

1
00:00:00,000 --> 00:00:04,950
dr. Frank summers of the office of

2
00:00:01,709 --> 00:00:06,798
public outreach and when you came in

3
00:00:04,950 --> 00:00:10,410
hopefully you picked up one of these

4
00:00:06,799 --> 00:00:13,259
these are our lithographs and tonight's

5
00:00:10,410 --> 00:00:18,359
lithograph is the Jets from a young star

6
00:00:13,259 --> 00:00:20,130
her big hair Oh 24 we astronomers just

7
00:00:18,359 --> 00:00:23,400
call these 8h objects and they're really

8
00:00:20,129 --> 00:00:27,358
kind of cool now I chose this one

9
00:00:23,399 --> 00:00:30,868
because just a few days ago was May the

10
00:00:27,359 --> 00:00:33,600
4th and those on the internet I'll call

11
00:00:30,868 --> 00:00:37,979
that Star Wars day for the phrase may

12
00:00:33,600 --> 00:00:39,270
the 4th be with you I figured some

13
00:00:37,979 --> 00:00:39,869
people in this audience hadn't heard

14
00:00:39,270 --> 00:00:44,489
that before

15
00:00:39,869 --> 00:00:47,218
ok anyways so we had Star Wars day last

16
00:00:44,488 --> 00:00:49,738
Saturday and if you look at this her big

17
00:00:47,219 --> 00:00:51,840
Harel object you can see the jets

18
00:00:49,738 --> 00:00:54,509
pointing away from the central heat

19
00:00:51,840 --> 00:00:56,969
thing and we like to call this celestial

20
00:00:54,509 --> 00:00:58,890
lightsaber because it has a resemblance

21
00:00:56,969 --> 00:01:02,879
to Darth Maul's double bladed lightsaber

22
00:00:58,890 --> 00:01:06,000
ok matter of fact I have a blog post out

23
00:01:02,878 --> 00:01:07,590
there about a celestial lightsaber thing

24
00:01:06,000 --> 00:01:09,659
and relating and telling you what's

25
00:01:07,590 --> 00:01:11,549
actually going on you don't need to read

26
00:01:09,659 --> 00:01:14,640
my blog post you can just turn the

27
00:01:11,549 --> 00:01:16,560
lithograph over and read about it on the

28
00:01:14,640 --> 00:01:19,140
back there and we've got a diagram

29

00:01:16,560 --> 00:01:22,200
showing you the Jets from this young

30
00:01:19,140 --> 00:01:25,469
star for those of you on the webcast you

31
00:01:22,200 --> 00:01:27,450
can see the URL down bottom where you

32
00:01:25,469 --> 00:01:31,700
can get the PDF of this and have

33
00:01:27,450 --> 00:01:36,140
yourself and get to view it yourself

34
00:01:31,700 --> 00:01:38,009
tonight speaker the fiery fate of

35
00:01:36,140 --> 00:01:41,368
exoplanets ooh

36
00:01:38,009 --> 00:01:44,938
burning death Joleen Carl boy we will be

37
00:01:41,368 --> 00:01:48,118
talking about this next month we have

38
00:01:44,938 --> 00:01:49,769
recycled your used pulsars hopefully

39
00:01:48,118 --> 00:01:51,209
hopefully everyone does do this you know

40
00:01:49,769 --> 00:01:54,539
at home in your recycling if you've got

41
00:01:51,209 --> 00:01:57,089
extra pulsars recycle them because they

42
00:01:54,540 --> 00:02:00,780
can explain the extra gamma radiation

43
00:01:57,090 --> 00:02:02,759

from the Central Milky Way and Chris

44

00:02:00,780 --> 00:02:07,290

Britt will talk about that on June 4th

45

00:02:02,759 --> 00:02:08,250

on July 2nd and Joe de Pascua one of my

46

00:02:07,290 --> 00:02:09,840

colleagues in the office of public

47

00:02:08,250 --> 00:02:12,919

outreach will be talking about the art

48

00:02:09,840 --> 00:02:15,789

and science of astronomical image

49

00:02:12,919 --> 00:02:19,280

these wonderful images that you see are

50

00:02:15,789 --> 00:02:22,068

prepared not by artists not by

51

00:02:19,280 --> 00:02:24,500

scientists by by combinations of artists

52

00:02:22,068 --> 00:02:27,318

and scientists generally inside the same

53

00:02:24,500 --> 00:02:29,989

brain people using both left and right

54

00:02:27,318 --> 00:02:32,238

brain to pull out the science but also

55

00:02:29,989 --> 00:02:33,890

make it beautiful for the public to

56

00:02:32,239 --> 00:02:36,170

increase our understanding and

57

00:02:33,889 --> 00:02:40,488

appreciation in August we have the

58
00:02:36,169 --> 00:02:41,899
dreaded TVA which is Frank yeah you got

59
00:02:40,489 --> 00:02:44,620
to send out an email this month and get

60
00:02:41,900 --> 00:02:48,250
a speaker for August ok but I always do

61
00:02:44,620 --> 00:02:51,049
when I do I will post it on our website

62
00:02:48,250 --> 00:02:52,129
and if you just take your favorite

63
00:02:51,049 --> 00:02:54,110
search engine and look for Space

64
00:02:52,129 --> 00:02:56,989
Telescope public lecture series you'll

65
00:02:54,110 --> 00:02:58,600
find this webpage with a list of the

66
00:02:56,989 --> 00:03:01,700
upcoming lectures over here on the right

67
00:02:58,599 --> 00:03:04,310
and on the left you can have you can see

68
00:03:01,699 --> 00:03:07,818
our webcasting the live links as well as

69
00:03:04,310 --> 00:03:12,099
the past lectures back to 2014 on

70
00:03:07,818 --> 00:03:16,030
YouTube and back to 2005 on the stsci

71
00:03:12,099 --> 00:03:19,039
webcasting I will note that the SGI

72
00:03:16,030 --> 00:03:21,590
webcasting just in a huge improvement

73
00:03:19,039 --> 00:03:23,900
not only to the quality of their

74
00:03:21,590 --> 00:03:25,969
presentation but also to the search

75
00:03:23,900 --> 00:03:27,319
capabilities on their website I'm gonna

76
00:03:25,969 --> 00:03:29,239
try and get somebody from stsci

77
00:03:27,319 --> 00:03:31,549
webcasting to show that off next month

78
00:03:29,239 --> 00:03:33,769
for you so you can so when you go there

79
00:03:31,549 --> 00:03:35,719
you can figure out how to find all those

80
00:03:33,769 --> 00:03:38,599
really cool lectures that we have been

81
00:03:35,719 --> 00:03:40,879
doing for Wow that's 14 years of

82
00:03:38,599 --> 00:03:43,489
webcasting that they have of this public

83
00:03:40,879 --> 00:03:47,930
lecture series ok and finally you can

84
00:03:43,489 --> 00:03:49,579
sign up for our email lists there if you

85
00:03:47,930 --> 00:03:52,310
do not want to sign up at the website

86

00:03:49,579 --> 00:03:54,409
you can do as one gentleman did tonight

87
00:03:52,310 --> 00:03:56,870
give me a piece of paper with a web

88
00:03:54,409 --> 00:03:58,579
address email address on it and I'll

89
00:03:56,870 --> 00:04:01,189
make sure it gets added to it

90
00:03:58,579 --> 00:04:03,109
if you have any questions for me or for

91
00:04:01,189 --> 00:04:05,239
the speaker about an NDA of our

92
00:04:03,109 --> 00:04:07,969
organization you can send them to the

93
00:04:05,239 --> 00:04:12,049
email address public lecture at stsci

94
00:04:07,969 --> 00:04:13,818
dot edu finally if you would like to

95
00:04:12,049 --> 00:04:16,430
follow us on social media we have a

96
00:04:13,818 --> 00:04:19,038
variety of things Facebook Twitter

97
00:04:16,430 --> 00:04:21,139
YouTube and Instagram not only for the

98
00:04:19,038 --> 00:04:23,300
Hubble Space Telescope not only for the

99
00:04:21,139 --> 00:04:26,079
Webb Space Telescope but also for our

100
00:04:23,300 --> 00:04:28,750

institution stsc I

101

00:04:26,079 --> 00:04:30,878

I do a little bit of social media on

102

00:04:28,750 --> 00:04:33,009

Facebook and Twitter as dr. Frank

103

00:04:30,879 --> 00:04:35,319

summers you can follow that if you like

104

00:04:33,009 --> 00:04:40,360

and tonight

105

00:04:35,319 --> 00:04:42,158

the observatory will be open it hasn't

106

00:04:40,360 --> 00:04:46,270

been open for several months okay so

107

00:04:42,158 --> 00:04:48,969

after the lecture Matt from the Maryland

108

00:04:46,269 --> 00:04:52,180

Space Grant observatory will be here and

109

00:04:48,970 --> 00:04:55,180

he will take up no more than thirty

110

00:04:52,180 --> 00:04:57,038

people I think okay so we can't take a

111

00:04:55,180 --> 00:04:59,560

huge group of 50 people he can only take

112

00:04:57,038 --> 00:05:01,538

ten - I think they prefer ten to 20

113

00:04:59,560 --> 00:05:03,519

people okay I'll let Matt figure it out

114

00:05:01,538 --> 00:05:05,589

afterwards but if you would like to go

115
00:05:03,519 --> 00:05:09,818
across the street and go up into that

116
00:05:05,589 --> 00:05:12,668
the Morris W off it telescope and look

117
00:05:09,819 --> 00:05:15,550
at the what so it's available we can do

118
00:05:12,668 --> 00:05:17,529
so afterwards hang around afterwards if

119
00:05:15,550 --> 00:05:20,530
I forget remind me to say hey

120
00:05:17,529 --> 00:05:22,718
Observatory and people will gather or

121
00:05:20,529 --> 00:05:26,888
probably over here and head out that

122
00:05:22,718 --> 00:05:31,569
door go across okay all right now our

123
00:05:26,889 --> 00:05:36,490
news from the universe for May 2019 our

124
00:05:31,569 --> 00:05:38,500
first story tonight wide and deep so

125
00:05:36,490 --> 00:05:41,769
this is one of Hubble's most famous

126
00:05:38,500 --> 00:05:43,930
images the Hubble Ultra Deep Field and

127
00:05:41,769 --> 00:05:47,468
it is the deepest accessible light

128
00:05:43,930 --> 00:05:50,348
exposure of the universe invisible and

129
00:05:47,468 --> 00:05:52,778
it basically we see more galaxies in

130
00:05:50,348 --> 00:05:54,478
this tiny patch of sky than we see

131
00:05:52,778 --> 00:05:57,339
anywhere else there basically about

132
00:05:54,478 --> 00:06:01,389
10,000 galaxies in this really tiny

133
00:05:57,339 --> 00:06:03,310
patch of sky how tiny is it well this is

134
00:06:01,389 --> 00:06:06,250
the Ultra Deep Field compared to the

135
00:06:03,310 --> 00:06:09,250
full moon okay all right so it's about

136
00:06:06,250 --> 00:06:10,930
you know 1% of the full of the full moon

137
00:06:09,250 --> 00:06:13,839
there about a hundred catches about this

138
00:06:10,930 --> 00:06:15,968
size they make up the full moon but

139
00:06:13,839 --> 00:06:18,189
contrary to what Hollywood may have

140
00:06:15,968 --> 00:06:18,699
taught you the full moons not that big

141
00:06:18,189 --> 00:06:21,189
in the sky

142
00:06:18,699 --> 00:06:23,800
here's a picture showing a wide field

143

00:06:21,189 --> 00:06:25,620
view oh yeah that's how big the full

144
00:06:23,800 --> 00:06:28,840
moon is in the sky it's pretty small

145
00:06:25,620 --> 00:06:31,959
matter of fact if you do the math there

146
00:06:28,839 --> 00:06:33,429
are twelve million seven hundred forty

147
00:06:31,959 --> 00:06:36,370
six thousand seven hundred and eighty

148
00:06:33,430 --> 00:06:40,050
four patches the same size as the Hubble

149
00:06:36,370 --> 00:06:44,079
Ultra Deep Field on the sky okay

150
00:06:40,050 --> 00:06:47,079
Hubble's field of view is 112 million of

151
00:06:44,079 --> 00:06:49,060
the night sky so when we study the

152
00:06:47,079 --> 00:06:51,310
Hubble ultra-deep field we're studying

153
00:06:49,060 --> 00:06:53,439
only one tiny little portion of the sky

154
00:06:51,310 --> 00:06:55,750
and what we would really like to do is

155
00:06:53,439 --> 00:06:58,089
touch a much larger portion so that we

156
00:06:55,750 --> 00:07:00,730
can get this surety in our statistics

157
00:06:58,089 --> 00:07:03,310

okay we want to be able to say what we

158

00:07:00,730 --> 00:07:05,530

see in this state field is the same as

159

00:07:03,310 --> 00:07:08,980

what we see over here is the same across

160

00:07:05,529 --> 00:07:10,899

the whole sky so what we have done is

161

00:07:08,980 --> 00:07:12,310

here is the Hubble ultra-deep field this

162

00:07:10,899 --> 00:07:15,029

is the patch of the sky where Hubble

163

00:07:12,310 --> 00:07:18,910

ultra-deep field we have done mosaics

164

00:07:15,029 --> 00:07:21,629

and field studies this is the goods the

165

00:07:18,910 --> 00:07:25,150

Great observatories origins deep survey

166

00:07:21,629 --> 00:07:28,600

which roughly covers about 15 times the

167

00:07:25,149 --> 00:07:30,849

field of the Hubble Ultra Deep Field and

168

00:07:28,600 --> 00:07:34,180

recently what we released is something

169

00:07:30,850 --> 00:07:36,400

called the Hubble legacy field which

170

00:07:34,180 --> 00:07:40,449

covers about twice as much as that again

171

00:07:36,399 --> 00:07:42,759

so in this Hubble legacy field they say

172
00:07:40,449 --> 00:07:45,729
and I didn't count them that there are

173
00:07:42,759 --> 00:07:49,329
two hundred and sixty thousand galaxies

174
00:07:45,730 --> 00:07:50,530
okay in looking at this patch of sky

175
00:07:49,329 --> 00:07:52,839
that's you know

176
00:07:50,529 --> 00:07:55,059
looks like 30 to 50 times the size of

177
00:07:52,839 --> 00:07:58,269
the Ultra Deep Field they're getting two

178
00:07:55,060 --> 00:08:00,790
hundred and sixty thousand galaxies now

179
00:07:58,269 --> 00:08:03,759
that gives you a lot more statistics

180
00:08:00,790 --> 00:08:07,360
okay makes you much more clear about

181
00:08:03,759 --> 00:08:11,289
your understanding and so this is the

182
00:08:07,360 --> 00:08:15,730
the recent image that we released it is

183
00:08:11,290 --> 00:08:19,090
actually massively huge I tried working

184
00:08:15,730 --> 00:08:20,770
with it in Photoshop today I was just

185
00:08:19,089 --> 00:08:24,159
trying to get these these graphics here

186
00:08:20,769 --> 00:08:27,129
for the for the PowerPoint oh my god I

187
00:08:24,160 --> 00:08:29,830
mean it's like a 3.2 gigabyte individual

188
00:08:27,129 --> 00:08:32,740
image file okay oh it's just a lot of

189
00:08:29,829 --> 00:08:35,259
things but because we are Hubble and

190
00:08:32,740 --> 00:08:36,970
we're paid for by your tax dollars you

191
00:08:35,259 --> 00:08:40,120
can download every single pixel in this

192
00:08:36,970 --> 00:08:42,310
image okay all right we have it we have

193
00:08:40,120 --> 00:08:44,590
it at like 50 thousand by fifty thousand

194
00:08:42,309 --> 00:08:46,479
pixels available for you to download if

195
00:08:44,590 --> 00:08:49,720
you are so masochist goal that you want

196
00:08:46,480 --> 00:08:52,539
to do that okay astronomers will of

197
00:08:49,720 --> 00:08:55,420
course be downloading this and doing

198
00:08:52,539 --> 00:08:57,189
some research studies on it so finally

199
00:08:55,419 --> 00:09:00,759
but we're getting to the Hubble legacy

200

00:08:57,190 --> 00:09:04,720
field we do have an image that covers

201
00:09:00,759 --> 00:09:08,169
roughly the size of the full moon okay

202
00:09:04,720 --> 00:09:10,930
and okay so maybe there's a few hundred

203
00:09:08,169 --> 00:09:12,789
thousand patches of the sky this side

204
00:09:10,929 --> 00:09:14,229
this size in the sky but we're going

205
00:09:12,789 --> 00:09:18,039
from 112 million through the night sky

206
00:09:14,230 --> 00:09:20,230
to about 1,000 so nice guy a hundred

207
00:09:18,039 --> 00:09:22,088
thousand for the night sky all right so

208
00:09:20,230 --> 00:09:24,759
you might think this is this is this the

209
00:09:22,089 --> 00:09:26,829
maximum what Hubble can do and I was

210
00:09:24,759 --> 00:09:28,600
like alright well I think we've done

211
00:09:26,828 --> 00:09:33,818
something bigger than this and I went

212
00:09:28,600 --> 00:09:35,889
through my oh yes we have so found this

213
00:09:33,818 --> 00:09:40,000
image from a few years ago this is again

214
00:09:35,889 --> 00:09:42,278

the moon for scale goods and the Jemez

215

00:09:40,000 --> 00:09:44,350

survey and you can see the gem survey

216

00:09:42,278 --> 00:09:46,750

and the legacy field are pretty much the

217

00:09:44,350 --> 00:09:48,730

same size of the field but the legacy

218

00:09:46,750 --> 00:09:51,909

survey is deeper okay so it's taking the

219

00:09:48,730 --> 00:09:54,250

gem survey data and augmenting that with

220

00:09:51,909 --> 00:09:56,948

even more observations okay in order to

221

00:09:54,250 --> 00:10:00,429

get this so you could call the legacy

222

00:09:56,948 --> 00:10:02,198

survey gems version 2 and deeper but the

223

00:10:00,429 --> 00:10:04,149

really big one that we did which

224

00:10:02,198 --> 00:10:06,609

unfortunately does not go as deep as

225

00:10:04,149 --> 00:10:09,068

necessary to get those kind of

226

00:10:06,610 --> 00:10:10,600

statistics is the cosmos survey and you

227

00:10:09,068 --> 00:10:13,599

can see that's you know like six times

228

00:10:10,600 --> 00:10:16,240

the size of the full moon so even though

229
00:10:13,600 --> 00:10:19,720
Hubble has a tiny field of view on the

230
00:10:16,240 --> 00:10:22,149
sky 112 million when you take these long

231
00:10:19,720 --> 00:10:24,850
surveys over many years and Hubble has

232
00:10:22,149 --> 00:10:26,528
been up for 29 years now you can end up

233
00:10:24,850 --> 00:10:28,629
getting some very large patches of the

234
00:10:26,528 --> 00:10:32,019
sky and this is what we need to be able

235
00:10:28,629 --> 00:10:36,068
to do to do statistics and just to blow

236
00:10:32,019 --> 00:10:38,289
your mind the wide the W first the

237
00:10:36,068 --> 00:10:41,679
wide-field infrared Space Telescope that

238
00:10:38,289 --> 00:10:45,120
we expect to launch in the 2020s will be

239
00:10:41,679 --> 00:10:47,588
able to do the entire cosmos survey in

240
00:10:45,120 --> 00:10:51,310
one image okay

241
00:10:47,589 --> 00:10:55,569
that's how Big W first detector is it's

242
00:10:51,309 --> 00:10:57,448
a 100 times the size of Hubble okay it's

243
00:10:55,568 --> 00:11:00,188
infrared goes a little bit into the red

244
00:10:57,448 --> 00:11:02,859
but we have another telescope coming in

245
00:11:00,188 --> 00:11:05,730
in about in about 10 less than 10 years

246
00:11:02,860 --> 00:11:09,480
hopefully that will be able to do these

247
00:11:05,730 --> 00:11:12,829
large patches in the infrared so data is

248
00:11:09,480 --> 00:11:17,339
gonna be huge in the next decade okay

249
00:11:12,828 --> 00:11:22,138
all right our second story tonight milky

250
00:11:17,339 --> 00:11:27,389
way all right so what we're talking

251
00:11:22,139 --> 00:11:27,750
about is how do you weigh a galaxy all

252
00:11:27,389 --> 00:11:29,669
right

253
00:11:27,750 --> 00:11:32,549
we don't have scales big enough for it

254
00:11:29,669 --> 00:11:34,740
okay and even if we did they wouldn't

255
00:11:32,549 --> 00:11:37,169
cover the the mat the mass ranges we

256
00:11:34,740 --> 00:11:39,720
have here so when you're looking at a

257

00:11:37,169 --> 00:11:41,879
galaxy in particular this spiral galaxy

258
00:11:39,720 --> 00:11:44,940
you can sort of see that these spiral

259
00:11:41,879 --> 00:11:47,698
disks rotate okay I believe that this is

260
00:11:44,940 --> 00:11:51,839
that this is a spinning disk alright so

261
00:11:47,698 --> 00:11:55,519
you mean galaxy not by measuring the

262
00:11:51,839 --> 00:11:58,880
mass but by measuring the motions okay

263
00:11:55,519 --> 00:12:01,769
so the motion of Earth around the Sun

264
00:11:58,879 --> 00:12:04,679
tells you the mass of the Sun because

265
00:12:01,769 --> 00:12:06,379
it's the Sun's gravity that constrains

266
00:12:04,679 --> 00:12:10,019
Earth's motion

267
00:12:06,379 --> 00:12:12,948
similarly the motions of stars and dust

268
00:12:10,019 --> 00:12:16,318
clouds and star clusters in a galaxy

269
00:12:12,948 --> 00:12:19,169
tells you about the mass inside a galaxy

270
00:12:16,318 --> 00:12:21,208
and so if you measure these motions in

271
00:12:19,169 --> 00:12:23,429

clothes and all the way out as far out

272

00:12:21,208 --> 00:12:26,879

as you can see in a galaxy you can get a

273

00:12:23,429 --> 00:12:28,948

mass profile of the galaxy and effective

274

00:12:26,879 --> 00:12:31,409

I figure out how much mass is in there

275

00:12:28,948 --> 00:12:33,240

okay and that's you know looks pretty

276

00:12:31,409 --> 00:12:35,969

straightforward for an external galaxy

277

00:12:33,240 --> 00:12:38,698

that you can see like this however we're

278

00:12:35,970 --> 00:12:41,129

inside the Milky Way okay and we've

279

00:12:38,698 --> 00:12:42,958

gathered go look and try and figure out

280

00:12:41,129 --> 00:12:44,789

and we're moving inside the Milky Way

281

00:12:42,958 --> 00:12:46,818

and we you've got a deconvolve the

282

00:12:44,789 --> 00:12:49,469

problem from being inside the Milky Way

283

00:12:46,818 --> 00:12:50,458

and whoops that was that was the image I

284

00:12:49,470 --> 00:12:52,110

was supposed to show you the axial

285

00:12:50,458 --> 00:12:55,469

Mellinger version of it okay so we're

286
00:12:52,110 --> 00:12:57,810
inside the Milky Way and do it it turns

287
00:12:55,470 --> 00:12:59,879
out that one of the best things to use

288
00:12:57,809 --> 00:13:02,250
are these globular star clusters these

289
00:12:59,879 --> 00:13:03,899
are very dense star clusters they're

290
00:13:02,250 --> 00:13:06,120
sort of gravitationally bound together

291
00:13:03,899 --> 00:13:08,578
and they're sort of moving as a group

292
00:13:06,120 --> 00:13:10,769
together so you can measure the motions

293
00:13:08,578 --> 00:13:12,929
of the stars the bulk motion of the

294
00:13:10,769 --> 00:13:17,730
stars in these clusters and use them to

295
00:13:12,929 --> 00:13:19,259
measure the Milky Way so one component

296
00:13:17,730 --> 00:13:22,170
of this result

297
00:13:19,259 --> 00:13:24,919
from the Gaia satellite now Gaia is an

298
00:13:22,169 --> 00:13:27,659
Astrometric satellite it's the most

299
00:13:24,919 --> 00:13:31,769
accurate astrometric satellite we've

300
00:13:27,659 --> 00:13:34,199
ever put up two billion stars with their

301
00:13:31,769 --> 00:13:35,029
positions and their motions etc across

302
00:13:34,200 --> 00:13:37,920
sky

303
00:13:35,029 --> 00:13:40,049
unbelievable data set that's still being

304
00:13:37,919 --> 00:13:42,299
developed and being developed more and I

305
00:13:40,049 --> 00:13:44,669
think I showed you guys this shot when

306
00:13:42,299 --> 00:13:46,469
guys first data release came out this is

307
00:13:44,669 --> 00:13:48,389
their radial velocity map and you can

308
00:13:46,470 --> 00:13:50,370
see over here in red on the right side

309
00:13:48,389 --> 00:13:52,529
those are the stars that are moving away

310
00:13:50,370 --> 00:13:53,789
from us and on the left side you can see

311
00:13:52,529 --> 00:13:55,799
the blue ones the ones that are coming

312
00:13:53,789 --> 00:13:57,599
towards us and then the center you can

313
00:13:55,799 --> 00:14:00,149
sort of see this flip which is the

314

00:13:57,600 --> 00:14:02,759
motions internal to our motions for the

315
00:14:00,149 --> 00:14:20,329
galaxies so Gaia has measured really

316
00:14:02,759 --> 00:14:23,279
carefully Bobby our clusters out to

317
00:14:20,330 --> 00:14:27,389
65,000 light which is a huge rate it's

318
00:14:23,279 --> 00:14:30,629
much beyond the size of the Milky Way's

319
00:14:27,389 --> 00:14:32,159
disk all right but that's not quite good

320
00:14:30,629 --> 00:14:33,809
enough to get the full measurement

321
00:14:32,159 --> 00:14:36,959
because the Milky Way really extends out

322
00:14:33,809 --> 00:14:42,449
there so who you gonna call

323
00:14:36,960 --> 00:14:44,310
of course Oh got you right Hubble can

324
00:14:42,450 --> 00:14:46,290
have the fine resolution to see the

325
00:14:44,309 --> 00:14:49,049
globular clusters much further out and

326
00:14:46,289 --> 00:14:51,149
so Hubble has started yet another dozen

327
00:14:49,049 --> 00:14:53,039
globular clusters out to twice the

328
00:14:51,149 --> 00:14:54,539

distance that guy I can do out to a

329

00:14:53,039 --> 00:14:57,360

hundred and thirty thousand light-years

330

00:14:54,539 --> 00:14:59,990

and if you combine the measurements from

331

00:14:57,360 --> 00:15:03,360

Gaia and the measurements from Hubble

332

00:14:59,990 --> 00:15:06,570

then you can make way through Milky Way

333

00:15:03,360 --> 00:15:09,810

with unprecedented accuracy so here's

334

00:15:06,570 --> 00:15:12,540

here is what Hubble can do and you can

335

00:15:09,809 --> 00:15:14,549

see the galaxies that are circled here

336

00:15:12,539 --> 00:15:16,199

they're not moving and what you're

337

00:15:14,549 --> 00:15:18,240

seeing are the stars that are moving and

338

00:15:16,200 --> 00:15:20,610

these stars are part of this star

339

00:15:18,240 --> 00:15:23,009

cluster here this is a deep deep deep

340

00:15:20,610 --> 00:15:24,000

part tiny part of this globular star

341

00:15:23,009 --> 00:15:26,100

cluster okay

342

00:15:24,000 --> 00:15:27,960

and there's tiny little motions that

343
00:15:26,100 --> 00:15:29,909
Hubble can measure can get you the bulk

344
00:15:27,960 --> 00:15:32,850
motions of those globular star clusters

345
00:15:29,909 --> 00:15:35,189
all right together

346
00:15:32,850 --> 00:15:38,040
Gaia and hub all put together - this is

347
00:15:35,190 --> 00:15:40,050
an artist draw drawing to give you idea

348
00:15:38,039 --> 00:15:42,569
of all these star clusters extending out

349
00:15:40,049 --> 00:15:45,629
to 130,000 light years and then you can

350
00:15:42,570 --> 00:15:47,340
extend that out even further to measure

351
00:15:45,629 --> 00:15:50,700
the full mass of the Milky Way

352
00:15:47,340 --> 00:15:54,780
now previous to this they had said that

353
00:15:50,700 --> 00:15:58,730
the best estimates were between half to

354
00:15:54,779 --> 00:16:01,949
about three trillion solar masses and

355
00:15:58,730 --> 00:16:04,350
fortunately the measurement from here is

356
00:16:01,950 --> 00:16:06,740
much more refined but it comes down to

357
00:16:04,350 --> 00:16:10,139
one point five trillion solar masses

358
00:16:06,740 --> 00:16:14,370
okay so that's million billion trillion

359
00:16:10,139 --> 00:16:16,199
okay 1.5 trillion solar masses now if

360
00:16:14,370 --> 00:16:18,450
you know the number of stars in the

361
00:16:16,200 --> 00:16:21,150
Milky Way the estimate of that is about

362
00:16:18,450 --> 00:16:23,460
200 billion stars in the Milky Way and

363
00:16:21,149 --> 00:16:26,100
the average mass of a star is about the

364
00:16:23,460 --> 00:16:28,350
same as the mass of our Sun so there's

365
00:16:26,100 --> 00:16:31,200
one point five trillion solar masses in

366
00:16:28,350 --> 00:16:35,129
the Milky Way but only about 200 billion

367
00:16:31,200 --> 00:16:37,920
of that is stars which indicates you

368
00:16:35,129 --> 00:16:40,950
know as we've all known that we got or

369
00:16:37,919 --> 00:16:44,429
dominated here our Milky Way by dark

370
00:16:40,950 --> 00:16:46,350
matter okay the unseen dark matter is

371

00:16:44,429 --> 00:16:48,839
the gravitationally dominant we see it

372
00:16:46,350 --> 00:16:51,750
in other galaxies we see it in our own

373
00:16:48,840 --> 00:16:54,960
galaxy that the dark matter in the Milky

374
00:16:51,750 --> 00:16:57,600
Way is about six or seven times more

375
00:16:54,960 --> 00:16:59,070
massive than the normal matter the stars

376
00:16:57,600 --> 00:17:03,170
and the gas and the dust and everything

377
00:16:59,070 --> 00:17:05,580
okay so why do we need to know this

378
00:17:03,169 --> 00:17:07,889
important thing is that we can see the

379
00:17:05,579 --> 00:17:10,079
Milky Way better than we can see any

380
00:17:07,890 --> 00:17:13,080
other galaxy we have detailed

381
00:17:10,079 --> 00:17:15,619
measurements inside our galaxy right but

382
00:17:13,079 --> 00:17:18,569
we need to know how our galaxy scales

383
00:17:15,619 --> 00:17:20,909
against other galaxies in order to be

384
00:17:18,569 --> 00:17:23,429
able to apply this local knowledge to

385
00:17:20,910 --> 00:17:25,940

these distant galaxies having this

386

00:17:23,430 --> 00:17:28,320

measurement of 1.5 trillion solar masses

387

00:17:25,940 --> 00:17:30,720

allows us to take this knowledge that we

388

00:17:28,319 --> 00:17:34,139

gained locally and then apply it more

389

00:17:30,720 --> 00:17:36,690

accurately to external galaxies so we

390

00:17:34,140 --> 00:17:39,780

have been able to make a more accurate

391

00:17:36,690 --> 00:17:43,980

measurement and able to weigh the Milky

392

00:17:39,779 --> 00:17:45,589

Way right okay any questions before we

393

00:17:43,980 --> 00:17:50,839

go on

394

00:17:45,589 --> 00:17:52,699

ah good question how does the Milky Way

395

00:17:50,839 --> 00:17:54,619

compare to other galaxies or the Milky

396

00:17:52,700 --> 00:17:57,679

Way at one point five trillion solar

397

00:17:54,619 --> 00:18:00,619

masses is relatively normal for a large

398

00:17:57,679 --> 00:18:02,150

galaxy of course we have some dwarf

399

00:18:00,619 --> 00:18:04,489

galaxies around us the large mammals

400
00:18:02,150 --> 00:18:07,788
non-cloud small Magellanic Cloud there

401
00:18:04,490 --> 00:18:09,380
are a few billion solar masses okay so

402
00:18:07,788 --> 00:18:12,349
they're you know one one thousandth the

403
00:18:09,380 --> 00:18:15,200
size of our Milky Way there are some

404
00:18:12,349 --> 00:18:17,808
giant elliptical galaxies that are about

405
00:18:15,200 --> 00:18:20,419
30 40 trillion solar masses okay so

406
00:18:17,808 --> 00:18:22,220
they're ten ten to twenty times the size

407
00:18:20,419 --> 00:18:24,409
in the Milky Way so we're in the large

408
00:18:22,220 --> 00:18:25,850
galaxy we're not in the extra-large but

409
00:18:24,409 --> 00:18:29,330
we're certainly not in the door sighs

410
00:18:25,849 --> 00:18:41,089
okay so we if we fit in reasonably well

411
00:18:29,329 --> 00:18:44,119
okay yes as we look at different pieces

412
00:18:41,089 --> 00:18:46,158
of the sky yes when you take an

413
00:18:44,119 --> 00:18:48,619
observation all right so the question is

414
00:18:46,159 --> 00:18:50,899
the density of galaxies the same in all

415
00:18:48,619 --> 00:18:53,000
these different deep fields when you

416
00:18:50,898 --> 00:18:56,898
take an observation to the same depth

417
00:18:53,000 --> 00:18:58,519
okay so you know if you go to I think

418
00:18:56,898 --> 00:19:01,129
the Deep Field goes to almost 30th

419
00:18:58,519 --> 00:19:02,509
magnitude that's how that's how and if

420
00:19:01,130 --> 00:19:05,240
you take another thirtieth magnitude

421
00:19:02,509 --> 00:19:09,038
Deep Field you get similar numbers of

422
00:19:05,240 --> 00:19:12,980
galaxies yes we have not seen any

423
00:19:09,038 --> 00:19:14,538
discrepancy from the the number counts

424
00:19:12,980 --> 00:19:15,649
in this direction over here and the

425
00:19:14,538 --> 00:19:16,669
number counts in this direction over

426
00:19:15,648 --> 00:19:18,558
here and the number counts in this

427
00:19:16,669 --> 00:19:20,750
direction over here they all seem to be

428

00:19:18,558 --> 00:19:22,730
you know roughly the same now they're

429
00:19:20,750 --> 00:19:24,798
not exactly the same of course but you

430
00:19:22,730 --> 00:19:26,630
know minor very minor variations we do

431
00:19:24,798 --> 00:19:28,730
not see any large variations in that

432
00:19:26,630 --> 00:19:33,100
okay all right thank you for the

433
00:19:28,730 --> 00:19:33,099
questions let me bring up our speakers

434
00:19:41,880 --> 00:19:50,350
okay our speaker tonight is Joleen

435
00:19:46,630 --> 00:19:53,830
Karlberg and you work in your work on

436
00:19:50,349 --> 00:19:56,589
stiff switch what group is that in it's

437
00:19:53,829 --> 00:19:58,720
it's Hyannis I&S we have all these

438
00:19:56,589 --> 00:20:00,250
acronyms and I gotta tell you I don't

439
00:19:58,720 --> 00:20:01,769
pay attention every single one of them

440
00:20:00,250 --> 00:20:05,410
but she works on the Space Telescope

441
00:20:01,769 --> 00:20:07,779
imaging spectrograph and the user

442
00:20:05,410 --> 00:20:10,360

support group and we were talking about

443

00:20:07,779 --> 00:20:13,450

this yesterday and she does amazing work

444

00:20:10,359 --> 00:20:16,149

to help the astronomers who are using

445

00:20:13,450 --> 00:20:19,029

Hubble to understand exactly how to use

446

00:20:16,150 --> 00:20:21,940

it and get the maximum science but the

447

00:20:19,029 --> 00:20:23,799

folks in our building not only do their

448

00:20:21,940 --> 00:20:26,049

functional work like that but they also

449

00:20:23,799 --> 00:20:27,220

do their amazing science and she'll tell

450

00:20:26,049 --> 00:20:34,599

you about it tonight ladies and Emin

451

00:20:27,220 --> 00:20:37,120

Joleen Karlberg all right thank you very

452

00:20:34,599 --> 00:20:38,740

much I'm really excited to come here

453

00:20:37,119 --> 00:20:39,879

today to talk to you because it's one of

454

00:20:38,740 --> 00:20:42,039

my absolute favorite things to talk

455

00:20:39,880 --> 00:20:46,030

about which is how exoplanets are going

456

00:20:42,039 --> 00:20:49,629

to be consumed by their stars so I think

457
00:20:46,029 --> 00:20:52,420
right now is a very exciting time in the

458
00:20:49,630 --> 00:20:55,660
world of astronomy because right now we

459
00:20:52,420 --> 00:20:57,600
know of thousands of planets exoplanets

460
00:20:55,660 --> 00:21:00,910
orbiting stars other than our Sun and

461
00:20:57,599 --> 00:21:04,089
because of this wide number of planets

462
00:21:00,910 --> 00:21:06,250
that we know we have found worlds that

463
00:21:04,089 --> 00:21:08,109
are very different from our own we have

464
00:21:06,250 --> 00:21:09,880
found planets that are unlike anything

465
00:21:08,109 --> 00:21:12,429
we would have imagined nature being able

466
00:21:09,880 --> 00:21:14,800
to put together and we're able to see

467
00:21:12,430 --> 00:21:16,509
planets around their stars at various

468
00:21:14,799 --> 00:21:18,849
stages of their star lot they're stars

469
00:21:16,509 --> 00:21:20,529
lives which allow people like me to do

470
00:21:18,849 --> 00:21:22,750
my research and try to think about what

471
00:21:20,529 --> 00:21:24,549
is going to happen when the stars evolve

472
00:21:22,750 --> 00:21:27,220
and what is going to happen to their

473
00:21:24,549 --> 00:21:28,359
planets so throughout this talk I'm

474
00:21:27,220 --> 00:21:30,160
going to be covering a couple of

475
00:21:28,359 --> 00:21:31,449
different things first I want to talk to

476
00:21:30,160 --> 00:21:33,880
you a little bit about what we know

477
00:21:31,450 --> 00:21:36,309
about the population of exoplanets that

478
00:21:33,880 --> 00:21:37,930
we have discovered thus far and then I'm

479
00:21:36,309 --> 00:21:39,639
going to talk a little bit about basic

480
00:21:37,930 --> 00:21:42,130
stellar evolution so you can get an idea

481
00:21:39,640 --> 00:21:43,690
of what the overall lifecycle of a star

482
00:21:42,130 --> 00:21:45,490
is so that you can have a better sense

483
00:21:43,690 --> 00:21:47,890
of how it impacts the planets around it

484
00:21:45,490 --> 00:21:51,309
and then I'm going to talk more about

485

00:21:47,890 --> 00:21:52,810
the meet of my talk which is the actual

486
00:21:51,309 --> 00:21:54,519
ways that planets are going to be

487
00:21:52,809 --> 00:21:55,329
destroyed by their stars which is very

488
00:21:54,519 --> 00:21:57,759
fun

489
00:21:55,329 --> 00:21:59,139
not a little bit more bit and then I'll

490
00:21:57,759 --> 00:22:00,339
kind of wrap up and try to give you a

491
00:21:59,140 --> 00:22:01,720
sense of some of the really exciting

492
00:22:00,339 --> 00:22:04,480
things that I think are coming down the

493
00:22:01,720 --> 00:22:06,009
pipeline in the next few years Frank

494
00:22:04,480 --> 00:22:08,470
talked about how there's going to be a

495
00:22:06,009 --> 00:22:09,970
plethora of data coming in the next 10

496
00:22:08,470 --> 00:22:12,130
years but I think we're really there

497
00:22:09,970 --> 00:22:13,839
already and even in the next one or two

498
00:22:12,130 --> 00:22:18,100
years we're going to have a firehose of

499
00:22:13,839 --> 00:22:20,019

data coming in all right so just some

500

00:22:18,099 --> 00:22:22,449

basics of exoplanets

501

00:22:20,019 --> 00:22:23,829

there are really two key characteristics

502

00:22:22,450 --> 00:22:25,539

that astronomers like to think about

503

00:22:23,829 --> 00:22:28,179

when we characterize planets that we

504

00:22:25,539 --> 00:22:29,889

discover one is how big they are and

505

00:22:28,180 --> 00:22:32,170

this can refer to either the mass of the

506

00:22:29,890 --> 00:22:33,820

planet or its physical radius and the

507

00:22:32,170 --> 00:22:36,610

other is the distance of the planet to

508

00:22:33,819 --> 00:22:37,960

its star so if you follow news articles

509

00:22:36,609 --> 00:22:39,699

about the latest discoveries that

510

00:22:37,960 --> 00:22:41,890

astronomers have an exoplanets you will

511

00:22:39,700 --> 00:22:45,250

frequently hear terms like a hot Jupiter

512

00:22:41,890 --> 00:22:48,190

or a warm Neptune or a cold this or you

513

00:22:45,250 --> 00:22:50,230

know warm that and really what this is

514
00:22:48,190 --> 00:22:52,029
trying to convey to you is roughly how

515
00:22:50,230 --> 00:22:54,759
big is this planet and roughly how close

516
00:22:52,029 --> 00:22:56,859
is it to the star so the hot warm cold

517
00:22:54,759 --> 00:22:58,480
is telling you is a you know really

518
00:22:56,859 --> 00:23:00,849
close by and getting cooked or is it so

519
00:22:58,480 --> 00:23:06,069
far away that the star's light really

520
00:23:00,849 --> 00:23:09,429
doesn't matter now when I'm applauding

521
00:23:06,069 --> 00:23:11,289
here is our up-to-date knowledge as of a

522
00:23:09,430 --> 00:23:13,779
few weeks ago of all of the confirmed

523
00:23:11,289 --> 00:23:15,789
planets around other stars and we've

524
00:23:13,779 --> 00:23:17,950
take a few minutes to explain the axes

525
00:23:15,789 --> 00:23:19,960
here so on the bottom which is a little

526
00:23:17,950 --> 00:23:21,850
bit more cut off than I was hoping is

527
00:23:19,960 --> 00:23:25,690
showing the separation of a planet from

528
00:23:21,849 --> 00:23:28,029
its host star and on the axis on the y

529
00:23:25,690 --> 00:23:31,150
axis I'm showing how massive the planet

530
00:23:28,029 --> 00:23:32,829
is in this plot and a lot of the plots

531
00:23:31,150 --> 00:23:34,240
that I'm showing the axes are going to

532
00:23:32,829 --> 00:23:36,399
be logarithmic which means they're going

533
00:23:34,240 --> 00:23:38,559
to be stepping in powers of 10 so in

534
00:23:36,400 --> 00:23:41,080
this case one refers to the separation

535
00:23:38,559 --> 00:23:42,879
of Earth from the Sun and will he step

536
00:23:41,079 --> 00:23:46,419
in powers of 10 times farther and a

537
00:23:42,880 --> 00:23:49,750
hundred times farther 1/10 1/100 etc and

538
00:23:46,420 --> 00:23:51,820
the y-axis here is scale to the mass of

539
00:23:49,750 --> 00:23:53,940
Jupiter so one here is the mass of

540
00:23:51,819 --> 00:23:58,569
Jupiter these are 10 times more massive

541
00:23:53,940 --> 00:24:00,130
1/10 1/100 etc so the big circles that

542

00:23:58,569 --> 00:24:02,470

I've drawn on here are the planets in

543

00:24:00,130 --> 00:24:03,940

our solar system and all of these other

544

00:24:02,470 --> 00:24:06,309

colored points are the planets that we

545

00:24:03,940 --> 00:24:07,870

know that exist around other stars the

546

00:24:06,309 --> 00:24:08,480

color coding of the points tell you how

547

00:24:07,869 --> 00:24:11,569

the planets

548

00:24:08,480 --> 00:24:14,929

discovered and you'll notice that this

549

00:24:11,569 --> 00:24:17,480

large swath of pink triangles are these

550

00:24:14,929 --> 00:24:19,790

are discovered by the transit method and

551

00:24:17,480 --> 00:24:24,200

the vast majority of them by the Kepler

552

00:24:19,789 --> 00:24:27,230

telescope itself now you'll notice that

553

00:24:24,200 --> 00:24:28,910

there still aren't very many things that

554

00:24:27,230 --> 00:24:31,819

we've discovered that look like the

555

00:24:28,910 --> 00:24:33,500

planets in our solar system but the

556

00:24:31,819 --> 00:24:35,029

reason for that isn't necessarily that

557

00:24:33,500 --> 00:24:37,069
they don't exist it's the fact that

558

00:24:35,029 --> 00:24:39,019
things that are in the top left portion

559

00:24:37,069 --> 00:24:40,609
of the plot are just easier to find so

560

00:24:39,019 --> 00:24:43,308
the more massive you are the bigger you

561

00:24:40,609 --> 00:24:44,509
are the easier it is to find and for

562

00:24:43,308 --> 00:24:46,279
most of the techniques that we've used

563

00:24:44,509 --> 00:24:48,289
thus far the closer you are to the star

564

00:24:46,279 --> 00:24:49,819
the easier they are to find and so this

565

00:24:48,289 --> 00:24:53,149
drop-off in this direction is just

566

00:24:49,819 --> 00:24:55,099
because we can't find anything however

567

00:24:53,150 --> 00:24:57,370
what I would like to point out for

568

00:24:55,099 --> 00:24:59,959
starters is this huge grouping of

569

00:24:57,369 --> 00:25:03,199
planets right here which you'll notice

570

00:24:59,960 --> 00:25:05,419
our terrestrial planets sit below this

571
00:25:03,200 --> 00:25:07,610
box and our ice and gas tray and sit

572
00:25:05,419 --> 00:25:09,770
above so Kepler has discovered this

573
00:25:07,609 --> 00:25:11,149
class of planets for which we have no

574
00:25:09,769 --> 00:25:13,759
examples in our solar system

575
00:25:11,150 --> 00:25:15,380
and so here terms like super Earths and

576
00:25:13,759 --> 00:25:17,929
mini Neptune's to describe the fact that

577
00:25:15,380 --> 00:25:19,640
we don't really know exactly what we

578
00:25:17,929 --> 00:25:21,830
expect for the composition and structure

579
00:25:19,640 --> 00:25:23,929
of these planets to be and so I think

580
00:25:21,829 --> 00:25:27,529
these are a really exciting thing that

581
00:25:23,929 --> 00:25:31,030
we that Kepler has discovered and these

582
00:25:27,529 --> 00:25:33,558
things are intrinsically popular

583
00:25:31,029 --> 00:25:35,418
abundant because like I said these

584
00:25:33,558 --> 00:25:37,910
things are easier to find so the fact

585
00:25:35,419 --> 00:25:39,710
that we find so many down here and

586
00:25:37,910 --> 00:25:43,880
they're harder to find means they are

587
00:25:39,710 --> 00:25:47,029
much much much more common however I do

588
00:25:43,880 --> 00:25:48,559
also find things in this box also be

589
00:25:47,029 --> 00:25:50,710
extremely interesting these are one of

590
00:25:48,558 --> 00:25:53,089
the first types of planets that

591
00:25:50,710 --> 00:25:55,308
astronomers discovered which we termed

592
00:25:53,089 --> 00:25:56,928
hot Jupiters which we didn't expect at

593
00:25:55,308 --> 00:25:59,539
all so these are things as massive or

594
00:25:56,929 --> 00:26:01,100
sometimes more massive than Jupiter that

595
00:25:59,539 --> 00:26:03,379
are sitting at distances that are

596
00:26:01,099 --> 00:26:05,959
significantly significantly closer to

597
00:26:03,380 --> 00:26:08,210
the star than mercury is and so why I

598
00:26:05,960 --> 00:26:09,798
think that's interesting is that if we

599

00:26:08,210 --> 00:26:11,870
drop for a little mercury into the Sun

600
00:26:09,798 --> 00:26:14,119
we might not not expect much to happen

601
00:26:11,869 --> 00:26:15,798
but if you start dropping things or the

602
00:26:14,119 --> 00:26:17,418
size of Jupiter are bigger into its host

603
00:26:15,798 --> 00:26:20,599
star you might actually have a chance of

604
00:26:17,419 --> 00:26:24,380
seeing the effects of that engulfment

605
00:26:20,599 --> 00:26:25,609
by studying the star itself okay so I

606
00:26:24,380 --> 00:26:27,019
promise to tell you a little bit about

607
00:26:25,609 --> 00:26:29,479
the different types of stars in here and

608
00:26:27,019 --> 00:26:31,009
how they evolved so this representation

609
00:26:29,480 --> 00:26:33,159
here is a very famous

610
00:26:31,009 --> 00:26:38,139
hertzsprung-russell diagram which plots

611
00:26:33,159 --> 00:26:40,880
the last pointer here which plots the

612
00:26:38,138 --> 00:26:43,339
temperature of the star from hot to cool

613
00:26:40,880 --> 00:26:46,340

versus the intrinsic brightness on the

614

00:26:43,339 --> 00:26:48,079

star from dim to very bright and we

615

00:26:46,339 --> 00:26:49,939

discovered that the majority of stars

616

00:26:48,079 --> 00:26:51,769

fall along this diagonal line which has

617

00:26:49,940 --> 00:26:53,808

turned the main sequence this is where

618

00:26:51,769 --> 00:26:55,339

stars will fall when they first become

619

00:26:53,808 --> 00:26:57,470

stars and are fusing hydrogen to helium

620

00:26:55,339 --> 00:26:59,089

in their course and this is a mass

621

00:26:57,470 --> 00:27:01,490

sequence these are very massive things

622

00:26:59,089 --> 00:27:02,778

these are very low-mass things but then

623

00:27:01,490 --> 00:27:04,278

as the stars evolved they will

624

00:27:02,778 --> 00:27:05,839

eventually become the type of stars that

625

00:27:04,278 --> 00:27:07,220

I like this today which are about giant

626

00:27:05,839 --> 00:27:08,240

stars and these are the stars that I'm

627

00:27:07,220 --> 00:27:11,659

going to be talking about a lot

628
00:27:08,240 --> 00:27:14,120
throughout this talk now to give you a

629
00:27:11,659 --> 00:27:15,620
sense of what we may not know about

630
00:27:14,119 --> 00:27:19,069
these stars I'm gonna run in this

631
00:27:15,619 --> 00:27:21,018
animation showing how stars evolve so at

632
00:27:19,069 --> 00:27:23,269
the very beginning of this animation all

633
00:27:21,019 --> 00:27:25,519
of those stars fell along the main

634
00:27:23,269 --> 00:27:27,288
sequence because the model was initiated

635
00:27:25,519 --> 00:27:30,230
for when all of these stars originally

636
00:27:27,288 --> 00:27:32,599
became stars and you'll notice that the

637
00:27:30,230 --> 00:27:34,339
top part of the diagram these massive

638
00:27:32,599 --> 00:27:36,109
stars evolve off really quickly so

639
00:27:34,339 --> 00:27:39,109
massive stars have short lives and

640
00:27:36,109 --> 00:27:41,178
you'll see when they become giants they

641
00:27:39,109 --> 00:27:44,209
pass out of this region really quickly

642
00:27:41,179 --> 00:27:46,700
so that the main sequence lifetime is

643
00:27:44,210 --> 00:27:48,740
relatively long but when stars become

644
00:27:46,700 --> 00:27:50,690
red giants they don't stay there for

645
00:27:48,740 --> 00:27:53,000
very long before they continue on and

646
00:27:50,690 --> 00:27:55,038
die so if you took a group of stars that

647
00:27:53,000 --> 00:27:56,388
formed all at the same time and observe

648
00:27:55,038 --> 00:27:59,388
them sometime today

649
00:27:56,388 --> 00:28:00,619
how many the most massive star that is

650
00:27:59,388 --> 00:28:03,528
still a main sequence or gives you a

651
00:28:00,619 --> 00:28:05,508
rough sense of how old that population

652
00:28:03,528 --> 00:28:07,190
of stars are and all of the stars that

653
00:28:05,509 --> 00:28:12,169
are currently red giants are actually

654
00:28:07,190 --> 00:28:13,610
almost all of identical mass and this is

655
00:28:12,169 --> 00:28:15,649
just to give a representation of just

656

00:28:13,609 --> 00:28:17,808
how big stars get when they become red

657
00:28:15,648 --> 00:28:20,599
giants so down here in this little

658
00:28:17,808 --> 00:28:22,878
corner if you can see is our Sun and to

659
00:28:20,599 --> 00:28:25,189
scale are the sizes of some well-known

660
00:28:22,878 --> 00:28:27,109
red giant stars that are naked I'd

661
00:28:25,190 --> 00:28:29,570
object so this is Pollux in the

662
00:28:27,109 --> 00:28:33,619
constellation Gemini our Taurus and

663
00:28:29,569 --> 00:28:34,369
Aldebaran but what I think is a bit more

664
00:28:33,619 --> 00:28:36,079
illuminating

665
00:28:34,369 --> 00:28:37,969
if how the sizes of these stars compared

666
00:28:36,079 --> 00:28:40,359
to the known separations between stars

667
00:28:37,970 --> 00:28:42,529
and planets so at what I'm showing here

668
00:28:40,359 --> 00:28:45,769
is the same plot I showed you earlier

669
00:28:42,529 --> 00:28:47,629
except now I'm showing where the Sun the

670
00:28:45,769 --> 00:28:49,579

edge of the sun's radius extends to

671

00:28:47,630 --> 00:28:52,400
scale on this plot which is not

672

00:28:49,579 --> 00:28:54,799
particularly interesting for the Sun but

673

00:28:52,400 --> 00:28:56,660
with the Sun becomes a red giant star

674

00:28:54,799 --> 00:28:59,450
and starts to become as big as these red

675

00:28:56,660 --> 00:29:01,279
giants like Pollux and our Taurus and

676

00:28:59,450 --> 00:29:03,620
Aldebaran you'll notice that it's radius

677

00:29:01,279 --> 00:29:06,529
is going to increase to a substantial

678

00:29:03,619 --> 00:29:07,969
fraction of the radius or of the

679

00:29:06,529 --> 00:29:10,190
distance to mercury in our solar system

680

00:29:07,970 --> 00:29:12,470
and then when you look at all of these

681

00:29:10,190 --> 00:29:14,000
other solar systems axial solar systems

682

00:29:12,470 --> 00:29:15,769
you see that many of these planets are

683

00:29:14,000 --> 00:29:17,808
at distances that are going to be inside

684

00:29:15,769 --> 00:29:21,410
the future' radius of their stars so

685
00:29:17,808 --> 00:29:23,750
these guys are goners but it turns out

686
00:29:21,410 --> 00:29:26,179
from a planet's point of view the story

687
00:29:23,750 --> 00:29:29,150
is even worse and that's because you

688
00:29:26,179 --> 00:29:31,670
cannot neglect the force of tides raised

689
00:29:29,150 --> 00:29:33,050
on the star by the planet so you're

690
00:29:31,670 --> 00:29:35,929
probably familiar with tides on earth

691
00:29:33,049 --> 00:29:39,230
this is due to the presence of the moon

692
00:29:35,929 --> 00:29:40,610
the nice washy water on the earth it

693
00:29:39,230 --> 00:29:42,529
feels the gravitational attraction of

694
00:29:40,609 --> 00:29:45,949
the Moon which pulls it into this kind

695
00:29:42,529 --> 00:29:47,750
of bulgy shape so this in this case I'm

696
00:29:45,950 --> 00:29:49,069
showing what the star looked like before

697
00:29:47,750 --> 00:29:51,289
you put a planet really close to it

698
00:29:49,069 --> 00:29:53,899
which forms this tidal bulge and this is

699
00:29:51,289 --> 00:29:57,200
due to the fact that the part of the

700
00:29:53,900 --> 00:29:59,030
body that is closer to in this case the

701
00:29:57,200 --> 00:30:00,620
planet feels a noticeably stronger

702
00:29:59,029 --> 00:30:01,779
gravity than the far side of the same

703
00:30:00,619 --> 00:30:05,029
object

704
00:30:01,779 --> 00:30:07,789
now if neither object were moving this

705
00:30:05,029 --> 00:30:10,250
is what this situation would continue to

706
00:30:07,789 --> 00:30:11,960
look like however in general the stars

707
00:30:10,250 --> 00:30:15,019
rotating and the planet is orbiting

708
00:30:11,960 --> 00:30:17,720
around it now if the planet is going

709
00:30:15,019 --> 00:30:19,690
slower around the star then the way that

710
00:30:17,720 --> 00:30:22,250
this star spins

711
00:30:19,690 --> 00:30:23,600
you'll be in the situation like you are

712
00:30:22,250 --> 00:30:25,700
with the Earth Moon system the earth

713

00:30:23,599 --> 00:30:29,619
spins once every 24 days the moon goes

714
00:30:25,700 --> 00:30:33,019
around once every month which means this

715
00:30:29,619 --> 00:30:36,139
this title bold of the fast spinning

716
00:30:33,019 --> 00:30:39,319
totally distorted body tends to lead

717
00:30:36,140 --> 00:30:41,720
where the position of the body that's

718
00:30:39,319 --> 00:30:43,159
causing the tide is and what this means

719
00:30:41,720 --> 00:30:45,319
is you kind of introduce a torque into

720
00:30:43,160 --> 00:30:48,080
the system gravity wants to realign this

721
00:30:45,319 --> 00:30:49,399
along a straight line to the planet

722
00:30:48,079 --> 00:30:51,169
so if you can think about the star

723
00:30:49,400 --> 00:30:53,000
trying to be pulled backwards and I

724
00:30:51,170 --> 00:30:56,210
should say in in this scenario both

725
00:30:53,000 --> 00:30:57,440
things are rotating counterclockwise so

726
00:30:56,210 --> 00:30:59,029
the gravity is going to try to pull this

727
00:30:57,440 --> 00:31:01,130

in a clockwise direction which is going

728

00:30:59,029 --> 00:31:02,509

to slow down the star you have angular

729

00:31:01,130 --> 00:31:04,430

momentum to the planet and push it

730

00:31:02,509 --> 00:31:05,839

outward the earth is doing this to the

731

00:31:04,430 --> 00:31:08,200

moon we are slowly pushing the moon away

732

00:31:05,839 --> 00:31:10,490

from us and we are slowly slowing down

733

00:31:08,200 --> 00:31:12,410

however if you're in the opposite

734

00:31:10,490 --> 00:31:14,089

rotation case where the star in this

735

00:31:12,410 --> 00:31:15,680

case is going slowly and the planet is

736

00:31:14,089 --> 00:31:18,169

orbiting quickly the angular momentum

737

00:31:15,680 --> 00:31:20,630

goes in the other direction and so the

738

00:31:18,170 --> 00:31:22,880

star spins faster and the planet gets

739

00:31:20,630 --> 00:31:24,680

pulled in closer but then once the

740

00:31:22,880 --> 00:31:27,380

planet is pulled in closer it actually

741

00:31:24,680 --> 00:31:29,509

raises a stronger title it has a

742
00:31:27,380 --> 00:31:30,860
stronger title interaction which means

743
00:31:29,509 --> 00:31:32,629
all of these processes have been much

744
00:31:30,859 --> 00:31:35,719
faster and it turns out the planet will

745
00:31:32,630 --> 00:31:36,590
rapidly spiral into the star and so on

746
00:31:35,720 --> 00:31:38,960
that plot that I showed you before

747
00:31:36,589 --> 00:31:40,519
really you need to go five times the

748
00:31:38,960 --> 00:31:42,049
radius of the star those are all the

749
00:31:40,519 --> 00:31:44,450
planets that actually really need to be

750
00:31:42,049 --> 00:31:47,960
worried that it's going to fall into its

751
00:31:44,450 --> 00:31:50,029
star so hopefully by this one I've

752
00:31:47,960 --> 00:31:51,350
convinced you that planets are going to

753
00:31:50,029 --> 00:31:53,180
be eaten by their stars there's no

754
00:31:51,349 --> 00:31:54,889
escaping it so the next interesting

755
00:31:53,180 --> 00:31:56,870
question that we can ask is what exactly

756
00:31:54,890 --> 00:31:58,940
happens to these planets and so I've

757
00:31:56,869 --> 00:32:01,099
listed here three different physical

758
00:31:58,940 --> 00:32:03,259
processes that might actually destroy

759
00:32:01,099 --> 00:32:04,689
your planet break it up into bits and do

760
00:32:03,259 --> 00:32:07,519
all sorts of fun things like that to it

761
00:32:04,690 --> 00:32:10,100
the first one is tidal disruption and

762
00:32:07,519 --> 00:32:13,000
this is the idea again related to the

763
00:32:10,099 --> 00:32:16,399
tidal effects the fact that in certain

764
00:32:13,000 --> 00:32:18,200
gravity scenarios the gravity on the

765
00:32:16,400 --> 00:32:19,610
closer side compared to the gravity

766
00:32:18,200 --> 00:32:23,539
filter on the farther side of an object

767
00:32:19,609 --> 00:32:25,519
matters and can be very strong so in

768
00:32:23,539 --> 00:32:27,649
this case if an object gets too close to

769
00:32:25,519 --> 00:32:29,269
a massive thing the that title

770

00:32:27,650 --> 00:32:30,830
stretching across the planet can

771
00:32:29,269 --> 00:32:32,539
actually just pull it apart pull it

772
00:32:30,829 --> 00:32:33,769
apart it'll be stronger than the energy

773
00:32:32,539 --> 00:32:36,529
that's used to hold the planet together

774
00:32:33,769 --> 00:32:38,269
and we think that this is part of what

775
00:32:36,529 --> 00:32:40,009
can be responsible for performing rings

776
00:32:38,269 --> 00:32:41,660
around planets in our solar system if

777
00:32:40,009 --> 00:32:44,150
small rocky bodies get close enough they

778
00:32:41,660 --> 00:32:47,600
can be totally shredded and pulled to

779
00:32:44,150 --> 00:32:50,300
bits a somewhat related phenomenon is

780
00:32:47,599 --> 00:32:51,919
one that's well studied in the studying

781
00:32:50,299 --> 00:32:54,649
binary stars just called Roche lobe

782
00:32:51,920 --> 00:32:56,960
overflow and in this case what you want

783
00:32:54,650 --> 00:32:58,550
to think about is the idea we would

784
00:32:56,960 --> 00:33:00,538

think about space-time as being like a

785

00:32:58,549 --> 00:33:02,519
sheet of like a rubber mat

786

00:33:00,538 --> 00:33:04,138
if you take two massive bodies and drop

787

00:33:02,519 --> 00:33:06,269
them on they form little gravity wells

788

00:33:04,138 --> 00:33:08,819
and so that's what's illustrated here so

789

00:33:06,269 --> 00:33:10,979
a more massive body has a deeper gravity

790

00:33:08,819 --> 00:33:12,448
well than a less massive body and so

791

00:33:10,979 --> 00:33:14,069
this cutout is showing if you were

792

00:33:12,449 --> 00:33:16,859
looking down on the system and draw

793

00:33:14,069 --> 00:33:19,588
regions where the gravity potential

794

00:33:16,858 --> 00:33:21,538
feels the same you get you got this

795

00:33:19,588 --> 00:33:23,278
bottom plot here and you can see that

796

00:33:21,538 --> 00:33:26,759
cliffs into the two each of these

797

00:33:23,278 --> 00:33:28,858
objects it's roughly circular so you can

798

00:33:26,759 --> 00:33:30,449
imagine so if this is a star and this is

799
00:33:28,858 --> 00:33:33,118
a planet you can imagine that if the

800
00:33:30,449 --> 00:33:35,459
planet is big and puffy enough and

801
00:33:33,118 --> 00:33:38,368
becomes bigger than the region around it

802
00:33:35,459 --> 00:33:39,989
where it's gravity wins then the outer

803
00:33:38,368 --> 00:33:42,088
layers of the star can actually start to

804
00:33:39,989 --> 00:33:43,919
spill over from that object and fall

805
00:33:42,088 --> 00:33:47,578
down into the gravity well of the star

806
00:33:43,919 --> 00:33:49,799
so that's Russia logo for flow now the

807
00:33:47,578 --> 00:33:51,658
other scenario is that if the planet

808
00:33:49,798 --> 00:33:54,118
manages to avoid both of these scenarios

809
00:33:51,659 --> 00:33:55,739
and actually come in contact to the

810
00:33:54,118 --> 00:33:57,658
outer layers or even deeper layers of

811
00:33:55,739 --> 00:33:59,419
the star then you're going to have

812
00:33:57,659 --> 00:34:01,559
processes such as ablation or

813
00:33:59,419 --> 00:34:05,989
vaporization where you're just stripping

814
00:34:01,558 --> 00:34:11,009
off the material from from the planet so

815
00:34:05,989 --> 00:34:13,500
where do these occur it turns out that

816
00:34:11,009 --> 00:34:15,240
some of the details of how and when and

817
00:34:13,500 --> 00:34:18,059
where a planet destroy is destroyed

818
00:34:15,239 --> 00:34:20,128
depends a lot on how evolved the star is

819
00:34:18,059 --> 00:34:21,539
when it happens so just to give you a

820
00:34:20,128 --> 00:34:23,159
sense of the difference of stars here's

821
00:34:21,539 --> 00:34:26,519
an example of the interior of a sun-like

822
00:34:23,159 --> 00:34:28,500
star which has a very thin convection

823
00:34:26,518 --> 00:34:30,298
zone so the convection is the part of

824
00:34:28,500 --> 00:34:31,559
the star outside of the outside of the

825
00:34:30,298 --> 00:34:35,788
star which is basically kind of boiling

826
00:34:31,559 --> 00:34:37,230
and here is an interior view of a red

827

00:34:35,789 --> 00:34:41,129
giant star which has a much deeper

828
00:34:37,230 --> 00:34:43,139
region of convection now one of the

829
00:34:41,128 --> 00:34:44,878
interesting things to note is that when

830
00:34:43,139 --> 00:34:46,980
you do the calculations for things like

831
00:34:44,878 --> 00:34:50,940
the tidal disruption and the role of

832
00:34:46,980 --> 00:34:53,219
overflow those calculations work out to

833
00:34:50,940 --> 00:34:55,139
be the same no matter what the mass of

834
00:34:53,219 --> 00:34:56,699
the star is and so if you take a

835
00:34:55,139 --> 00:34:58,858
sun-like star and evolve it to a red

836
00:34:56,699 --> 00:35:03,328
giant the point at which Roche lobe

837
00:34:58,858 --> 00:35:05,880
overflow occurs only depends on the

838
00:35:03,329 --> 00:35:08,880
masses of these things and so in this

839
00:35:05,880 --> 00:35:10,470
case here if the star is a sort of

840
00:35:08,880 --> 00:35:12,970
smallish red giant that hasn't evolved

841
00:35:10,469 --> 00:35:15,578

very far you can see in both cases

842

00:35:12,969 --> 00:35:16,989

you know the Jupiter will undergo rocha

843

00:35:15,579 --> 00:35:19,329

love overflow before it gets to the

844

00:35:16,989 --> 00:35:21,639

surface of the star but if this is one

845

00:35:19,329 --> 00:35:23,230

of those much larger red giant stars

846

00:35:21,639 --> 00:35:26,199

like I talked about like more like and

847

00:35:23,230 --> 00:35:28,389

Arcturus adore Aldebaran that is many

848

00:35:26,199 --> 00:35:30,429

times the solar radius and the Jupiter

849

00:35:28,389 --> 00:35:32,469

will actually can remain intact before

850

00:35:30,429 --> 00:35:36,278

something like commercial overflow would

851

00:35:32,469 --> 00:35:38,018

occur and similarly for a small compact

852

00:35:36,278 --> 00:35:40,480

bodies like the earth tidal disruption

853

00:35:38,018 --> 00:35:43,508

is more likely way of destroying these

854

00:35:40,480 --> 00:35:45,579

and even for the present-day Sun the

855

00:35:43,509 --> 00:35:46,869

earth can actually plop itself into the

856
00:35:45,579 --> 00:35:48,818
star before something like tidal

857
00:35:46,869 --> 00:35:50,380
disruption would pull it apart and so

858
00:35:48,818 --> 00:35:51,940
then you can start thinking about well

859
00:35:50,380 --> 00:35:53,318
in those situations you not have to

860
00:35:51,940 --> 00:35:55,000
start thinking about ablation and

861
00:35:53,318 --> 00:35:59,318
vaporization as a process that will

862
00:35:55,000 --> 00:36:00,730
destroy them so the next thing we want

863
00:35:59,318 --> 00:36:03,489
to think about is whether or not we can

864
00:36:00,730 --> 00:36:05,170
figure out if this engulfment of planets

865
00:36:03,489 --> 00:36:08,139
is happening if we can identify stars

866
00:36:05,170 --> 00:36:09,369
for which this has happened so I'm again

867
00:36:08,139 --> 00:36:12,429
showing that plot from the very

868
00:36:09,369 --> 00:36:14,740
beginning of the separation and masses

869
00:36:12,429 --> 00:36:16,210
of known exoplanets except now I've

870
00:36:14,739 --> 00:36:18,848
color the color code of the points

871
00:36:16,210 --> 00:36:20,259
differently these black points here are

872
00:36:18,849 --> 00:36:22,509
dwarf stars these are main sequence

873
00:36:20,259 --> 00:36:25,150
stars like our Sun whereas all of these

874
00:36:22,509 --> 00:36:26,980
color-coded points are giant stars we're

875
00:36:25,150 --> 00:36:29,318
reusing the surface gravity as a proxy

876
00:36:26,980 --> 00:36:32,019
for how large they are and one thing

877
00:36:29,318 --> 00:36:35,829
you'll notice is that there seems to be

878
00:36:32,018 --> 00:36:37,538
an absence of very large closeby planets

879
00:36:35,829 --> 00:36:39,818
which remember are the easiest to

880
00:36:37,539 --> 00:36:41,890
discover and this could be potential

881
00:36:39,818 --> 00:36:43,838
evidence that we are seeing that any

882
00:36:41,889 --> 00:36:45,730
planets that may have once existed

883
00:36:43,838 --> 00:36:49,538
around these stars no longer do and they

884

00:36:45,730 --> 00:36:51,519
may have been involved there are some

885
00:36:49,539 --> 00:36:56,049
other signatures that we can look for

886
00:36:51,518 --> 00:36:58,328
so again stars grow very large when when

887
00:36:56,048 --> 00:37:00,250
they become red giants but one thing you

888
00:36:58,329 --> 00:37:02,798
have to remember is that angular

889
00:37:00,250 --> 00:37:05,289
momentum is a conserved quantity and so

890
00:37:02,798 --> 00:37:06,759
I'm especially now based on Frank's

891
00:37:05,289 --> 00:37:09,069
story I have to bring in the ice skating

892
00:37:06,759 --> 00:37:10,539
analogy that we frequently use for

893
00:37:09,068 --> 00:37:13,239
showing conservation of angular momentum

894
00:37:10,539 --> 00:37:15,519
you picture a figure skater starting a

895
00:37:13,239 --> 00:37:18,278
spin and when he or she pulls their arms

896
00:37:15,518 --> 00:37:23,199
in they spin faster and when you expand

897
00:37:18,278 --> 00:37:25,358
again you slow down so the kind of fun

898
00:37:23,199 --> 00:37:26,529

thing about this is that for angular

899

00:37:25,358 --> 00:37:30,340
momentum

900

00:37:26,530 --> 00:37:33,070
the rate of rotation goes as a factor of

901

00:37:30,340 --> 00:37:34,870
the square of the radius so in this case

902

00:37:33,070 --> 00:37:36,820
if you take a star and increase its

903

00:37:34,869 --> 00:37:39,039
radius by a factor of four its rotation

904

00:37:36,820 --> 00:37:40,780
slows by a factor of sixteen so now if

905

00:37:39,039 --> 00:37:42,639
you can then extrapolate in your mind to

906

00:37:40,780 --> 00:37:44,019
these even like ten and a hundred times

907

00:37:42,639 --> 00:37:45,730
larger

908

00:37:44,019 --> 00:37:48,250
you then have to square those as well so

909

00:37:45,730 --> 00:37:51,670
that you really expect red giants to be

910

00:37:48,250 --> 00:37:54,219
very very slow rotators on the other

911

00:37:51,670 --> 00:37:56,139
hand if you engulf a planet then that

912

00:37:54,219 --> 00:37:57,639
planet is dumping angular momentum back

913
00:37:56,139 --> 00:37:59,529
into the system and can spin the stars

914
00:37:57,639 --> 00:38:02,769
back up and so that could be one

915
00:37:59,530 --> 00:38:05,140
signature another signature we could

916
00:38:02,769 --> 00:38:06,670
look for is pollution and so by

917
00:38:05,139 --> 00:38:08,650
pollution I have this little graphic

918
00:38:06,670 --> 00:38:11,110
here just to give you a sort of an

919
00:38:08,650 --> 00:38:13,720
analogy is if you can imagine taking a

920
00:38:11,110 --> 00:38:16,840
little dropper of dye and dropping it

921
00:38:13,719 --> 00:38:19,480
into a beaker of red water or you know

922
00:38:16,840 --> 00:38:23,260
even clear water the question is how

923
00:38:19,480 --> 00:38:24,490
much do you need to put in for you to be

924
00:38:23,260 --> 00:38:27,250
able to notice it in the much larger

925
00:38:24,489 --> 00:38:29,049
sample so you can imagine if you're you

926
00:38:27,250 --> 00:38:30,519
know putting in a dropper of additional

927
00:38:29,050 --> 00:38:31,870
red stuff in you're probably not going

928
00:38:30,519 --> 00:38:33,789
to notice but if you drop in a color

929
00:38:31,869 --> 00:38:38,469
like blue maybe you'll notice a little

930
00:38:33,789 --> 00:38:40,269
bit more so by analogy we can think

931
00:38:38,469 --> 00:38:42,069
about what the compositions of stars are

932
00:38:40,269 --> 00:38:43,690
compared to their planets to try to see

933
00:38:42,070 --> 00:38:45,880
is there a way that we can determine

934
00:38:43,690 --> 00:38:48,030
whether or not the composition of the

935
00:38:45,880 --> 00:38:50,349
star has changed in a meaningful way and

936
00:38:48,030 --> 00:38:54,040
the reason we might be able to do that

937
00:38:50,349 --> 00:38:55,509
is that stars are predominantly hydrogen

938
00:38:54,039 --> 00:38:59,340
and helium like most things in the

939
00:38:55,510 --> 00:39:01,030
universe with a very tiny slice of

940
00:38:59,340 --> 00:39:04,210
basically everything else on the

941

00:39:01,030 --> 00:39:05,860
periodic table okay so let's not think

942
00:39:04,210 --> 00:39:08,619
well what happens if we try to drop a

943
00:39:05,860 --> 00:39:10,780
Jupiter in well it turns out Jupiter is

944
00:39:08,619 --> 00:39:13,569
mostly hydrogen and mostly helium with a

945
00:39:10,780 --> 00:39:16,090
very teeny tiny percentage of everything

946
00:39:13,570 --> 00:39:17,500
else so in this scenario you can then

947
00:39:16,090 --> 00:39:19,890
imagine that you're basically taking a

948
00:39:17,500 --> 00:39:22,119
beaker of red that you're dropping into

949
00:39:19,889 --> 00:39:26,889
red material so you're not going to

950
00:39:22,119 --> 00:39:28,929
notice anything earth by contrast is has

951
00:39:26,889 --> 00:39:31,359
a completely different ratio of

952
00:39:28,929 --> 00:39:32,949
abundances helium is practically

953
00:39:31,360 --> 00:39:34,240
non-existent on the earth that's

954
00:39:32,949 --> 00:39:35,769
actually how it got its name it was

955
00:39:34,239 --> 00:39:37,899

first discovered by its spectrum in the

956

00:39:35,769 --> 00:39:39,309

Sun and so now you can imagine that

957

00:39:37,900 --> 00:39:39,769

you're dropping something that looks

958

00:39:39,309 --> 00:39:42,889

very

959

00:39:39,769 --> 00:39:44,539

different into the Sun but of course one

960

00:39:42,889 --> 00:39:46,250

of the caveats here is that earth is of

961

00:39:44,539 --> 00:39:47,179

course a much smaller thing and so even

962

00:39:46,250 --> 00:39:50,090

though it's composition is very

963

00:39:47,179 --> 00:39:51,379

different there's the concern that you

964

00:39:50,090 --> 00:39:53,660

know maybe you still wouldn't notice

965

00:39:51,380 --> 00:39:55,519

because it's so small and this is where

966

00:39:53,659 --> 00:39:56,750

the discovery of Kepler or of all those

967

00:39:55,519 --> 00:39:58,699

things that are sort of sitting between

968

00:39:56,750 --> 00:40:00,230

the terrestrials in our solar system and

969

00:39:58,699 --> 00:40:03,079

the giants in our solar system is very

970
00:40:00,230 --> 00:40:04,610
interesting because they could be scaled

971
00:40:03,079 --> 00:40:06,619
up versions of the earth which are much

972
00:40:04,610 --> 00:40:09,590
more massive but still very chemically

973
00:40:06,619 --> 00:40:14,469
different fundamentally from from their

974
00:40:09,590 --> 00:40:17,090
stars you can also take advantage of

975
00:40:14,469 --> 00:40:19,609
special elements that happen to be

976
00:40:17,090 --> 00:40:22,519
relatively rare in the star and this is

977
00:40:19,610 --> 00:40:24,050
actually field that I study a lot so

978
00:40:22,519 --> 00:40:26,239
what I'm showing here this is again on a

979
00:40:24,050 --> 00:40:27,680
logarithmic scale the relative abundance

980
00:40:26,239 --> 00:40:30,289
of all the elements of the periodic

981
00:40:27,679 --> 00:40:31,460
table as a function of their position so

982
00:40:30,289 --> 00:40:33,980
we're starting at hydrogen helium

983
00:40:31,460 --> 00:40:36,590
lithium beryllium boron and all the way

984
00:40:33,980 --> 00:40:38,780
down this nice zigzag pattern is just

985
00:40:36,590 --> 00:40:41,720
due to the way that elements are formed

986
00:40:38,780 --> 00:40:42,920
in the Centers of stars but what I would

987
00:40:41,719 --> 00:40:44,509
need to bring your attention to are

988
00:40:42,920 --> 00:40:46,519
these three elements lithium beryllium

989
00:40:44,510 --> 00:40:48,710
and boron which are very depleted in the

990
00:40:46,519 --> 00:40:51,829
Sun and this is because they happen to

991
00:40:48,710 --> 00:40:53,949
be destroyed relatively easily by what's

992
00:40:51,829 --> 00:40:56,059
called proton capture reactions at

993
00:40:53,949 --> 00:40:58,489
temperatures that are relatively cool

994
00:40:56,059 --> 00:41:02,590
from a star's perspective which is you

995
00:40:58,489 --> 00:41:05,859
know a few million degrees very chilly

996
00:41:02,590 --> 00:41:08,990
but it turns out that our sun's

997
00:41:05,860 --> 00:41:12,079
abundance of lithium is very depleted

998

00:41:08,989 --> 00:41:13,549
from what we think started so now what

999
00:41:12,079 --> 00:41:17,449
I'm showing here is if you take a sample

1000
00:41:13,550 --> 00:41:20,090
of red giant stars and look at a measure

1001
00:41:17,449 --> 00:41:22,730
their lithium abundance the present-day

1002
00:41:20,090 --> 00:41:25,160
Sun which we saw on the last plot sits

1003
00:41:22,730 --> 00:41:27,590
here the red giant stars are

1004
00:41:25,159 --> 00:41:29,899
fundamentally very very lithium poor

1005
00:41:27,590 --> 00:41:31,760
compared to that and the Sun itself is

1006
00:41:29,900 --> 00:41:33,440
quite lithium poor compared to what we

1007
00:41:31,760 --> 00:41:35,300
thought it was so this line here is

1008
00:41:33,440 --> 00:41:37,490
showing the lithium abundance we believe

1009
00:41:35,300 --> 00:41:38,870
the Sun started with we get this from

1010
00:41:37,489 --> 00:41:40,339
measurements of the relative lithium

1011
00:41:38,869 --> 00:41:42,829
abundance of things like meteorites in

1012
00:41:40,340 --> 00:41:44,780

our solar system and this lithium

1013

00:41:42,829 --> 00:41:46,730
abundance is again on a log of

1014

00:41:44,780 --> 00:41:49,160
fundamentally on a logarithmic scale so

1015

00:41:46,730 --> 00:41:50,840
every time you step by a Delta one here

1016

00:41:49,159 --> 00:41:52,819
you're stepping by another power of 10

1017

00:41:50,840 --> 00:41:53,300
so the Sun has already depleted by

1018

00:41:52,820 --> 00:41:56,120
nearly

1019

00:41:53,300 --> 00:41:58,789
a factor of a hundred from its current

1020

00:41:56,119 --> 00:42:00,289
state and red giants are can be ten a

1021

00:41:58,789 --> 00:42:02,929
hundred or even a thousand times more

1022

00:42:00,289 --> 00:42:07,759
medal for their or more lithium poorer

1023

00:42:02,929 --> 00:42:09,919
than the Sun and to put that in

1024

00:42:07,760 --> 00:42:13,040
perspective some of these most lithium

1025

00:42:09,920 --> 00:42:16,579
poor red giants actually have less total

1026

00:42:13,039 --> 00:42:19,909
lithium than a planet and so now if you

1027
00:42:16,579 --> 00:42:22,519
can imagine taking an observation of a

1028
00:42:19,909 --> 00:42:24,739
red giant star you might intrinsically

1029
00:42:22,519 --> 00:42:26,090
measure a couple of different lithium

1030
00:42:24,739 --> 00:42:27,619
abundances and you can do the

1031
00:42:26,090 --> 00:42:29,600
calculation of what happens if you start

1032
00:42:27,619 --> 00:42:32,000
dropping Jupiter's into them and add

1033
00:42:29,599 --> 00:42:35,210
that lithium to the star and you can see

1034
00:42:32,000 --> 00:42:37,309
as you add more and more planets at some

1035
00:42:35,210 --> 00:42:41,300
point the the lithium abundance that you

1036
00:42:37,309 --> 00:42:43,099
measure almost doesn't care about what

1037
00:42:41,300 --> 00:42:44,750
lithium was originally there in the star

1038
00:42:43,099 --> 00:42:46,219
because the vast majority of the lithium

1039
00:42:44,750 --> 00:42:47,960
atoms are actually coming from the stuff

1040
00:42:46,219 --> 00:42:52,369
that you've dropped in so this I think

1041
00:42:47,960 --> 00:42:53,990
is something that's really exciting but

1042
00:42:52,369 --> 00:42:56,359
then the question is alright so now that

1043
00:42:53,989 --> 00:42:58,309
we know these signatures other than you

1044
00:42:56,360 --> 00:42:59,840
know maybe not discovering planets close

1045
00:42:58,309 --> 00:43:02,360
to stars how do we go about measuring

1046
00:42:59,840 --> 00:43:05,510
these things and the way astronomers do

1047
00:43:02,360 --> 00:43:07,160
this is by using the spectra of stars so

1048
00:43:05,510 --> 00:43:10,210
we take the light from a star and we

1049
00:43:07,159 --> 00:43:14,149
break it up into the component colors

1050
00:43:10,210 --> 00:43:15,949
now the energy and light that's created

1051
00:43:14,150 --> 00:43:18,110
by the star happens deep within its core

1052
00:43:15,949 --> 00:43:20,119
on that light propagates out and so

1053
00:43:18,110 --> 00:43:22,160
right before that light leaves the star

1054
00:43:20,119 --> 00:43:23,659
it interacts with the very cool atoms

1055

00:43:22,159 --> 00:43:26,149
and molecules in the atmosphere of the

1056
00:43:23,659 --> 00:43:28,099
star and these things absorb at very

1057
00:43:26,150 --> 00:43:30,860
specific colors which leaves behind

1058
00:43:28,099 --> 00:43:32,809
these nice lines on your observed

1059
00:43:30,860 --> 00:43:35,930
spectrum so what we measure is the

1060
00:43:32,809 --> 00:43:39,409
brightness along different colors and we

1061
00:43:35,929 --> 00:43:41,629
see the absence of colors at regions

1062
00:43:39,409 --> 00:43:45,969
that tell us about the relative amount

1063
00:43:41,630 --> 00:43:49,280
of different elements in the star so

1064
00:43:45,969 --> 00:43:52,579
here is a very very very very very

1065
00:43:49,280 --> 00:43:55,510
zoomed in part of that spectrum looking

1066
00:43:52,579 --> 00:43:57,889
at a very miniscule range of wavelengths

1067
00:43:55,510 --> 00:44:00,470
of two stars that are nearly identical

1068
00:43:57,889 --> 00:44:03,019
in every way they turn out to be in the

1069
00:44:00,469 --> 00:44:04,609

same open cluster they have almost the

1070

00:44:03,019 --> 00:44:06,559

same temperature almost the same almost

1071

00:44:04,610 --> 00:44:07,579

everything that you can think of

1072

00:44:06,559 --> 00:44:09,380

but if you look at all these little

1073

00:44:07,579 --> 00:44:11,420

Wiggles here these are actually these

1074

00:44:09,380 --> 00:44:13,369

Wiggles are the absorption of light due

1075

00:44:11,420 --> 00:44:16,070

to various elements and I'm pointing

1076

00:44:13,369 --> 00:44:18,859

here to the absorption due to the atom

1077

00:44:16,070 --> 00:44:21,950

lithium and so in this case here this

1078

00:44:18,860 --> 00:44:23,480

star has this very strong lithium

1079

00:44:21,949 --> 00:44:25,369

feature and actually has more than 80

1080

00:44:23,480 --> 00:44:25,969

times the amount of lithium than this

1081

00:44:25,369 --> 00:44:28,039

star here

1082

00:44:25,969 --> 00:44:29,989

and both of these are red giant stars so

1083

00:44:28,039 --> 00:44:32,929

it does in fact actually quite easy to

1084
00:44:29,989 --> 00:44:36,319
measure very big differences in lithium

1085
00:44:32,929 --> 00:44:37,309
abundances now the rotation of stars is

1086
00:44:36,320 --> 00:44:39,230
actually something that can also be

1087
00:44:37,309 --> 00:44:41,119
relatively easy to measure so what I'm

1088
00:44:39,230 --> 00:44:43,400
showing here is the progression of what

1089
00:44:41,119 --> 00:44:45,589
happens to a spectrum if you have a star

1090
00:44:43,400 --> 00:44:48,289
that is rotating slowly and moderately

1091
00:44:45,590 --> 00:44:51,500
fast and very fast the lines of these

1092
00:44:48,289 --> 00:44:54,590
stars get broader and the reason is that

1093
00:44:51,500 --> 00:44:55,969
if your star is rotating what I've done

1094
00:44:54,590 --> 00:44:57,800
here is for this rotating star I've

1095
00:44:55,969 --> 00:44:59,389
color-coded it to indicate the red and

1096
00:44:57,800 --> 00:45:01,340
blue shift that you get because you're

1097
00:44:59,389 --> 00:45:02,599
looking at a star that's rotating part

1098
00:45:01,340 --> 00:45:04,570
of the star is coming towards you part

1099
00:45:02,599 --> 00:45:07,549
of the star is going away from you and

1100
00:45:04,570 --> 00:45:11,150
each little dot each little region on

1101
00:45:07,550 --> 00:45:13,130
the star is basically you can think of

1102
00:45:11,150 --> 00:45:16,190
as create in its own individual spectrum

1103
00:45:13,130 --> 00:45:17,390
but all of the spectra come in from this

1104
00:45:16,190 --> 00:45:19,970
part of the star is going to be slightly

1105
00:45:17,389 --> 00:45:21,230
blue shifted and all of the part coming

1106
00:45:19,969 --> 00:45:23,359
from this side of the stars are gonna be

1107
00:45:21,230 --> 00:45:25,159
slightly red shifted you can't see that

1108
00:45:23,360 --> 00:45:26,660
individually you just see the the sum

1109
00:45:25,159 --> 00:45:28,940
over all those different regions of the

1110
00:45:26,659 --> 00:45:31,129
star and so the result is that you get

1111
00:45:28,940 --> 00:45:32,450
these very broadened or very fat

1112

00:45:31,130 --> 00:45:36,890
features that tell you the star is

1113
00:45:32,449 --> 00:45:38,809
rotating quickly okay so we expect high

1114
00:45:36,889 --> 00:45:41,779
lithium and high rotation to maybe be an

1115
00:45:38,809 --> 00:45:42,860
indication of planet engulf 'men and

1116
00:45:41,780 --> 00:45:45,050
this is something that I've actually

1117
00:45:42,860 --> 00:45:46,760
started studying way back when I was

1118
00:45:45,050 --> 00:45:48,830
doing my PhD and this was one of the

1119
00:45:46,760 --> 00:45:50,450
results that came out of it right I went

1120
00:45:48,829 --> 00:45:51,739
and looked at a big sample of red giant

1121
00:45:50,449 --> 00:45:53,539
stars I measured how fast they were

1122
00:45:51,739 --> 00:45:55,399
rotating and I measured how much lithium

1123
00:45:53,539 --> 00:45:58,460
they have so here's that rotation from

1124
00:45:55,400 --> 00:46:01,130
slow to fast here and relative lithium

1125
00:45:58,460 --> 00:46:04,400
abundances from practically none to lots

1126
00:46:01,130 --> 00:46:06,650

on this axis the blue dots here are the

1127

00:46:04,400 --> 00:46:08,119

ones that were rotating faster than we

1128

00:46:06,650 --> 00:46:10,309

thought red giant should be and

1129

00:46:08,119 --> 00:46:13,130

everything over here are relatively slow

1130

00:46:10,309 --> 00:46:14,929

and the main result of this was that if

1131

00:46:13,130 --> 00:46:18,019

you look at the average difference

1132

00:46:14,929 --> 00:46:19,629

between the two on average fast rotators

1133

00:46:18,019 --> 00:46:22,900

have a have ten times more

1134

00:46:19,630 --> 00:46:24,250

lithium then the slow guys and if you

1135

00:46:22,900 --> 00:46:26,860

make a whole bunch of assumptions about

1136

00:46:24,250 --> 00:46:28,449

how much mass is in the stars on average

1137

00:46:26,860 --> 00:46:29,920

all the BLA you can kind of convert this

1138

00:46:28,449 --> 00:46:31,750

to how many planets would you might eat

1139

00:46:29,920 --> 00:46:35,110

and the answer comes out to be a couple

1140

00:46:31,750 --> 00:46:36,760

of Jupiter's however you may notice that

1141
00:46:35,110 --> 00:46:38,140
there is a very large scatter here of

1142
00:46:36,760 --> 00:46:40,510
points and I do have a little

1143
00:46:38,139 --> 00:46:41,679
representative error bar stars in

1144
00:46:40,510 --> 00:46:43,840
general can have lots of different

1145
00:46:41,679 --> 00:46:45,599
lithium abundances for things that have

1146
00:46:43,840 --> 00:46:49,450
absolutely nothing to do with planets

1147
00:46:45,599 --> 00:46:51,400
which is a problem one of the things

1148
00:46:49,449 --> 00:46:53,259
that it depends on its how much lithium

1149
00:46:51,400 --> 00:46:55,110
it started with and how much lithium it

1150
00:46:53,260 --> 00:46:57,510
destroyed and both those things very

1151
00:46:55,110 --> 00:46:59,530
sensitively on how massive the star is

1152
00:46:57,510 --> 00:47:01,630
so one of the ways you can go around

1153
00:46:59,530 --> 00:47:02,890
that is to try to get a sample of stars

1154
00:47:01,630 --> 00:47:05,320
where you think everything is the same

1155
00:47:02,889 --> 00:47:07,599
mass so what I'm gonna tell you about

1156
00:47:05,320 --> 00:47:10,960
now is one of my favorite story is the

1157
00:47:07,599 --> 00:47:13,630
story of NGC 68 19 this is gonna be a

1158
00:47:10,960 --> 00:47:15,460
longest story about some of the really

1159
00:47:13,630 --> 00:47:18,250
interesting things you can do when you

1160
00:47:15,460 --> 00:47:21,099
combine information from all sorts of

1161
00:47:18,250 --> 00:47:24,460
different methods of studying the same

1162
00:47:21,099 --> 00:47:26,529
thing so what what's shown here is a

1163
00:47:24,460 --> 00:47:27,670
color magnitude diagram so this is

1164
00:47:26,530 --> 00:47:30,550
basically like a hertzsprung-russell

1165
00:47:27,670 --> 00:47:32,260
diagram so this is the temperature or

1166
00:47:30,550 --> 00:47:34,780
color of the star so blue hot things

1167
00:47:32,260 --> 00:47:37,530
here cool red things here feature things

1168
00:47:34,780 --> 00:47:40,990
in the visible here brighter things here

1169

00:47:37,530 --> 00:47:43,060
the line here is showing what you would

1170
00:47:40,989 --> 00:47:44,979
expect for a group of stars that all

1171
00:47:43,059 --> 00:47:47,409
formed at the same time and are now all

1172
00:47:44,980 --> 00:47:49,210
at a specific age and if you remember

1173
00:47:47,409 --> 00:47:52,389
from the very beginning I said that when

1174
00:47:49,210 --> 00:47:54,130
that happens you expect a lot of stars

1175
00:47:52,389 --> 00:47:56,049
to be on the main sequence all of the

1176
00:47:54,130 --> 00:47:57,430
massive stars to be gone and the stars

1177
00:47:56,050 --> 00:47:59,680
that are currently in the red giant face

1178
00:47:57,429 --> 00:48:01,239
would be all roughly the same mass so

1179
00:47:59,679 --> 00:48:03,069
all of these purple circles are the

1180
00:48:01,239 --> 00:48:04,599
stars that are the red giants we think

1181
00:48:03,070 --> 00:48:06,910
these are all roughly the same mass and

1182
00:48:04,599 --> 00:48:09,099
this one star here which appears to be

1183
00:48:06,909 --> 00:48:11,379

right where you may expect has a lot of

1184

00:48:09,099 --> 00:48:12,699

lithium in fact it has more than 40

1185

00:48:11,380 --> 00:48:16,570

times the lithium than all the other

1186

00:48:12,699 --> 00:48:18,309

giants now I haven't talked to you too

1187

00:48:16,570 --> 00:48:21,930

much yet about why red giants have so

1188

00:48:18,309 --> 00:48:24,400

little lithium but it has to do with

1189

00:48:21,929 --> 00:48:26,829

with again with this convection region

1190

00:48:24,400 --> 00:48:29,380

in the star so when the when the star is

1191

00:48:26,829 --> 00:48:31,389

like our Sun there's a it has a very

1192

00:48:29,380 --> 00:48:32,809

thin convection region on the very edge

1193

00:48:31,389 --> 00:48:34,879

of it which is cool enough that

1194

00:48:32,809 --> 00:48:37,099

there is fine but some of that lithium

1195

00:48:34,880 --> 00:48:40,340

gets mixed down into the star where it

1196

00:48:37,099 --> 00:48:42,049

gets destroyed and is gone but that's a

1197

00:48:40,340 --> 00:48:43,579

relatively slow process and so that's

1198
00:48:42,050 --> 00:48:47,300
why the lithium and the Sun has gone

1199
00:48:43,579 --> 00:48:49,699
down pretty slowly but below that region

1200
00:48:47,300 --> 00:48:51,170
basically there's no lithium left and if

1201
00:48:49,699 --> 00:48:53,599
you go even deeper in the star there are

1202
00:48:51,170 --> 00:48:55,309
some byproducts of the nuclear fusion

1203
00:48:53,599 --> 00:48:58,250
that has powered the Sun for its entire

1204
00:48:55,309 --> 00:49:01,159
life when the star becomes a red giant

1205
00:48:58,250 --> 00:49:03,349
this mixing region goes deep into the

1206
00:49:01,159 --> 00:49:05,869
star and so it mixes it into the lithium

1207
00:49:03,349 --> 00:49:08,389
poor interior and so that's why all the

1208
00:49:05,869 --> 00:49:09,829
lithium gets diluted and so you it looks

1209
00:49:08,389 --> 00:49:12,500
like the Stars pretty much no lithium

1210
00:49:09,829 --> 00:49:14,599
and the important thing here is that it

1211
00:49:12,500 --> 00:49:16,039
also brings up some of these nuclear

1212
00:49:14,599 --> 00:49:17,690
byproducts that actually changes the

1213
00:49:16,039 --> 00:49:19,969
ratio of carbon to nitrogen in the star

1214
00:49:17,690 --> 00:49:22,070
and this star shows all the evidence

1215
00:49:19,969 --> 00:49:23,659
that it has become a red giant so we

1216
00:49:22,070 --> 00:49:25,820
know this mixing has occurred so we know

1217
00:49:23,659 --> 00:49:28,069
it should be lithium poor so that's

1218
00:49:25,820 --> 00:49:29,840
important so the first thing you can do

1219
00:49:28,070 --> 00:49:32,240
is ask yourself okay how big of a thing

1220
00:49:29,840 --> 00:49:34,220
would you need to drop in to explain the

1221
00:49:32,239 --> 00:49:35,869
lithium that we see if we assume that it

1222
00:49:34,219 --> 00:49:38,329
should have the lithium that all the

1223
00:49:35,869 --> 00:49:39,500
other stars in the cluster do and when

1224
00:49:38,329 --> 00:49:41,630
you work at the mouth it turns out to be

1225
00:49:39,500 --> 00:49:43,670
a small star which is a problem because

1226

00:49:41,630 --> 00:49:45,019
the small star also burns its lithium so

1227
00:49:43,670 --> 00:49:46,250
it's not going to supply any lithium so

1228
00:49:45,019 --> 00:49:47,920
that actually doesn't work at all so

1229
00:49:46,250 --> 00:49:51,800
that's the problem

1230
00:49:47,920 --> 00:49:53,710
another potential problem is that so

1231
00:49:51,800 --> 00:49:57,650
that lithium star was discovered in 2013

1232
00:49:53,710 --> 00:49:59,269
two years previously there was a paper

1233
00:49:57,650 --> 00:50:00,680
that brought up the possibility that

1234
00:49:59,269 --> 00:50:03,829
this star may not even be part of the

1235
00:50:00,679 --> 00:50:04,969
cluster so this was an astro seismology

1236
00:50:03,829 --> 00:50:06,440
paper I'm going to talk a little bit

1237
00:50:04,969 --> 00:50:08,000
more about asteroseismology in a minute

1238
00:50:06,440 --> 00:50:09,139
but basically what they were doing is

1239
00:50:08,000 --> 00:50:11,300
they're trying to show that there is

1240
00:50:09,139 --> 00:50:13,759

this oscillating parameter which is

1241
00:50:11,300 --> 00:50:15,680
shown on this bottom axis here and they

1242
00:50:13,760 --> 00:50:17,270
the point of this was to show that it

1243
00:50:15,679 --> 00:50:18,589
correlated very strongly with the

1244
00:50:17,269 --> 00:50:20,719
brightness of the stars in each cluster

1245
00:50:18,590 --> 00:50:21,860
and so they're like hey here are three

1246
00:50:20,719 --> 00:50:23,539
different clusters at different

1247
00:50:21,860 --> 00:50:26,090
distances if you measure this

1248
00:50:23,539 --> 00:50:27,590
oscillating parameter you can very

1249
00:50:26,090 --> 00:50:28,940
easily tell which guys are part of the

1250
00:50:27,590 --> 00:50:29,809
clusters in which guys aren't because

1251
00:50:28,940 --> 00:50:31,579
they fall on this nice tight

1252
00:50:29,809 --> 00:50:33,469
relationship and so this is the lithium

1253
00:50:31,579 --> 00:50:34,610
rich star they classify this one not

1254
00:50:33,469 --> 00:50:37,459
knowing that it was lithium I feel like

1255
00:50:34,610 --> 00:50:39,440
it's probably not a member but the

1256
00:50:37,460 --> 00:50:41,570
problem is that if you believe that you

1257
00:50:39,440 --> 00:50:43,909
have to ignore a lot of other evidence

1258
00:50:41,570 --> 00:50:46,220
that says otherwise so when you look at

1259
00:50:43,909 --> 00:50:47,319
the star cluster if

1260
00:50:46,219 --> 00:50:49,279
believe everything in the cluster

1261
00:50:47,320 --> 00:50:51,080
belongs together they're gravitationally

1262
00:50:49,280 --> 00:50:52,880
bound you expect them to all move

1263
00:50:51,079 --> 00:50:54,319
together and if you look at how the star

1264
00:50:52,880 --> 00:50:56,119
is moving in the proper motion so this

1265
00:50:54,320 --> 00:50:57,559
is on the plane of the sky it's moving

1266
00:50:56,119 --> 00:50:59,750
the same way as all the other stars if

1267
00:50:57,559 --> 00:51:01,279
you then measure that third parameter

1268
00:50:59,750 --> 00:51:03,289
the velocity towards her away from you

1269
00:51:01,280 --> 00:51:04,970
it's also moving the same way all the

1270
00:51:03,289 --> 00:51:06,829
other stars are so this is just showing

1271
00:51:04,969 --> 00:51:09,079
the distribution of the radial velocity

1272
00:51:06,829 --> 00:51:11,750
towards her away it's pretty much spot

1273
00:51:09,079 --> 00:51:13,219
on exactly where you expect I also

1274
00:51:11,750 --> 00:51:14,750
showed you that you know in terms of the

1275
00:51:13,219 --> 00:51:16,250
color and brightness it's also where you

1276
00:51:14,750 --> 00:51:17,809
expect so how does this thing that looks

1277
00:51:16,250 --> 00:51:19,480
in every way you can think of like it's

1278
00:51:17,809 --> 00:51:22,279
part of the cluster not be there and

1279
00:51:19,480 --> 00:51:24,440
then even better this was not available

1280
00:51:22,280 --> 00:51:26,300
to us at the time but Gaia measured a

1281
00:51:24,440 --> 00:51:28,039
parallax where the star it is at the

1282
00:51:26,300 --> 00:51:29,359
distance to the cluster so it's at the

1283

00:51:28,039 --> 00:51:31,340
same spot it's the right brightness it's

1284
00:51:29,358 --> 00:51:34,239
the right everything how on earth is it

1285
00:51:31,340 --> 00:51:36,260
the sastra seismology parameter weird

1286
00:51:34,239 --> 00:51:40,429
okay well let me explain to you a little

1287
00:51:36,260 --> 00:51:43,010
bit of about Ashta seismology so if you

1288
00:51:40,429 --> 00:51:45,289
think about a star the star is not just

1289
00:51:43,010 --> 00:51:47,420
sitting there it is actually oscillating

1290
00:51:45,289 --> 00:51:50,960
up and down as waves of various types

1291
00:51:47,420 --> 00:51:52,460
propagate around the around the star as

1292
00:51:50,960 --> 00:51:54,650
my three-year-old calls is the squishy

1293
00:51:52,460 --> 00:51:56,690
starts it's doing lots of things and

1294
00:51:54,650 --> 00:51:59,150
there's the squishy star pulsate

1295
00:51:56,690 --> 00:52:01,519
what ends up happening is that the star

1296
00:51:59,150 --> 00:52:03,349
is actually slowly increasing and

1297
00:52:01,519 --> 00:52:04,579

decreasing in brightness and so if you

1298

00:52:03,349 --> 00:52:05,900
stare at a star and watch how it

1299

00:52:04,579 --> 00:52:08,509
increases and decreases in brightness

1300

00:52:05,900 --> 00:52:11,838
for a very long time you can figure out

1301

00:52:08,510 --> 00:52:13,820
the modes at which it oscillates and so

1302

00:52:11,838 --> 00:52:15,529
this is kind of like ringing objects

1303

00:52:13,820 --> 00:52:18,559
ringing bells right so they they will

1304

00:52:15,530 --> 00:52:19,700
make a particular sound depending on you

1305

00:52:18,559 --> 00:52:22,369
know how big they are and what they're

1306

00:52:19,699 --> 00:52:23,299
made of and the and that really if you

1307

00:52:22,369 --> 00:52:25,490
could break it down there's a whole

1308

00:52:23,300 --> 00:52:27,500
bunch of different modes of oscillation

1309

00:52:25,489 --> 00:52:29,299
and so you can do the same thing for

1310

00:52:27,500 --> 00:52:31,460
stars by looking at the light and so

1311

00:52:29,300 --> 00:52:32,810
what I'm showing here or power spectra

1312
00:52:31,460 --> 00:52:34,940
of three different types of stars so

1313
00:52:32,809 --> 00:52:37,219
this is the oscillation frequency for so

1314
00:52:34,940 --> 00:52:39,380
this is low frequency high frequency and

1315
00:52:37,219 --> 00:52:42,259
then this is how much powers into each

1316
00:52:39,380 --> 00:52:44,230
of those frequencies and if you're able

1317
00:52:42,260 --> 00:52:49,670
to tell that there is this cluster of

1318
00:52:44,230 --> 00:52:51,920
lines here that moves slowly from the

1319
00:52:49,670 --> 00:52:53,838
high frequency to the low frequency you

1320
00:52:51,920 --> 00:52:56,900
have just measured the change in the

1321
00:52:53,838 --> 00:52:59,059
surface gravity of these three stars so

1322
00:52:56,900 --> 00:52:59,930
just like how very large things have

1323
00:52:59,059 --> 00:53:02,088
that low like

1324
00:52:59,929 --> 00:53:04,399
Gong Hana noise but a higher smaller

1325
00:53:02,088 --> 00:53:09,318
object has a much higher pitch your

1326
00:53:04,400 --> 00:53:12,710
smaller stars will rain basically at

1327
00:53:09,318 --> 00:53:14,329
higher pitches and the smaller ones will

1328
00:53:12,710 --> 00:53:15,528
have a much more low frequency you so

1329
00:53:14,329 --> 00:53:16,880
you've just measured changing surface

1330
00:53:15,528 --> 00:53:19,880
gravity congratulations you're an astro

1331
00:53:16,880 --> 00:53:21,559
seismologist and so you can use that

1332
00:53:19,880 --> 00:53:24,710
information to actually very precisely

1333
00:53:21,559 --> 00:53:26,390
measure the mass and the radius of the

1334
00:53:24,710 --> 00:53:29,179
star independent of the other things

1335
00:53:26,389 --> 00:53:31,940
that you usually need to know and what

1336
00:53:29,179 --> 00:53:33,710
we did is that we compare that to the

1337
00:53:31,940 --> 00:53:35,619
expected mass and radius of the star if

1338
00:53:33,710 --> 00:53:38,990
you assume the stars in the cluster and

1339
00:53:35,619 --> 00:53:41,240
so we find that the radius comes out to

1340

00:53:38,989 --> 00:53:43,098
be roughly what we expect the successor

1341
00:53:41,239 --> 00:53:44,568
seismology is really telling us that the

1342
00:53:43,099 --> 00:53:47,390
star is actually significantly less

1343
00:53:44,568 --> 00:53:49,489
massive than you would expect and yet

1344
00:53:47,389 --> 00:53:51,650
it's still a red giant and our best

1345
00:53:49,489 --> 00:53:53,719
explanation for what is going on is

1346
00:53:51,650 --> 00:53:55,338
illustrated by this cross cut of what's

1347
00:53:53,719 --> 00:53:57,379
going on inside of a red giant star

1348
00:53:55,338 --> 00:53:59,750
again you have this very deep convection

1349
00:53:57,380 --> 00:54:00,740
zone you have this tiny core of helium

1350
00:53:59,750 --> 00:54:02,809
you have a little bit of hydrogen

1351
00:54:00,739 --> 00:54:05,269
burning shell going on so you can

1352
00:54:02,809 --> 00:54:08,210
imagine if this thing had a companion

1353
00:54:05,269 --> 00:54:09,920
that it interacted with as the star had

1354
00:54:08,210 --> 00:54:12,588

expanded the outermost regions the star

1355

00:54:09,920 --> 00:54:14,329

are the least dense so perhaps as the

1356

00:54:12,588 --> 00:54:16,639

planet went in it was able to strip off

1357

00:54:14,329 --> 00:54:18,019

the least dense part of it and then

1358

00:54:16,639 --> 00:54:20,739

eventually get destroyed slightly deeper

1359

00:54:18,019 --> 00:54:23,259

in the star and mixed up all of its

1360

00:54:20,739 --> 00:54:25,519

material in there and enriched the star

1361

00:54:23,260 --> 00:54:27,140

now if you're thinking well how is this

1362

00:54:25,519 --> 00:54:28,730

star still the same size if you take off

1363

00:54:27,139 --> 00:54:30,318

all that mass I had that same thought

1364

00:54:28,730 --> 00:54:32,179

but it turns out one of the funny things

1365

00:54:30,318 --> 00:54:34,190

with stars that are structured this way

1366

00:54:32,179 --> 00:54:35,509

is that the radius of this are actually

1367

00:54:34,190 --> 00:54:38,059

really only depends on how much helium

1368

00:54:35,510 --> 00:54:40,369

you have in the core which really has

1369
00:54:38,059 --> 00:54:42,079
absolutely nothing to do with the planet

1370
00:54:40,369 --> 00:54:43,309
so if you strip off all the material the

1371
00:54:42,079 --> 00:54:44,599
star actually kind of bounces back a

1372
00:54:43,309 --> 00:54:47,660
little bit it would still be roughly the

1373
00:54:44,599 --> 00:54:48,740
same size so our leading hypothesis then

1374
00:54:47,659 --> 00:54:51,679
when we pull all that information

1375
00:54:48,739 --> 00:54:54,048
together is that the star is actually

1376
00:54:51,679 --> 00:54:55,969
has lost a lot of material and so now if

1377
00:54:54,048 --> 00:54:57,440
you run the calculation of how big of an

1378
00:54:55,969 --> 00:54:59,328
object do you need to explain the

1379
00:54:57,440 --> 00:55:02,059
illithia m-- you're at least well within

1380
00:54:59,329 --> 00:55:03,559
the range of a not a star not quite a

1381
00:55:02,059 --> 00:55:05,690
planet either um so this is a brown

1382
00:55:03,559 --> 00:55:07,460
dwarf size so this is something about 45

1383
00:55:05,690 --> 00:55:08,539
times more massive than Jupiter but it's

1384
00:55:07,460 --> 00:55:09,608
still something that you expect to have

1385
00:55:08,539 --> 00:55:12,380
a lot of lithium in it

1386
00:55:09,608 --> 00:55:13,038
those one of my favorite stories so the

1387
00:55:12,380 --> 00:55:14,209
power of

1388
00:55:13,039 --> 00:55:16,939
you know combining all these sorts of

1389
00:55:14,208 --> 00:55:18,528
things together I'm going to go a little

1390
00:55:16,938 --> 00:55:20,778
bit quickly on through this next part

1391
00:55:18,528 --> 00:55:23,630
just cuz I'm running short on time but

1392
00:55:20,778 --> 00:55:25,849
this idea that planets can help strip

1393
00:55:23,630 --> 00:55:27,919
the star um is something that has is an

1394
00:55:25,849 --> 00:55:29,329
idea that's been around for a while the

1395
00:55:27,918 --> 00:55:31,058
Kepler mission has discovered some

1396
00:55:29,329 --> 00:55:34,339
interesting things where they have found

1397

00:55:31,059 --> 00:55:37,099
what are called these D sub 4 stars so

1398
00:55:34,338 --> 00:55:38,958
these are things that are hot but

1399
00:55:37,099 --> 00:55:41,088
significantly less luminous than you

1400
00:55:38,958 --> 00:55:44,149
would expect them to be for other types

1401
00:55:41,088 --> 00:55:47,179
of normal types of stars and what we

1402
00:55:44,150 --> 00:55:48,798
think they are is so we have our Sun

1403
00:55:47,179 --> 00:55:50,298
converts hydrogen to helium in the core

1404
00:55:48,798 --> 00:55:52,068
and then later the helium will

1405
00:55:50,298 --> 00:55:52,548
eventually start to fuse into higher

1406
00:55:52,068 --> 00:55:54,619
things

1407
00:55:52,548 --> 00:55:56,538
but if you strip off the atmosphere you

1408
00:55:54,619 --> 00:55:58,939
can actually stall that and the helium

1409
00:55:56,539 --> 00:56:00,049
core will never start fusing helium so

1410
00:55:58,938 --> 00:56:03,108
we think these things are the bare

1411
00:56:00,048 --> 00:56:05,208

helium cores and so in this case what

1412

00:56:03,108 --> 00:56:07,818

was discovered is this jupiter-mass

1413

00:56:05,208 --> 00:56:09,678

thing orbiting at almost twice the

1414

00:56:07,818 --> 00:56:13,159

separation you know that Earth does to

1415

00:56:09,679 --> 00:56:14,959

our Sun and the prevailing idea of what

1416

00:56:13,159 --> 00:56:16,368

happened is that it was once closer and

1417

00:56:14,958 --> 00:56:17,928

when the star became a red giant it

1418

00:56:16,369 --> 00:56:20,269

actually helped strip off the atmosphere

1419

00:56:17,929 --> 00:56:22,789

and once that mass was gone the orbit of

1420

00:56:20,268 --> 00:56:24,649

the planet expanded there's another

1421

00:56:22,789 --> 00:56:26,239

example where these very very tiny

1422

00:56:24,650 --> 00:56:28,309

things so now like half an earth-mass

1423

00:56:26,239 --> 00:56:30,528

things were found around another type of

1424

00:56:28,309 --> 00:56:32,329

these stars and in this case the

1425

00:56:30,528 --> 00:56:35,028

scenario that is thought that these were

1426
00:56:32,329 --> 00:56:37,999
once a giant again giant planets like

1427
00:56:35,028 --> 00:56:40,188
Jupiter orbiting closer and so in this

1428
00:56:37,998 --> 00:56:41,688
case when they interacted with the star

1429
00:56:40,188 --> 00:56:44,088
the star was much smaller it wasn't

1430
00:56:41,688 --> 00:56:47,239
quite as giant of a red giant and so

1431
00:56:44,088 --> 00:56:49,159
these planets went into the star where

1432
00:56:47,239 --> 00:56:50,478
some amount of ablation separation

1433
00:56:49,159 --> 00:56:51,949
happened so they lost some of their

1434
00:56:50,478 --> 00:56:53,838
atmosphere the giant lost some of their

1435
00:56:51,949 --> 00:56:56,119
atmosphere and so we now have cores

1436
00:56:53,838 --> 00:57:00,739
orbiting cores so planet cores orbiting

1437
00:56:56,119 --> 00:57:03,709
the cores of a red giant star alright so

1438
00:57:00,739 --> 00:57:04,818
looking ahead a lot of the results that

1439
00:57:03,708 --> 00:57:07,058
I talked to you about have been made

1440
00:57:04,818 --> 00:57:11,389
possible by the wonderful Kepler mission

1441
00:57:07,059 --> 00:57:14,749
so Kepler which is so I keep losing the

1442
00:57:11,389 --> 00:57:17,449
pointer here so the Kepler telescope

1443
00:57:14,748 --> 00:57:18,978
have this big Center it pointed during

1444
00:57:17,449 --> 00:57:23,298
its prime mission at one location in the

1445
00:57:18,978 --> 00:57:26,509
sky for four years continuously so this

1446
00:57:23,298 --> 00:57:29,079
is just showing a zone of the

1447
00:57:26,510 --> 00:57:32,750
part of the galaxy that was covered by

1448
00:57:29,079 --> 00:57:36,108
by Kepler and the reason for this is we

1449
00:57:32,750 --> 00:57:37,070
wanted we needed the longtime baseline

1450
00:57:36,108 --> 00:57:38,690
where they're trying to discover

1451
00:57:37,070 --> 00:57:41,660
earth-type planets orbiting sun-like

1452
00:57:38,690 --> 00:57:43,099
stars but one of the great things that

1453
00:57:41,659 --> 00:57:44,839
came out of is this very long time

1454

00:57:43,099 --> 00:57:46,579
series observations of all these stars

1455
00:57:44,840 --> 00:57:48,260
and how their brightness was changing

1456
00:57:46,579 --> 00:57:50,299
over time which led us to all this astro

1457
00:57:48,260 --> 00:57:53,119
seismology things in addition to the

1458
00:57:50,300 --> 00:57:56,030
the prime mission the downside to that

1459
00:57:53,119 --> 00:57:57,769
is to make the mission as effective as

1460
00:57:56,030 --> 00:57:59,930
possible it had to avoid the brightest

1461
00:57:57,769 --> 00:58:02,300
stars which would saturate a lot of the

1462
00:57:59,929 --> 00:58:03,559
detectors and really focus on large

1463
00:58:02,300 --> 00:58:05,090
numbers of feature stars which

1464
00:58:03,559 --> 00:58:07,869
unfortunately makes it very hard to

1465
00:58:05,090 --> 00:58:11,329
follow these things up and so the future

1466
00:58:07,869 --> 00:58:13,010
which is also the today is the test

1467
00:58:11,329 --> 00:58:15,829
which is the translating exoplanet Sky

1468
00:58:13,010 --> 00:58:18,470

Survey which is doing a complimentary

1469

00:58:15,829 --> 00:58:20,809

search so instead of Kepler you know

1470

00:58:18,469 --> 00:58:24,259

looking in one area for a long time

1471

00:58:20,809 --> 00:58:27,799

Tess is spending one month covering the

1472

00:58:24,260 --> 00:58:29,060

whole sky so it's camera looks like the

1473

00:58:27,800 --> 00:58:34,010

spacecraft looks like this so it has

1474

00:58:29,059 --> 00:58:36,440

four four lenses and it covers actually

1475

00:58:34,010 --> 00:58:38,240

over ninety degrees in one pointing in

1476

00:58:36,440 --> 00:58:40,130

one dimension it's covering over ninety

1477

00:58:38,239 --> 00:58:43,189

degrees at once and so what it does is

1478

00:58:40,130 --> 00:58:45,079

it stares at the sky the for 27 days and

1479

00:58:43,190 --> 00:58:47,389

then steps over and then does that every

1480

00:58:45,079 --> 00:58:49,759

27 days and then I'll do a 180 degree

1481

00:58:47,389 --> 00:58:53,358

flip and it'll do the other half of this

1482

00:58:49,760 --> 00:58:54,920

guy and so right now this is upside down

1483
00:58:53,358 --> 00:58:56,679
from our normal perspective because it's

1484
00:58:54,920 --> 00:58:58,849
working in the southern ecliptic pole

1485
00:58:56,679 --> 00:59:00,829
and so right now I think it's on sector

1486
00:58:58,849 --> 00:59:03,858
10 or 12 and then it'll eventually flip

1487
00:59:00,829 --> 00:59:06,108
over and do the north and I should also

1488
00:59:03,858 --> 00:59:09,019
point out that Kepler's extended mission

1489
00:59:06,108 --> 00:59:10,549
when after it broke a little bit it

1490
00:59:09,019 --> 00:59:12,829
could only point along the ecliptic

1491
00:59:10,550 --> 00:59:15,019
plane and you'll notice the ecliptic

1492
00:59:12,829 --> 00:59:16,489
plane here is actually the one place

1493
00:59:15,019 --> 00:59:17,900
where Tess is not covering so it's

1494
00:59:16,489 --> 00:59:19,849
actually very complementary in that

1495
00:59:17,900 --> 00:59:21,950
sense and so the goal of this is to

1496
00:59:19,849 --> 00:59:23,539
really get the brightest stars so the

1497
00:59:21,949 --> 00:59:24,858
Stars where we already know that there

1498
00:59:23,539 --> 00:59:26,900
are planets around where we're gonna

1499
00:59:24,858 --> 00:59:28,579
discover new planets that are going to

1500
00:59:26,900 --> 00:59:30,858
be very easily accessible to the James

1501
00:59:28,579 --> 00:59:32,619
Webb Space Telescope where every photon

1502
00:59:30,858 --> 00:59:36,440
counts so we need things that are bright

1503
00:59:32,619 --> 00:59:38,000
so we're we are already getting data

1504
00:59:36,440 --> 00:59:39,260
from this mission the first two sectors

1505
00:59:38,000 --> 00:59:41,280
of data are now publicly available

1506
00:59:39,260 --> 00:59:43,350
anybody can look

1507
00:59:41,280 --> 00:59:45,330
and again it in terms of current data

1508
00:59:43,349 --> 00:59:50,339
taking it's almost done with the first

1509
00:59:45,329 --> 00:59:52,110
half of its mission and there are some

1510
00:59:50,340 --> 00:59:53,910
other really important complementary

1511

00:59:52,110 --> 00:59:55,370
missions that are coming up so you've

1512
00:59:53,909 --> 00:59:58,679
heard a little bit about Gaia already

1513
00:59:55,369 --> 01:00:01,529
Gaia is basically measuring on the

1514
00:59:58,679 --> 01:00:03,029
positions of stars very precisely it

1515
01:00:01,530 --> 01:00:04,560
gets the distance student parallax

1516
01:00:03,030 --> 01:00:05,700
alright this is the idea if you you know

1517
01:00:04,559 --> 01:00:07,799
hold your finger up and blink your eyes

1518
01:00:05,699 --> 01:00:09,960
back and forth things close by move a

1519
01:00:07,800 --> 01:00:12,240
lot things farther away not so much and

1520
01:00:09,960 --> 01:00:13,860
so guy uses you know looks at the sky

1521
01:00:12,239 --> 01:00:17,549
here wait six months until it's on the

1522
01:00:13,860 --> 01:00:19,590
other side of the Sun and so far it's

1523
01:00:17,550 --> 01:00:21,690
had two data releases it's given us

1524
01:00:19,590 --> 01:00:23,760
precise positions the most recent data

1525
01:00:21,690 --> 01:00:25,230

release gave us parallaxes does it

1526

01:00:23,760 --> 01:00:26,730

continues to look at these stars over

1527

01:00:25,230 --> 01:00:28,260

and over it'll start to show the proper

1528

01:00:26,730 --> 01:00:30,360

motion so this is how the relative

1529

01:00:28,260 --> 01:00:32,190

motions of stars due to the orbits of

1530

01:00:30,360 --> 01:00:34,170

the Milky Way and then if they have

1531

01:00:32,190 --> 01:00:36,659

companions either stellar or sub stellar

1532

01:00:34,170 --> 01:00:40,079

then they'll also have orbital wobbling

1533

01:00:36,659 --> 01:00:41,849

on as you know as their companions do

1534

01:00:40,079 --> 01:00:43,619

the dance and so you can get these very

1535

01:00:41,849 --> 01:00:45,809

complex motions when you add all these

1536

01:00:43,619 --> 01:00:47,909

things together and then I'm a

1537

01:00:45,809 --> 01:00:50,309

spectroscope as a spectroscopy at heart

1538

01:00:47,909 --> 01:00:53,309

so I have to talk about spectroscopy one

1539

01:00:50,309 --> 01:00:55,829

of the projects I'm working on is this

1540
01:00:53,309 --> 01:00:58,289
called this Panoptix spectroscopy from

1541
01:00:55,829 --> 01:01:01,440
the Sloan Digital Sky Survey v so this

1542
01:00:58,289 --> 01:01:03,750
is using two telescopes in both the

1543
01:01:01,440 --> 01:01:06,659
north and south hemisphere to look to

1544
01:01:03,750 --> 01:01:08,610
obtain optical and infrared spectra high

1545
01:01:06,659 --> 01:01:10,589
resolution of you know like everything

1546
01:01:08,610 --> 01:01:14,070
not quite everything but a lot of stars

1547
01:01:10,590 --> 01:01:15,600
with there's three major programs I'm

1548
01:01:14,070 --> 01:01:17,450
involved in the Milky Way mapper so this

1549
01:01:15,599 --> 01:01:20,880
is studying stars in in the Milky Way

1550
01:01:17,449 --> 01:01:22,589
it's building on the current the ongoing

1551
01:01:20,880 --> 01:01:25,260
Apogee one in two surveys which were

1552
01:01:22,590 --> 01:01:26,640
part of sdss three and four so this map

1553
01:01:25,260 --> 01:01:28,020
is assuring an artist's rendition of

1554
01:01:26,639 --> 01:01:30,000
what we think our Milky Way looks like

1555
01:01:28,019 --> 01:01:31,829
and this is showing density coverage of

1556
01:01:30,000 --> 01:01:36,960
what Apogee 1 & 2 is get and then the

1557
01:01:31,829 --> 01:01:38,159
very ambitious of Sloan 5 and one of the

1558
01:01:36,960 --> 01:01:39,570
components which is actually the part

1559
01:01:38,159 --> 01:01:41,429
that I'm working on is we want to do

1560
01:01:39,570 --> 01:01:43,530
radial velocities and so go back and

1561
01:01:41,429 --> 01:01:45,269
measure over and over the velocities of

1562
01:01:43,530 --> 01:01:49,170
stars to learn about the companions both

1563
01:01:45,269 --> 01:01:53,250
big small everything in between around

1564
01:01:49,170 --> 01:01:53,880
these stars so just to wrap up like I

1565
01:01:53,250 --> 01:01:56,489
said

1566
01:01:53,880 --> 01:01:58,829
in the beginning I think the time of big

1567
01:01:56,489 --> 01:02:00,299
data in astronomy is actually now we've

1568

01:01:58,829 --> 01:02:02,849
really started we have a lot of eyes in

1569
01:02:00,300 --> 01:02:04,140
the sky there there are missions that I

1570
01:02:02,849 --> 01:02:06,059
haven't even talked about where we're

1571
01:02:04,139 --> 01:02:09,539
getting a lot of complimentary all Sky's

1572
01:02:06,059 --> 01:02:11,670
coverage we have all sky coverage you

1573
01:02:09,539 --> 01:02:13,980
know we have we're taking images we're

1574
01:02:11,670 --> 01:02:15,480
looking at spectra and it's really going

1575
01:02:13,980 --> 01:02:18,199
to give us a lot of new information

1576
01:02:15,480 --> 01:02:20,699
about things we've never dreamed of and

1577
01:02:18,199 --> 01:02:22,439
a lot of new types of planets we're

1578
01:02:20,699 --> 01:02:24,569
going to discover a lot of good

1579
01:02:22,440 --> 01:02:26,909
follow-up for our upcoming missions like

1580
01:02:24,570 --> 01:02:28,350
James Webb and what I think can be

1581
01:02:26,909 --> 01:02:29,969
really exciting is the fact that once

1582
01:02:28,349 --> 01:02:32,099

you start looking at such large number

1583

01:02:29,969 --> 01:02:35,809

of things you start to increase your

1584

01:02:32,099 --> 01:02:38,159

chances of finding these very odd odd

1585

01:02:35,809 --> 01:02:42,179

systems that can actually teach you a

1586

01:02:38,159 --> 01:03:16,529

lot about the kind of universe of the

1587

01:02:42,179 --> 01:03:19,109

whole so thank you I'm going to repeat

1588

01:03:16,530 --> 01:03:20,160

the question for the webcast and then

1589

01:03:19,110 --> 01:03:22,740

we'll use the microphone

1590

01:03:20,159 --> 01:03:24,899

the question was I've heard the planets

1591

01:03:22,739 --> 01:03:28,409

in our solar system moved around a bit

1592

01:03:24,900 --> 01:03:30,450

can you comment on that yeah so um I

1593

01:03:28,409 --> 01:03:32,339

actually know a little bit less about

1594

01:03:30,449 --> 01:03:33,629

what we think happened in our solar

1595

01:03:32,340 --> 01:03:36,530

system a little bit more about what we

1596

01:03:33,630 --> 01:03:39,539

think happen in other solar systems

1597
01:03:36,530 --> 01:03:41,640
because again the discovery of the hot

1598
01:03:39,539 --> 01:03:43,860
Jupiters was completely unlooked-for

1599
01:03:41,639 --> 01:03:45,420
that is one of those things that we see

1600
01:03:43,860 --> 01:03:47,789
they're like no that can't be right like

1601
01:03:45,420 --> 01:03:50,849
so we must be doing something wrong and

1602
01:03:47,789 --> 01:03:52,920
and from that we have gotten the sense

1603
01:03:50,849 --> 01:03:55,230
that there just wasn't enough stuff

1604
01:03:52,920 --> 01:03:56,730
close to the stars to form something

1605
01:03:55,230 --> 01:03:57,420
that big so they had to have come from

1606
01:03:56,730 --> 01:04:01,579
somewhere else

1607
01:03:57,420 --> 01:04:04,230
and so they really LED observational ii

1608
01:04:01,579 --> 01:04:06,179
let let our theories because we had a

1609
01:04:04,230 --> 01:04:06,750
beautiful theory of how the soldiers

1610
01:04:06,179 --> 01:04:09,299
have worked

1611
01:04:06,750 --> 01:04:10,889
made sense and then we found other

1612
01:04:09,300 --> 01:04:13,050
planets and it just threw everything out

1613
01:04:10,889 --> 01:04:15,210
out the window and so now we know that

1614
01:04:13,050 --> 01:04:17,820
things have to be a lot more dynamic I

1615
01:04:15,210 --> 01:04:19,829
have heard of models that showed that

1616
01:04:17,820 --> 01:04:22,380
you know particularly the outer planets

1617
01:04:19,829 --> 01:04:23,909
had to have interacted a bit I know less

1618
01:04:22,380 --> 01:04:25,680
unfortunately about the details of those

1619
01:04:23,909 --> 01:04:35,039
interactions so I can't comment them on

1620
01:04:25,679 --> 01:04:37,949
them any further sorry planets ever get

1621
01:04:35,039 --> 01:04:40,710
flung outside of its stars absolutely

1622
01:04:37,949 --> 01:04:42,889
yeah and so that is something that I

1623
01:04:40,710 --> 01:04:47,159
think is a bit more common when you have

1624
01:04:42,889 --> 01:04:49,889
other stars well two times actually so

1625

01:04:47,159 --> 01:04:53,489
early on in the planet formation process

1626
01:04:49,889 --> 01:04:54,900
when you are building up the planets you

1627
01:04:53,489 --> 01:04:56,519
have lots of things that could become

1628
01:04:54,900 --> 01:04:58,769
planets and they interact rava tation Li

1629
01:04:56,519 --> 01:05:00,719
and some things get flung out but then

1630
01:04:58,769 --> 01:05:03,530
the other place where it can happen is

1631
01:05:00,719 --> 01:05:07,409
when you start having other stars

1632
01:05:03,530 --> 01:05:08,790
involved which you know as I and many of

1633
01:05:07,409 --> 01:05:10,440
the SHA numbers like to talk about stars

1634
01:05:08,789 --> 01:05:11,519
as if they you know exist in isolation

1635
01:05:10,440 --> 01:05:13,320
but you actually know that the vast

1636
01:05:11,519 --> 01:05:16,170
majority of stars come come with

1637
01:05:13,320 --> 01:05:19,820
siblings and so those processes are

1638
01:05:16,170 --> 01:05:19,820
common yes

1639
01:05:37,349 --> 01:05:43,950

you had mentioned earlier in one of your

1640

01:05:39,719 --> 01:05:47,789

PowerPoint slides that it was possible

1641

01:05:43,949 --> 01:05:50,219

that earth was a red giant beforehand um

1642

01:05:47,789 --> 01:05:52,619

does that make it possible that we may

1643

01:05:50,219 --> 01:05:57,209

have more earths within our own solar

1644

01:05:52,619 --> 01:05:59,760

system I'm sorry I said before that I've

1645

01:05:57,210 --> 01:06:03,150

missed the question um my question is

1646

01:05:59,760 --> 01:06:06,390

that you had mentioned that earth was at

1647

01:06:03,150 --> 01:06:09,059

one point possibly a red giant as their

1648

01:06:06,389 --> 01:06:10,889

possible is it possible that are the red

1649

01:06:09,059 --> 01:06:14,340

giants that are existing in our solar

1650

01:06:10,889 --> 01:06:20,579

system right now may become another

1651

01:06:14,340 --> 01:06:23,269

earth so I'm gonna so I guess the

1652

01:06:20,579 --> 01:06:26,489

question is so so in our solar system

1653

01:06:23,269 --> 01:06:28,079

whether or not the earth is actually

1654
01:06:26,489 --> 01:06:29,729
earth is kind of on the hairy edge so

1655
01:06:28,079 --> 01:06:31,230
we're not sure

1656
01:06:29,730 --> 01:06:33,420
this is your question more along the

1657
01:06:31,230 --> 01:06:35,519
lines ours can some of the planets

1658
01:06:33,420 --> 01:06:38,400
around these other stars be habitable

1659
01:06:35,519 --> 01:06:41,219
like the earth yes yeah okay I just

1660
01:06:38,400 --> 01:06:45,150
making sure I understood yeah so it

1661
01:06:41,219 --> 01:06:47,039
certainly is possible right so as as the

1662
01:06:45,150 --> 01:06:49,619
Sun gets larger becomes a red giant star

1663
01:06:47,039 --> 01:06:51,570
it's gonna get really hot here but for

1664
01:06:49,619 --> 01:06:53,880
colder planets right maybe that's a good

1665
01:06:51,570 --> 01:06:56,160
thing for things like life and so you

1666
01:06:53,880 --> 01:06:57,960
can imagine that in planets around red

1667
01:06:56,159 --> 01:07:00,559
giant stars that were once very cool

1668
01:06:57,960 --> 01:07:04,199
they could potentially become earth-like

1669
01:07:00,559 --> 01:07:06,659
the problem with that it could happen

1670
01:07:04,199 --> 01:07:09,809
but the difficulty for any life there is

1671
01:07:06,659 --> 01:07:12,179
that the red giant family is very short

1672
01:07:09,809 --> 01:07:15,719
and the star actually changes very

1673
01:07:12,179 --> 01:07:18,088
rapidly and so any conditions that are

1674
01:07:15,719 --> 01:07:20,909
suitable for such things to happen it

1675
01:07:18,088 --> 01:07:23,480
will rapidly go away and then then

1676
01:07:20,909 --> 01:07:23,480
they're just again

1677
01:07:30,349 --> 01:07:35,059
as you mentioned as he explained this

1678
01:07:35,179 --> 01:07:40,048
transfer that sometimes happened between

1679
01:07:37,978 --> 01:07:41,669
a star and a planet is there any

1680
01:07:40,048 --> 01:07:43,048
possibility and if that's the

1681
01:07:41,670 --> 01:07:46,220
possibility is there any evidence that

1682

01:07:43,048 --> 01:07:48,748
that might happen between planets of

1683
01:07:46,219 --> 01:07:51,929
different mass that they can actually

1684
01:07:48,748 --> 01:07:55,969
kind of suck out some materials into

1685
01:07:51,929 --> 01:08:01,139
another planet or oh that's interesting

1686
01:07:55,969 --> 01:08:03,058
again I think definitely in the planet

1687
01:08:01,139 --> 01:08:05,818
building phase when there's a lot of

1688
01:08:03,059 --> 01:08:07,739
gases around that's how some of the

1689
01:08:05,818 --> 01:08:09,690
planets win and become planets and the

1690
01:08:07,739 --> 01:08:11,548
other thing has become not planets is

1691
01:08:09,690 --> 01:08:13,259
that the you know the things that kind

1692
01:08:11,548 --> 01:08:15,088
of build up the quickest then start

1693
01:08:13,259 --> 01:08:16,469
basically start hoarding all the

1694
01:08:15,088 --> 01:08:17,818
resources and then they become the

1695
01:08:16,469 --> 01:08:19,109
dominant thing and kick everyone else

1696
01:08:17,819 --> 01:08:26,548

out there kind of tyrants in that way I

1697

01:08:19,109 --> 01:08:28,380

guess but I think once once things are

1698

01:08:26,548 --> 01:08:29,819

in more stable kin configurations I

1699

01:08:28,380 --> 01:08:32,009

think it's a lot less likely just

1700

01:08:29,819 --> 01:08:34,529

because the you know the relative sizes

1701

01:08:32,009 --> 01:08:36,420

are are pretty similar and so I think

1702

01:08:34,529 --> 01:08:38,849

it's harder yeah I'm not sure but I

1703

01:08:36,420 --> 01:08:41,908

think it's harder okay we have a

1704

01:08:38,849 --> 01:08:44,789

question from online says when the Sun

1705

01:08:41,908 --> 01:08:48,388

expands into a red giant will the gas

1706

01:08:44,789 --> 01:08:58,528

giants of moons like Europa Enceladus or

1707

01:08:48,389 --> 01:08:59,849

Triton become habitable well yes they

1708

01:08:58,529 --> 01:09:02,790

will go it's not gonna be half of the

1709

01:08:59,849 --> 01:09:05,789

world oh yes that's a good question um

1710

01:09:02,789 --> 01:09:07,829

they will get warmer but I actually

1711
01:09:05,789 --> 01:09:09,539
haven't thought about by how much that's

1712
01:09:07,829 --> 01:09:11,189
a great question we have to go do that

1713
01:09:09,539 --> 01:09:12,750
but again going back to the other

1714
01:09:11,189 --> 01:09:18,448
question is even if they do it will

1715
01:09:12,750 --> 01:09:22,859
unfortunately be short-lived but it's

1716
01:09:18,448 --> 01:09:24,118
still like 100 million a million about

1717
01:09:22,859 --> 01:09:27,210
ten million years for the red giant

1718
01:09:24,118 --> 01:09:28,889
phase yeah but so I mean I'm gonna show

1719
01:09:27,210 --> 01:09:31,319
a little bit of my biology ignorance I

1720
01:09:28,889 --> 01:09:33,770
mean for you know bugs great but for

1721
01:09:31,319 --> 01:09:33,770
people

1722
01:09:42,609 --> 01:09:51,579
are there planetary systems in binary

1723
01:09:46,640 --> 01:09:56,680
star systems and what is their prognosis

1724
01:09:51,579 --> 01:10:01,760
the prognosis is a lot more complicated

1725
01:09:56,680 --> 01:10:04,960
now I know there are two types of stable

1726
01:10:01,760 --> 01:10:06,980
orbits that you can have one is where

1727
01:10:04,960 --> 01:10:08,659
you know the stars are more tightly

1728
01:10:06,979 --> 01:10:10,459
bound and the planets orbiting both so

1729
01:10:08,659 --> 01:10:11,720
this is like a Tatoonie you know if

1730
01:10:10,460 --> 01:10:13,480
you're a star Wars fan at that screen

1731
01:10:11,720 --> 01:10:16,670
style where you get two suns in the sky

1732
01:10:13,479 --> 01:10:19,669
if my relaxed recollection is correct I

1733
01:10:16,670 --> 01:10:22,579
think that is the of the stars that we

1734
01:10:19,670 --> 01:10:26,060
know set the mark that might be the more

1735
01:10:22,579 --> 01:10:31,579
common one whereas having the planet

1736
01:10:26,060 --> 01:10:33,260
around you know one one object where you

1737
01:10:31,579 --> 01:10:35,180
know the star you know the the other

1738
01:10:33,260 --> 01:10:37,789
star is very far away I think those tend

1739

01:10:35,180 --> 01:10:42,770
to be very very widely separated in

1740
01:10:37,789 --> 01:10:45,079
which case you can mostly treat them as

1741
01:10:42,770 --> 01:10:47,480
you know as a single point but there's a

1742
01:10:45,079 --> 01:10:50,210
lot of interactions that actually will

1743
01:10:47,479 --> 01:10:52,579
sculpt the the planet forming disk and

1744
01:10:50,210 --> 01:10:54,109
will affect you know the resulting

1745
01:10:52,579 --> 01:10:55,939
inclinations of the system so actually

1746
01:10:54,109 --> 01:10:58,609
one thing that they think is that when

1747
01:10:55,939 --> 01:10:59,899
you find so in in our solar system right

1748
01:10:58,609 --> 01:11:01,819
you have the Sun rotating and all the

1749
01:10:59,899 --> 01:11:04,399
planets going around all in roughly the

1750
01:11:01,819 --> 01:11:06,139
same plane in the same direction they

1751
01:11:04,399 --> 01:11:07,729
have found instances where you have a

1752
01:11:06,140 --> 01:11:09,710
star that's rotating like this and a

1753
01:11:07,729 --> 01:11:09,949

planet going like this how did that get

1754

01:11:09,710 --> 01:11:11,750
there

1755

01:11:09,949 --> 01:11:14,300
and one of the ways that you can do it

1756

01:11:11,750 --> 01:11:16,430
is that if you do have a wide binary if

1757

01:11:14,300 --> 01:11:18,320
that is on sort of that similar

1758

01:11:16,430 --> 01:11:21,409
inclination it can force you know the

1759

01:11:18,319 --> 01:11:23,420
angles of orbit and so I know there's

1760

01:11:21,409 --> 01:11:24,859
evidence of that but yeah it gets it

1761

01:11:23,420 --> 01:11:28,460
gets messy very quickly once you start

1762

01:11:24,859 --> 01:11:30,609
adding more things other questions over

1763

01:11:28,460 --> 01:11:30,609
here

1764

01:11:31,649 --> 01:11:39,750
for perspective you tell us quickly

1765

01:11:36,239 --> 01:11:41,519
about some of the interesting orbits

1766

01:11:39,750 --> 01:11:43,170
that some of these like hot Jupiters

1767

01:11:41,520 --> 01:11:46,950
that they're orbiting their stars in

1768
01:11:43,170 --> 01:11:48,989
like less than two days yeah yeah so

1769
01:11:46,949 --> 01:11:51,869
it's it's short and actually so one of

1770
01:11:48,989 --> 01:11:53,579
the things I didn't what else

1771
01:11:51,869 --> 01:11:56,369
interesting have you found out about

1772
01:11:53,579 --> 01:11:59,100
some of these exoplanets in terms of

1773
01:11:56,369 --> 01:12:00,659
their orbits yes so one thing that I

1774
01:11:59,100 --> 01:12:03,660
didn't really talk about but which i

1775
01:12:00,659 --> 01:12:06,479
think is really cool and there are a lot

1776
01:12:03,659 --> 01:12:09,869
of things like this but so this is down

1777
01:12:06,479 --> 01:12:15,329
here is this is the Kepler 11 system so

1778
01:12:09,869 --> 01:12:18,569
to scale this is the separation of six

1779
01:12:15,329 --> 01:12:22,859
planets around kepler-11 all six of

1780
01:12:18,569 --> 01:12:26,009
these are more massive than mercury and

1781
01:12:22,859 --> 01:12:27,920
all five are inside Mercury's orbit so

1782
01:12:26,010 --> 01:12:30,600
like the like so this is like really

1783
01:12:27,920 --> 01:12:34,829
stuffing like basically as many planets

1784
01:12:30,600 --> 01:12:36,360
as you can and this comes back to the

1785
01:12:34,829 --> 01:12:37,529
question of you know like then they

1786
01:12:36,359 --> 01:12:39,599
start interacting with each other at

1787
01:12:37,529 --> 01:12:41,250
this point and actually a lot of because

1788
01:12:39,600 --> 01:12:43,410
this is actually surprisingly not that

1789
01:12:41,250 --> 01:12:44,460
common you you can confirm and actually

1790
01:12:43,409 --> 01:12:45,720
measure the masses of these things

1791
01:12:44,460 --> 01:12:47,460
because these are close enough and big

1792
01:12:45,720 --> 01:12:48,960
enough that the gravitational

1793
01:12:47,460 --> 01:12:52,050
interaction between the two is

1794
01:12:48,960 --> 01:12:54,090
measurable and so you can see that their

1795
01:12:52,050 --> 01:12:55,890
orbits are being perturbed a little bit

1796

01:12:54,090 --> 01:12:57,779
by the fact that okay it would normally

1797
01:12:55,890 --> 01:12:59,039
be on this orbit but now the next one

1798
01:12:57,779 --> 01:13:00,569
out is about to pass it and so it's

1799
01:12:59,039 --> 01:13:05,039
going to come back a little bit on it

1800
01:13:00,569 --> 01:13:07,849
and it affects the dynamics so we find

1801
01:13:05,039 --> 01:13:10,229
things basically as packed together as

1802
01:13:07,850 --> 01:13:12,329
to the point of like just barely being

1803
01:13:10,229 --> 01:13:13,289
dynamically stable where you try to put

1804
01:13:12,329 --> 01:13:15,329
one more thing in there and then it's

1805
01:13:13,289 --> 01:13:17,069
all gonna scatter so I think that's one

1806
01:13:15,329 --> 01:13:21,319
really cool thing that's come out of it

1807
01:13:17,069 --> 01:13:24,090
I said online we had a little chat about

1808
01:13:21,319 --> 01:13:26,219
where these hot Jupiters formed and that

1809
01:13:24,090 --> 01:13:28,860
you know the standard idea is that they

1810
01:13:26,220 --> 01:13:31,409

formed out where our planet our Jupiter

1811

01:13:28,859 --> 01:13:32,609

is now but they migrated inward and one

1812

01:13:31,409 --> 01:13:34,319

of the questions that sort of came up

1813

01:13:32,609 --> 01:13:36,719

was all right well what stops them if

1814

01:13:34,319 --> 01:13:38,939

they're migrating that far inward what

1815

01:13:36,720 --> 01:13:43,560

stops them from just crashing into their

1816

01:13:38,939 --> 01:13:45,219

star I mean yeah so I don't know that

1817

01:13:43,560 --> 01:13:47,350

we've answered that

1818

01:13:45,220 --> 01:13:52,690

necessarily but one of the things that's

1819

01:13:47,350 --> 01:13:54,550

important is that so this migration

1820

01:13:52,689 --> 01:13:57,000

happens while the disk of material that

1821

01:13:54,550 --> 01:14:00,640

forms the planets are still there and so

1822

01:13:57,000 --> 01:14:02,859

if you can truncate the disk and get rid

1823

01:14:00,640 --> 01:14:04,210

of the that material they basically get

1824

01:14:02,859 --> 01:14:06,099

all the way into where where the edge of

1825
01:14:04,210 --> 01:14:07,149
the disk is and then there's nothing

1826
01:14:06,100 --> 01:14:10,420
elsewhere to interact with them so it

1827
01:14:07,149 --> 01:14:12,039
can stop but I know that was certainly

1828
01:14:10,420 --> 01:14:14,829
an early problem I don't work on the the

1829
01:14:12,039 --> 01:14:19,029
models myself so I don't know how solved

1830
01:14:14,829 --> 01:14:20,229
that is but that was actually one of the

1831
01:14:19,029 --> 01:14:21,609
things that came out was like okay great

1832
01:14:20,229 --> 01:14:24,009
we now understand how we can make the

1833
01:14:21,609 --> 01:14:27,339
move how do we stop them and one way is

1834
01:14:24,010 --> 01:14:30,100
to processes that is the T Tauri wind

1835
01:14:27,340 --> 01:14:31,960
just blows all that stuff out right yeah

1836
01:14:30,100 --> 01:14:33,280
so is another way of yeah clear and

1837
01:14:31,960 --> 01:14:35,619
clearing out the region around the star

1838
01:14:33,279 --> 01:14:37,000
whether by processes you know from the

1839
01:14:35,619 --> 01:14:39,489
star could be the wind could be magnetic

1840
01:14:37,000 --> 01:14:40,750
field I think have ways of you know

1841
01:14:39,489 --> 01:14:43,659
stopped in the material from going

1842
01:14:40,750 --> 01:14:48,819
directly to the star okay do we have one

1843
01:14:43,659 --> 01:14:49,449
last question we do not alright so next

1844
01:14:48,819 --> 01:14:52,119
month

1845
01:14:49,449 --> 01:14:55,569
learn how to recycle your used pulsars

1846
01:14:52,119 --> 01:14:58,890
okay and do gamma rays

1847
01:14:55,569 --> 01:14:58,889
let's give Jolie in another hand

1848
01:15:02,310 --> 01:15:09,150
thank you oh alright so if you would

1849
01:15:07,260 --> 01:15:13,380
like to go across the street for

1850
01:15:09,149 --> 01:15:16,079
observing we have our telescope operator

1851
01:15:13,380 --> 01:15:18,449
here - you want to get over here buddy

1852
01:15:16,079 --> 01:15:19,710
go over by the the doors alright so if

1853

01:15:18,449 --> 01:15:24,139
you would like to go across the street

1854
01:15:19,710 --> 01:15:24,140
and the Maryland spacecraft servitor II