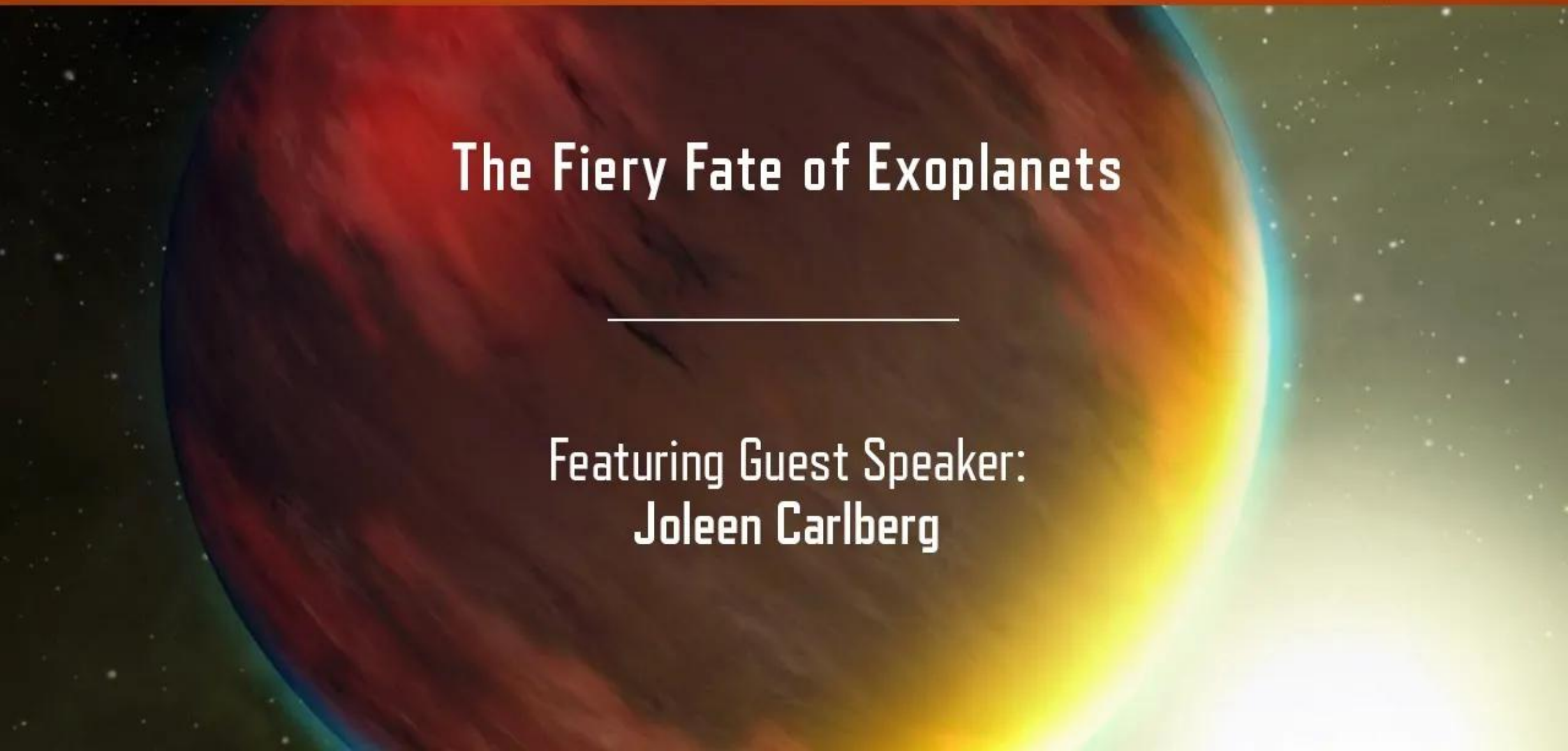
PUBLIC LECTURE SERIES



The Fiery Fate of Exoplanets

Featuring Guest Speaker:
Joleen Carlberg

1
00:00:03,669 --> 00:00:01,829
host dr frank summers of the office of

2
00:00:05,829 --> 00:00:03,679
public outreach

3
00:00:07,510 --> 00:00:05,839
and when you came in hopefully you

4
00:00:10,070 --> 00:00:07,520
picked up one of these

5
00:00:12,870 --> 00:00:10,080
uh these are our lithographs and

6
00:00:14,070 --> 00:00:12,880
tonight's lithograph is the jets from a

7
00:00:17,590 --> 00:00:14,080
young star

8
00:00:19,349 --> 00:00:17,600
her big hero 24.

9
00:00:21,510 --> 00:00:19,359
we astronomers just call these hh

10
00:00:24,230 --> 00:00:21,520
objects and they're really kind of cool

11
00:00:26,390 --> 00:00:24,240
now i chose this one

12
00:00:29,189 --> 00:00:26,400
because just a few days ago

13
00:00:31,269 --> 00:00:29,199

was may the 4th

14
00:00:33,830 --> 00:00:31,279
uh those on the internet all call that

15
00:00:37,350 --> 00:00:33,840
star wars day for the phrase may the

16
00:00:40,869 --> 00:00:38,869
i figured some people in this audience

17
00:00:44,790 --> 00:00:40,879
hadn't heard that before okay

18
00:00:46,950 --> 00:00:44,800
anyways so we had star wars day uh last

19
00:00:49,590 --> 00:00:46,960
saturday um and if you look at this

20
00:00:52,069 --> 00:00:49,600
herbig herald object you can see the

21
00:00:54,069 --> 00:00:52,079
jets pointing away from the central heat

22
00:00:56,709 --> 00:00:54,079
thing and we like to call this the

23
00:00:58,229 --> 00:00:56,719
celestial lightsaber because it has a

24
00:01:00,709 --> 00:00:58,239
resemblance to darth maul's

25
00:01:03,110 --> 00:01:00,719
double-bladed lightsaber okay

26
00:01:05,910 --> 00:01:03,120
um matter of fact i have a blog post out

27
00:01:07,510 --> 00:01:05,920
there uh about the celestial lightsaber

28
00:01:09,429 --> 00:01:07,520
thing and relating and telling you

29
00:01:11,429 --> 00:01:09,439
what's actually going on you don't need

30
00:01:13,510 --> 00:01:11,439
to read my blog post you can just turn

31
00:01:15,750 --> 00:01:13,520
the lithograph over

32
00:01:17,990 --> 00:01:15,760
and read about it on the back there and

33
00:01:20,550 --> 00:01:18,000
we've got a diagram showing you

34
00:01:22,469 --> 00:01:20,560
the jets from this young star

35
00:01:25,670 --> 00:01:22,479
for those of you on the webcast you can

36
00:01:29,350 --> 00:01:25,680
see the url down bottom uh where you can

37
00:01:32,550 --> 00:01:29,360
get the pdf of this and have yourself uh

38
00:01:36,190 --> 00:01:32,560

and and get to view it yourself

39
00:01:39,590 --> 00:01:36,200
tonight's speaker uh the fiery fate of

40
00:01:41,830 --> 00:01:39,600
exoplanets oh burning death

41
00:01:43,030 --> 00:01:41,840
uh jolene carlboro we'll be talking

42
00:01:46,630 --> 00:01:43,040
about this

43
00:01:48,789 --> 00:01:46,640
uh next month we have recycled your used

44
00:01:50,469 --> 00:01:48,799
pulsars hopefully hopefully everyone

45
00:01:52,469 --> 00:01:50,479
does do this you know at home in your

46
00:01:53,830 --> 00:01:52,479
recycling if you've got extra pulsars

47
00:01:56,630 --> 00:01:53,840
recycle them

48
00:02:00,310 --> 00:01:56,640
because they can explain the extra gamma

49
00:02:02,149 --> 00:02:00,320
radiation from the central milky way

50
00:02:03,510 --> 00:02:02,159
and chris britt will talk about that on

51
00:02:06,950 --> 00:02:03,520
june 4th

52
00:02:08,150 --> 00:02:06,960
on july 2nd joe de pascual

53
00:02:09,589 --> 00:02:08,160
one of my colleagues in the office of

54
00:02:12,150 --> 00:02:09,599
public outreach will be talking about

55
00:02:14,550 --> 00:02:12,160
the art and science of astronomical

56
00:02:15,910 --> 00:02:14,560
image processing these wonderful images

57
00:02:19,430 --> 00:02:15,920
that you see

58
00:02:22,390 --> 00:02:19,440
are prepared not by artists not by

59
00:02:24,630 --> 00:02:22,400
scientists by by combinations of artists

60
00:02:25,750 --> 00:02:24,640
and scientists generally inside the same

61
00:02:31,270 --> 00:02:25,760
brain

62
00:02:32,949 --> 00:02:31,280
to pull out the science but also make it

63
00:02:33,990 --> 00:02:32,959

beautiful for the public to

64
00:02:35,270 --> 00:02:34,000
increase our understanding and

65
00:02:37,910 --> 00:02:35,280
appreciation

66
00:02:40,710 --> 00:02:37,920
in august we have the dreaded tba

67
00:02:41,990 --> 00:02:40,720
which is frank uh get you got to send

68
00:02:45,350 --> 00:02:42,000
out an email this month and get a

69
00:02:47,589 --> 00:02:45,360
speaker for august okay but i always do

70
00:02:50,790 --> 00:02:47,599
uh when i do i will post it on our

71
00:02:51,910 --> 00:02:50,800
website um and if you just take your

72
00:02:53,990 --> 00:02:51,920
favorite search engine and look for

73
00:02:56,790 --> 00:02:54,000
space telescope public lecture series

74
00:02:58,309 --> 00:02:56,800
you'll find this web page with the list

75
00:02:59,270 --> 00:02:58,319
of the upcoming lectures over here on

76
00:03:01,430 --> 00:02:59,280
the right

77
00:03:04,070 --> 00:03:01,440
uh and on the left you can have uh you

78
00:03:07,750 --> 00:03:04,080
can see our webcasting the live links as

79
00:03:10,030 --> 00:03:07,760
well as the past lectures back to 2014

80
00:03:13,990 --> 00:03:10,040
on youtube and back to

81
00:03:17,670 --> 00:03:14,000
2005 on the sdsci webcasting

82
00:03:20,550 --> 00:03:17,680
i will note that the sti webcasting just

83
00:03:23,270 --> 00:03:20,560
did a huge improvement not only to the

84
00:03:24,949 --> 00:03:23,280
quality of their presentation but also

85
00:03:26,390 --> 00:03:24,959
to the search capabilities on their

86
00:03:28,390 --> 00:03:26,400
website i'm going to try and get

87
00:03:30,710 --> 00:03:28,400
somebody from sdsi webcasting to show

88
00:03:32,789 --> 00:03:30,720

that off next month for you so you can

89
00:03:34,470 --> 00:03:32,799
so when you go there you can figure out

90
00:03:37,030 --> 00:03:34,480
how to find all those really cool

91
00:03:39,509 --> 00:03:37,040
lectures that we've been doing for

92
00:03:41,589 --> 00:03:39,519
wow that's 14 years of webcasting that

93
00:03:42,470 --> 00:03:41,599
they have of this public lecture series

94
00:03:44,550 --> 00:03:42,480
okay

95
00:03:46,630 --> 00:03:44,560
um and finally you can sign up for our

96
00:03:47,670 --> 00:03:46,640
email list there

97
00:03:49,270 --> 00:03:47,680
um

98
00:03:52,070 --> 00:03:49,280
if you do not want to sign up at the

99
00:03:54,070 --> 00:03:52,080
website uh you can do as one gentleman

100
00:03:56,789 --> 00:03:54,080
did tonight give me a piece of paper

101
00:03:59,270 --> 00:03:56,799
with a web addre email address on it and

102
00:04:01,429 --> 00:03:59,280
i will make sure it gets added to it

103
00:04:03,190 --> 00:04:01,439
if you have any questions for me or for

104
00:04:04,470 --> 00:04:03,200
the speaker about any of our

105
00:04:06,070 --> 00:04:04,480
organization

106
00:04:10,710 --> 00:04:06,080
you can send them to the email address

107
00:04:14,869 --> 00:04:12,550
finally if you would like to follow us

108
00:04:17,430 --> 00:04:14,879
on social media we have a variety of

109
00:04:19,349 --> 00:04:17,440
things facebook twitter youtube and

110
00:04:21,509 --> 00:04:19,359
instagram not only for the hubble

111
00:04:23,430 --> 00:04:21,519
spelling telescope not only for the web

112
00:04:26,310 --> 00:04:23,440
space telescope but also for our

113
00:04:29,110 --> 00:04:26,320

institution stsci

114
00:04:31,830 --> 00:04:29,120
i do a little bit of social media on

115
00:04:34,070 --> 00:04:31,840
facebook and twitter as dr frank summers

116
00:04:35,909 --> 00:04:34,080
you can follow that if you like

117
00:04:39,430 --> 00:04:35,919
and tonight

118
00:04:41,270 --> 00:04:39,440
the observatory will be open yay

119
00:04:44,950 --> 00:04:41,280
um it hasn't been open for several

120
00:04:46,710 --> 00:04:44,960
months okay so after the lecture um matt

121
00:04:49,670 --> 00:04:46,720
from the um maryland space grant

122
00:04:50,550 --> 00:04:49,680
observatory will be here um and he will

123
00:04:53,110 --> 00:04:50,560
take

124
00:04:53,990 --> 00:04:53,120
a pro no more than 30 people i think

125
00:04:56,230 --> 00:04:54,000
okay

126
00:04:58,469 --> 00:04:56,240
um so we can't take a huge group of 50

127
00:05:00,629 --> 00:04:58,479
people he can only take 10 to i think

128
00:05:02,950 --> 00:05:00,639
they prefer 10 to 20 people okay i'll

129
00:05:04,790 --> 00:05:02,960
let matt figure it out afterwards but if

130
00:05:08,230 --> 00:05:04,800
you would like to go across the street

131
00:05:10,790 --> 00:05:08,240
and go up into that the boris w offit uh

132
00:05:13,029 --> 00:05:10,800
telescope um and look at the what's

133
00:05:15,830 --> 00:05:13,039
what's available um we can do so

134
00:05:17,909 --> 00:05:15,840
afterwards uh hang around afterwards if

135
00:05:20,629 --> 00:05:17,919
i forget remind me to say hey

136
00:05:22,790 --> 00:05:20,639
observatory and people will gather

137
00:05:25,110 --> 00:05:22,800
probably over here um and head out that

138
00:05:26,469 --> 00:05:25,120

door and go across okay

139
00:05:28,710 --> 00:05:26,479
all right

140
00:05:31,510 --> 00:05:28,720
now our news from the universe for may

141
00:05:33,510 --> 00:05:31,520
2019

142
00:05:35,189 --> 00:05:33,520
our first story tonight

143
00:05:36,390 --> 00:05:35,199
wide and

144
00:05:38,629 --> 00:05:36,400
deep

145
00:05:41,749 --> 00:05:38,639
so this is one of hubble's most famous

146
00:05:44,070 --> 00:05:41,759
images the hubble ultra deep field um

147
00:05:46,230 --> 00:05:44,080
and it is the deepest visible light

148
00:05:49,350 --> 00:05:46,240
exposure of the universe

149
00:05:52,230 --> 00:05:49,360
uh invisible uh and it basically we see

150
00:05:53,990 --> 00:05:52,240
more galaxies in this tiny patch of sky

151
00:05:56,629 --> 00:05:54,000
than we see anywhere else they're

152
00:05:59,189 --> 00:05:56,639
basically about ten thousand galaxies in

153
00:06:01,990 --> 00:05:59,199
this really tiny patch of sky

154
00:06:04,390 --> 00:06:02,000
how tiny is it well this is the ultra

155
00:06:05,270 --> 00:06:04,400
deep field compared to the full moon

156
00:06:07,430 --> 00:06:05,280
okay

157
00:06:08,790 --> 00:06:07,440
all right so it's about you know one

158
00:06:10,150 --> 00:06:08,800
percent of the

159
00:06:12,070 --> 00:06:10,160
of the full moon they're about 100

160
00:06:13,670 --> 00:06:12,080
patches about this size that make up the

161
00:06:16,070 --> 00:06:13,680
full moon

162
00:06:18,309 --> 00:06:16,080
but contrary to what hollywood may have

163
00:06:19,430 --> 00:06:18,319

taught you the full moon's not that big

164
00:06:21,430 --> 00:06:19,440
in the sky

165
00:06:23,590 --> 00:06:21,440
here's a picture showing a wide field

166
00:06:25,110 --> 00:06:23,600
view showing yeah that's how big the

167
00:06:26,390 --> 00:06:25,120
full moon is in the sky it's pretty

168
00:06:28,710 --> 00:06:26,400
small

169
00:06:30,469 --> 00:06:28,720
matter of fact if you do the math

170
00:06:32,830 --> 00:06:30,479
there are

171
00:06:36,629 --> 00:06:32,840
12 million 746

172
00:06:40,710 --> 00:06:36,639
784 patches the same size as the hubble

173
00:06:44,230 --> 00:06:40,720
ultra deep field on the sky okay

174
00:06:45,749 --> 00:06:44,240
hubble's field of view is 1 12 millionth

175
00:06:48,070 --> 00:06:45,759
of the night sky

176
00:06:50,309 --> 00:06:48,080
so when we study the hubble ultra deep

177
00:06:52,469 --> 00:06:50,319
field we're studying only one tiny

178
00:06:54,230 --> 00:06:52,479
little portion of the sky and what we

179
00:06:56,230 --> 00:06:54,240
would really like to do is touch a much

180
00:06:59,270 --> 00:06:56,240
larger portion so that we can get the

181
00:07:01,029 --> 00:06:59,280
star surety in our statistics okay we

182
00:07:01,990 --> 00:07:01,039
want to be able to say what we see in

183
00:07:04,309 --> 00:07:02,000
this

184
00:07:07,430 --> 00:07:04,319
field is the same as what we see over

185
00:07:09,830 --> 00:07:07,440
here as the same across the whole sky

186
00:07:11,189 --> 00:07:09,840
so what we have done is here is the

187
00:07:12,790 --> 00:07:11,199
hubble ultra deep field this is the

188
00:07:16,070 --> 00:07:12,800

patch of the sky where hubble alternate

189
00:07:19,029 --> 00:07:16,080
field we have done mosaics

190
00:07:22,469 --> 00:07:19,039
and field studies this is the goods the

191
00:07:25,270 --> 00:07:22,479
great observatories origins deep survey

192
00:07:28,710 --> 00:07:25,280
which roughly covers about 15 times the

193
00:07:30,550 --> 00:07:28,720
field of the hubble alternate field

194
00:07:32,309 --> 00:07:30,560
and recently what we released is

195
00:07:33,990 --> 00:07:32,319
something called the hubble

196
00:07:35,990 --> 00:07:34,000
legacy field

197
00:07:37,110 --> 00:07:36,000
which covers about twice as much as that

198
00:07:39,990 --> 00:07:37,120
again

199
00:07:42,550 --> 00:07:40,000
so in this hubble legacy field

200
00:07:44,469 --> 00:07:42,560
they say and i didn't count them that

201
00:07:47,350 --> 00:07:44,479
there are 260

202
00:07:49,749 --> 00:07:47,360
000 galaxies okay

203
00:07:52,309 --> 00:07:49,759
and looking at this patch of sky that's

204
00:07:54,469 --> 00:07:52,319
you know uh looks like 30 to 50 times

205
00:07:56,550 --> 00:07:54,479
the size of the ultra deep field they're

206
00:07:57,510 --> 00:07:56,560
getting 260

207
00:08:00,230 --> 00:07:57,520
000

208
00:08:03,350 --> 00:08:00,240
galaxies now that gives you a lot more

209
00:08:06,710 --> 00:08:03,360
statistics okay makes you much more

210
00:08:09,589 --> 00:08:06,720
clear about your understanding and so uh

211
00:08:13,029 --> 00:08:09,599
this is the uh the recent uh image that

212
00:08:16,150 --> 00:08:13,039
we we released it is actually

213
00:08:17,990 --> 00:08:16,160

massively huge um i tried working with

214
00:08:20,230 --> 00:08:18,000
it in photoshop today

215
00:08:22,550 --> 00:08:20,240
um i was just trying to get these these

216
00:08:24,390 --> 00:08:22,560
graphics here for the for the powerpoint

217
00:08:26,710 --> 00:08:24,400
oh my god

218
00:08:29,589 --> 00:08:26,720
i mean it's like a 3.2 gigabyte

219
00:08:31,270 --> 00:08:29,599
individual image file okay um it's just

220
00:08:33,509 --> 00:08:31,280
a lot of things but

221
00:08:35,110 --> 00:08:33,519
because we are hubble and we're paid for

222
00:08:36,870 --> 00:08:35,120
by your tax dollars

223
00:08:39,990 --> 00:08:36,880
you can download every single pixel in

224
00:08:41,670 --> 00:08:40,000
this image okay all right we have it uh

225
00:08:43,670 --> 00:08:41,680
we have it at like fifty thousand by

226
00:08:46,070 --> 00:08:43,680
fifty thousand pixels available for you

227
00:08:47,750 --> 00:08:46,080
to download if you are so masochistical

228
00:08:50,230 --> 00:08:47,760
that you wanna do that okay

229
00:08:52,790 --> 00:08:50,240
um astronomers will of course be

230
00:08:54,630 --> 00:08:52,800
downloading this um and doing uh lots of

231
00:08:56,870 --> 00:08:54,640
research studies on it

232
00:08:59,990 --> 00:08:56,880
so finally by by getting to the hubble

233
00:09:03,110 --> 00:09:00,000
legacy field we do have an image

234
00:09:04,470 --> 00:09:03,120
that covers roughly the size of the full

235
00:09:06,949 --> 00:09:04,480
moon okay

236
00:09:08,790 --> 00:09:06,959
um and okay so

237
00:09:11,750 --> 00:09:08,800
maybe there's a few hundred thousand

238
00:09:13,190 --> 00:09:11,760

patches of the sky uh this side uh this

239
00:09:15,509 --> 00:09:13,200
size in the sky but we're going from one

240
00:09:17,829 --> 00:09:15,519
twelve million to the night sky to about

241
00:09:19,829 --> 00:09:17,839
one thousandth of the night sky

242
00:09:21,350 --> 00:09:19,839
a hundred thousand to the night sky

243
00:09:23,190 --> 00:09:21,360
all right so you might think this is

244
00:09:23,990 --> 00:09:23,200
this is this the maximum what hubble can

245
00:09:26,150 --> 00:09:24,000
do

246
00:09:27,590 --> 00:09:26,160
uh and i was like all right well

247
00:09:30,630 --> 00:09:27,600
i think we've done something bigger than

248
00:09:33,750 --> 00:09:30,640
this and i went through my my

249
00:09:35,670 --> 00:09:33,760
images i said oh yes we have so i found

250
00:09:37,590 --> 00:09:35,680
this image from a few years ago this is

251
00:09:41,030 --> 00:09:37,600
again the moon for scale

252
00:09:42,949 --> 00:09:41,040
uh http goods and the gems survey and

253
00:09:45,030 --> 00:09:42,959
you can see the gems survey and the

254
00:09:47,269 --> 00:09:45,040
legacy field are pretty much the same

255
00:09:49,190 --> 00:09:47,279
size of the field but the legacy survey

256
00:09:52,070 --> 00:09:49,200
is deeper okay so it's taking the gem

257
00:09:54,310 --> 00:09:52,080
survey data and augmenting that with

258
00:09:57,030 --> 00:09:54,320
even more observations okay in order to

259
00:09:59,190 --> 00:09:57,040
get this so um you could call the legacy

260
00:10:01,350 --> 00:09:59,200
survey gems version 2

261
00:10:03,590 --> 00:10:01,360
and deeper but the really big one that

262
00:10:06,389 --> 00:10:03,600
we did which unfortunately does not go

263
00:10:08,790 --> 00:10:06,399

as deep as necessary um to get those

264
00:10:10,470 --> 00:10:08,800
kind of statistics is the cosmos survey

265
00:10:12,550 --> 00:10:10,480
and you can see that's you know like six

266
00:10:15,829 --> 00:10:12,560
times the size of the full moon

267
00:10:18,389 --> 00:10:15,839
so even though hubble has a tiny field

268
00:10:21,190 --> 00:10:18,399
of view on the sky 112 million

269
00:10:23,030 --> 00:10:21,200
when you take these long surveys over

270
00:10:24,230 --> 00:10:23,040
many years and hubble's been up for 29

271
00:10:25,990 --> 00:10:24,240
years now

272
00:10:28,150 --> 00:10:26,000
you can end up getting some very large

273
00:10:30,949 --> 00:10:28,160
patches of the sky and this is what we

274
00:10:33,430 --> 00:10:30,959
need to be able to do to do statistics

275
00:10:36,949 --> 00:10:33,440
now just to blow your mind

276
00:10:38,949 --> 00:10:36,959
the wide the w first the wide field

277
00:10:41,430 --> 00:10:38,959
infrared space telescope that we expect

278
00:10:44,310 --> 00:10:41,440
to launch in the 2020s

279
00:10:45,670 --> 00:10:44,320
will be able to do the entire cosmos

280
00:10:47,110 --> 00:10:45,680
survey

281
00:10:48,470 --> 00:10:47,120
in one image

282
00:10:51,670 --> 00:10:48,480
okay

283
00:10:54,949 --> 00:10:51,680
that's how big wfirst detector is it's

284
00:10:56,949 --> 00:10:54,959
100 times the size of hubble

285
00:10:58,310 --> 00:10:56,959
okay it's infrared goes a little bit

286
00:11:00,870 --> 00:10:58,320
into the red

287
00:11:03,030 --> 00:11:00,880
but we have another telescope coming in

288
00:11:05,190 --> 00:11:03,040

in about in about 10 less than 10 years

289
00:11:07,509 --> 00:11:05,200
hopefully uh that will be able to do

290
00:11:11,269 --> 00:11:07,519
these really large patches uh in the

291
00:11:13,750 --> 00:11:11,279
infrared so data is going to be huge in

292
00:11:17,030 --> 00:11:13,760
the next decade

293
00:11:19,829 --> 00:11:17,040
all right our second story tonight

294
00:11:21,430 --> 00:11:19,839
milky way

295
00:11:24,550 --> 00:11:21,440
all right so

296
00:11:25,750 --> 00:11:24,560
what we're talking about is how do you

297
00:11:27,269 --> 00:11:25,760
weigh

298
00:11:29,190 --> 00:11:27,279
a galaxy

299
00:11:32,150 --> 00:11:29,200
all right we don't have scales big

300
00:11:34,310 --> 00:11:32,160
enough for it okay um and even if we did

301
00:11:35,990 --> 00:11:34,320
they wouldn't uh cover the the mass

302
00:11:37,990 --> 00:11:36,000
ranges we have here

303
00:11:40,470 --> 00:11:38,000
uh so when you're looking at a galaxy uh

304
00:11:42,389 --> 00:11:40,480
in particular this spiral galaxy um you

305
00:11:43,829 --> 00:11:42,399
can sort of see that these spiral discs

306
00:11:45,590 --> 00:11:43,839
rotate okay

307
00:11:47,030 --> 00:11:45,600
i believe that this is this is a

308
00:11:50,550 --> 00:11:47,040
spinning disc

309
00:11:52,949 --> 00:11:50,560
all right so you measure a galaxy

310
00:11:56,389 --> 00:11:52,959
not by measuring the mass

311
00:11:59,670 --> 00:11:56,399
but by measuring the motions okay

312
00:12:01,829 --> 00:11:59,680
so the motion of earth around the sun

313
00:12:03,829 --> 00:12:01,839

tells you the mass of the sun because

314
00:12:06,949 --> 00:12:03,839
it's the sun's gravity

315
00:12:10,150 --> 00:12:06,959
that constrains earth's motion

316
00:12:13,750 --> 00:12:10,160
similarly the emotions of stars and dust

317
00:12:16,790 --> 00:12:13,760
clouds and stars clusters in a galaxy

318
00:12:19,110 --> 00:12:16,800
tells you about the mass inside a galaxy

319
00:12:21,269 --> 00:12:19,120
and so if you measure these motions uh

320
00:12:23,750 --> 00:12:21,279
in close and all the way out as far out

321
00:12:26,550 --> 00:12:23,760
as you can see in a galaxy you can get a

322
00:12:28,710 --> 00:12:26,560
mass profile of the galaxy and

323
00:12:31,269 --> 00:12:28,720
effectively figure out how much mass is

324
00:12:32,870 --> 00:12:31,279
in there okay and that's you know looks

325
00:12:34,870 --> 00:12:32,880
pretty straightforward for an external

326
00:12:38,389 --> 00:12:34,880
galaxy that you can see like this

327
00:12:40,870 --> 00:12:38,399
however we're inside the milky way okay

328
00:12:42,550 --> 00:12:40,880
and we've got to go look and try and

329
00:12:43,990 --> 00:12:42,560
figure out and we're moving inside the

330
00:12:46,069 --> 00:12:44,000
milky way and we you've got to

331
00:12:47,829 --> 00:12:46,079
deconvolve the problem from being inside

332
00:12:49,509 --> 00:12:47,839
the milky way

333
00:12:50,470 --> 00:12:49,519
and whoops that was that was the image i

334
00:12:52,230 --> 00:12:50,480
was supposed to show you the actual

335
00:12:55,269 --> 00:12:52,240
mellinger version of it okay so we're

336
00:12:57,670 --> 00:12:55,279
inside the milky way um and to do it it

337
00:12:59,829 --> 00:12:57,680
turns out that one of the best things to

338
00:13:02,069 --> 00:12:59,839

use are these globular star clusters

339
00:13:03,750 --> 00:13:02,079
these are very dense star clusters

340
00:13:05,910 --> 00:13:03,760
they're sort of gravitationally bound

341
00:13:08,230 --> 00:13:05,920
together and they're sort of moving as a

342
00:13:10,710 --> 00:13:08,240
group together so you can measure the

343
00:13:13,030 --> 00:13:10,720
motions of the stars the bulk motion of

344
00:13:16,230 --> 00:13:13,040
the stars in these clusters and use them

345
00:13:17,269 --> 00:13:16,240
to measure the milky way

346
00:13:19,750 --> 00:13:17,279
so

347
00:13:22,230 --> 00:13:19,760
one component of this result comes from

348
00:13:25,990 --> 00:13:22,240
the gaia satellite now gaia is an

349
00:13:27,990 --> 00:13:26,000
astrometric satellite it's the most

350
00:13:29,190 --> 00:13:28,000
accurate astrometric satellite we've

351
00:13:32,790 --> 00:13:29,200
ever put up

352
00:13:35,350 --> 00:13:32,800
two billion stars with their positions

353
00:13:37,990 --> 00:13:35,360
and their motions etc across the sky

354
00:13:40,150 --> 00:13:38,000
unbelievable data set that's still being

355
00:13:42,389 --> 00:13:40,160
developed and being developed more and i

356
00:13:44,710 --> 00:13:42,399
think i showed you guys this shot when

357
00:13:46,550 --> 00:13:44,720
guys first data release came out this is

358
00:13:48,870 --> 00:13:46,560
their radial velocity map and you can

359
00:13:50,629 --> 00:13:48,880
see over here in red on the right side

360
00:13:52,550 --> 00:13:50,639
those are the stars that are moving away

361
00:13:53,910 --> 00:13:52,560
from us and on the left side you can see

362
00:13:55,829 --> 00:13:53,920
the blue ones the ones that are coming

363
00:13:57,670 --> 00:13:55,839

towards us and in the center you can

364
00:14:00,069 --> 00:13:57,680
sort of see this flip which is the

365
00:14:02,870 --> 00:14:00,079
motions internal to our motion through

366
00:14:12,949 --> 00:14:02,880
the galaxy so gaia has measured really

367
00:14:12,959 --> 00:14:19,590
globular clusters

368
00:14:25,430 --> 00:14:22,470
out to 65 000 light years okay which is

369
00:14:26,949 --> 00:14:25,440
a huge rate it's much beyond the size of

370
00:14:28,629 --> 00:14:26,959
the uh

371
00:14:30,710 --> 00:14:28,639
milky way's disk

372
00:14:32,150 --> 00:14:30,720
all right but that's not quite good

373
00:14:33,910 --> 00:14:32,160
enough to get the full measurement

374
00:14:34,870 --> 00:14:33,920
because the milky way really extends out

375
00:14:35,670 --> 00:14:34,880
there

376
00:14:37,990 --> 00:14:35,680
so

377
00:14:41,509 --> 00:14:38,000
who are you going to call

378
00:14:43,990 --> 00:14:41,519
of course hubble got you right

379
00:14:45,990 --> 00:14:44,000
hubble can have the fine resolution to

380
00:14:48,069 --> 00:14:46,000
see the globular clusters much further

381
00:14:50,710 --> 00:14:48,079
out and so hubble has started yet

382
00:14:52,949 --> 00:14:50,720
another dozen globular clusters out to

383
00:14:55,750 --> 00:14:52,959
twice the distance that gaia can do out

384
00:14:58,470 --> 00:14:55,760
to 130 000 light years and if you

385
00:15:00,870 --> 00:14:58,480
combine the measurements from gaia and

386
00:15:01,990 --> 00:15:00,880
the measurements from hubble

387
00:15:04,069 --> 00:15:02,000
then

388
00:15:06,069 --> 00:15:04,079

you can make way through milky way with

389
00:15:09,430 --> 00:15:06,079
unprecedented accuracy

390
00:15:11,030 --> 00:15:09,440
so here's here is what hubble can do

391
00:15:12,629 --> 00:15:11,040
and you can see

392
00:15:14,150 --> 00:15:12,639
the galaxies that are circled here

393
00:15:15,670 --> 00:15:14,160
they're not moving

394
00:15:17,430 --> 00:15:15,680
and what you're seeing are the stars

395
00:15:20,230 --> 00:15:17,440
that are moving and these stars are part

396
00:15:22,310 --> 00:15:20,240
of this star cluster here this is a deep

397
00:15:24,710 --> 00:15:22,320
deep deep part tiny part of this

398
00:15:26,150 --> 00:15:24,720
globular star cluster okay

399
00:15:28,150 --> 00:15:26,160
and those tiny little emotions that

400
00:15:30,550 --> 00:15:28,160
hubble can measure can get you the bulk

401
00:15:31,509 --> 00:15:30,560
motions of those globular star clusters

402
00:15:32,710 --> 00:15:31,519
all right

403
00:15:37,110 --> 00:15:32,720
together

404
00:15:38,470 --> 00:15:37,120
is an artist

405
00:15:40,949 --> 00:15:38,480
drawing to give you the idea of all

406
00:15:43,269 --> 00:15:40,959
these star clusters extending out to 130

407
00:15:45,110 --> 00:15:43,279
000 light years and then you can extend

408
00:15:47,030 --> 00:15:45,120
that out even further

409
00:15:48,230 --> 00:15:47,040
to measure the full mass of the milky

410
00:15:51,030 --> 00:15:48,240
way

411
00:15:51,990 --> 00:15:51,040
now previous to this they had said that

412
00:15:54,629 --> 00:15:52,000
the

413
00:15:58,230 --> 00:15:54,639

best estimates were between half

414
00:15:59,269 --> 00:15:58,240
to about 3 trillion solar masses

415
00:16:00,470 --> 00:15:59,279
and

416
00:16:02,470 --> 00:16:00,480
fortunately

417
00:16:03,670 --> 00:16:02,480
the measurement from here is much more

418
00:16:06,389 --> 00:16:03,680
refined

419
00:16:07,509 --> 00:16:06,399
but it comes down to 1.5 trillion solar

420
00:16:10,470 --> 00:16:07,519
masses

421
00:16:13,990 --> 00:16:10,480
okay so that's million billion trillion

422
00:16:16,150 --> 00:16:14,000
okay 1.5 trillion solar masses

423
00:16:18,310 --> 00:16:16,160
now if you know the number of stars in

424
00:16:20,230 --> 00:16:18,320
the milky way the estimate of that is

425
00:16:22,230 --> 00:16:20,240
about 200 billion

426
00:16:24,069 --> 00:16:22,240
stars in the milky way and the average

427
00:16:25,430 --> 00:16:24,079
mass of a star is about the same as the

428
00:16:28,389 --> 00:16:25,440
mass of our sun

429
00:16:29,590 --> 00:16:28,399
so there's 1.5 trillion solar masses in

430
00:16:32,150 --> 00:16:29,600
the milky way

431
00:16:33,749 --> 00:16:32,160
but only about 200 billion of that is

432
00:16:35,990 --> 00:16:33,759
stars

433
00:16:39,189 --> 00:16:36,000
which indicates you know as we've all

434
00:16:42,550 --> 00:16:39,199
known that we got or dominated here in

435
00:16:44,790 --> 00:16:42,560
our milky way by dark matter okay

436
00:16:46,470 --> 00:16:44,800
the unseen dark matter is the

437
00:16:49,189 --> 00:16:46,480
gravitationally dominant we see it in

438
00:16:51,829 --> 00:16:49,199

other galaxies we see it in our own

439
00:16:54,870 --> 00:16:51,839
galaxy that the dark matter in the milky

440
00:16:57,350 --> 00:16:54,880
way is about six or seven times

441
00:16:59,110 --> 00:16:57,360
more massive than the normal matter the

442
00:17:00,470 --> 00:16:59,120
stars and the gas and the dust and

443
00:17:01,509 --> 00:17:00,480
everything okay

444
00:17:03,749 --> 00:17:01,519
so

445
00:17:05,590 --> 00:17:03,759
why do we need to know this

446
00:17:06,870 --> 00:17:05,600
important thing is that we can see the

447
00:17:09,189 --> 00:17:06,880
milky way

448
00:17:11,429 --> 00:17:09,199
better than we can see any other galaxy

449
00:17:12,549 --> 00:17:11,439
we have detailed measurements inside our

450
00:17:18,390 --> 00:17:12,559
galaxy

451
00:17:20,789 --> 00:17:18,400
scales against other galaxies in order

452
00:17:23,029 --> 00:17:20,799
to be able to apply this local knowledge

453
00:17:25,429 --> 00:17:23,039
to these distant galaxies

454
00:17:27,909 --> 00:17:25,439
having this measurement of 1.5 trillion

455
00:17:30,070 --> 00:17:27,919
solar masses allows us to take this

456
00:17:32,549 --> 00:17:30,080
knowledge that we gain locally and then

457
00:17:33,750 --> 00:17:32,559
apply it more accurately to external

458
00:17:35,190 --> 00:17:33,760
galaxies

459
00:17:37,110 --> 00:17:35,200
so we have

460
00:17:38,150 --> 00:17:37,120
been able to make a more accurate

461
00:17:40,789 --> 00:17:38,160
measurement

462
00:17:42,310 --> 00:17:40,799
and able to weigh the milky way

463
00:17:47,510 --> 00:17:42,320

right

464
00:17:51,270 --> 00:17:49,669
compared to other galaxies ah good

465
00:17:53,270 --> 00:17:51,280
question how does the milky way compare

466
00:17:55,990 --> 00:17:53,280
to other galaxies well the milky way at

467
00:17:59,110 --> 00:17:56,000
1.5 trillion solar masses is

468
00:18:01,190 --> 00:17:59,120
relatively normal for a large galaxy

469
00:18:02,470 --> 00:18:01,200
of course we have some dwarf galaxies

470
00:18:04,789 --> 00:18:02,480
around us the large mountains on the

471
00:18:07,110 --> 00:18:04,799
cloud small magellanic cloud there are a

472
00:18:08,950 --> 00:18:07,120
few billion solar masses okay

473
00:18:11,350 --> 00:18:08,960
um so they're you know one one

474
00:18:14,549 --> 00:18:11,360
thousandth the size of our milky way uh

475
00:18:17,110 --> 00:18:14,559
there are some giant elliptical galaxies

476
00:18:20,230 --> 00:18:17,120
that are about 30 40 trillion solar

477
00:18:21,909 --> 00:18:20,240
masses okay so they're 10 10 to 20 times

478
00:18:23,270 --> 00:18:21,919
the size of the milky way so we're in

479
00:18:25,270 --> 00:18:23,280
the large galaxy we're not in the

480
00:18:28,630 --> 00:18:25,280
extra-large but we're certainly not in

481
00:18:31,590 --> 00:18:28,640
the dwarf size okay so we it we fit in

482
00:18:32,470 --> 00:18:31,600
uh reasonably well okay

483
00:18:35,909 --> 00:18:32,480
yes

484
00:18:39,350 --> 00:18:35,919
as you expand those uh deep field uh is

485
00:18:41,430 --> 00:18:39,360
the density of galaxies about the same

486
00:18:44,230 --> 00:18:41,440
as we look at different um pieces of the

487
00:18:45,830 --> 00:18:44,240
sky yeah yes when you take an

488
00:18:47,350 --> 00:18:45,840

observation all right so the the

489
00:18:49,110 --> 00:18:47,360
question is are is the density of

490
00:18:51,350 --> 00:18:49,120
galaxies the same in all these different

491
00:18:54,630 --> 00:18:51,360
deep fields uh when you take an

492
00:18:57,110 --> 00:18:54,640
observation to the same depth okay

493
00:18:59,590 --> 00:18:57,120
so you know if you go to i think the

494
00:19:01,430 --> 00:18:59,600
deep field goes to almost 30th magnitude

495
00:19:03,830 --> 00:19:01,440
uh that's how that's how and if you take

496
00:19:06,870 --> 00:19:03,840
another 30th magnitude deep field you

497
00:19:09,430 --> 00:19:06,880
get similar numbers of galaxies yes um

498
00:19:12,710 --> 00:19:09,440
we have not seen any um

499
00:19:14,470 --> 00:19:12,720
discrepancy from the uh the the number

500
00:19:15,750 --> 00:19:14,480
counts in this direction over here and

501
00:19:16,789 --> 00:19:15,760
the number counts in this direction over

502
00:19:18,950 --> 00:19:16,799
here and the number counts in this

503
00:19:20,789 --> 00:19:18,960
direction over here they all seem to be

504
00:19:22,710 --> 00:19:20,799
you know roughly the same now they're

505
00:19:24,630 --> 00:19:22,720
not exactly the same of course but you

506
00:19:26,470 --> 00:19:24,640
know minor barrier not minor variations

507
00:19:27,990 --> 00:19:26,480
we do not see any large variations in

508
00:19:29,669 --> 00:19:28,000
that okay

509
00:19:42,630 --> 00:19:29,679
all right thank you for the questions

510
00:19:47,909 --> 00:19:44,390
okay

511
00:19:50,950 --> 00:19:47,919
our speaker tonight is jolene karlberg

512
00:19:53,750 --> 00:19:50,960
uh and you work in your work on stis

513
00:19:56,710 --> 00:19:53,760

what group is that in

514
00:19:58,789 --> 00:19:56,720
it's just it's ins ins we have all these

515
00:20:00,230 --> 00:19:58,799
acronyms and i've got to tell you i

516
00:20:01,590 --> 00:20:00,240
don't pay attention every single one of

517
00:20:04,870 --> 00:20:01,600
them but she works on the space

518
00:20:07,029 --> 00:20:04,880
telescope imaging spectrograph

519
00:20:08,549 --> 00:20:07,039
and the user support group

520
00:20:11,750 --> 00:20:08,559
and we were talking about this yesterday

521
00:20:14,549 --> 00:20:11,760
and she does uh amazing work to help the

522
00:20:16,710 --> 00:20:14,559
astronomers who are using hubble

523
00:20:18,630 --> 00:20:16,720
to understand exactly how to use it and

524
00:20:20,390 --> 00:20:18,640
get the maximum science

525
00:20:22,470 --> 00:20:20,400
but the folks in our

526
00:20:24,470 --> 00:20:22,480
building not only do their functional

527
00:20:26,150 --> 00:20:24,480
work like that but they also do their

528
00:20:27,350 --> 00:20:26,160
amazing science and she'll tell you

529
00:20:29,600 --> 00:20:27,360
about it tonight ladies and gentlemen

530
00:20:32,830 --> 00:20:29,610
jolene

531
00:20:37,590 --> 00:20:35,510
karlberg all right thank you very much

532
00:20:38,870 --> 00:20:37,600
i'm really excited to come here today to

533
00:20:40,470 --> 00:20:38,880
talk to you because it's one of my

534
00:20:42,470 --> 00:20:40,480
absolute favorite things to talk about

535
00:20:45,669 --> 00:20:42,480
which is how exoplanets are going to be

536
00:20:48,390 --> 00:20:45,679
consumed by their stars

537
00:20:49,830 --> 00:20:48,400
so i think right now is a very exciting

538
00:20:52,310 --> 00:20:49,840

time

539
00:20:55,029 --> 00:20:52,320
in the world of astronomy because right

540
00:20:57,029 --> 00:20:55,039
now we know of thousands of planets

541
00:20:58,070 --> 00:20:57,039
exoplanets orbiting stars other than our

542
00:20:59,830 --> 00:20:58,080
sun

543
00:21:01,990 --> 00:20:59,840
and because of this

544
00:21:03,590 --> 00:21:02,000
wide number of planets that we know we

545
00:21:05,110 --> 00:21:03,600
have found

546
00:21:05,990 --> 00:21:05,120
worlds that are very different from our

547
00:21:07,990 --> 00:21:06,000
own

548
00:21:09,590 --> 00:21:08,000
we have found planets that are unlike

549
00:21:11,350 --> 00:21:09,600
anything we would have imagined nature

550
00:21:13,750 --> 00:21:11,360
being able to put together

551
00:21:15,510 --> 00:21:13,760
and we're able to see planets around

552
00:21:17,909 --> 00:21:15,520
their stars at various stages of their

553
00:21:19,669 --> 00:21:17,919
star a lot their stars lives which allow

554
00:21:21,430 --> 00:21:19,679
people like me to do my research and try

555
00:21:23,909 --> 00:21:21,440
to think about what is going to happen

556
00:21:25,909 --> 00:21:23,919
when the stars evolve and what is going

557
00:21:27,590 --> 00:21:25,919
to happen to their planets

558
00:21:29,270 --> 00:21:27,600
so throughout this talk i'm going to be

559
00:21:30,870 --> 00:21:29,280
covering a couple of different things

560
00:21:32,950 --> 00:21:30,880
first i want to talk to you a little bit

561
00:21:34,630 --> 00:21:32,960
about what we know about the population

562
00:21:35,909 --> 00:21:34,640
of exoplanets that we have discovered

563
00:21:37,430 --> 00:21:35,919

thus far

564
00:21:39,270 --> 00:21:37,440
and then i'm going to talk a little bit

565
00:21:41,270 --> 00:21:39,280
about basic stellar evolution so you can

566
00:21:43,270 --> 00:21:41,280
get an idea of what the overall life

567
00:21:44,789 --> 00:21:43,280
cycle of a star is so that you can have

568
00:21:46,870 --> 00:21:44,799
a better sense of how it impacts the

569
00:21:48,070 --> 00:21:46,880
planets around it

570
00:21:49,909 --> 00:21:48,080
and then i'm going to talk more about

571
00:21:51,990 --> 00:21:49,919
the meat of

572
00:21:53,350 --> 00:21:52,000
my talk which is the actual ways that

573
00:21:55,830 --> 00:21:53,360
planets are going to be destroyed by

574
00:21:57,430 --> 00:21:55,840
their stars which is very fun if not a

575
00:21:58,870 --> 00:21:57,440
little bit morbid

576
00:22:00,310 --> 00:21:58,880
and then i'll kind of rack up and try to

577
00:22:01,510 --> 00:22:00,320
give you a sense of some of the really

578
00:22:04,230 --> 00:22:01,520
exciting things that i think are coming

579
00:22:05,669 --> 00:22:04,240
down the pipeline in the next few years

580
00:22:07,909 --> 00:22:05,679
frank talked about how there's going to

581
00:22:09,510 --> 00:22:07,919
be a plethora of data coming

582
00:22:11,110 --> 00:22:09,520
in the next 10 years but i think we're

583
00:22:13,190 --> 00:22:11,120
really there already and even in the

584
00:22:17,029 --> 00:22:13,200
next one or two years we're going to

585
00:22:21,750 --> 00:22:19,270
all right so just some basics of

586
00:22:23,430 --> 00:22:21,760
exoplanets there are really two key

587
00:22:25,350 --> 00:22:23,440
characteristics that astronomers like to

588
00:22:26,710 --> 00:22:25,360

think about when we characterize planets

589
00:22:28,710 --> 00:22:26,720
that we discover

590
00:22:30,310 --> 00:22:28,720
one is how big they are and this can

591
00:22:32,710 --> 00:22:30,320
refer to either the mass of the planet

592
00:22:35,029 --> 00:22:32,720
or its physical radius and the other is

593
00:22:37,029 --> 00:22:35,039
the distance of the planet to its star

594
00:22:38,710 --> 00:22:37,039
so if you follow news articles about the

595
00:22:40,630 --> 00:22:38,720
latest discoveries that astronomers have

596
00:22:43,029 --> 00:22:40,640
on exoplanets you will frequently hear

597
00:22:46,149 --> 00:22:43,039
terms like a hot jupiter or a warm

598
00:22:48,310 --> 00:22:46,159
neptune or a cold this or you know

599
00:22:50,230 --> 00:22:48,320
a warm that and really what this is

600
00:22:52,149 --> 00:22:50,240
trying to convey to you is roughly how

601
00:22:53,750 --> 00:22:52,159
big is this planet and roughly how close

602
00:22:55,909 --> 00:22:53,760
is it to the star

603
00:22:57,750 --> 00:22:55,919
so the hot warm cold is telling you is

604
00:22:59,990 --> 00:22:57,760
it you know really close by and getting

605
00:23:04,710 --> 00:23:00,000
cooked or is it so far away that the

606
00:23:09,669 --> 00:23:07,190
now what i'm applauding here

607
00:23:11,590 --> 00:23:09,679
is our up-to-date knowledge as of a few

608
00:23:13,830 --> 00:23:11,600
weeks ago of all of the confirmed

609
00:23:15,909 --> 00:23:13,840
planets around other stars i'm going to

610
00:23:17,909 --> 00:23:15,919
take a few minutes to explain the axis

611
00:23:20,070 --> 00:23:17,919
here so on the bottom which is a little

612
00:23:21,909 --> 00:23:20,080
bit more cut off than i was hoping is

613
00:23:23,350 --> 00:23:21,919

showing the separation of a planet from

614
00:23:26,470 --> 00:23:23,360
its host star

615
00:23:29,669 --> 00:23:26,480
and on the axis on the y-axis i'm

616
00:23:31,350 --> 00:23:29,679
showing how massive the planet is

617
00:23:32,950 --> 00:23:31,360
in this plot and a lot of the plots that

618
00:23:34,390 --> 00:23:32,960
i'm showing the axes are going to be

619
00:23:36,710 --> 00:23:34,400
logarithmic which means they're going to

620
00:23:39,510 --> 00:23:36,720
be stepping in powers of 10. so in this

621
00:23:42,149 --> 00:23:39,520
case 1 refers to the separation of earth

622
00:23:44,950 --> 00:23:42,159
from the sun and we step in powers of 10

623
00:23:48,390 --> 00:23:44,960
times farther and 100 times farther 1 10

624
00:23:50,950 --> 00:23:48,400
1 100 etc and the y axis here

625
00:23:53,110 --> 00:23:50,960
is scaled to the mass of jupiter so one

626
00:23:55,669 --> 00:23:53,120
here is the mass of jupiter these are

627
00:23:57,590 --> 00:23:55,679
ten times more massive one tenth one one

628
00:23:59,190 --> 00:23:57,600
hundredth etc

629
00:24:01,669 --> 00:23:59,200
so the big circles that i've drawn on

630
00:24:03,190 --> 00:24:01,679
here are the planets in our solar system

631
00:24:04,710 --> 00:24:03,200
and all of these other colored points

632
00:24:06,230 --> 00:24:04,720
are the planets that we know that exist

633
00:24:07,750 --> 00:24:06,240
around other stars

634
00:24:10,390 --> 00:24:07,760
the color coding of the points tell you

635
00:24:12,470 --> 00:24:10,400
how the planets were discovered

636
00:24:15,110 --> 00:24:12,480
and you'll notice that this large swath

637
00:24:18,149 --> 00:24:15,120
of pink triangles are these were

638
00:24:20,310 --> 00:24:18,159

discovered by the transit method the

639
00:24:22,870 --> 00:24:20,320
vast majority of them by the kepler's

640
00:24:25,510 --> 00:24:22,880
telescope itself

641
00:24:27,510 --> 00:24:25,520
now you'll notice that there still

642
00:24:29,350 --> 00:24:27,520
aren't very many things that we've

643
00:24:31,269 --> 00:24:29,360
discovered that look like the planets in

644
00:24:32,950 --> 00:24:31,279
our solar system

645
00:24:34,630 --> 00:24:32,960
but the reason for that isn't

646
00:24:36,710 --> 00:24:34,640
necessarily that they don't exist it's

647
00:24:38,390 --> 00:24:36,720
the fact that things that are in the top

648
00:24:40,230 --> 00:24:38,400
left portion of the plot are just easier

649
00:24:42,870 --> 00:24:40,240
to find so the more massive you are the

650
00:24:44,310 --> 00:24:42,880
bigger you are the easier it is to find

651
00:24:45,750 --> 00:24:44,320
and for most of the techniques that

652
00:24:47,909 --> 00:24:45,760
we've used thus far the closer you are

653
00:24:49,590 --> 00:24:47,919
to the star the easier they are to find

654
00:24:52,950 --> 00:24:49,600
and so this drop off in this direction

655
00:24:54,950 --> 00:24:52,960
is just because we can't find anything

656
00:24:57,990 --> 00:24:54,960
however what i would like to point out

657
00:25:00,390 --> 00:24:58,000
for starters is this huge grouping of

658
00:25:03,110 --> 00:25:00,400
planets right here which you'll notice

659
00:25:05,510 --> 00:25:03,120
um are terrestrial planets sit below

660
00:25:07,750 --> 00:25:05,520
this box and our ice and gastritis sit

661
00:25:09,909 --> 00:25:07,760
above so kepler has discovered this

662
00:25:12,070 --> 00:25:09,919
class of planets for which we have no

663
00:25:13,750 --> 00:25:12,080

examples in our solar system and so

664
00:25:15,510 --> 00:25:13,760
you'll hear terms like super earths and

665
00:25:17,190 --> 00:25:15,520
mini neptunes to describe the fact that

666
00:25:18,710 --> 00:25:17,200
we don't really know

667
00:25:20,070 --> 00:25:18,720
exactly what we expect for the

668
00:25:21,510 --> 00:25:20,080
composition and structure of these

669
00:25:22,789 --> 00:25:21,520
planets to be

670
00:25:25,990 --> 00:25:22,799
and so i think these are a really

671
00:25:28,230 --> 00:25:26,000
exciting thing that we that kepler

672
00:25:32,870 --> 00:25:28,240
has discovered and these things are

673
00:25:33,990 --> 00:25:32,880
intrinsically um popular um abundant um

674
00:25:36,789 --> 00:25:34,000
because like i said these things are

675
00:25:38,789 --> 00:25:36,799
easier to find so the fact that we find

676
00:25:41,110 --> 00:25:38,799
so many down here and they're harder to

677
00:25:43,190 --> 00:25:41,120
find means they are much much much more

678
00:25:45,510 --> 00:25:43,200
common

679
00:25:47,510 --> 00:25:45,520
however i do also find

680
00:25:49,510 --> 00:25:47,520
things in this box also be extremely

681
00:25:51,830 --> 00:25:49,520
interesting these are one of the first

682
00:25:54,390 --> 00:25:51,840
types of planets that astronomers

683
00:25:55,750 --> 00:25:54,400
discovered which we termed hot jupiters

684
00:25:57,909 --> 00:25:55,760
which we didn't expect at all so these

685
00:26:00,310 --> 00:25:57,919
are things as massive or sometimes more

686
00:26:02,310 --> 00:26:00,320
massive than jupiter that are sitting at

687
00:26:03,909 --> 00:26:02,320
distances that are significantly

688
00:26:05,190 --> 00:26:03,919

significantly closer to the star than

689
00:26:07,750 --> 00:26:05,200
mercury is

690
00:26:09,510 --> 00:26:07,760
and so why i think that's interesting is

691
00:26:11,590 --> 00:26:09,520
that if we drop poor little mercury into

692
00:26:12,470 --> 00:26:11,600
the sun we might not expect much to

693
00:26:13,909 --> 00:26:12,480
happen

694
00:26:15,510 --> 00:26:13,919
but if you start dropping things that

695
00:26:17,029 --> 00:26:15,520
are the size of jupiter or bigger into

696
00:26:19,190 --> 00:26:17,039
its host star you might actually have a

697
00:26:20,470 --> 00:26:19,200
chance of seeing the effects of that

698
00:26:23,990 --> 00:26:20,480
engulfment

699
00:26:25,350 --> 00:26:24,000
in by studying the star itself

700
00:26:26,630 --> 00:26:25,360
okay so i promised to tell you a little

701
00:26:28,549 --> 00:26:26,640
bit about the different types of stars

702
00:26:30,870 --> 00:26:28,559
and here and how they evolved

703
00:26:32,549 --> 00:26:30,880
so this representation here is a very

704
00:26:34,789 --> 00:26:32,559
famous hertz spring russell diagram

705
00:26:36,870 --> 00:26:34,799
which plots um the

706
00:26:38,710 --> 00:26:36,880
last white pointer here

707
00:26:41,510 --> 00:26:38,720
which plots the

708
00:26:43,430 --> 00:26:41,520
temperature of the star from hot to cool

709
00:26:46,070 --> 00:26:43,440
versus the intrinsic brightness on the

710
00:26:47,830 --> 00:26:46,080
star from dim to very bright

711
00:26:49,750 --> 00:26:47,840
and we discovered that the majority of

712
00:26:51,350 --> 00:26:49,760
stars fall along this diagonal line

713
00:26:53,590 --> 00:26:51,360

which has turned the main sequence this

714
00:26:55,350 --> 00:26:53,600
is where stars will fall when they first

715
00:26:57,590 --> 00:26:55,360
become stars and are fusing hydrogen to

716
00:26:59,190 --> 00:26:57,600
helium in their cores and this is a mass

717
00:27:01,190 --> 00:26:59,200
sequence these are very massive things

718
00:27:02,789 --> 00:27:01,200
these are very low mass things

719
00:27:04,390 --> 00:27:02,799
but then as the stars evolve they will

720
00:27:05,909 --> 00:27:04,400
eventually become the type of stars that

721
00:27:07,269 --> 00:27:05,919
i like to study which are red giant

722
00:27:08,549 --> 00:27:07,279
stars and these are the stars that i'm

723
00:27:11,029 --> 00:27:08,559
going to be talking about a lot

724
00:27:13,510 --> 00:27:11,039
throughout this talk

725
00:27:15,110 --> 00:27:13,520
now to give you a sense of what we may

726
00:27:17,110 --> 00:27:15,120
or may not know about these stars i'm

727
00:27:18,789 --> 00:27:17,120
going to run this animation showing how

728
00:27:20,310 --> 00:27:18,799
stars evolve

729
00:27:22,390 --> 00:27:20,320
so at the very beginning of this

730
00:27:24,950 --> 00:27:22,400
animation all of those stars fell along

731
00:27:26,870 --> 00:27:24,960
the main sequence because the model was

732
00:27:28,870 --> 00:27:26,880
initiated for when all of these stars

733
00:27:31,510 --> 00:27:28,880
originally became stars

734
00:27:33,430 --> 00:27:31,520
and you'll notice that the top part of

735
00:27:35,350 --> 00:27:33,440
the diagram these massive stars evolve

736
00:27:36,549 --> 00:27:35,360
off really quickly so massive stars have

737
00:27:39,029 --> 00:27:36,559
short lives

738
00:27:40,870 --> 00:27:39,039

and you'll see when they become giants

739
00:27:41,909 --> 00:27:40,880
they pass out of this region really

740
00:27:44,390 --> 00:27:41,919
quickly

741
00:27:46,710 --> 00:27:44,400
so that the main sequence lifetime is

742
00:27:48,710 --> 00:27:46,720
relatively long but when stars become

743
00:27:50,789 --> 00:27:48,720
red giants they don't stay there for

744
00:27:51,669 --> 00:27:50,799
very long before they continue on and

745
00:27:53,269 --> 00:27:51,679
die

746
00:27:55,190 --> 00:27:53,279
so if you took a group of stars that

747
00:27:57,029 --> 00:27:55,200
formed all at the same time and observed

748
00:27:59,269 --> 00:27:57,039
them sometime today

749
00:28:00,630 --> 00:27:59,279
how many uh the most massive star that

750
00:28:02,870 --> 00:28:00,640
is still a main sequence star gives you

751
00:28:05,029 --> 00:28:02,880
a rough sense of how old

752
00:28:06,789 --> 00:28:05,039
that population of stars are and all of

753
00:28:08,630 --> 00:28:06,799
the stars that are currently red giant

754
00:28:11,750 --> 00:28:08,640
are actually almost all of identical

755
00:28:14,950 --> 00:28:12,710
and this is just to give a

756
00:28:16,710 --> 00:28:14,960
representation of just how big stars get

757
00:28:18,630 --> 00:28:16,720
when they become red giants

758
00:28:21,350 --> 00:28:18,640
so down here in this little corner if

759
00:28:23,909 --> 00:28:21,360
you can see is our sun and two scale are

760
00:28:25,750 --> 00:28:23,919
the sizes of some well-known red giant

761
00:28:27,590 --> 00:28:25,760
stars that are naked-eyed objects so

762
00:28:28,789 --> 00:28:27,600
this is pollux in the constellation

763
00:28:32,630 --> 00:28:28,799

gemini

764
00:28:35,510 --> 00:28:33,669
but what i think is a bit more

765
00:28:37,510 --> 00:28:35,520
illuminating is how the sizes of these

766
00:28:39,830 --> 00:28:37,520
stars compare to the known separations

767
00:28:41,430 --> 00:28:39,840
between stars and planets so at what i'm

768
00:28:43,029 --> 00:28:41,440
showing here

769
00:28:45,830 --> 00:28:43,039
is the same plot i showed you earlier

770
00:28:47,669 --> 00:28:45,840
except now i'm showing where the sun the

771
00:28:49,669 --> 00:28:47,679
edge of the sun's radius extends to

772
00:28:52,310 --> 00:28:49,679
scale on this plot which is not

773
00:28:54,630 --> 00:28:52,320
particularly interesting for the sun

774
00:28:56,230 --> 00:28:54,640
but when the sun becomes a red giant

775
00:28:58,470 --> 00:28:56,240
star and starts to become as big as

776
00:29:00,789 --> 00:28:58,480
these red giants like pollux

777
00:29:02,950 --> 00:29:00,799
and arcturus and aldebaran you'll notice

778
00:29:04,789 --> 00:29:02,960
that its radius is going to increase to

779
00:29:07,029 --> 00:29:04,799
a substantial fraction

780
00:29:09,269 --> 00:29:07,039
of the radius or of the distance to

781
00:29:10,470 --> 00:29:09,279
mercury in our solar system and then

782
00:29:12,950 --> 00:29:10,480
when you look at all of these other

783
00:29:14,149 --> 00:29:12,960
solar systems exosolar systems you see

784
00:29:15,909 --> 00:29:14,159
that many of these planets are at

785
00:29:17,830 --> 00:29:15,919
distances that are going to be inside

786
00:29:20,710 --> 00:29:17,840
the future radius of their stars so

787
00:29:22,149 --> 00:29:20,720
these guys are goners

788
00:29:23,909 --> 00:29:22,159

but it turns out

789
00:29:25,430 --> 00:29:23,919
from a planet's point of view the story

790
00:29:27,510 --> 00:29:25,440
is even worse

791
00:29:30,070 --> 00:29:27,520
and that's because you cannot neglect

792
00:29:31,430 --> 00:29:30,080
the force of tides raised on the star by

793
00:29:33,029 --> 00:29:31,440
the planet

794
00:29:35,590 --> 00:29:33,039
now you're probably familiar with tides

795
00:29:38,310 --> 00:29:35,600
on earth this is due to the presence of

796
00:29:39,190 --> 00:29:38,320
the moon the nice sloshy water on the

797
00:29:40,630 --> 00:29:39,200
earth

798
00:29:42,470 --> 00:29:40,640
it feels the gravitational attraction of

799
00:29:44,789 --> 00:29:42,480
the moon which pulls it into this kind

800
00:29:46,710 --> 00:29:44,799
of bulgy shape

801
00:29:48,149 --> 00:29:46,720
so this in this case i'm showing what

802
00:29:49,909 --> 00:29:48,159
the star looked like before you put a

803
00:29:51,750 --> 00:29:49,919
planet really close to it which forms

804
00:29:53,350 --> 00:29:51,760
this tidal bulge and this is due to the

805
00:29:56,149 --> 00:29:53,360
fact that the

806
00:29:57,990 --> 00:29:56,159
part of the body that is closer to

807
00:30:00,070 --> 00:29:58,000
um in this case the planet feels a

808
00:30:02,710 --> 00:30:00,080
noticeably stronger gravity than the far

809
00:30:05,190 --> 00:30:02,720
side of the same object

810
00:30:07,830 --> 00:30:05,200
now if neither object were moving this

811
00:30:10,389 --> 00:30:07,840
is what this situation would continue to

812
00:30:12,230 --> 00:30:10,399
look like however in general the star is

813
00:30:13,430 --> 00:30:12,240

rotating in the planet is orbiting

814
00:30:15,990 --> 00:30:13,440
around it

815
00:30:18,710 --> 00:30:16,000
now if the planet is going slower around

816
00:30:20,549 --> 00:30:18,720
the star than the way that this

817
00:30:22,310 --> 00:30:20,559
star spins

818
00:30:23,750 --> 00:30:22,320
you'll be in the situation like you are

819
00:30:25,750 --> 00:30:23,760
with the earth moon system the earth

820
00:30:27,430 --> 00:30:25,760
spins once every 24 days the moon goes

821
00:30:28,630 --> 00:30:27,440
around once every

822
00:30:32,230 --> 00:30:28,640
month

823
00:30:34,470 --> 00:30:32,240
which means this um this tidal bulge of

824
00:30:38,149 --> 00:30:34,480
the fast spinning uh tidally distorted

825
00:30:41,110 --> 00:30:38,159
body tends to lead where the position of

826
00:30:42,230 --> 00:30:41,120
the body that's causing the tide is

827
00:30:43,750 --> 00:30:42,240
and what this means is you kind of

828
00:30:46,149 --> 00:30:43,760
introduce a torque into the system

829
00:30:47,909 --> 00:30:46,159
gravity wants to realign this along a

830
00:30:49,750 --> 00:30:47,919
straight line to the planet

831
00:30:51,190 --> 00:30:49,760
and so if you can think about the star

832
00:30:53,110 --> 00:30:51,200
trying to be pulled backwards and i

833
00:30:56,070 --> 00:30:53,120
should say in in this scenario both

834
00:30:57,350 --> 00:30:56,080
things are um rotating counterclockwise

835
00:30:58,950 --> 00:30:57,360
so the gravity is going to try to pull

836
00:31:01,269 --> 00:30:58,960
this in a clockwise direction which is

837
00:31:02,630 --> 00:31:01,279
going to slow down the star give angular

838
00:31:04,470 --> 00:31:02,640

momentum to the planet and push it

839
00:31:05,990 --> 00:31:04,480
outward the earth is doing this to the

840
00:31:08,870 --> 00:31:06,000
moon we are slowly pushing the moon away

841
00:31:10,549 --> 00:31:08,880
from us and we are slowly slowing down

842
00:31:12,470 --> 00:31:10,559
however if you're in the opposite

843
00:31:14,070 --> 00:31:12,480
rotation case where the star in this

844
00:31:16,230 --> 00:31:14,080
case is going slowly and the planet is

845
00:31:18,230 --> 00:31:16,240
orbiting quickly the angular momentum

846
00:31:20,710 --> 00:31:18,240
goes in the other direction and so the

847
00:31:22,149 --> 00:31:20,720
star spins faster and the planet gets

848
00:31:23,669 --> 00:31:22,159
pulled in closer

849
00:31:26,310 --> 00:31:23,679
but then once the planet is pulled in

850
00:31:28,149 --> 00:31:26,320
closer it actually raises a stronger

851
00:31:29,990 --> 00:31:28,159
title it has a stronger title

852
00:31:31,669 --> 00:31:30,000
interaction which means all of these

853
00:31:33,750 --> 00:31:31,679
processes happen much faster and it

854
00:31:35,110 --> 00:31:33,760
turns out the planet will rapidly spiral

855
00:31:36,630 --> 00:31:35,120
into the star

856
00:31:38,870 --> 00:31:36,640
and so on that plot that i showed you

857
00:31:40,630 --> 00:31:38,880
before really you need to go five times

858
00:31:42,149 --> 00:31:40,640
the radius of the star those are all the

859
00:31:44,549 --> 00:31:42,159
planets that actually really need to be

860
00:31:46,789 --> 00:31:44,559
worried that it's going to fall into its

861
00:31:47,990 --> 00:31:46,799
star

862
00:31:49,990 --> 00:31:48,000
so hopefully by this point i've

863
00:31:51,430 --> 00:31:50,000

convinced you that planets are going to

864
00:31:53,350 --> 00:31:51,440
be eaten by their stars there's no

865
00:31:54,950 --> 00:31:53,360
escaping it so the next interesting

866
00:31:56,950 --> 00:31:54,960
question that we can ask is what exactly

867
00:31:59,509 --> 00:31:56,960
happens to these planets and so i've

868
00:32:01,190 --> 00:31:59,519
listed here three different physical

869
00:32:03,269 --> 00:32:01,200
processes that might actually destroy

870
00:32:05,590 --> 00:32:03,279
your planet break it up into bits and do

871
00:32:07,669 --> 00:32:05,600
all sorts of fun things like that to it

872
00:32:10,149 --> 00:32:07,679
the first one is title disruption and

873
00:32:13,190 --> 00:32:10,159
this is the idea again related to the

874
00:32:15,430 --> 00:32:13,200
title effects the fact that in certain

875
00:32:17,750 --> 00:32:15,440
um gravity scenarios

876
00:32:18,870 --> 00:32:17,760
the gravity on the closer side compared

877
00:32:20,549 --> 00:32:18,880
to the gravity filter on the farther

878
00:32:23,269 --> 00:32:20,559
side of an object matters and can be

879
00:32:27,110 --> 00:32:25,190
so in this case if an object gets too

880
00:32:29,190 --> 00:32:27,120
close to a massive thing

881
00:32:30,870 --> 00:32:29,200
that tidal stretching across the planet

882
00:32:32,549 --> 00:32:30,880
can actually just pull it apart pull it

883
00:32:34,870 --> 00:32:32,559
apart it'll be stronger than the energy

884
00:32:36,549 --> 00:32:34,880
that's used to hold the planet together

885
00:32:38,389 --> 00:32:36,559
and we think that this is part of what

886
00:32:40,149 --> 00:32:38,399
can be responsible for forming rings

887
00:32:41,750 --> 00:32:40,159
around planets in our solar system if

888
00:32:43,750 --> 00:32:41,760

small rocky bodies get close enough they

889
00:32:45,509 --> 00:32:43,760
can be tidally shredded

890
00:32:48,389 --> 00:32:45,519
and pulled to beds

891
00:32:50,310 --> 00:32:48,399
a somewhat related phenomenon is one

892
00:32:52,149 --> 00:32:50,320
that's well studied in the study of

893
00:32:53,350 --> 00:32:52,159
binary stars which is called rush lobe

894
00:32:54,950 --> 00:32:53,360
overflow

895
00:32:57,590 --> 00:32:54,960
and in this case what you want to think

896
00:32:59,669 --> 00:32:57,600
about is the idea um when we think about

897
00:33:01,590 --> 00:32:59,679
space-time as being like a sheet of uh

898
00:33:03,110 --> 00:33:01,600
like a rubber mat if you take two

899
00:33:05,110 --> 00:33:03,120
massive bodies and drop them on they

900
00:33:06,630 --> 00:33:05,120
form little gravity wells and so that's

901
00:33:09,110 --> 00:33:06,640
what's illustrated here so a more

902
00:33:11,350 --> 00:33:09,120
massive body has a deeper gravity well

903
00:33:12,789 --> 00:33:11,360
than a less massive body and so this

904
00:33:14,789 --> 00:33:12,799
cutout is showing if you were looking

905
00:33:16,950 --> 00:33:14,799
down on the system and draw

906
00:33:19,669 --> 00:33:16,960
regions where the gravity potential

907
00:33:21,669 --> 00:33:19,679
feels the same you get you get this

908
00:33:24,230 --> 00:33:21,679
bottom plot here and you can see that

909
00:33:26,389 --> 00:33:24,240
close into the to each of these objects

910
00:33:28,549 --> 00:33:26,399
it's roughly circular

911
00:33:30,070 --> 00:33:28,559
so you can imagine so if this is a star

912
00:33:31,830 --> 00:33:30,080
and this is a planet you can imagine

913
00:33:33,110 --> 00:33:31,840

that if the planet is big and puffy

914
00:33:35,029 --> 00:33:33,120
enough

915
00:33:38,070 --> 00:33:35,039
and becomes bigger than the region

916
00:33:39,509 --> 00:33:38,080
around it where its gravity wins then

917
00:33:41,430 --> 00:33:39,519
the outer layers of the star can

918
00:33:43,190 --> 00:33:41,440
actually start to spill over from that

919
00:33:45,029 --> 00:33:43,200
object and fall down into the gravity

920
00:33:47,350 --> 00:33:45,039
well of the star so that's racial

921
00:33:49,509 --> 00:33:47,360
overflow

922
00:33:51,430 --> 00:33:49,519
now the other scenario is that if the

923
00:33:53,830 --> 00:33:51,440
planet manages to avoid both of these

924
00:33:55,509 --> 00:33:53,840
scenarios and actually come in contact

925
00:33:56,950 --> 00:33:55,519
to the outer layers or even deeper

926
00:33:58,389 --> 00:33:56,960
layers of the star

927
00:34:00,149 --> 00:33:58,399
then you're going to have processes such

928
00:34:01,669 --> 00:34:00,159
as ablation or

929
00:34:05,669 --> 00:34:01,679
vaporization where you're just stripping

930
00:34:08,230 --> 00:34:06,789
so

931
00:34:09,750 --> 00:34:08,240
where do these

932
00:34:12,230 --> 00:34:09,760
occur

933
00:34:14,230 --> 00:34:12,240
um it turns out that some of the details

934
00:34:16,950 --> 00:34:14,240
of how and when and where a planet

935
00:34:19,349 --> 00:34:16,960
destroy is destroyed depends a lot on

936
00:34:20,629 --> 00:34:19,359
how evolved the star is when it happens

937
00:34:22,149 --> 00:34:20,639
so just to give you a sense of the

938
00:34:24,310 --> 00:34:22,159

difference of stars here's an example of

939
00:34:25,990 --> 00:34:24,320
the interior of a sun-like star which

940
00:34:28,230 --> 00:34:26,000
has a very thin

941
00:34:29,829 --> 00:34:28,240
convection zone so the convection is the

942
00:34:31,109 --> 00:34:29,839
part of the star that's outside the

943
00:34:33,030 --> 00:34:31,119
outside of the star which is basically

944
00:34:35,829 --> 00:34:33,040
kind of boiling

945
00:34:37,510 --> 00:34:35,839
and here is an interior view of a red

946
00:34:40,629 --> 00:34:37,520
giant star which has a much deeper

947
00:34:42,069 --> 00:34:40,639
region of convection

948
00:34:43,589 --> 00:34:42,079
now one of the interesting things to

949
00:34:45,430 --> 00:34:43,599
note is that when you do the

950
00:34:49,430 --> 00:34:45,440
calculations for things like the tidal

951
00:34:51,270 --> 00:34:49,440
disruption and the rochelle of overflow

952
00:34:52,230 --> 00:34:51,280
those calculations work out to be the

953
00:34:54,310 --> 00:34:52,240
same

954
00:34:55,909 --> 00:34:54,320
no matter what the mass of the star is

955
00:34:58,150 --> 00:34:55,919
and so if you take a sunlight star and

956
00:35:02,390 --> 00:34:58,160
evolve it to a red giant the point at

957
00:35:04,950 --> 00:35:02,400
which roche lobe overflow occurs um only

958
00:35:07,910 --> 00:35:04,960
depends on the masses of these things

959
00:35:09,829 --> 00:35:07,920
and so in this case here if the

960
00:35:11,349 --> 00:35:09,839
star is a sort of smallish red giant

961
00:35:12,710 --> 00:35:11,359
that hasn't evolved very far you can see

962
00:35:14,230 --> 00:35:12,720
in both cases

963
00:35:15,829 --> 00:35:14,240

um you know the

964
00:35:17,349 --> 00:35:15,839
jupiter will undergo rochelle of

965
00:35:19,750 --> 00:35:17,359
overflow before it gets to the surface

966
00:35:21,990 --> 00:35:19,760
of the star but if this is one of those

967
00:35:23,670 --> 00:35:22,000
much larger red giant stars like i

968
00:35:26,630 --> 00:35:23,680
talked about like more like an um

969
00:35:28,550 --> 00:35:26,640
arcturus or aldebaran that is many times

970
00:35:31,030 --> 00:35:28,560
the solar radius and the jupiter will

971
00:35:32,550 --> 00:35:31,040
actually can remain intact before um

972
00:35:33,910 --> 00:35:32,560
something like racial overflow would

973
00:35:36,710 --> 00:35:33,920
occur

974
00:35:38,630 --> 00:35:36,720
and similarly for small compact bodies

975
00:35:41,670 --> 00:35:38,640
like the earth tidal disruption is more

976
00:35:43,910 --> 00:35:41,680
likely way of destroying these and even

977
00:35:45,910 --> 00:35:43,920
for the present day sun the earth can

978
00:35:47,430 --> 00:35:45,920
actually plop itself into the star

979
00:35:49,510 --> 00:35:47,440
before something like tidal disruption

980
00:35:50,950 --> 00:35:49,520
would pull it apart and so then you can

981
00:35:52,150 --> 00:35:50,960
start thinking about well in those

982
00:35:54,150 --> 00:35:52,160
situations you now have to start

983
00:35:56,829 --> 00:35:54,160
thinking about ablation and vaporization

984
00:35:59,589 --> 00:35:56,839
as a process that will destroy

985
00:36:01,190 --> 00:35:59,599
them so the next thing we want to think

986
00:36:03,670 --> 00:36:01,200
about is whether or not we can figure

987
00:36:05,430 --> 00:36:03,680
out um if this engulfment of planets is

988
00:36:07,190 --> 00:36:05,440

happening if we can identify stars for

989
00:36:09,109 --> 00:36:07,200
which this has happened

990
00:36:11,270 --> 00:36:09,119
um so i'm again showing that plot from

991
00:36:12,790 --> 00:36:11,280
the very beginning of the

992
00:36:14,150 --> 00:36:12,800
separation and masses of known

993
00:36:15,829 --> 00:36:14,160
exoplanets

994
00:36:17,670 --> 00:36:15,839
except now i've colored the color code

995
00:36:19,510 --> 00:36:17,680
of the points differently

996
00:36:20,870 --> 00:36:19,520
these black points here are dwarf stars

997
00:36:21,750 --> 00:36:20,880
these are main sequence stars like our

998
00:36:23,829 --> 00:36:21,760
sun

999
00:36:25,910 --> 00:36:23,839
whereas all of these color-coded points

1000
00:36:27,990 --> 00:36:25,920
are giant stars we're reusing the

1001
00:36:31,349 --> 00:36:28,000
surface gravity as a proxy for how large

1002
00:36:33,270 --> 00:36:31,359
they are and one thing you'll notice is

1003
00:36:34,470 --> 00:36:33,280
that there seems to be an absence of

1004
00:36:36,790 --> 00:36:34,480
very

1005
00:36:38,950 --> 00:36:36,800
large close by planets which remember

1006
00:36:40,790 --> 00:36:38,960
are the easiest to discover and this

1007
00:36:43,510 --> 00:36:40,800
could be potential evidence that we are

1008
00:36:44,950 --> 00:36:43,520
seeing that any planets that may have

1009
00:36:46,230 --> 00:36:44,960
once existed around these stars no

1010
00:36:48,870 --> 00:36:46,240
longer do and they may have been

1011
00:36:52,950 --> 00:36:50,870
there are some other signatures that we

1012
00:36:55,910 --> 00:36:52,960
can look for so again

1013
00:36:57,829 --> 00:36:55,920

stars grow very large when

1014
00:36:59,750 --> 00:36:57,839
when they become red giants

1015
00:37:01,589 --> 00:36:59,760
but one thing you have to remember

1016
00:37:03,829 --> 00:37:01,599
is that angular momentum is a conserved

1017
00:37:05,670 --> 00:37:03,839
quantity and so i

1018
00:37:07,589 --> 00:37:05,680
especially now based on frank's story i

1019
00:37:09,589 --> 00:37:07,599
have to bring in the ice skating analogy

1020
00:37:11,430 --> 00:37:09,599
that we frequently use for showing

1021
00:37:13,910 --> 00:37:11,440
conservation of angular momentum you

1022
00:37:15,910 --> 00:37:13,920
picture a figure skater starting a spin

1023
00:37:18,470 --> 00:37:15,920
and when he or she pulls their arms in

1024
00:37:19,510 --> 00:37:18,480
they spin faster and when you expand

1025
00:37:20,829 --> 00:37:19,520
again

1026
00:37:23,910 --> 00:37:20,839
you slow

1027
00:37:26,950 --> 00:37:23,920
down so the kind of fun thing about this

1028
00:37:30,550 --> 00:37:26,960
is that for angle momentum

1029
00:37:32,470 --> 00:37:30,560
the rate of rotation goes as a factor of

1030
00:37:34,390 --> 00:37:32,480
the square of the radius

1031
00:37:36,230 --> 00:37:34,400
so in this case if you take a star and

1032
00:37:38,790 --> 00:37:36,240
increase its radius by a factor of four

1033
00:37:40,470 --> 00:37:38,800
its rotation slows by a factor of 16. so

1034
00:37:42,790 --> 00:37:40,480
now if you can then extrapolate in your

1035
00:37:45,270 --> 00:37:42,800
mind to these even like 10 and 100 times

1036
00:37:46,390 --> 00:37:45,280
larger um you then have to square those

1037
00:37:48,230 --> 00:37:46,400
as well

1038
00:37:51,349 --> 00:37:48,240

so that you really expect red giants to

1039
00:37:53,750 --> 00:37:51,359
be very very slow rotators

1040
00:37:55,589 --> 00:37:53,760
on the other hand if you engulf a planet

1041
00:37:57,109 --> 00:37:55,599
then that planet is dumping angular

1042
00:37:59,270 --> 00:37:57,119
momentum back into the system and can

1043
00:38:01,750 --> 00:37:59,280
spin the stars back up and so that could

1044
00:38:03,430 --> 00:38:01,760
be one signature

1045
00:38:04,790 --> 00:38:03,440
another signature we could look for is

1046
00:38:08,390 --> 00:38:04,800
pollution

1047
00:38:10,790 --> 00:38:08,400
graphic here just to give you um a sort

1048
00:38:12,790 --> 00:38:10,800
of an analogy is if you can imagine

1049
00:38:15,510 --> 00:38:12,800
taking a little dropper of

1050
00:38:18,390 --> 00:38:15,520
dye and dropping it into a beaker of red

1051
00:38:20,950 --> 00:38:18,400
water or you know even clear water

1052
00:38:22,870 --> 00:38:20,960
the question is how much um do you need

1053
00:38:24,390 --> 00:38:22,880
to put in for

1054
00:38:25,750 --> 00:38:24,400
you to be able to notice it in the much

1055
00:38:27,349 --> 00:38:25,760
larger sample

1056
00:38:29,349 --> 00:38:27,359
so you can imagine if you're you know

1057
00:38:30,630 --> 00:38:29,359
putting a dropper of additional red

1058
00:38:32,470 --> 00:38:30,640
stuff in you're probably not going to

1059
00:38:34,069 --> 00:38:32,480
notice but if you drop in a color like

1060
00:38:36,310 --> 00:38:34,079
blue maybe you'll notice a little bit

1061
00:38:37,270 --> 00:38:36,320
more

1062
00:38:39,030 --> 00:38:37,280
so

1063
00:38:40,790 --> 00:38:39,040

by analogy we can think about what the

1064
00:38:42,710 --> 00:38:40,800
compositions of stars are compared to

1065
00:38:44,710 --> 00:38:42,720
their planets to try to see is there a

1066
00:38:46,630 --> 00:38:44,720
way that we can determine whether or not

1067
00:38:48,790 --> 00:38:46,640
the composition of the star has changed

1068
00:38:50,310 --> 00:38:48,800
in a meaningful way

1069
00:38:53,270 --> 00:38:50,320
and the reason we might be able to do

1070
00:38:55,349 --> 00:38:53,280
that um is that stars are predominantly

1071
00:38:56,790 --> 00:38:55,359
um hydrogen and helium like most things

1072
00:38:59,990 --> 00:38:56,800
in the universe

1073
00:39:01,030 --> 00:39:00,000
with a very tiny slice of

1074
00:39:02,870 --> 00:39:01,040
basically everything else on the

1075
00:39:04,710 --> 00:39:02,880
periodic table

1076
00:39:07,270 --> 00:39:04,720
okay so let's now think well what

1077
00:39:09,270 --> 00:39:07,280
happens if we try to drop a jupiter in

1078
00:39:11,109 --> 00:39:09,280
well it turns out jupiter is mostly

1079
00:39:13,349 --> 00:39:11,119
hydrogen and mostly helium with a very

1080
00:39:14,630 --> 00:39:13,359
teeny tiny percentage of

1081
00:39:16,470 --> 00:39:14,640
everything else

1082
00:39:18,390 --> 00:39:16,480
so in this scenario you can then imagine

1083
00:39:20,710 --> 00:39:18,400
that you're basically taking a beaker of

1084
00:39:22,069 --> 00:39:20,720
red that you're dropping into

1085
00:39:24,069 --> 00:39:22,079
red material so you're not going to

1086
00:39:26,790 --> 00:39:24,079
notice anything

1087
00:39:28,950 --> 00:39:26,800
earth by contrast is

1088
00:39:31,430 --> 00:39:28,960

has a completely different ratio of

1089
00:39:33,030 --> 00:39:31,440
abundances um helium is practically

1090
00:39:34,310 --> 00:39:33,040
non-existent on the earth that's

1091
00:39:35,829 --> 00:39:34,320
actually how it got its name it was

1092
00:39:36,630 --> 00:39:35,839
first discovered by a spectrum in the

1093
00:39:38,310 --> 00:39:36,640
sun

1094
00:39:39,750 --> 00:39:38,320
and so now you can imagine that you're

1095
00:39:42,950 --> 00:39:39,760
dropping something that looks very

1096
00:39:44,550 --> 00:39:42,960
different into the sun but of course one

1097
00:39:46,230 --> 00:39:44,560
of the caveats here is that earth is of

1098
00:39:48,550 --> 00:39:46,240
course a much smaller thing and so even

1099
00:39:50,630 --> 00:39:48,560
though its composition is very different

1100
00:39:51,829 --> 00:39:50,640
um there's a concern that you know maybe

1101
00:39:52,950 --> 00:39:51,839
you still wouldn't notice because it's

1102
00:39:54,550 --> 00:39:52,960
so small

1103
00:39:56,150 --> 00:39:54,560
and this is where the discovery of

1104
00:39:57,829 --> 00:39:56,160
kepler of all those things that are sort

1105
00:39:59,349 --> 00:39:57,839
of sitting between the terrestrials in

1106
00:40:01,430 --> 00:39:59,359
our solar system and the giants in our

1107
00:40:02,790 --> 00:40:01,440
solar system is very interesting because

1108
00:40:04,390 --> 00:40:02,800
they could be

1109
00:40:06,310 --> 00:40:04,400
scaled up versions of the earth which

1110
00:40:08,150 --> 00:40:06,320
are much more massive but still very

1111
00:40:12,310 --> 00:40:08,160
chemically different

1112
00:40:17,349 --> 00:40:15,109
you can also take advantage of

1113
00:40:19,670 --> 00:40:17,359

special elements that happen to be

1114
00:40:22,310 --> 00:40:19,680
relatively rare in the star and this is

1115
00:40:23,990 --> 00:40:22,320
actually a field that i study a lot

1116
00:40:25,910 --> 00:40:24,000
so what i'm showing here this is again

1117
00:40:27,349 --> 00:40:25,920
on a logarithmic scale um the relative

1118
00:40:29,589 --> 00:40:27,359
abundance of all the elements of the

1119
00:40:31,270 --> 00:40:29,599
periodic table as a function of their

1120
00:40:33,829 --> 00:40:31,280
position so we're starting at hydrogen

1121
00:40:34,950 --> 00:40:33,839
helium lithium beryllium boron and all

1122
00:40:37,030 --> 00:40:34,960
the way down

1123
00:40:39,750 --> 00:40:37,040
this nice zigzag pattern is just due to

1124
00:40:41,190 --> 00:40:39,760
the way that elements are formed in the

1125
00:40:42,630 --> 00:40:41,200
centers of stars

1126
00:40:44,390 --> 00:40:42,640
but what i need to bring your attention

1127
00:40:45,910 --> 00:40:44,400
to are these three elements lithium

1128
00:40:48,150 --> 00:40:45,920
beryllium and boron which are very

1129
00:40:50,150 --> 00:40:48,160
depleted in the sun and this is because

1130
00:40:52,870 --> 00:40:50,160
they happen to be destroyed relatively

1131
00:40:53,990 --> 00:40:52,880
easily by what's called proton capture

1132
00:40:56,630 --> 00:40:54,000
reactions

1133
00:40:58,550 --> 00:40:56,640
at temperatures that are relatively cool

1134
00:41:01,430 --> 00:40:58,560
from a star's perspective which is you

1135
00:41:03,430 --> 00:41:01,440
know a few million degrees

1136
00:41:06,470 --> 00:41:03,440
very chilly

1137
00:41:09,190 --> 00:41:06,480
but it turns out that our sun's

1138
00:41:11,589 --> 00:41:09,200

abundance of lithium is very depleted

1139
00:41:13,109 --> 00:41:11,599
from what we think started

1140
00:41:15,910 --> 00:41:13,119
so now what i'm showing here is if you

1141
00:41:17,190 --> 00:41:15,920
take a sample of red giant stars and

1142
00:41:19,349 --> 00:41:17,200
look at

1143
00:41:21,990 --> 00:41:19,359
and measure their lithium abundance

1144
00:41:23,990 --> 00:41:22,000
the present-day sun which we saw on the

1145
00:41:25,990 --> 00:41:24,000
last plot sits here

1146
00:41:28,870 --> 00:41:26,000
the red giant stars are fundamentally

1147
00:41:31,030 --> 00:41:28,880
very very lithium poor compared to that

1148
00:41:32,790 --> 00:41:31,040
and the sun itself is quite lithium poor

1149
00:41:34,550 --> 00:41:32,800
compared to what we thought it was so

1150
00:41:36,230 --> 00:41:34,560
this line here is showing the lithium

1151
00:41:38,230 --> 00:41:36,240
abundance we believe the sun started

1152
00:41:39,589 --> 00:41:38,240
with we get this for measurements of the

1153
00:41:42,150 --> 00:41:39,599
relative lithium abundance of things

1154
00:41:44,150 --> 00:41:42,160
like meteorites in our solar system

1155
00:41:45,109 --> 00:41:44,160
and this lithium abundance is again on a

1156
00:41:49,190 --> 00:41:45,119
log

1157
00:41:51,190 --> 00:41:49,200
every time you step by a delta one here

1158
00:41:52,870 --> 00:41:51,200
you're stepping by another power of ten

1159
00:41:54,950 --> 00:41:52,880
so the sun has already depleted by

1160
00:41:57,829 --> 00:41:54,960
nearly a factor of a hundred

1161
00:41:59,670 --> 00:41:57,839
um from its current state and red giants

1162
00:42:02,069 --> 00:41:59,680
are can be ten a hundred or even a

1163
00:42:05,829 --> 00:42:02,079

thousand times more metal for their are

1164
00:42:07,190 --> 00:42:05,839
more lithium-poor than the sun

1165
00:42:09,109 --> 00:42:07,200
and

1166
00:42:11,910 --> 00:42:09,119
to put that in perspective some of these

1167
00:42:15,589 --> 00:42:11,920
most lithium-poor red giants actually

1168
00:42:18,470 --> 00:42:15,599
have less total lithium than a planet

1169
00:42:20,950 --> 00:42:18,480
and so now if you can imagine um taking

1170
00:42:23,829 --> 00:42:20,960
an observation of a red giant star you

1171
00:42:25,510 --> 00:42:23,839
might um intrinsically measure um a

1172
00:42:26,950 --> 00:42:25,520
couple of different lithium abundances

1173
00:42:28,550 --> 00:42:26,960
and you can do the calculation of what

1174
00:42:30,470 --> 00:42:28,560
happens if you start dropping jupiters

1175
00:42:31,430 --> 00:42:30,480
into them and add that lithium to the

1176
00:42:33,510 --> 00:42:31,440
star

1177
00:42:34,870 --> 00:42:33,520
and you can see as you add more and more

1178
00:42:37,270 --> 00:42:34,880
planets

1179
00:42:38,790 --> 00:42:37,280
at some point the the lithium abundance

1180
00:42:41,190 --> 00:42:38,800
that you measure

1181
00:42:42,950 --> 00:42:41,200
almost doesn't care about

1182
00:42:44,470 --> 00:42:42,960
what lithium was originally there in the

1183
00:42:45,910 --> 00:42:44,480
star because the vast majority of the

1184
00:42:47,910 --> 00:42:45,920
lithium atoms are actually coming from

1185
00:42:49,349 --> 00:42:47,920
the stuff that you've dropped in so this

1186
00:42:52,230 --> 00:42:49,359
i think is something that's really

1187
00:42:55,910 --> 00:42:53,829
but then the question is all right so

1188
00:42:57,750 --> 00:42:55,920

now that we know these signatures other

1189
00:42:59,430 --> 00:42:57,760
than you know maybe not discovering

1190
00:43:01,349 --> 00:42:59,440
planets close to stars how do we go

1191
00:43:03,030 --> 00:43:01,359
about measuring these things

1192
00:43:05,349 --> 00:43:03,040
and the way astronomers do this is by

1193
00:43:07,270 --> 00:43:05,359
using the spectra of stars

1194
00:43:09,270 --> 00:43:07,280
so we take the light from a star and we

1195
00:43:11,109 --> 00:43:09,280
break it up into the component

1196
00:43:13,829 --> 00:43:11,119
colors

1197
00:43:15,589 --> 00:43:13,839
now the energy um and light that's

1198
00:43:17,829 --> 00:43:15,599
created by the star happens deep within

1199
00:43:19,750 --> 00:43:17,839
its core and that light propagates out

1200
00:43:21,910 --> 00:43:19,760
and so right before that light leaves

1201
00:43:23,670 --> 00:43:21,920
the star it interacts with the very cool

1202
00:43:26,230 --> 00:43:23,680
atoms and molecules in the atmosphere of

1203
00:43:28,550 --> 00:43:26,240
the star and these things absorb at very

1204
00:43:29,829 --> 00:43:28,560
specific colors which leaves behind

1205
00:43:32,069 --> 00:43:29,839
these nice

1206
00:43:34,550 --> 00:43:32,079
lines on your observed spectrum so what

1207
00:43:36,390 --> 00:43:34,560
we measure is the brightness

1208
00:43:38,150 --> 00:43:36,400
along different colors and we see the

1209
00:43:41,030 --> 00:43:38,160
absence of

1210
00:43:42,550 --> 00:43:41,040
colors at regions that tell us about the

1211
00:43:45,670 --> 00:43:42,560
relative amount of different elements in

1212
00:43:49,910 --> 00:43:46,790
so

1213
00:43:52,710 --> 00:43:49,920

here is a very very very very very

1214
00:43:56,470 --> 00:43:52,720
zoomed in part of that spectrum looking

1215
00:43:58,470 --> 00:43:56,480
at a very minuscule range of wavelengths

1216
00:43:59,190 --> 00:43:58,480
of two stars that are nearly identical

1217
00:44:01,750 --> 00:43:59,200
in

1218
00:44:06,790 --> 00:44:01,760
same

1219
00:44:08,150 --> 00:44:06,800
everything that you can think of but if

1220
00:44:09,910 --> 00:44:08,160
you look at all these little wiggles

1221
00:44:11,589 --> 00:44:09,920
here these are actually these wiggles

1222
00:44:13,990 --> 00:44:11,599
are the absorption of light due to

1223
00:44:16,150 --> 00:44:14,000
various elements and i'm pointing here

1224
00:44:19,030 --> 00:44:16,160
um to the absorption due to the atom

1225
00:44:21,990 --> 00:44:19,040
lithium and so in this case here this

1226
00:44:23,670 --> 00:44:22,000
star has um this very strong lithium

1227
00:44:25,430 --> 00:44:23,680
feature and actually has more than 80

1228
00:44:27,030 --> 00:44:25,440
times the amount of lithium than this

1229
00:44:29,270 --> 00:44:27,040
star here and both of these are red

1230
00:44:32,069 --> 00:44:29,280
giant stars so it is in fact actually

1231
00:44:35,190 --> 00:44:32,079
quite easy to measure um very big

1232
00:44:36,630 --> 00:44:35,200
differences in lithium abundances

1233
00:44:37,910 --> 00:44:36,640
now the rotation of stars is actually

1234
00:44:39,910 --> 00:44:37,920
something that can also be relatively

1235
00:44:41,910 --> 00:44:39,920
easy to measure so what i'm showing here

1236
00:44:43,829 --> 00:44:41,920
is the progression of what happens to a

1237
00:44:46,309 --> 00:44:43,839
spectrum if you have a star that is

1238
00:44:49,190 --> 00:44:46,319

rotating slowly and moderately fast and

1239
00:44:50,550 --> 00:44:49,200
very fast the lines of these stars get

1240
00:44:52,630 --> 00:44:50,560
broader

1241
00:44:55,030 --> 00:44:52,640
and the reason is that if your star is

1242
00:44:56,790 --> 00:44:55,040
rotating um what i've done here is for

1243
00:44:58,550 --> 00:44:56,800
this rotating star i've color coded it

1244
00:45:00,069 --> 00:44:58,560
to indicate the red and blue shift that

1245
00:45:01,829 --> 00:45:00,079
you get because you're looking at a star

1246
00:45:03,109 --> 00:45:01,839
that's rotating part of the star is

1247
00:45:05,190 --> 00:45:03,119
coming towards you part of the star is

1248
00:45:07,510 --> 00:45:05,200
going away from you

1249
00:45:10,550 --> 00:45:07,520
and each little dot each little region

1250
00:45:12,230 --> 00:45:10,560
on the star is basically um

1251
00:45:13,829 --> 00:45:12,240
you can think of as creating its own

1252
00:45:15,190 --> 00:45:13,839
individual spectrum

1253
00:45:16,630 --> 00:45:15,200
but all of the

1254
00:45:17,829 --> 00:45:16,640
spectra coming from this part of the

1255
00:45:20,150 --> 00:45:17,839
star is going to be slightly blue

1256
00:45:21,270 --> 00:45:20,160
shifted and all of the part coming from

1257
00:45:23,430 --> 00:45:21,280
this side of the stars are going to be

1258
00:45:25,349 --> 00:45:23,440
slightly red-shifted you can't see that

1259
00:45:26,790 --> 00:45:25,359
individually you just see the the sun

1260
00:45:29,030 --> 00:45:26,800
over all those different regions of the

1261
00:45:31,190 --> 00:45:29,040
star and so the result is that you get

1262
00:45:32,550 --> 00:45:31,200
these very broadened or very fat

1263
00:45:35,349 --> 00:45:32,560

features that tell you the star is

1264
00:45:37,670 --> 00:45:35,359
rotating quickly

1265
00:45:40,870 --> 00:45:37,680
okay so we expect high lithium and high

1266
00:45:42,390 --> 00:45:40,880
rotation to maybe be an indication of um

1267
00:45:43,910 --> 00:45:42,400
planet engulfment and this is something

1268
00:45:46,309 --> 00:45:43,920
that i've actually started studying way

1269
00:45:47,750 --> 00:45:46,319
back when i was doing my phd and this

1270
00:45:49,589 --> 00:45:47,760
was one of the results that came out of

1271
00:45:51,349 --> 00:45:49,599
it where i went and looked at a big

1272
00:45:52,950 --> 00:45:51,359
sample of red giant stars i measured how

1273
00:45:54,630 --> 00:45:52,960
fast they were rotating and i measured

1274
00:45:57,750 --> 00:45:54,640
how much lithium they have so here's

1275
00:45:59,670 --> 00:45:57,760
that rotation from slow to fast here and

1276
00:46:03,109 --> 00:45:59,680
relative lithium abundances from

1277
00:46:05,109 --> 00:46:03,119
practically none to lots on this axis

1278
00:46:07,190 --> 00:46:05,119
the blue dots here are the ones that

1279
00:46:09,510 --> 00:46:07,200
were rotating faster than we thought red

1280
00:46:11,349 --> 00:46:09,520
giant should be and everything over here

1281
00:46:13,190 --> 00:46:11,359
are relatively slow

1282
00:46:15,109 --> 00:46:13,200
and the main result of this was that if

1283
00:46:18,150 --> 00:46:15,119
you look at the average difference

1284
00:46:20,950 --> 00:46:18,160
between the two on average fast rotators

1285
00:46:22,470 --> 00:46:20,960
have it have 10 times more lithium than

1286
00:46:23,670 --> 00:46:22,480
the slow guys

1287
00:46:25,750 --> 00:46:23,680
and if you make a whole bunch of

1288
00:46:27,589 --> 00:46:25,760

assumptions about how much mass is in

1289
00:46:29,030 --> 00:46:27,599
the stars on average blah blah blah you

1290
00:46:30,470 --> 00:46:29,040
can kind of convert this to how many

1291
00:46:31,829 --> 00:46:30,480
planets would you might eat and the

1292
00:46:33,990 --> 00:46:31,839
answer comes out to be a couple of

1293
00:46:35,589 --> 00:46:34,000
jupiters

1294
00:46:37,670 --> 00:46:35,599
however you may notice that there is a

1295
00:46:39,190 --> 00:46:37,680
very large scatter here of points and i

1296
00:46:39,990 --> 00:46:39,200
do have a little representative error

1297
00:46:41,589 --> 00:46:40,000
bar

1298
00:46:43,670 --> 00:46:41,599
stars in general can have lots of

1299
00:46:45,190 --> 00:46:43,680
different lithium abundances for things

1300
00:46:46,390 --> 00:46:45,200
that have absolutely nothing to do with

1301
00:46:48,550 --> 00:46:46,400
planets

1302
00:46:50,390 --> 00:46:48,560
which is a problem

1303
00:46:52,470 --> 00:46:50,400
um one of the things that it depends on

1304
00:46:53,829 --> 00:46:52,480
um is how much lithium it started with

1305
00:46:55,670 --> 00:46:53,839
and how much lithium it destroyed and

1306
00:46:58,309 --> 00:46:55,680
both those things vary

1307
00:46:59,829 --> 00:46:58,319
sensitively on how massive the star is

1308
00:47:01,750 --> 00:46:59,839
so one of the ways you can go around

1309
00:47:03,030 --> 00:47:01,760
that is to try to get a sample of stars

1310
00:47:04,150 --> 00:47:03,040
where you think everything is the same

1311
00:47:06,230 --> 00:47:04,160
mass

1312
00:47:07,910 --> 00:47:06,240
so what i'm going to tell you about now

1313
00:47:11,030 --> 00:47:07,920

is one of my favorite stories the story

1314
00:47:13,190 --> 00:47:11,040
of ngc 6819 this is going to be

1315
00:47:14,710 --> 00:47:13,200
a longish story about

1316
00:47:16,950 --> 00:47:14,720
some of the really interesting things

1317
00:47:19,990 --> 00:47:16,960
you can do when you combine

1318
00:47:22,630 --> 00:47:20,000
information from all sorts of different

1319
00:47:24,950 --> 00:47:22,640
methods of studying the same thing

1320
00:47:27,030 --> 00:47:24,960
so what what's shown here is a color

1321
00:47:28,550 --> 00:47:27,040
magnitude diagram so this is basically

1322
00:47:31,109 --> 00:47:28,560
like a hearthstone russell diagram so

1323
00:47:33,030 --> 00:47:31,119
this is the temperature um or color of

1324
00:47:35,109 --> 00:47:33,040
the star so blue hot things here cool

1325
00:47:38,390 --> 00:47:35,119
red things here fainter things in the

1326
00:47:40,470 --> 00:47:38,400
visible here brighter things here

1327
00:47:42,470 --> 00:47:40,480
the line here is showing

1328
00:47:44,150 --> 00:47:42,480
what you would expect for a group of

1329
00:47:46,870 --> 00:47:44,160
stars that all formed at the same time

1330
00:47:48,550 --> 00:47:46,880
and are now all at a specific age

1331
00:47:50,630 --> 00:47:48,560
if you remember from the very beginning

1332
00:47:52,790 --> 00:47:50,640
i said that when that happens

1333
00:47:54,870 --> 00:47:52,800
you expect a lot of stars to be on the

1334
00:47:56,390 --> 00:47:54,880
main sequence all of the massive stars

1335
00:47:57,910 --> 00:47:56,400
to be gone and the stars that are

1336
00:47:59,990 --> 00:47:57,920
currently in the red giant face would be

1337
00:48:01,910 --> 00:48:00,000
all roughly the same mass so all of

1338
00:48:03,510 --> 00:48:01,920

these purple circles are the stars that

1339
00:48:05,589 --> 00:48:03,520
are the red giant we think these are all

1340
00:48:07,750 --> 00:48:05,599
roughly the same mass and this one star

1341
00:48:10,390 --> 00:48:07,760
here which appears to be right where you

1342
00:48:11,910 --> 00:48:10,400
may expect has a lot of lithium

1343
00:48:14,630 --> 00:48:11,920
in fact it has more than 40 times the

1344
00:48:16,790 --> 00:48:14,640
lithium than all the other giants

1345
00:48:18,630 --> 00:48:16,800
now i haven't uh talked to you too much

1346
00:48:19,829 --> 00:48:18,640
yet about why red giants have so little

1347
00:48:22,790 --> 00:48:19,839
lithium

1348
00:48:24,470 --> 00:48:22,800
but it has to do with um

1349
00:48:27,109 --> 00:48:24,480
with again with this convection region

1350
00:48:29,670 --> 00:48:27,119
in the star so in the when the star is

1351
00:48:31,510 --> 00:48:29,680
like our sun there's a it has a very

1352
00:48:33,109 --> 00:48:31,520
thin convection region on the very edge

1353
00:48:35,430 --> 00:48:33,119
of it which is cool enough that lithium

1354
00:48:37,349 --> 00:48:35,440
is fine but some of that lithium gets

1355
00:48:39,910 --> 00:48:37,359
mixed down into the star where it gets

1356
00:48:41,750 --> 00:48:39,920
destroyed and is gone

1357
00:48:43,510 --> 00:48:41,760
but that's a relatively slow process and

1358
00:48:45,030 --> 00:48:43,520
so that's why the lithium in the sun has

1359
00:48:47,829 --> 00:48:45,040
gone down

1360
00:48:49,670 --> 00:48:47,839
pretty slowly but below that region

1361
00:48:51,589 --> 00:48:49,680
basically there's no lithium left and if

1362
00:48:53,750 --> 00:48:51,599
you go even deeper in the star there are

1363
00:48:55,510 --> 00:48:53,760

some byproducts of the nuclear fusion

1364
00:48:57,190 --> 00:48:55,520
that has powered the sun for its entire

1365
00:48:59,030 --> 00:48:57,200
life

1366
00:49:00,390 --> 00:48:59,040
when the star becomes a red giant this

1367
00:49:02,630 --> 00:49:00,400
mixing region

1368
00:49:04,950 --> 00:49:02,640
goes deep into the star and so it mixes

1369
00:49:07,670 --> 00:49:04,960
it into the lithium pore interior and so

1370
00:49:09,030 --> 00:49:07,680
that's why all the lithium gets diluted

1371
00:49:10,790 --> 00:49:09,040
and so you it looks like the star is

1372
00:49:12,710 --> 00:49:10,800
pretty much no lithium

1373
00:49:14,630 --> 00:49:12,720
and the important thing here is that it

1374
00:49:16,309 --> 00:49:14,640
also brings up some of these nuclear

1375
00:49:18,470 --> 00:49:16,319
byproducts it actually changes the ratio

1376
00:49:20,470 --> 00:49:18,480
of carbon to nitrogen in the star and

1377
00:49:22,390 --> 00:49:20,480
this star shows all the evidence that it

1378
00:49:23,990 --> 00:49:22,400
has become a red giant so we know this

1379
00:49:25,510 --> 00:49:24,000
mixing has occurred so we know it should

1380
00:49:27,109 --> 00:49:25,520
be lithium poor

1381
00:49:28,549 --> 00:49:27,119
so that's important

1382
00:49:29,990 --> 00:49:28,559
so the first thing you can do is ask

1383
00:49:31,349 --> 00:49:30,000
yourself okay how big of a thing would

1384
00:49:33,589 --> 00:49:31,359
you need to drop in

1385
00:49:35,510 --> 00:49:33,599
to explain the lithium that we see if we

1386
00:49:36,870 --> 00:49:35,520
assume that it should have the lithium

1387
00:49:38,069 --> 00:49:36,880
that all the other stars in the cluster

1388
00:49:39,270 --> 00:49:38,079

do

1389
00:49:41,030 --> 00:49:39,280
and when you work in the mouth it turns

1390
00:49:43,030 --> 00:49:41,040
out to be a small star which is a

1391
00:49:44,390 --> 00:49:43,040
problem because a small star also burns

1392
00:49:45,670 --> 00:49:44,400
its lithium so it's not going to supply

1393
00:49:46,710 --> 00:49:45,680
any lithium so that actually doesn't

1394
00:49:48,630 --> 00:49:46,720
work at all

1395
00:49:50,630 --> 00:49:48,640
so that's a problem

1396
00:49:51,670 --> 00:49:50,640
another potential problem

1397
00:49:53,270 --> 00:49:51,680
is that

1398
00:49:54,549 --> 00:49:53,280
so that lithium star was discovered in

1399
00:49:57,270 --> 00:49:54,559
2013

1400
00:49:59,270 --> 00:49:57,280
two years previously there was

1401
00:50:00,630 --> 00:49:59,280
a paper that brought up the possibility

1402
00:50:01,829 --> 00:50:00,640
that this star may not even be part of

1403
00:50:04,230 --> 00:50:01,839
the cluster

1404
00:50:05,109 --> 00:50:04,240
so this was an astro seismology paper

1405
00:50:06,950 --> 00:50:05,119
i'm going to talk a little bit more

1406
00:50:08,309 --> 00:50:06,960
about astroseismology in a minute but

1407
00:50:09,829 --> 00:50:08,319
basically what they're doing is they're

1408
00:50:11,829 --> 00:50:09,839
trying to show that there's this

1409
00:50:14,470 --> 00:50:11,839
oscillating parameter which is shown on

1410
00:50:15,750 --> 00:50:14,480
this bottom axis here and there the

1411
00:50:17,349 --> 00:50:15,760
point of this was to show that it

1412
00:50:19,270 --> 00:50:17,359
correlated very strongly with the

1413
00:50:20,790 --> 00:50:19,280

brightness of the stars in each cluster

1414
00:50:21,829 --> 00:50:20,800
and so they're like hey here are three

1415
00:50:23,829 --> 00:50:21,839
different clusters at different

1416
00:50:25,670 --> 00:50:23,839
distances if you measure this

1417
00:50:27,270 --> 00:50:25,680
oscillating parameter

1418
00:50:28,470 --> 00:50:27,280
you can very easily tell which guys are

1419
00:50:29,670 --> 00:50:28,480
part of the clusters and which guys

1420
00:50:31,430 --> 00:50:29,680
aren't because they fall in this nice

1421
00:50:33,190 --> 00:50:31,440
tight relationship and so this is the

1422
00:50:34,870 --> 00:50:33,200
lithium-rich star they classified this

1423
00:50:37,190 --> 00:50:34,880
one not knowing that it was lithium-ion

1424
00:50:39,190 --> 00:50:37,200
it's probably not a member

1425
00:50:41,190 --> 00:50:39,200
but the problem is that if you believe

1426
00:50:43,190 --> 00:50:41,200
that you have to ignore a lot of other

1427
00:50:45,990 --> 00:50:43,200
evidence that says otherwise

1428
00:50:48,069 --> 00:50:46,000
so when you look at the star cluster

1429
00:50:49,589 --> 00:50:48,079
if you believe everything in the cluster

1430
00:50:51,190 --> 00:50:49,599
belongs together they're gravitationally

1431
00:50:52,950 --> 00:50:51,200
bound you expect them to all move

1432
00:50:54,390 --> 00:50:52,960
together and if you look at how the star

1433
00:50:56,150 --> 00:50:54,400
is moving in the proper motion so this

1434
00:50:58,150 --> 00:50:56,160
is on the plane of the sky it's moving

1435
00:50:59,829 --> 00:50:58,160
the same way as all the other stars

1436
00:51:01,750 --> 00:50:59,839
if you then measure that third parameter

1437
00:51:03,349 --> 00:51:01,760
the velocity towards or away from you

1438
00:51:04,950 --> 00:51:03,359

it's also moving the same way all the

1439
00:51:07,190 --> 00:51:04,960
other stars are so this is just showing

1440
00:51:09,510 --> 00:51:07,200
the distribution of the radial velocity

1441
00:51:11,510 --> 00:51:09,520
towards or away it's pretty much spot on

1442
00:51:13,109 --> 00:51:11,520
exactly where you expect

1443
00:51:14,470 --> 00:51:13,119
i also showed you that you know in terms

1444
00:51:15,910 --> 00:51:14,480
of the color and brightness it's also

1445
00:51:17,510 --> 00:51:15,920
where you expect so how does this thing

1446
00:51:18,790 --> 00:51:17,520
that looks in every way you can think of

1447
00:51:20,150 --> 00:51:18,800
like it's part of the cluster not be

1448
00:51:22,230 --> 00:51:20,160
there

1449
00:51:24,069 --> 00:51:22,240
and then even better this was not

1450
00:51:26,069 --> 00:51:24,079
available to us at the time but gaia

1451
00:51:27,750 --> 00:51:26,079
measured a parallax for the star it is

1452
00:51:28,950 --> 00:51:27,760
at the distance to the cluster so it's

1453
00:51:30,710 --> 00:51:28,960
at the same spot it's the right

1454
00:51:32,950 --> 00:51:30,720
brightness it's the right everything how

1455
00:51:35,030 --> 00:51:32,960
on earth is it this astro seismology

1456
00:51:36,309 --> 00:51:35,040
parameter weird

1457
00:51:39,109 --> 00:51:36,319
okay well let me explain to you a little

1458
00:51:40,230 --> 00:51:39,119
bit of um about astro seismology

1459
00:51:41,829 --> 00:51:40,240
so

1460
00:51:43,910 --> 00:51:41,839
if you think about a star

1461
00:51:46,309 --> 00:51:43,920
the star is not just sitting there it is

1462
00:51:48,710 --> 00:51:46,319
actually oscillating up and down as

1463
00:51:51,190 --> 00:51:48,720

waves of various types propagate around

1464
00:51:52,630 --> 00:51:51,200
um the around the star so as my

1465
00:51:54,870 --> 00:51:52,640
three-year-old calls this the squishy

1466
00:51:57,750 --> 00:51:54,880
starts it's doing lots of things and as

1467
00:51:59,349 --> 00:51:57,760
the squishy star pulsates um what ends

1468
00:52:00,309 --> 00:51:59,359
up happening is that the star is

1469
00:52:02,230 --> 00:52:00,319
actually

1470
00:52:04,069 --> 00:52:02,240
slowly increasing and decreasing in

1471
00:52:05,670 --> 00:52:04,079
brightness and so if you stare at a star

1472
00:52:07,829 --> 00:52:05,680
and watch how it increases and decreases

1473
00:52:10,630 --> 00:52:07,839
in brightness for a very long time

1474
00:52:12,870 --> 00:52:10,640
you can figure out the modes at which it

1475
00:52:14,950 --> 00:52:12,880
oscillates and so this is kind of like

1476
00:52:17,430 --> 00:52:14,960
ringing objects ringing bells right so

1477
00:52:19,349 --> 00:52:17,440
they they will make a particular sound

1478
00:52:21,270 --> 00:52:19,359
depending on you know how big they are

1479
00:52:22,470 --> 00:52:21,280
and what they're made of

1480
00:52:23,670 --> 00:52:22,480
and the and that really if you could

1481
00:52:26,390 --> 00:52:23,680
break it down is a whole bunch of

1482
00:52:27,510 --> 00:52:26,400
different um modes of oscillation

1483
00:52:29,349 --> 00:52:27,520
and so you can do the same thing for

1484
00:52:31,109 --> 00:52:29,359
stars by looking at the light and so

1485
00:52:32,309 --> 00:52:31,119
what i'm showing here um our power

1486
00:52:33,910 --> 00:52:32,319
specter of three different types of

1487
00:52:36,390 --> 00:52:33,920
stars so this is the oscillation

1488
00:52:38,549 --> 00:52:36,400

frequency for so this is low frequency

1489
00:52:39,750 --> 00:52:38,559
high frequency and then this is how much

1490
00:52:41,190 --> 00:52:39,760
power is each of each of those

1491
00:52:43,190 --> 00:52:41,200
frequencies

1492
00:52:46,390 --> 00:52:43,200
and if you're able to tell that there's

1493
00:52:47,270 --> 00:52:46,400
this cluster of lines

1494
00:52:50,069 --> 00:52:47,280
here

1495
00:52:52,230 --> 00:52:50,079
that moves slowly from the high

1496
00:52:54,230 --> 00:52:52,240
frequency to the low frequency you have

1497
00:52:56,790 --> 00:52:54,240
just measured the change in the surface

1498
00:52:59,109 --> 00:52:56,800
gravity of these three stars

1499
00:53:01,270 --> 00:52:59,119
so just like how very large things have

1500
00:53:03,030 --> 00:53:01,280
that low like gong kind of noise but a

1501
00:53:04,309 --> 00:53:03,040
higher a smaller object has a much

1502
00:53:06,230 --> 00:53:04,319
higher pitch

1503
00:53:08,470 --> 00:53:06,240
your smaller stars

1504
00:53:11,030 --> 00:53:08,480
will

1505
00:53:12,549 --> 00:53:11,040
ring basically at higher pitches and the

1506
00:53:14,309 --> 00:53:12,559
smaller ones

1507
00:53:15,589 --> 00:53:14,319
will have a much more low frequency so

1508
00:53:16,950 --> 00:53:15,599
you've just measured change in surface

1509
00:53:18,470 --> 00:53:16,960
gravity congratulations you're an astro

1510
00:53:20,549 --> 00:53:18,480
seismologist

1511
00:53:23,109 --> 00:53:20,559
um and so you can use that information

1512
00:53:25,030 --> 00:53:23,119
to actually very precisely measure

1513
00:53:26,630 --> 00:53:25,040

um the mass and the radius of the star

1514
00:53:28,950 --> 00:53:26,640
independent of the other things that you

1515
00:53:31,510 --> 00:53:28,960
usually need to know

1516
00:53:33,349 --> 00:53:31,520
and what we did is that we compared that

1517
00:53:34,870 --> 00:53:33,359
to the expected mass and radius of the

1518
00:53:36,309 --> 00:53:34,880
star if you assume the star was in the

1519
00:53:38,950 --> 00:53:36,319
cluster

1520
00:53:40,870 --> 00:53:38,960
and so we find that the radius comes out

1521
00:53:42,870 --> 00:53:40,880
to be roughly what we expect but the

1522
00:53:44,470 --> 00:53:42,880
disaster seismology is really telling us

1523
00:53:47,109 --> 00:53:44,480
that the star is actually significantly

1524
00:53:49,349 --> 00:53:47,119
less massive than you would expect

1525
00:53:51,750 --> 00:53:49,359
and yet it's still a red giant and our

1526
00:53:53,750 --> 00:53:51,760
best explanation for what is going on is

1527
00:53:55,750 --> 00:53:53,760
illustrated by this cross cut of what's

1528
00:53:57,670 --> 00:53:55,760
going on inside of a red giant star

1529
00:53:59,829 --> 00:53:57,680
again you have this very deep convection

1530
00:54:00,950 --> 00:53:59,839
zone you have this tiny core of helium

1531
00:54:02,470 --> 00:54:00,960
you have a little bit of hydrogen

1532
00:54:04,630 --> 00:54:02,480
burning shell going on

1533
00:54:07,430 --> 00:54:04,640
so you can imagine if this thing had

1534
00:54:09,270 --> 00:54:07,440
a companion that it interacted with

1535
00:54:11,670 --> 00:54:09,280
as the star had expanded the outermost

1536
00:54:13,589 --> 00:54:11,680
regions of the star are the least dense

1537
00:54:15,750 --> 00:54:13,599
so perhaps as the planet went in it was

1538
00:54:17,589 --> 00:54:15,760

able to strip off the least dense part

1539
00:54:19,270 --> 00:54:17,599
of it and then eventually get destroyed

1540
00:54:21,270 --> 00:54:19,280
slightly deeper in the star and mixed up

1541
00:54:24,150 --> 00:54:21,280
all of its

1542
00:54:25,510 --> 00:54:24,160
material in there and enriched the star

1543
00:54:27,190 --> 00:54:25,520
now if you're thinking well how's the

1544
00:54:28,950 --> 00:54:27,200
star still the same size if you take off

1545
00:54:30,630 --> 00:54:28,960
all that mass i had that same thought

1546
00:54:32,870 --> 00:54:30,640
but it turns out one of the funny things

1547
00:54:34,230 --> 00:54:32,880
with stars that are structured this way

1548
00:54:35,750 --> 00:54:34,240
is that the radius of the star actually

1549
00:54:38,150 --> 00:54:35,760
really only depends on how much helium

1550
00:54:40,069 --> 00:54:38,160
you have in the core which really has

1551
00:54:41,349 --> 00:54:40,079
absolutely nothing to do with um the

1552
00:54:42,790 --> 00:54:41,359
planet so if you strip off all the

1553
00:54:44,309 --> 00:54:42,800
material the star actually kind of

1554
00:54:46,069 --> 00:54:44,319
bounces back a little bit would still be

1555
00:54:48,069 --> 00:54:46,079
roughly the same size

1556
00:54:50,470 --> 00:54:48,079
so our leading hypothesis then when we

1557
00:54:52,630 --> 00:54:50,480
pull all that information together

1558
00:54:54,390 --> 00:54:52,640
is that the star is actually has lost a

1559
00:54:56,470 --> 00:54:54,400
lot of material and so now if you run

1560
00:54:58,549 --> 00:54:56,480
the calculation of how big of an object

1561
00:55:00,790 --> 00:54:58,559
you need to explain the lithium you're

1562
00:55:03,190 --> 00:55:00,800
at least well within the range of a not

1563
00:55:04,870 --> 00:55:03,200

a star not quite a planet either so this

1564
00:55:06,710 --> 00:55:04,880
is a brown dwarf size so this is

1565
00:55:07,910 --> 00:55:06,720
something about 45 times more method

1566
00:55:09,270 --> 00:55:07,920
than jupiter but it's still something

1567
00:55:10,470 --> 00:55:09,280
that you expect to have a lot of lithium

1568
00:55:12,390 --> 00:55:10,480
in it

1569
00:55:13,990 --> 00:55:12,400
that's one of my favorite stories so the

1570
00:55:16,309 --> 00:55:14,000
power of you know combining all these

1571
00:55:17,829 --> 00:55:16,319
sorts of things together

1572
00:55:19,270 --> 00:55:17,839
i'm going to go a little bit quickly on

1573
00:55:21,910 --> 00:55:19,280
through this next part just because i'm

1574
00:55:24,630 --> 00:55:21,920
running short on time but this idea that

1575
00:55:26,230 --> 00:55:24,640
planets can help strip the star is

1576
00:55:27,829 --> 00:55:26,240
something that has is an idea that's

1577
00:55:29,430 --> 00:55:27,839
been around for a while

1578
00:55:31,910 --> 00:55:29,440
the kepler mission has discovered some

1579
00:55:34,230 --> 00:55:31,920
interesting things where they have found

1580
00:55:37,030 --> 00:55:34,240
what are called these b subdwarf stars

1581
00:55:39,030 --> 00:55:37,040
so these are things that are hot

1582
00:55:41,750 --> 00:55:39,040
but significantly less luminous than you

1583
00:55:44,230 --> 00:55:41,760
would expect them to be for other types

1584
00:55:45,430 --> 00:55:44,240
of normal types of stars and what we

1585
00:55:48,069 --> 00:55:45,440
think they are

1586
00:55:49,829 --> 00:55:48,079
is so we have our sun converts hydrogen

1587
00:55:51,750 --> 00:55:49,839
to helium in the core and then later the

1588
00:55:53,750 --> 00:55:51,760

helium will eventually start to fuse

1589
00:55:55,430 --> 00:55:53,760
into higher things but if you strip off

1590
00:55:57,430 --> 00:55:55,440
the atmosphere you can actually stall

1591
00:55:59,430 --> 00:55:57,440
that and the helium core will never

1592
00:56:01,589 --> 00:55:59,440
start fusing helium so we think these

1593
00:56:03,910 --> 00:56:01,599
things are the bare helium cores

1594
00:56:06,950 --> 00:56:03,920
and so in this case what was discovered

1595
00:56:09,030 --> 00:56:06,960
is this jupiter mass thing orbiting

1596
00:56:10,710 --> 00:56:09,040
at almost twice the separation you know

1597
00:56:12,710 --> 00:56:10,720
that earth does to our sun

1598
00:56:13,990 --> 00:56:12,720
and the prevailing

1599
00:56:15,750 --> 00:56:14,000
idea of what happened is that it was

1600
00:56:17,349 --> 00:56:15,760
once closer and when the star became a

1601
00:56:19,270 --> 00:56:17,359
red giant it actually helped strip off

1602
00:56:22,390 --> 00:56:19,280
the atmosphere and once that mass was

1603
00:56:24,069 --> 00:56:22,400
gone the orbit of the planet expanded

1604
00:56:26,150 --> 00:56:24,079
there's another example where these very

1605
00:56:27,829 --> 00:56:26,160
very tiny things so now like half in

1606
00:56:30,069 --> 00:56:27,839
earth mass things were found around

1607
00:56:31,990 --> 00:56:30,079
another type of these stars and in this

1608
00:56:33,109 --> 00:56:32,000
case the scenarios i just thought um

1609
00:56:35,109 --> 00:56:33,119
that these were

1610
00:56:37,910 --> 00:56:35,119
once giant again giant planets like

1611
00:56:39,990 --> 00:56:37,920
jupiter um orbiting closer and so in

1612
00:56:41,750 --> 00:56:40,000
this case when they interacted with the

1613
00:56:44,230 --> 00:56:41,760

star the star was much smaller it wasn't

1614
00:56:46,549 --> 00:56:44,240
quite as giant of a red giant and so

1615
00:56:48,630 --> 00:56:46,559
these planets went into the star

1616
00:56:50,230 --> 00:56:48,640
um where some amount of ablation

1617
00:56:51,910 --> 00:56:50,240
evaporation happened so they lost some

1618
00:56:53,670 --> 00:56:51,920
of their atmosphere the giant loss of

1619
00:56:55,829 --> 00:56:53,680
their atmosphere and so we now have

1620
00:56:59,829 --> 00:56:55,839
cores orbiting cores so planet core is

1621
00:57:03,109 --> 00:56:59,839
already in the cores of a red giant star

1622
00:57:04,390 --> 00:57:03,119
all right so looking ahead um a lot of

1623
00:57:06,150 --> 00:57:04,400
the results that i talked to you about

1624
00:57:07,430 --> 00:57:06,160
have been made possible by the wonderful

1625
00:57:09,910 --> 00:57:07,440
kepler mission

1626
00:57:11,910 --> 00:57:09,920
um so kepler

1627
00:57:14,549 --> 00:57:11,920
which is so i keep losing the pointer

1628
00:57:17,030 --> 00:57:14,559
here um so the kepler us

1629
00:57:18,390 --> 00:57:17,040
telescope had this big center it pointed

1630
00:57:21,109 --> 00:57:18,400
um during its prime mission at one

1631
00:57:22,710 --> 00:57:21,119
location in the sky for four years

1632
00:57:25,270 --> 00:57:22,720
continuously

1633
00:57:28,309 --> 00:57:25,280
um so this is just showing a

1634
00:57:29,670 --> 00:57:28,319
zone of the part of the galaxy that was

1635
00:57:32,710 --> 00:57:29,680
covered by

1636
00:57:34,390 --> 00:57:32,720
um by kepler and the reason for this is

1637
00:57:36,309 --> 00:57:34,400
we wanted um

1638
00:57:37,829 --> 00:57:36,319

we needed the long time baseline where

1639
00:57:40,470 --> 00:57:37,839
they were trying to discover earth type

1640
00:57:41,910 --> 00:57:40,480
planets orbiting sun like stars

1641
00:57:43,589 --> 00:57:41,920
but one of the great things that came

1642
00:57:45,589 --> 00:57:43,599
out is this very long time series

1643
00:57:47,109 --> 00:57:45,599
observations of all these stars and how

1644
00:57:48,309 --> 00:57:47,119
their brightness was changing over time

1645
00:57:50,710 --> 00:57:48,319
which led us to all this astro

1646
00:57:52,069 --> 00:57:50,720
seismology things in in addition to the

1647
00:57:54,789 --> 00:57:52,079
the prime mission

1648
00:57:56,630 --> 00:57:54,799
um the downside to that is uh to make

1649
00:57:58,470 --> 00:57:56,640
the mission as effective as possible it

1650
00:58:01,190 --> 00:57:58,480
had to avoid the brightest stars which

1651
00:58:02,789 --> 00:58:01,200
would saturate a lot of the detectors

1652
00:58:04,470 --> 00:58:02,799
and really focus on large numbers of

1653
00:58:06,870 --> 00:58:04,480
fainter stars which unfortunately makes

1654
00:58:09,510 --> 00:58:06,880
it very hard to follow these things up

1655
00:58:11,190 --> 00:58:09,520
and so the future um which is also the

1656
00:58:12,870 --> 00:58:11,200
today um is the

1657
00:58:15,270 --> 00:58:12,880
tess which is the translating exoplanet

1658
00:58:17,670 --> 00:58:15,280
sky survey which is doing a

1659
00:58:19,990 --> 00:58:17,680
complementary search so instead of

1660
00:58:23,829 --> 00:58:20,000
kepler you know looking in one area for

1661
00:58:26,390 --> 00:58:23,839
a long time tess is spending one month

1662
00:58:27,670 --> 00:58:26,400
covering the whole sky so its camera

1663
00:58:30,309 --> 00:58:27,680

looks like

1664
00:58:32,950 --> 00:58:30,319
four

1665
00:58:35,589 --> 00:58:32,960
and

1666
00:58:37,430 --> 00:58:35,599
it covers actually over 90 degrees in

1667
00:58:39,589 --> 00:58:37,440
one pointing in one dimension it's

1668
00:58:41,990 --> 00:58:39,599
covering over 90 degrees at once and so

1669
00:58:44,630 --> 00:58:42,000
what it does is it stares at the sky

1670
00:58:46,390 --> 00:58:44,640
for 27 days and then steps over and then

1671
00:58:49,349 --> 00:58:46,400
does that every 27 days and then i'll do

1672
00:58:50,549 --> 00:58:49,359
a 180 degree flip and it'll do the other

1673
00:58:53,030 --> 00:58:50,559
half of the sky

1674
00:58:54,630 --> 00:58:53,040
and so right now this is

1675
00:58:55,829 --> 00:58:54,640
upside down from our normal perspective

1676
00:58:57,270 --> 00:58:55,839
because it's working in the southern

1677
00:58:58,630 --> 00:58:57,280
ecliptic pole

1678
00:59:00,309 --> 00:58:58,640
um and so right now i think it's on

1679
00:59:03,430 --> 00:59:00,319
sector 10 or 12 and then it'll

1680
00:59:04,870 --> 00:59:03,440
eventually flip over and do the north

1681
00:59:07,430 --> 00:59:04,880
and i should also point out that

1682
00:59:09,589 --> 00:59:07,440
kepler's extended mission when um after

1683
00:59:11,910 --> 00:59:09,599
it broke a little bit um it could only

1684
00:59:14,150 --> 00:59:11,920
point along the ecliptic plane and

1685
00:59:15,750 --> 00:59:14,160
you'll notice the ecliptic plane here um

1686
00:59:17,109 --> 00:59:15,760
is actually the one place where tess is

1687
00:59:18,870 --> 00:59:17,119
not covering so it's actually very

1688
00:59:20,390 --> 00:59:18,880

complementary in that sense

1689
00:59:22,630 --> 00:59:20,400
and so the goal of this is to really get

1690
00:59:24,069 --> 00:59:22,640
the brightest stars so the stars where

1691
00:59:25,750 --> 00:59:24,079
we already know that there are planets

1692
00:59:27,750 --> 00:59:25,760
around where we're going to discover new

1693
00:59:29,190 --> 00:59:27,760
planets that are going to be very easily

1694
00:59:31,430 --> 00:59:29,200
accessible to the james webb space

1695
00:59:33,670 --> 00:59:31,440
telescope where every photon counts so

1696
00:59:36,309 --> 00:59:33,680
we need things that are bright um so

1697
00:59:37,750 --> 00:59:36,319
we're we are already getting um

1698
00:59:39,109 --> 00:59:37,760
data from this mission the first two

1699
00:59:41,190 --> 00:59:39,119
sectors of data are now publicly

1700
00:59:42,549 --> 00:59:41,200
available anybody can look at them

1701
00:59:44,069 --> 00:59:42,559
um and again

1702
00:59:45,910 --> 00:59:44,079
in terms of current data taking it's

1703
00:59:49,190 --> 00:59:45,920
almost done with the first half of its

1704
00:59:53,109 --> 00:59:51,109
and there are some other really

1705
00:59:54,309 --> 00:59:53,119
important complementary missions that

1706
00:59:56,230 --> 00:59:54,319
are coming up so you've heard a little

1707
00:59:58,950 --> 00:59:56,240
bit about gaia already

1708
01:00:01,430 --> 00:59:58,960
gaia is basically measuring the

1709
01:00:03,190 --> 01:00:01,440
positions of stars very precisely

1710
01:00:04,789 --> 01:00:03,200
it gets the distance during parallax all

1711
01:00:06,150 --> 01:00:04,799
right this is the idea if you hold your

1712
01:00:08,230 --> 01:00:06,160
finger up and blink your eyes back and

1713
01:00:11,030 --> 01:00:08,240

forth things close by move a lot things

1714
01:00:13,109 --> 01:00:11,040
farther away not so much and so guy uses

1715
01:00:15,270 --> 01:00:13,119
you know looks at the sky here wait six

1716
01:00:16,470 --> 01:00:15,280
months until it's on the other side of

1717
01:00:18,630 --> 01:00:16,480
the sun

1718
01:00:21,270 --> 01:00:18,640
and so far it's had two data releases

1719
01:00:23,510 --> 01:00:21,280
it's given us precise positions the most

1720
01:00:25,109 --> 01:00:23,520
recent data release gave us parallaxes

1721
01:00:26,470 --> 01:00:25,119
as it continues to look at these stars

1722
01:00:27,910 --> 01:00:26,480
over and over it'll start to show the

1723
01:00:30,069 --> 01:00:27,920
proper motion so this is how the

1724
01:00:32,069 --> 01:00:30,079
relative motions of stars do to the

1725
01:00:33,750 --> 01:00:32,079
orbits of the milky way and then if they

1726
01:00:35,750 --> 01:00:33,760
have companions either stellar or

1727
01:00:39,270 --> 01:00:35,760
substellar then they'll also have

1728
01:00:41,349 --> 01:00:39,280
orbital wobbling on as you know as

1729
01:00:43,109 --> 01:00:41,359
their companions do the dance and so you

1730
01:00:45,430 --> 01:00:43,119
can get these very complex motions when

1731
01:00:46,950 --> 01:00:45,440
you add all these things together

1732
01:00:48,630 --> 01:00:46,960
and then i'm a spectroscopist a

1733
01:00:50,470 --> 01:00:48,640
spectroscopist at heart um so i have to

1734
01:00:52,390 --> 01:00:50,480
talk about spectroscopy uh one of the

1735
01:00:54,870 --> 01:00:52,400
projects i'm i'm

1736
01:00:56,630 --> 01:00:54,880
working on is this called this panoptix

1737
01:00:57,990 --> 01:00:56,640
spectroscopy from the slow digital sky

1738
01:01:01,349 --> 01:00:58,000

survey 5.

1739
01:01:03,589 --> 01:01:01,359
so this is using two telescopes in both

1740
01:01:06,549 --> 01:01:03,599
the north and south hemisphere to look

1741
01:01:08,470 --> 01:01:06,559
to obtain optical and infrared spectra

1742
01:01:10,069 --> 01:01:08,480
high resolution of you know like

1743
01:01:13,109 --> 01:01:10,079
everything not quite everything but a

1744
01:01:14,870 --> 01:01:13,119
lot of stars with um there's three major

1745
01:01:16,789 --> 01:01:14,880
programs um i'm involved in the milky

1746
01:01:18,069 --> 01:01:16,799
way mapper so this is studying stars in

1747
01:01:20,390 --> 01:01:18,079
in the milky way

1748
01:01:22,470 --> 01:01:20,400
um it's building on the current the

1749
01:01:24,950 --> 01:01:22,480
ongoing apogee one and two surveys which

1750
01:01:26,230 --> 01:01:24,960
were part of sdss three and four um so

1751
01:01:27,750 --> 01:01:26,240
this map is just showing an artist's

1752
01:01:29,510 --> 01:01:27,760
rendition of what we think our milky way

1753
01:01:31,109 --> 01:01:29,520
looks like and this is showing density

1754
01:01:33,910 --> 01:01:31,119
coverage of what apogee one and two is

1755
01:01:36,870 --> 01:01:33,920
get and then the very um

1756
01:01:37,990 --> 01:01:36,880
uh ambitious of sloan five and one of

1757
01:01:39,430 --> 01:01:38,000
the components which is actually the

1758
01:01:41,430 --> 01:01:39,440
part that i'm working on is we want to

1759
01:01:43,589 --> 01:01:41,440
do radial velocities and so go back and

1760
01:01:45,349 --> 01:01:43,599
measure over and over the velocities of

1761
01:01:48,950 --> 01:01:45,359
stars to learn about the companions both

1762
01:01:51,430 --> 01:01:48,960
big small everything in between

1763
01:01:53,990 --> 01:01:51,440

around these stars

1764
01:01:56,549 --> 01:01:54,000
um so just to wrap up like i said uh in

1765
01:01:58,870 --> 01:01:56,559
the beginning um i think the time of big

1766
01:02:00,309 --> 01:01:58,880
data in astronomy is actually now we've

1767
01:02:01,270 --> 01:02:00,319
really started we have a lot of eyes in

1768
01:02:02,870 --> 01:02:01,280
the sky

1769
01:02:04,230 --> 01:02:02,880
um there there are missions that i

1770
01:02:06,069 --> 01:02:04,240
haven't even talked about where we're

1771
01:02:08,950 --> 01:02:06,079
getting a lot of complimentary all sky

1772
01:02:10,710 --> 01:02:08,960
scarves we have all sky coverage

1773
01:02:12,069 --> 01:02:10,720
um you know we have

1774
01:02:14,390 --> 01:02:12,079
we're taking images we're looking at

1775
01:02:16,069 --> 01:02:14,400
spectra and it's really going to give us

1776
01:02:18,069 --> 01:02:16,079
a lot of new information about things

1777
01:02:20,549 --> 01:02:18,079
we've never dreamed of

1778
01:02:22,549 --> 01:02:20,559
and um a lot of new types of planets

1779
01:02:24,630 --> 01:02:22,559
we're going to discover um a lot of good

1780
01:02:25,750 --> 01:02:24,640
follow-up for our upcoming missions like

1781
01:02:27,589 --> 01:02:25,760
james webb

1782
01:02:29,030 --> 01:02:27,599
and what i think can be really exciting

1783
01:02:30,870 --> 01:02:29,040
is the fact that once you start looking

1784
01:02:31,589 --> 01:02:30,880
at such large number of things you start

1785
01:02:33,349 --> 01:02:31,599
to

1786
01:02:35,670 --> 01:02:33,359
increase your your chances of finding

1787
01:02:36,470 --> 01:02:35,680
these very odd

1788
01:02:38,470 --> 01:02:36,480

odd

1789
01:02:39,589 --> 01:02:38,480
systems that can actually teach you a

1790
01:02:41,270 --> 01:02:39,599
lot

1791
01:02:43,270 --> 01:02:41,280
about

1792
01:02:44,530 --> 01:02:43,280
the kind of universe as a whole so thank

1793
01:02:52,430 --> 01:02:44,540
you

1794
01:02:55,990 --> 01:02:52,440
[Applause]

1795
01:03:02,789 --> 01:02:57,829
okay

1796
01:03:08,710 --> 01:03:05,190
um kind of coming back to our solar

1797
01:03:10,390 --> 01:03:08,720
system if i read somewhere once the

1798
01:03:12,829 --> 01:03:10,400
gas giant's actually

1799
01:03:16,710 --> 01:03:14,829
around

1800
01:03:18,870 --> 01:03:16,720
there so i'm going to repeat the

1801
01:03:20,870 --> 01:03:18,880
question for the webcast um

1802
01:03:23,029 --> 01:03:20,880
and then we'll use the microphone uh the

1803
01:03:25,270 --> 01:03:23,039
question was i've heard that planets in

1804
01:03:27,190 --> 01:03:25,280
our solar system moved around a bit can

1805
01:03:30,150 --> 01:03:27,200
you comment on that

1806
01:03:32,150 --> 01:03:30,160
yeah so um i actually know a little bit

1807
01:03:33,430 --> 01:03:32,160
less about what we think happened in our

1808
01:03:35,430 --> 01:03:33,440
solar system a little bit more about

1809
01:03:36,390 --> 01:03:35,440
what we think happened in other solar

1810
01:03:37,270 --> 01:03:36,400
systems

1811
01:03:38,390 --> 01:03:37,280
um

1812
01:03:40,150 --> 01:03:38,400
because

1813
01:03:42,789 --> 01:03:40,160

again the discovery of the hot jupiters

1814
01:03:43,910 --> 01:03:42,799
was completely unlooked for um that it

1815
01:03:45,589 --> 01:03:43,920
was one of those things that we see

1816
01:03:47,430 --> 01:03:45,599
they're like no that can't be right like

1817
01:03:50,549 --> 01:03:47,440
we must be doing something wrong

1818
01:03:52,710 --> 01:03:50,559
um and and from that um we have gotten

1819
01:03:54,630 --> 01:03:52,720
the sense that there just wasn't enough

1820
01:03:56,150 --> 01:03:54,640
stuff close to the stars

1821
01:03:58,390 --> 01:03:56,160
to form something that big so they had

1822
01:04:02,789 --> 01:03:58,400
to have come from somewhere else and so

1823
01:04:06,390 --> 01:04:04,390
led our theories because we we had a

1824
01:04:09,190 --> 01:04:06,400
beautiful theory of how the solar system

1825
01:04:10,549 --> 01:04:09,200
worked it made sense and then we found

1826
01:04:12,390 --> 01:04:10,559
other planets and it just threw

1827
01:04:13,670 --> 01:04:12,400
everything out out the window

1828
01:04:15,349 --> 01:04:13,680
and so now we know that things have to

1829
01:04:17,910 --> 01:04:15,359
be a lot more dynamic

1830
01:04:19,510 --> 01:04:17,920
i have heard of models that showed that

1831
01:04:21,910 --> 01:04:19,520
you know particularly the the outer

1832
01:04:23,349 --> 01:04:21,920
planets had to have interacted a bit i

1833
01:04:24,789 --> 01:04:23,359
know less unfortunately about the

1834
01:04:27,190 --> 01:04:24,799
details of those interactions so i can't

1835
01:04:34,069 --> 01:04:27,200
comment them on them any further

1836
01:04:39,430 --> 01:04:36,630
do planets ever get flung outside of its

1837
01:04:41,109 --> 01:04:39,440
stars absolutely yeah

1838
01:04:44,150 --> 01:04:41,119

and so that is something that i think is

1839
01:04:45,990 --> 01:04:44,160
a bit more common when you have um other

1840
01:04:48,870 --> 01:04:46,000
stars well

1841
01:04:50,870 --> 01:04:48,880
two times actually so early on in the

1842
01:04:52,309 --> 01:04:50,880
planet formation process when you are

1843
01:04:54,390 --> 01:04:52,319
building up

1844
01:04:55,589 --> 01:04:54,400
the planets um you have lots of things

1845
01:04:57,190 --> 01:04:55,599
that could become planets and they

1846
01:04:58,470 --> 01:04:57,200
interact gravitationally and some things

1847
01:05:00,150 --> 01:04:58,480
get flung out

1848
01:05:02,630 --> 01:05:00,160
but then the other place where it can

1849
01:05:03,750 --> 01:05:02,640
happen is when you start having other

1850
01:05:06,069 --> 01:05:03,760
stars

1851
01:05:07,430 --> 01:05:06,079
um involved which

1852
01:05:09,029 --> 01:05:07,440
you know as i and many of the

1853
01:05:10,710 --> 01:05:09,039
astronomers like to talk about stars as

1854
01:05:11,910 --> 01:05:10,720
if they you know exist in isolation but

1855
01:05:14,470 --> 01:05:11,920
we actually know that the vast majority

1856
01:05:17,510 --> 01:05:14,480
of stars come come with siblings um and

1857
01:05:26,549 --> 01:05:17,520
so those processes are common

1858
01:05:26,559 --> 01:05:37,270
other questions

1859
01:05:43,190 --> 01:05:39,589
um you had mentioned earlier in one of

1860
01:05:46,069 --> 01:05:43,200
your powerpoint slides that um

1861
01:05:48,150 --> 01:05:46,079
it was possible that earth was a

1862
01:05:50,309 --> 01:05:48,160
red giant beforehand

1863
01:05:52,789 --> 01:05:50,319

does that make it possible that we may

1864
01:05:54,870 --> 01:05:52,799
have more earths within our own solar

1865
01:05:55,670 --> 01:05:54,880
system

1866
01:05:58,390 --> 01:05:55,680
sorry

1867
01:06:01,349 --> 01:05:58,400
i said before that i missed the question

1868
01:06:02,390 --> 01:06:01,359
um my question is that you had mentioned

1869
01:06:05,349 --> 01:06:02,400
that

1870
01:06:07,430 --> 01:06:05,359
earth was at one point possibly a red

1871
01:06:09,510 --> 01:06:07,440
giant as they were possible is it

1872
01:06:11,589 --> 01:06:09,520
possible that are the red giants that

1873
01:06:12,390 --> 01:06:11,599
are existing in our solar system right

1874
01:06:14,069 --> 01:06:12,400
now

1875
01:06:15,910 --> 01:06:14,079
may become

1876
01:06:18,470 --> 01:06:15,920
another earth

1877
01:06:19,990 --> 01:06:18,480
um so

1878
01:06:22,309 --> 01:06:20,000
i'm gonna

1879
01:06:24,069 --> 01:06:22,319
so i guess the question is um so so in

1880
01:06:26,309 --> 01:06:24,079
our solar system

1881
01:06:27,430 --> 01:06:26,319
whether or not the earth goes to the sun

1882
01:06:30,069 --> 01:06:27,440
is actually earth is kind of on the

1883
01:06:31,589 --> 01:06:30,079
hairy edge so so we're not sure um but

1884
01:06:33,670 --> 01:06:31,599
is your question more along the lines

1885
01:06:35,910 --> 01:06:33,680
ours um can some of the planets around

1886
01:06:36,789 --> 01:06:35,920
these other stars be habitable like the

1887
01:06:38,710 --> 01:06:36,799
earth

1888
01:06:41,190 --> 01:06:38,720

yes yeah okay thank you just making sure

1889
01:06:44,470 --> 01:06:41,200
i understood um yeah so

1890
01:06:46,710 --> 01:06:44,480
it certainly is possible right so as as

1891
01:06:48,309 --> 01:06:46,720
um the sun gets larger becomes a red

1892
01:06:49,270 --> 01:06:48,319
giant star it's going to get really hot

1893
01:06:51,190 --> 01:06:49,280
here

1894
01:06:53,510 --> 01:06:51,200
but for colder planets right maybe

1895
01:06:55,670 --> 01:06:53,520
that's a good thing for things like life

1896
01:06:57,510 --> 01:06:55,680
and so you can imagine that in planets

1897
01:06:59,829 --> 01:06:57,520
around red giant stars that were once

1898
01:07:00,950 --> 01:06:59,839
very cold they could potentially become

1899
01:07:04,069 --> 01:07:00,960
earth-like

1900
01:07:06,309 --> 01:07:04,079
um the problem with that um it could

1901
01:07:09,349 --> 01:07:06,319
happen but the difficulty for any life

1902
01:07:12,069 --> 01:07:09,359
there is that the red giant phase is

1903
01:07:14,870 --> 01:07:12,079
very short and the star actually changes

1904
01:07:17,430 --> 01:07:14,880
very rapidly and so any

1905
01:07:19,829 --> 01:07:17,440
conditions that are suitable for such

1906
01:07:20,710 --> 01:07:19,839
things to happen it will rapidly go away

1907
01:07:30,950 --> 01:07:20,720
and then

1908
01:07:35,750 --> 01:07:33,349
uh as you mentioned as you explain this

1909
01:07:40,230 --> 01:07:38,309
transfer that sometimes happen between a

1910
01:07:41,670 --> 01:07:40,240
star and a planet is there any

1911
01:07:43,670 --> 01:07:41,680
possibility and if that's the

1912
01:07:46,230 --> 01:07:43,680
possibility is there any evidence that

1913
01:07:49,029 --> 01:07:46,240

that might happen between planets of

1914
01:07:50,150 --> 01:07:49,039
uh different mass that they can actually

1915
01:07:52,309 --> 01:07:50,160
kind of

1916
01:07:54,230 --> 01:07:52,319
suck out some materials into another

1917
01:07:56,710 --> 01:07:54,240
planet or

1918
01:07:59,910 --> 01:07:56,720
oh that's interesting um

1919
01:08:02,230 --> 01:07:59,920
again i think

1920
01:08:04,950 --> 01:08:02,240
definitely in the planet building phase

1921
01:08:06,710 --> 01:08:04,960
when there's a lot of gases around um

1922
01:08:08,230 --> 01:08:06,720
that's how some of the planets win and

1923
01:08:10,230 --> 01:08:08,240
become planets and the other things

1924
01:08:11,349 --> 01:08:10,240
become not planets

1925
01:08:13,910 --> 01:08:11,359
is that the you know the things that

1926
01:08:15,109 --> 01:08:13,920
kind of build up the quickest then start

1927
01:08:16,550 --> 01:08:15,119
basically start hoarding all the

1928
01:08:17,910 --> 01:08:16,560
resources and then they become the

1929
01:08:19,189 --> 01:08:17,920
dominant thing and kick everyone else

1930
01:08:20,870 --> 01:08:19,199
out they're kind of tyrants in that way

1931
01:08:25,990 --> 01:08:20,880
i guess um

1932
01:08:29,189 --> 01:08:27,669
once things are in more stable

1933
01:08:31,269 --> 01:08:29,199
configurations i think it's a lot less

1934
01:08:33,910 --> 01:08:31,279
likely just because the you know the

1935
01:08:35,829 --> 01:08:33,920
relative sizes are are pretty similar

1936
01:08:38,309 --> 01:08:35,839
and so i think it's harder

1937
01:08:40,309 --> 01:08:38,319
i'm not sure but i think it's harder

1938
01:08:43,349 --> 01:08:40,319

okay we have a question from online it

1939
01:08:44,309 --> 01:08:43,359
says uh when the sun expands into a red

1940
01:08:52,390 --> 01:08:44,319
giant

1941
01:08:55,829 --> 01:08:52,400
enceladus or triton become habitable

1942
01:08:57,510 --> 01:08:55,839
sadly i haven't done that calculation

1943
01:08:59,430 --> 01:08:57,520
um

1944
01:09:01,510 --> 01:08:59,440
they will yes they will get not going to

1945
01:09:03,749 --> 01:09:01,520
be habitable

1946
01:09:06,390 --> 01:09:03,759
yes that's a good question um they will

1947
01:09:08,070 --> 01:09:06,400
get warmer um but i actually haven't

1948
01:09:09,110 --> 01:09:08,080
thought about by how much that's a great

1949
01:09:10,870 --> 01:09:09,120
question i'm gonna have to i'm gonna

1950
01:09:12,390 --> 01:09:10,880
have to go do that but again going back

1951
01:09:17,910 --> 01:09:12,400
to the other question is even if they do

1952
01:09:23,590 --> 01:09:21,269
but it's still like a hundred million i

1953
01:09:26,709 --> 01:09:23,600
mean a million uh about 10 million years

1954
01:09:28,309 --> 01:09:26,719
for the red giant phase yeah but so i'm

1955
01:09:30,950 --> 01:09:28,319
gonna show a little bit of my biology

1956
01:09:43,510 --> 01:09:30,960
ignorance i mean for you know bugs great

1957
01:09:47,990 --> 01:09:44,950
are there

1958
01:09:49,590 --> 01:09:48,000
planetary systems in binary star systems

1959
01:09:52,470 --> 01:09:49,600
and what is their

1960
01:09:57,590 --> 01:09:54,390
their prognosis is a lot more

1961
01:10:02,390 --> 01:10:01,350
now i know there are two types of

1962
01:10:05,110 --> 01:10:02,400
stable

1963
01:10:07,189 --> 01:10:05,120

orbits that you can have one is where

1964
01:10:08,709 --> 01:10:07,199
um you know the stars are more tightly

1965
01:10:10,470 --> 01:10:08,719
bound and the planet's orbiting both so

1966
01:10:12,070 --> 01:10:10,480
this is like a tatooine you know if

1967
01:10:14,630 --> 01:10:12,080
you're a star wars fan a tatooine style

1968
01:10:16,870 --> 01:10:14,640
where you get two suns in the sky um

1969
01:10:18,390 --> 01:10:16,880
if my election recollection is correct i

1970
01:10:21,270 --> 01:10:18,400
think that is the

1971
01:10:22,709 --> 01:10:21,280
uh of the stars that we know

1972
01:10:24,070 --> 01:10:22,719
is that the more that might be the more

1973
01:10:27,590 --> 01:10:24,080
common one

1974
01:10:29,430 --> 01:10:27,600
um whereas having the planet around um

1975
01:10:31,510 --> 01:10:29,440
you know one

1976
01:10:33,430 --> 01:10:31,520
one object where

1977
01:10:35,189 --> 01:10:33,440
you know the star you know the other

1978
01:10:38,229 --> 01:10:35,199
star is very far away i think those tend

1979
01:10:40,470 --> 01:10:38,239
to be very very widely separated

1980
01:10:42,470 --> 01:10:40,480
in which case um

1981
01:10:44,709 --> 01:10:42,480
you can mostly treat

1982
01:10:46,390 --> 01:10:44,719
them as you know as a single point um

1983
01:10:47,350 --> 01:10:46,400
but there's a lot of interactions that

1984
01:10:50,630 --> 01:10:47,360
actually

1985
01:10:52,630 --> 01:10:50,640
will sculpt the the platforming disc and

1986
01:10:54,229 --> 01:10:52,640
will affect um you know the resulting

1987
01:10:55,990 --> 01:10:54,239
inclinations of the system so actually

1988
01:10:58,870 --> 01:10:56,000

one thing that they think is that when

1989
01:10:59,910 --> 01:10:58,880
you find so in in our solar system right

1990
01:11:01,910 --> 01:10:59,920
you have the sun rotating all the

1991
01:11:03,910 --> 01:11:01,920
planets going around all in roughly the

1992
01:11:05,990 --> 01:11:03,920
same plane in the same direction

1993
01:11:07,590 --> 01:11:06,000
um they have found instances where you

1994
01:11:09,189 --> 01:11:07,600
have a star that's rotating like this

1995
01:11:10,630 --> 01:11:09,199
and a planet going like this which is

1996
01:11:11,910 --> 01:11:10,640
how did that get there

1997
01:11:14,310 --> 01:11:11,920
and one of the ways that you can do it

1998
01:11:16,149 --> 01:11:14,320
is that if you do have a wide binary

1999
01:11:18,149 --> 01:11:16,159
that is on sort of that

2000
01:11:21,110 --> 01:11:18,159
similar inclination it can force you

2001
01:11:22,790 --> 01:11:21,120
know the angles of orbit um and so i

2002
01:11:24,390 --> 01:11:22,800
know there's evidence of that um but

2003
01:11:27,669 --> 01:11:24,400
yeah it gets it gets messy very quickly

2004
01:11:32,149 --> 01:11:27,679
once you start adding more things

2005
01:11:36,070 --> 01:11:34,070
for perspective

2006
01:11:38,149 --> 01:11:36,080
can you tell us

2007
01:11:39,350 --> 01:11:38,159
quickly about some of the

2008
01:11:41,110 --> 01:11:39,360
interesting

2009
01:11:42,709 --> 01:11:41,120
orbits that some of these like hot

2010
01:11:46,550 --> 01:11:42,719
jupiters that they're orbiting their

2011
01:11:48,709 --> 01:11:46,560
stars in like less than two days yeah

2012
01:11:50,390 --> 01:11:48,719
yeah so it's it's sure and actually um

2013
01:11:51,590 --> 01:11:50,400

so one of the things i didn't let's see

2014
01:11:53,669 --> 01:11:51,600
if i could do this super quickly and

2015
01:11:55,990 --> 01:11:53,679
what else interesting have you found out

2016
01:11:58,870 --> 01:11:56,000
about some of these exoplanets uh in

2017
01:12:00,390 --> 01:11:58,880
terms of their orbits yes so one thing

2018
01:12:03,110 --> 01:12:00,400
that i didn't really talk about but

2019
01:12:04,630 --> 01:12:03,120
which i think is really cool um

2020
01:12:07,669 --> 01:12:04,640
and there are a lot of things like this

2021
01:12:09,830 --> 01:12:07,679
um but so this is um down here is this

2022
01:12:10,790 --> 01:12:09,840
is the kepler 11 system

2023
01:12:14,070 --> 01:12:10,800
so

2024
01:12:15,990 --> 01:12:14,080
two scale this is the separation of

2025
01:12:17,750 --> 01:12:16,000
one two three four five six planets

2026
01:12:19,830 --> 01:12:17,760
around kepler-11

2027
01:12:22,229 --> 01:12:19,840
all six of these

2028
01:12:25,270 --> 01:12:22,239
are more massive than mercury

2029
01:12:27,990 --> 01:12:25,280
um and all five are inside mercury's

2030
01:12:30,310 --> 01:12:28,000
orbit so like the like so this is like

2031
01:12:32,709 --> 01:12:30,320
really stuffing like basically as many

2032
01:12:33,590 --> 01:12:32,719
planets as you can

2033
01:12:35,270 --> 01:12:33,600
um

2034
01:12:36,630 --> 01:12:35,280
and this comes back to the question of

2035
01:12:37,750 --> 01:12:36,640
you know like then they started

2036
01:12:39,910 --> 01:12:37,760
interacting with each other at this

2037
01:12:41,669 --> 01:12:39,920
point and actually a lot of because this

2038
01:12:43,669 --> 01:12:41,679

is actually surprisingly not that common

2039
01:12:44,950 --> 01:12:43,679
you you can confirm and actually measure

2040
01:12:46,870 --> 01:12:44,960
the masses of these things because these

2041
01:12:48,470 --> 01:12:46,880
are close enough and big enough that

2042
01:12:51,590 --> 01:12:48,480
the gravitational interaction between

2043
01:12:53,270 --> 01:12:51,600
the two is measurable um and so you can

2044
01:12:54,950 --> 01:12:53,280
see that their orbits are being

2045
01:12:56,870 --> 01:12:54,960
perturbed a little bit by the fact that

2046
01:12:58,390 --> 01:12:56,880
okay it would normally be on this orbit

2047
01:12:59,990 --> 01:12:58,400
but now the next one out is about to

2048
01:13:01,430 --> 01:13:00,000
pass it and so it's going to tug back a

2049
01:13:04,630 --> 01:13:01,440
little bit on it and it affects the

2050
01:13:06,870 --> 01:13:04,640
dynamics um so

2051
01:13:08,709 --> 01:13:06,880
we find things basically as

2052
01:13:10,310 --> 01:13:08,719
packed together as

2053
01:13:12,070 --> 01:13:10,320
to the point of like just barely being

2054
01:13:13,030 --> 01:13:12,080
dynamically stable or you know if you

2055
01:13:14,870 --> 01:13:13,040
try to put one more thing in there and

2056
01:13:16,390 --> 01:13:14,880
then it's all gonna scatter um so i

2057
01:13:18,870 --> 01:13:16,400
think that's one really cool thing

2058
01:13:20,550 --> 01:13:18,880
that's come out of it

2059
01:13:23,430 --> 01:13:20,560
i'll say that online we had a little

2060
01:13:25,669 --> 01:13:23,440
chat about uh where these hot jupiters

2061
01:13:27,510 --> 01:13:25,679
formed and that you know the standard

2062
01:13:29,590 --> 01:13:27,520
ideas that they formed out where

2063
01:13:31,590 --> 01:13:29,600

our planet our our jupiter is now but

2064
01:13:33,030 --> 01:13:31,600
they migrated inward and one of the

2065
01:13:34,870 --> 01:13:33,040
questions that sort of came up was all

2066
01:13:37,270 --> 01:13:34,880
right well what stops them if they're

2067
01:13:39,510 --> 01:13:37,280
migrating that far inward what stops

2068
01:13:42,310 --> 01:13:39,520
them from just crashing into their star

2069
01:13:45,030 --> 01:13:42,320
i mean yeah um so

2070
01:13:47,110 --> 01:13:45,040
um i don't know that we've answered that

2071
01:13:49,910 --> 01:13:47,120
question necessarily um but one of the

2072
01:13:52,070 --> 01:13:49,920
things that's important um

2073
01:13:53,990 --> 01:13:52,080
is that

2074
01:13:55,590 --> 01:13:54,000
so this migration happens while the disk

2075
01:13:57,669 --> 01:13:55,600
of material that forms the planets are

2076
01:14:00,470 --> 01:13:57,679
still there and so

2077
01:14:01,510 --> 01:14:00,480
um if you can truncate the disc and get

2078
01:14:03,110 --> 01:14:01,520
rid of the

2079
01:14:04,310 --> 01:14:03,120
that material they basically get all the

2080
01:14:06,470 --> 01:14:04,320
way into where where the edge of the

2081
01:14:08,229 --> 01:14:06,480
disc is and then there's nothing else to

2082
01:14:09,669 --> 01:14:08,239
interact with them so it can stop

2083
01:14:10,790 --> 01:14:09,679
um but

2084
01:14:12,310 --> 01:14:10,800
i know that was certainly an early

2085
01:14:14,390 --> 01:14:12,320
problem i don't work on the models

2086
01:14:18,709 --> 01:14:14,400
myself so i don't know how

2087
01:14:19,910 --> 01:14:18,719
solved that is but um that was actually

2088
01:14:21,430 --> 01:14:19,920

one of the things that came out was like

2089
01:14:23,350 --> 01:14:21,440
okay great we now understand how we can

2090
01:14:25,590 --> 01:14:23,360
make the move but how do we stop them um

2091
01:14:27,189 --> 01:14:25,600
and and one way is to um process these

2092
01:14:29,990 --> 01:14:27,199
that truck perhaps the

2093
01:14:31,510 --> 01:14:30,000
wind just blows all that stuff out right

2094
01:14:33,030 --> 01:14:31,520
yeah so it's another way of yeah

2095
01:14:35,350 --> 01:14:33,040
clearing clearing out the region around

2096
01:14:36,310 --> 01:14:35,360
the star whether um by processes you

2097
01:14:38,709 --> 01:14:36,320
know from the star could be the wind

2098
01:14:39,910 --> 01:14:38,719
could be magnetic fields um i think um

2099
01:14:42,870 --> 01:14:39,920
have ways of you know stopping the

2100
01:14:46,950 --> 01:14:42,880
material from going directly to the star

2101
01:14:52,390 --> 01:14:49,830
we do not all right so next month

2102
01:14:54,070 --> 01:14:52,400
learn how to recycle your used pulsars

2103
01:14:56,470 --> 01:14:54,080
okay