578
01:08:07,150 --> 01:08:14,630
what happens to the dust can the dust

1579
01:08:10,070 --> 01:08:16,579
form planets yes in fact it see the dust

1580
01:08:14,630 --> 01:08:20,000
appears to be a key part of planetary

1581
01:08:16,579 --> 01:08:22,039
formation but not necessarily the you

1582
01:08:20,000 --> 01:08:23,720

know as I said we're having a bit of a

1583

01:08:22,039 --> 01:08:26,119

difficulty understanding the path of the

1584

01:08:23,720 --> 01:08:29,180

dust in the interstellar medium but once

1585

01:08:26,119 --> 01:08:30,890

you have a star starting to form you

1586

01:08:29,180 --> 01:08:32,300

know it's at the cloud that it's in has

1587

01:08:30,890 --> 01:08:33,560

a lot of dust with it so the dust will

1588

01:08:32,300 --> 01:08:35,449

form into a disc

1589

01:08:33,560 --> 01:08:37,660

and then the planets will start to

1590

01:08:35,449 --> 01:08:39,858

basically form you know you'll get

1591

01:08:37,659 --> 01:08:41,420

planetesimals and you'll get planets

1592

01:08:39,859 --> 01:08:43,640

forming and the dust appears to be a key

1593

01:08:41,420 --> 01:08:45,920

part of that process there's some debate

1594

01:08:43,640 --> 01:08:47,569

about like is Jupiter

1595

01:08:45,920 --> 01:08:49,390

there's been some debate whether the

1596

01:08:47,569 --> 01:08:52,010

jovian planets are actually just

1597
01:08:49,390 --> 01:08:53,329
gravitational collapses of gas whether

1598
01:08:52,010 --> 01:08:55,940
you have to first have a terrestrial

1599
01:08:53,329 --> 01:08:58,789
core formed from accumulating a lot of

1600
01:08:55,939 --> 01:09:00,318
dust particles I think that's that was

1601
01:08:58,789 --> 01:09:05,210
an open question the last time I looked

1602
01:09:00,319 --> 01:09:08,240
carefully so the short answer is yet

1603
01:09:05,210 --> 01:09:09,739
dust you need us to make planets all

1604
01:09:08,239 --> 01:09:13,489
right just to make my life easier I'm

1605
01:09:09,739 --> 01:09:16,250
gonna go to someone nearby you in one of

1606
01:09:13,489 --> 01:09:20,649
the last slides water is being formed

1607
01:09:16,250 --> 01:09:32,930
yes is that evaporated it's water vapor

1608
01:09:20,649 --> 01:09:34,789
so it's it's gaseous red giants yeah so

1609
01:09:32,930 --> 01:09:35,690
yeah in a really cool red giant you can

1610
01:09:34,789 --> 01:09:39,050
see this water vapor

1611
01:09:35,689 --> 01:09:41,719
we actually a colleague of mine Kathleen

1612
01:09:39,050 --> 01:09:44,480
Cramer at Boston College and then some

1613
01:09:41,720 --> 01:09:46,609
colleagues at UC Davis Matt ripped it we

1614
01:09:44,479 --> 01:09:47,959
have a proposal in and we just found I

1615
01:09:46,609 --> 01:09:50,660
found out today that we're scheduled

1616
01:09:47,960 --> 01:09:52,550
we're going to be looking at very high

1617
01:09:50,659 --> 01:09:57,170
spectral resolution at some of these

1618
01:09:52,550 --> 01:09:59,210
water vapor lines in some of these these

1619
01:09:57,170 --> 01:10:00,920
these red giants using Sofia which is

1620
01:09:59,210 --> 01:10:04,189
the airborne telescope that flies out of

1621
01:10:00,920 --> 01:10:05,930
California and the hope is that we can

1622
01:10:04,189 --> 01:10:09,169
we can get enough information to work

1623
01:10:05,930 --> 01:10:10,610
out how far above the photosphere this

1624
01:10:09,170 --> 01:10:12,739
water vapor is because that there's a

1625

01:10:10,609 --> 01:10:15,099
big debate is it is in clouds that in

1626
01:10:12,739 --> 01:10:19,939
the east so we're hoping to address that

1627
01:10:15,100 --> 01:10:25,550
so yeah so on that last slide there was

1628
01:10:19,939 --> 01:10:27,229
an adenine thymine complex so is there

1629
01:10:25,550 --> 01:10:29,510
actually evidence that would but there

1630
01:10:27,229 --> 01:10:31,699
is that complex coming from stars and

1631
01:10:29,510 --> 01:10:33,970
I'm curious I'm just I'm a I'm not

1632
01:10:31,699 --> 01:10:36,199
familiar with the idea of such complex

1633
01:10:33,970 --> 01:10:39,409
molecules coming right out of stars I

1634
01:10:36,199 --> 01:10:41,149
always thought that I was I'm curious

1635
01:10:39,409 --> 01:10:42,260
what more evidence there is about stuff

1636
01:10:41,149 --> 01:10:46,299
like that that's really interesting

1637
01:10:42,260 --> 01:10:47,400
if I remember correctly an amino acid

1638
01:10:46,300 --> 01:10:51,929
had

1639
01:10:47,399 --> 01:10:54,539

been seen in in rate using using its

1640

01:10:51,929 --> 01:10:57,239

radio emission they've been able to

1641

01:10:54,539 --> 01:10:58,350

identify this as an amino acid but

1642

01:10:57,238 --> 01:10:59,369

something minimum acids are fairly

1643

01:10:58,350 --> 01:11:01,219

simple and you can see some of the

1644

01:10:59,369 --> 01:11:08,219

molecules were seeing are pretty complex

1645

01:11:01,219 --> 01:11:10,380

so hi I'm wondering if you have any

1646

01:11:08,219 --> 01:11:13,198

thoughts on the fact that there was a

1647

01:11:10,380 --> 01:11:19,500

hexagon on top of Saturn and then your

1648

01:11:13,198 --> 01:11:21,389

last two slides I knew these hexagons

1649

01:11:19,500 --> 01:11:22,619

keep popping up so the question energy

1650

01:11:21,390 --> 01:11:24,510

you guys catch the question is there any

1651

01:11:22,619 --> 01:11:25,800

you know just-just we had a hexagon on

1652

01:11:24,510 --> 01:11:28,679

Saturn's North Pole

1653

01:11:25,800 --> 01:11:30,840

we got carbon arranged in hexagons I

1654
01:11:28,679 --> 01:11:32,520
will just say that you know before we

1655
01:11:30,840 --> 01:11:34,289
had PowerPoint presentations and I was

1656
01:11:32,520 --> 01:11:35,610
doing these with with overheads and I

1657
01:11:34,289 --> 01:11:37,469
would take my talk and a big stack of

1658
01:11:35,609 --> 01:11:39,269
overheads I would have a little envelope

1659
01:11:37,469 --> 01:11:42,239
every long I would do little cutouts a

1660
01:11:39,270 --> 01:11:43,860
chicken wire because you know cuz it's a

1661
01:11:42,238 --> 01:11:45,359
hexagonal shape right within it you'd

1662
01:11:43,859 --> 01:11:47,369
cut the links and be like the hydrogen

1663
01:11:45,359 --> 01:11:48,960
bonds and I would pass those out so

1664
01:11:47,369 --> 01:11:52,738
people could kind of hold quarantine and

1665
01:11:48,960 --> 01:11:56,210
other pause yeah so it's it's I think

1666
01:11:52,738 --> 01:11:56,209
the common thread here is chicken wire

1667
01:11:56,479 --> 01:12:03,959
and symmetry yeah

1668
01:12:00,179 --> 01:12:06,779
can you describe in graphic detail as

1669
01:12:03,960 --> 01:12:11,119
much as you can what's gonna happen and

1670
01:12:06,779 --> 01:12:13,198
when our our star our Sun starts to die

1671
01:12:11,119 --> 01:12:15,149
well my wife and I have been discussing

1672
01:12:13,198 --> 01:12:19,349
if we should keep investing in real

1673
01:12:15,149 --> 01:12:22,619
estate yes so the process we'll get to

1674
01:12:19,350 --> 01:12:24,960
see we are 4.6 billion years in to a ten

1675
01:12:22,619 --> 01:12:27,719
billion year process right so another

1676
01:12:24,960 --> 01:12:29,520
4.2 million years the problem is 10

1677
01:12:27,719 --> 01:12:31,469
billion years there's an aero bar there

1678
01:12:29,520 --> 01:12:33,719
right now I don't it's it's probably

1679
01:12:31,469 --> 01:12:36,569
plus I'm gonna just wait your guess it's

1680
01:12:33,719 --> 01:12:38,069
half a billion years plus or minus then

1681
01:12:36,569 --> 01:12:40,649
at that point the Sun will start to

1682

01:12:38,069 --> 01:12:44,130
ascend the red giant branch but actually

1683
01:12:40,649 --> 01:12:45,719
the scary part of all of this is that

1684
01:12:44,130 --> 01:12:48,270
you remember the part I said is that as

1685
01:12:45,719 --> 01:12:50,969
the core collapses as the core starts to

1686
01:12:48,270 --> 01:12:55,830
contract then the luminosity of the star

1687
01:12:50,969 --> 01:12:58,170
goes up that's already happening yeah so

1688
01:12:55,829 --> 01:13:01,099
every day the Sun is just slightly

1689
01:12:58,170 --> 01:13:07,880
brighter and hotter than it was before

1690
01:13:01,099 --> 01:13:11,010
right so you know the the the the

1691
01:13:07,880 --> 01:13:13,069
climate change caused by the burning of

1692
01:13:11,010 --> 01:13:15,630
fossil fuels just making an already

1693
01:13:13,069 --> 01:13:17,670
slowly deteriorating situation worse

1694
01:13:15,630 --> 01:13:19,710
right we're just adding to the problem

1695
01:13:17,670 --> 01:13:21,739
so I guess one of the ways to look at is

1696
01:13:19,710 --> 01:13:24,539

that we're since we clearly can't stop

1697

01:13:21,738 --> 01:13:25,709

consuming fossil fuels we're gonna have

1698

01:13:24,539 --> 01:13:27,809

to figure out some other way to mitigate

1699

01:13:25,710 --> 01:13:30,059

for the problem I don't like that

1700

01:13:27,809 --> 01:13:31,500

solution at all just agreements how

1701

01:13:30,059 --> 01:13:40,800

about fewer fossil fuels might be nice

1702

01:13:31,500 --> 01:13:43,800

but the point is yeah we'll be fried

1703

01:13:40,800 --> 01:13:45,630

before we burn that's good yeah but I

1704

01:13:43,800 --> 01:13:48,210

guess what I'm getting at is that we're

1705

01:13:45,630 --> 01:13:51,328

gonna have to figure out how to mitigate

1706

01:13:48,210 --> 01:13:54,510

for the fact that the earth is warming

1707

01:13:51,328 --> 01:13:57,359

up in the long term anyway because the

1708

01:13:54,510 --> 01:13:59,909

Sun is going to get hotter over the you

1709

01:13:57,359 --> 01:14:02,339

know over the next million years so now

1710

01:13:59,908 --> 01:14:03,539

we have him you know that we need to get

1711
01:14:02,340 --> 01:14:07,619
little bit of a head start because we

1712
01:14:03,539 --> 01:14:10,769
can't stop burning fossil fuels so so

1713
01:14:07,618 --> 01:14:12,420
I'm in my experience the estimate is

1714
01:14:10,770 --> 01:14:15,119
that the earth is totally uninhabitable

1715
01:14:12,420 --> 01:14:17,090
by about three billion years from now is

1716
01:14:15,118 --> 01:14:19,710
that the number that you had in your I

1717
01:14:17,090 --> 01:14:23,429
don't know actually I mean no matter

1718
01:14:19,710 --> 01:14:25,550
what humans do they the earth is an

1719
01:14:23,429 --> 01:14:27,840
uninhabitable in three billion years not

1720
01:14:25,550 --> 01:14:30,090
but before it starts going up the red

1721
01:14:27,840 --> 01:14:31,500
giant branch yeah this is something like

1722
01:14:30,090 --> 01:14:33,869
that would be I think they'd be true all

1723
01:14:31,500 --> 01:14:43,050
I know is that Mars does not look

1724
01:14:33,868 --> 01:14:48,839
particularly appealing right now okay

1725
01:14:43,050 --> 01:14:51,840
you had oh yeah get his attention

1726
01:14:48,840 --> 01:14:56,010
yes a quick question about variable

1727
01:14:51,840 --> 01:15:00,090
stars so when you see a variable star is

1728
01:14:56,010 --> 01:15:03,389
it always an Ag B there are many many

1729
01:15:00,090 --> 01:15:04,980
kinds of variable stars for example you

1730
01:15:03,389 --> 01:15:06,449
could have two completely normal non

1731
01:15:04,979 --> 01:15:08,609
variable stars that are in a binary

1732
01:15:06,448 --> 01:15:09,359
system and if they happen to eclipse

1733
01:15:08,609 --> 01:15:11,848
each other

1734
01:15:09,359 --> 01:15:15,009
then that's an eclipsing binary that's a

1735
01:15:11,849 --> 01:15:16,960
kind of variable star

1736
01:15:15,010 --> 01:15:18,550
there's this there are I mean I could

1737
01:15:16,960 --> 01:15:21,100
not if I could start making a list of

1738
01:15:18,550 --> 01:15:23,500
variable stars and I would get one-tenth

1739

01:15:21,100 --> 01:15:24,750
the way for my memories exhausted there

1740
01:15:23,500 --> 01:15:29,350
are so many different kinds of variables

1741
01:15:24,750 --> 01:15:30,850
Vega is a class of air is a class of

1742
01:15:29,350 --> 01:15:33,070
variable stars actually very low

1743
01:15:30,850 --> 01:15:36,610
amplitude but still yeah there's all

1744
01:15:33,069 --> 01:15:39,250
sorts of different kinds that's just one

1745
01:15:36,609 --> 01:15:46,299
of them yes yes stars do not really

1746
01:15:39,250 --> 01:15:49,270
behave themselves give a question so as

1747
01:15:46,300 --> 01:15:51,670
I understand our Sun transports energy

1748
01:15:49,270 --> 01:15:53,470
through convection and then to the

1749
01:15:51,670 --> 01:15:56,770
photosphere and most of the energy goes

1750
01:15:53,470 --> 01:15:57,970
out that way and you said when it went

1751
01:15:56,770 --> 01:16:00,580
into the death branch that the

1752
01:15:57,970 --> 01:16:02,860
convection went all the way out to near

1753
01:16:00,579 --> 01:16:05,109

Earth's orbit that's because the star

1754

01:16:02,859 --> 01:16:06,909

goes out to Earth's orbit so why isn't

1755

01:16:05,109 --> 01:16:08,349

there like a photosphere where is the

1756

01:16:06,909 --> 01:16:10,149

photosphere at that point is there still

1757

01:16:08,350 --> 01:16:12,130

a photosphere at that point is that are

1758

01:16:10,149 --> 01:16:14,469

we seeing something outside of Earth's

1759

01:16:12,130 --> 01:16:17,380

orbit when we look at these it's still

1760

01:16:14,470 --> 01:16:21,100

yes it's still a photosphere sort of but

1761

01:16:17,380 --> 01:16:23,500

I think that it's the idea that we have

1762

01:16:21,100 --> 01:16:26,200

an with the Sun now we have a reasonably

1763

01:16:23,500 --> 01:16:28,449

good boundary and I think as these

1764

01:16:26,199 --> 01:16:30,010

things get bigger and bigger where you

1765

01:16:28,449 --> 01:16:33,429

draw that boundary becomes a little bit

1766

01:16:30,010 --> 01:16:37,210

more challenging it's it's very

1767

01:16:33,430 --> 01:16:38,710

wavelength dependent yeah it's the it

1768
01:16:37,210 --> 01:16:39,850
gets to the question you're asking is

1769
01:16:38,710 --> 01:16:41,439
actually a really good one

1770
01:16:39,850 --> 01:16:43,810
where's the boundary where does the star

1771
01:16:41,439 --> 01:16:46,869
stop and that's that's that's not

1772
01:16:43,810 --> 01:16:48,880
actually a trivial question to answer it

1773
01:16:46,869 --> 01:16:51,519
gives the theorists fits I'll put it

1774
01:16:48,880 --> 01:16:53,289
that way all right is there there's a

1775
01:16:51,520 --> 01:16:55,660
question I think over here by the by the

1776
01:16:53,289 --> 01:16:59,680
exit I think we have to be quick because

1777
01:16:55,659 --> 01:17:01,930
there's an exit involved actually as

1778
01:16:59,680 --> 01:17:03,520
pertains to the slide you just had up

1779
01:17:01,930 --> 01:17:07,030
there before but Oh

1780
01:17:03,520 --> 01:17:13,060
when does this oxygen start to show up

1781
01:17:07,029 --> 01:17:16,359
and in the scheme of things I think it

1782
01:17:13,060 --> 01:17:22,000
went oh there we go for a more massive

1783
01:17:16,359 --> 01:17:23,380
AGB star you could you can make off do

1784
01:17:22,000 --> 01:17:24,670
you make some oxygen when you make the

1785
01:17:23,380 --> 01:17:28,449
carbon it's sort of like you know you

1786
01:17:24,670 --> 01:17:28,920
just just an extra helium atom in the in

1787
01:17:28,449 --> 01:17:31,409
the middle

1788
01:17:28,920 --> 01:17:32,909
process of boom there's an oxygen so

1789
01:17:31,409 --> 01:17:35,760
yeah we get we get some of that but for

1790
01:17:32,909 --> 01:17:38,369
its for more massive stars I think it's

1791
01:17:35,760 --> 01:17:41,100
solar medallist ease on the on the on

1792
01:17:38,369 --> 01:17:43,469
the other side of the carbon limit so

1793
01:17:41,100 --> 01:17:46,320
five six seven solar masses kind of a

1794
01:17:43,469 --> 01:17:48,060
thing there's another process there and

1795
01:17:46,319 --> 01:17:49,529
I didn't talk about which astronomers

1796

01:17:48,060 --> 01:17:52,039
with their love for really bad names

1797
01:17:49,529 --> 01:17:55,529
called it's called hot bottom burning

1798
01:17:52,039 --> 01:17:57,960
which is involves involves protons

1799
01:17:55,529 --> 01:17:59,519
getting captured and what happens in as

1800
01:17:57,960 --> 01:18:02,119
you actually wind up you make carbon but

1801
01:17:59,520 --> 01:18:05,400
then you're converting it into nitrogen

1802
01:18:02,119 --> 01:18:07,529
yeah there's a this quickly gets I'm not

1803
01:18:05,399 --> 01:18:09,269
a nuclear fusion expert and and the more

1804
01:18:07,529 --> 01:18:10,529
I start to keep talking on the subject

1805
01:18:09,270 --> 01:18:13,800
that quickly you're the more quickly you

1806
01:18:10,529 --> 01:18:16,500
will realize that yeah is that that did

1807
01:18:13,800 --> 01:18:20,219
that help though okay okay so we have a

1808
01:18:16,500 --> 01:18:22,560
question from online asking what are you

1809
01:18:20,219 --> 01:18:26,730
most excited to learn about the Sun from

1810
01:18:22,560 --> 01:18:30,060

the Parker Solar Probe mission is that

1811

01:18:26,729 --> 01:18:35,129

the new one that's that's the next the

1812

01:18:30,060 --> 01:18:36,989

mission I'd yeah I don't know enough to

1813

01:18:35,130 --> 01:18:38,969

answer the question except that I know

1814

01:18:36,988 --> 01:18:43,169

that they're there they're getting the

1815

01:18:38,969 --> 01:18:46,079

probe is going into like the corona yep

1816

01:18:43,170 --> 01:18:47,880

and and that's gonna be really

1817

01:18:46,079 --> 01:18:50,819

impressive I sort of am naturally

1818

01:18:47,880 --> 01:18:54,630

curious about the solar wind because

1819

01:18:50,819 --> 01:18:57,238

we're launching JWST and there's this

1820

01:18:54,630 --> 01:18:59,880

thing called space weathering which is

1821

01:18:57,238 --> 01:19:03,809

basically the result of sort of a steady

1822

01:18:59,880 --> 01:19:06,900

cosmic ray bombardment so what happens

1823

01:19:03,810 --> 01:19:09,060

is over time the detectors that we've

1824

01:19:06,899 --> 01:19:11,609

launched will slowly be degraded by

1825
01:19:09,060 --> 01:19:13,620
getting hit by cosmic rays and the

1826
01:19:11,609 --> 01:19:16,349
cosmic rays which are really the problem

1827
01:19:13,619 --> 01:19:17,729
are the ones that come from the Sun so

1828
01:19:16,350 --> 01:19:21,660
I'd be very CUTE anything we can learn

1829
01:19:17,729 --> 01:19:24,889
more about that process so we know when

1830
01:19:21,659 --> 01:19:24,889
to take James T and duck

1831
01:19:25,760 --> 01:19:37,890
okay so our son has about four billion

1832
01:19:33,930 --> 01:19:41,789
years left and change and change can

1833
01:19:37,890 --> 01:19:44,369
anything catastrophic unexpected occur

1834
01:19:41,789 --> 01:19:46,920
that would derail that timeline for the

1835
01:19:44,369 --> 01:19:49,050
son yeah does anything you know like

1836
01:19:46,920 --> 01:19:50,670
humans might live to 80 or 90 but then

1837
01:19:49,050 --> 01:19:56,310
things happen and some humans live the

1838
01:19:50,670 --> 01:20:03,000
30 or 40 can the same happen something

1839
01:19:56,310 --> 01:20:10,710
unexpected occurs I was thinking of a

1840
01:20:03,000 --> 01:20:15,300
stroke there is no process that I'm

1841
01:20:10,710 --> 01:20:17,850
aware of so I'm thinking probably not

1842
01:20:15,300 --> 01:20:20,430
but i I've learned over the years to

1843
01:20:17,850 --> 01:20:22,500
always hedge my bets ever so slightly

1844
01:20:20,430 --> 01:20:24,600
now I don't there's you know we've been

1845
01:20:22,500 --> 01:20:26,159
studying these systems like these

1846
01:20:24,600 --> 01:20:29,160
globular clusters and stuff at different

1847
01:20:26,159 --> 01:20:32,250
metallicity and every the stars are

1848
01:20:29,159 --> 01:20:33,599
behaving more or less as we expect there

1849
01:20:32,250 --> 01:20:35,029
there's certainly a lot of surprises is

1850
01:20:33,600 --> 01:20:39,420
why we study them but there's nothing

1851
01:20:35,029 --> 01:20:41,309
grand on that scale so I think we're

1852
01:20:39,420 --> 01:20:44,310
okay I think the real estate is safe for

1853

01:20:41,310 --> 01:20:45,990
a bit I will say there was that one Star

1854
01:20:44,310 --> 01:20:47,580
Trek film where the villain shot

1855
01:20:45,989 --> 01:20:49,849
something into the star and made it

1856
01:20:47,579 --> 01:20:52,699
explode yeah we don't know about that

1857
01:20:49,850 --> 01:20:56,300
[Laughter]

1858
01:20:52,699 --> 01:20:58,920
other questions oh we had a questions

1859
01:20:56,300 --> 01:21:01,520
one final question oh yes he's been

1860
01:20:58,920 --> 01:21:01,520
trying to ask

1861
01:21:03,079 --> 01:21:08,819
I'm actually just kind of curious about

1862
01:21:05,939 --> 01:21:11,699
the fusion reaction in a normal star

1863
01:21:08,819 --> 01:21:13,799
like the Sun aha does the fusion

1864
01:21:11,699 --> 01:21:16,979
reaction begin in the center and move

1865
01:21:13,800 --> 01:21:19,529
outward and if that's true how long does

1866
01:21:16,979 --> 01:21:21,779
it take for the fusion reaction to get

1867
01:21:19,529 --> 01:21:24,539

to the from the core of the Sun of the

1868

01:21:21,779 --> 01:21:28,229

surface okay so the fusion reaction is

1869

01:21:24,539 --> 01:21:30,510

always just in the core I think it's the

1870

01:21:28,229 --> 01:21:33,059

number twenty percent by mass is in my

1871

01:21:30,510 --> 01:21:38,050

head but this is a fact check the

1872

01:21:33,060 --> 01:21:40,030

speaker kind of a thing so the

1873

01:21:38,050 --> 01:21:41,289

is that the the fusion reaction operates

1874

01:21:40,029 --> 01:21:43,118

more efficiently in the center because

1875

01:21:41,289 --> 01:21:45,039

the temperature is higher but there's

1876

01:21:43,118 --> 01:21:46,569

sort of a radius out to which the

1877

01:21:45,039 --> 01:21:48,760

temperatures high enough to sustain some

1878

01:21:46,569 --> 01:21:50,799

fusion right so what happens is since

1879

01:21:48,760 --> 01:21:52,719

the core is radiative which means

1880

01:21:50,800 --> 01:21:55,239

everything just sits there there's no

1881

01:21:52,719 --> 01:21:57,939

convection the the hydrogen gets

1882
01:21:55,238 --> 01:22:03,669
exhausted faster in the center of the

1883
01:21:57,939 --> 01:22:06,039
Sun so I don't I think it's pretty

1884
01:22:03,670 --> 01:22:09,099
stable configuration for the last 4.7

1885
01:22:06,039 --> 01:22:10,779
billion years by and large but what's

1886
01:22:09,099 --> 01:22:13,360
happening is that the the the amount of

1887
01:22:10,779 --> 01:22:15,279
hydrogen in the core is going in the

1888
01:22:13,359 --> 01:22:17,889
center of the core is dropping fastest

1889
01:22:15,279 --> 01:22:20,050
and so it's slowly the core slowly

1890
01:22:17,889 --> 01:22:21,400
gravitationally contracting and the Sun

1891
01:22:20,050 --> 01:22:23,260
sitting up if I remember right then the

1892
01:22:21,399 --> 01:22:28,808
number is the Sun is twice as bright now

1893
01:22:23,260 --> 01:22:32,969
as it was when it first formed when I

1894
01:22:28,809 --> 01:22:34,329
was at Cornell we just before I left we

1895
01:22:32,969 --> 01:22:36,399
inherited

1896
01:22:34,328 --> 01:22:38,769
Lisa Kelton Egger and then her her group

1897
01:22:36,399 --> 01:22:40,719
which is studying questions like the

1898
01:22:38,770 --> 01:22:42,070
habitability of plants one of the stars

1899
01:22:40,719 --> 01:22:43,809
they've been spending a lot of time

1900
01:22:42,069 --> 01:22:46,479
looking into questions like this like as

1901
01:22:43,809 --> 01:22:50,309
the Sun has evolved the habitable zone

1902
01:22:46,479 --> 01:22:52,328
in the solar system has moved outward

1903
01:22:50,309 --> 01:22:54,190
right because it's getting it's too hot

1904
01:22:52,328 --> 01:22:56,558
venus may have been in a habitable

1905
01:22:54,189 --> 01:22:58,058
planet early in the system or early in

1906
01:22:56,559 --> 01:23:00,219
the history of the solar system for

1907
01:22:58,059 --> 01:23:01,659
example there's other reasons it might

1908
01:23:00,219 --> 01:23:03,670
not have been because the atmosphere got

1909
01:23:01,658 --> 01:23:04,929
pretty thick pretty quick but you know

1910

01:23:03,670 --> 01:23:06,368
it's these kinds of things things aren't

1911
01:23:04,929 --> 01:23:08,618
quite as static as we think of them

1912
01:23:06,368 --> 01:23:09,908
being it's a really neat question it

1913
01:23:08,618 --> 01:23:11,308
gets even more intriguing when you start

1914
01:23:09,908 --> 01:23:13,598
talking about exoplanetary systems

1915
01:23:11,309 --> 01:23:15,730
because now going well the handles own

1916
01:23:13,599 --> 01:23:20,889
is between x and y I it's not that

1917
01:23:15,729 --> 01:23:25,419
simple so yeah all right we are getting

1918
01:23:20,889 --> 01:23:28,889
to the end of our time as i have to cut

1919
01:23:25,420 --> 01:23:32,889
off questions we will see you again in

1920
01:23:28,889 --> 01:23:35,920
September for 100 ways to die in the

1921
01:23:32,889 --> 01:23:38,469
universe so you know a little more death

1922
01:23:35,920 --> 01:23:41,789
and destruction let us give one great

1923
01:23:38,469 --> 01:23:41,789
big hand for very long

1924
01:23:50,168 --> 01:23:54,998

and and thank y'all that was a lot of

1925

01:23:52,899 --> 01:23:58,050

fun I appreciate that appreciate y'all

1926

01:23:54,998 --> 01:23:58,050

coming out that was fun