PUBLIC LECTURE SERIES

Mapping the United Federation of Planets: An Astronomer's Guide to the Galaxy

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Featuring Guest Speaker:

Mia Bovill

1
00:00:08,530 --> 00:00:02,330
our YouTube channel mr. grant justice

2
00:00:14,980 --> 00:00:08,540
give him a hand alright check this

3
00:00:19,849 --> 00:00:17,180
good evening ladies and gentlemen and

4
00:00:22,790 --> 00:00:19,859
welcome to the Space Telescope public

5
00:00:25,099 --> 00:00:22,800
lecture series I am dr. Frank summers of

6
00:00:28,189 --> 00:00:25,109
the office of public outreach and it is

7
00:00:32,060 --> 00:00:28,199
my pleasure to be your host when you

8
00:00:34,010 --> 00:00:32,070
came in you came in early you might have

9
00:00:37,190 --> 00:00:34,020
gotten a picture of the star cluster

10
00:00:40,220 --> 00:00:37,200
westerlyn - if you came in a little bit

11
00:00:42,470 --> 00:00:40,230
later we ran out of westerlyn - and now

12
00:00:46,970 --> 00:00:42,480
we have the star-forming nebula and 90

13
00:00:48,860 --> 00:00:46,980

available if you get these the n 90s are

14
00:00:50,900 --> 00:00:48,870
still available if you want the

15
00:00:53,900 --> 00:00:50,910
westerlyn - well you might have to trade

16
00:00:56,450 --> 00:00:53,910
with somebody okay so do your best horse

17
00:00:57,860 --> 00:00:56,460
trading and you can get your wonderful

18
00:00:58,910 --> 00:00:57,870
pictures if you'd like to know more

19
00:01:00,709 --> 00:00:58,920
about them of course

20
00:01:03,619 --> 00:01:00,719
turn over on the back and we have a

21
00:01:07,219 --> 00:01:03,629
short essay telling you about them art

22
00:01:09,590 --> 00:01:07,229
its topic tonight a fun one mapping the

23
00:01:13,100 --> 00:01:09,600
United Federation of Planets and

24
00:01:14,600 --> 00:01:13,110
astronomers guide to the galaxy and of

25
00:01:16,310 --> 00:01:14,610
course everyone recognizes that the

26
00:01:19,609 --> 00:01:16,320
United Federation of Planets is a

27
00:01:21,770 --> 00:01:19,619
reference to Star Trek and mia has told

28
00:01:27,370 --> 00:01:21,780
me that yes she will tell you where the

29
00:01:30,319 --> 00:01:27,380
Klingons are alright next month

30
00:01:37,249 --> 00:01:30,329
susannah days tua will be talking about

31
00:01:41,630 --> 00:01:37,259
the plumes of Europa ice water life find

32
00:01:42,980 --> 00:01:41,640
out next month April 3rd in May one of

33
00:01:46,389 --> 00:01:42,990
the talks we've been trying to get for a

34
00:01:50,350 --> 00:01:46,399
while recently won a Nobel Prize

35
00:01:53,060 --> 00:01:50,360
gravitational wave astronomy a new

36
00:01:54,950 --> 00:01:53,070
method for examining the universe that

37
00:01:55,609 --> 00:01:54,960
we can now finally detect gravitational

38
00:01:58,130 --> 00:01:55,619

waves

39
00:02:01,609 --> 00:01:58,140
we've only been trying for about 40 or

40
00:02:03,469 --> 00:02:01,619
50 years to see what we can do we can

41
00:02:05,149 --> 00:02:03,479
finally detect them and and 'if Richter

42
00:02:08,660 --> 00:02:05,159
is our local expert who will tell you

43
00:02:10,910 --> 00:02:08,670
about that on June we'll Fischer will

44
00:02:13,780 --> 00:02:10,920
speak on one of my favorite nebula in

45
00:02:16,869 --> 00:02:13,790
the entire universe the Orion Nebula

46
00:02:19,179 --> 00:02:16,879
it is the nearest large star-forming

47
00:02:21,339 --> 00:02:19,189
region is our template for understanding

48
00:02:24,250 --> 00:02:21,349
star formation in the universe and the

49
00:02:26,470 --> 00:02:24,260
guys here know so much about it he'll

50
00:02:28,990 --> 00:02:26,480
give you all sorts of cool detail on how

51
00:02:31,720 --> 00:02:29,000
stars are born actually not only stars

52
00:02:35,410 --> 00:02:31,730
but also planetary systems all right

53
00:02:38,110 --> 00:02:35,420
that will be in June the details are on

54
00:02:40,270 --> 00:02:38,120
our website in your favorite search

55
00:02:42,399 --> 00:02:40,280
engine type in Hubble public lectures

56
00:02:44,199 --> 00:02:42,409
and you should find this webpage where

57
00:02:47,610 --> 00:02:44,209
we have the list of the upcoming talks

58
00:02:52,059 --> 00:02:47,620
oh by the way I see me above all is on

59
00:02:55,839 --> 00:02:52,069
undergrad from 2016 so she has spoken

60
00:02:59,170 --> 00:02:55,849
here before that was just a screengrab I

61
00:03:02,470 --> 00:02:59,180
did here we also have the online the

62
00:03:05,409 --> 00:03:02,480
live the YouTube and stsci webcasting as

63
00:03:08,770 --> 00:03:05,419

well as the archives the YouTube goes

64
00:03:12,599 --> 00:03:08,780
back to 2014 the webcast goes all the

65
00:03:15,759 --> 00:03:12,609
way back to 2005 that's a lot of

66
00:03:17,710 --> 00:03:15,769
astronaut astronomy topics I dare you to

67
00:03:21,219 --> 00:03:17,720
binge watch that in one weekend I don't

68
00:03:23,409 --> 00:03:21,229
think you can do it if you would like to

69
00:03:25,719 --> 00:03:23,419
be informed we have our sign up for our

70
00:03:29,740 --> 00:03:25,729
email list both subscribe and

71
00:03:31,539 --> 00:03:29,750
unsubscribe if you would like the

72
00:03:33,550 --> 00:03:31,549
announcements we say as I just told you

73
00:03:36,789 --> 00:03:33,560
sign up the website or if you can't

74
00:03:38,339 --> 00:03:36,799
possibly do that give me your email okay

75
00:03:40,869 --> 00:03:38,349
I'll write it down on a piece of paper

76
00:03:43,569 --> 00:03:40,879
hand it to me and I'll make sure you get

77
00:03:45,520 --> 00:03:43,579
on the list if you have comments or

78
00:03:48,729 --> 00:03:45,530
questions we have an email public

79
00:03:50,830 --> 00:03:48,739
lecture at STScI dot edu you can send

80
00:03:52,420 --> 00:03:50,840
email to that and we'll get to the

81
00:03:56,379 --> 00:03:52,430
answer all right

82
00:03:58,119 --> 00:03:56,389
social media Hubbell web and STScI have

83
00:04:01,479 --> 00:03:58,129
a variety of Facebook Twitter YouTube

84
00:04:04,210 --> 00:04:01,489
and Instagram I myself do a little bit

85
00:04:06,069 --> 00:04:04,220
of Facebook Google+ and Twitter and some

86
00:04:09,390 --> 00:04:06,079
occasionally write some blog posts if

87
00:04:11,830 --> 00:04:09,400
you want to hear more from me

88
00:04:14,439 --> 00:04:11,840

unfortunately if you looked up you could

89
00:04:16,479 --> 00:04:14,449
not see any stars tonight it's cloudy

90
00:04:18,249 --> 00:04:16,489
it's actually he's gonna rain and

91
00:04:20,680 --> 00:04:18,259
possibly even snow a little bit tonight

92
00:04:23,560 --> 00:04:20,690
so ya know Maryland Space Grant

93
00:04:27,010 --> 00:04:23,570
Observatory tonight but if you go to MD

94
00:04:29,830 --> 00:04:27,020
dot space grant o RG you can find this

95
00:04:32,439 --> 00:04:29,840
and they have open houses every Friday

96
00:04:34,659 --> 00:04:32,449
you want to check this page for the

97
00:04:37,420 --> 00:04:34,669
observatory status right over here on

98
00:04:38,589 --> 00:04:37,430
the right-hand side and they'll tell you

99
00:04:43,390 --> 00:04:38,599
whether or not they're going to be open

100
00:04:47,010 --> 00:04:43,400
on various Fridays okay and now the news

101
00:04:49,960 --> 00:04:47,020
from the universe for March 2018 and

102
00:04:53,290 --> 00:04:49,970
since our speaker has chosen a sort of

103
00:04:54,760 --> 00:04:53,300
Star Trek theme to her talk I decided I

104
00:04:57,700 --> 00:04:54,770
would add a little bit of Star Trek

105
00:05:07,029 --> 00:04:57,710
flavor to my news summary so our first

106
00:05:09,399 --> 00:05:07,039
topic is what factor 500 million when

107
00:05:11,830 --> 00:05:09,409
I'm talking about warp I'm actually not

108
00:05:15,339 --> 00:05:11,840
talking about the Star Trek warp I'm

109
00:05:18,700 --> 00:05:15,349
talking about warped images and this is

110
00:05:21,909 --> 00:05:18,710
Baltimore's Inner Harbor with a Saturn

111
00:05:24,580 --> 00:05:21,919
mass black hole passing over the Inner

112
00:05:27,969 --> 00:05:24,590
Harbor and you can see that the images

113
00:05:30,520 --> 00:05:27,979

of the background buildings are warped

114
00:05:34,420 --> 00:05:30,530
by the passage of that black hole

115
00:05:40,029 --> 00:05:34,430
because due to general relativity mass

116
00:05:43,029 --> 00:05:40,039
bends the mass bends space which changes

117
00:05:45,670 --> 00:05:43,039
the direction of light so as you look

118
00:05:47,350 --> 00:05:45,680
past a black hole think the light goes

119
00:05:49,270 --> 00:05:47,360
around in different directions and it

120
00:05:50,980 --> 00:05:49,280
warps the images of the background

121
00:05:52,330 --> 00:05:50,990
objects it doesn't actually warp the

122
00:05:54,969 --> 00:05:52,340
background objects but it warps those

123
00:05:56,409 --> 00:05:54,979
images now that cannot just happen here

124
00:05:58,779 --> 00:05:56,419
in Baltimore actually it's never

125
00:06:01,180 --> 00:05:58,789
happened here in Baltimore that's just

126
00:06:03,939 --> 00:06:01,190
an example but it can actually happen

127
00:06:06,850 --> 00:06:03,949
out in the universe in clusters of

128
00:06:09,909 --> 00:06:06,860
galaxies these clusters of galaxies have

129
00:06:13,059 --> 00:06:09,919
so much matter more mostly dark matter

130
00:06:15,790 --> 00:06:13,069
in them that they are massive enough to

131
00:06:17,800 --> 00:06:15,800
bend the space around them which

132
00:06:20,350 --> 00:06:17,810
actually changes the direction of the

133
00:06:24,189 --> 00:06:20,360
light passing through them we call this

134
00:06:26,200 --> 00:06:24,199
gravitational lensing gravity changes

135
00:06:28,779 --> 00:06:26,210
the direction of the light and it acts

136
00:06:31,120 --> 00:06:28,789
like a lens in space so if you've got

137
00:06:33,640 --> 00:06:31,130
this lens in space and you've got a

138
00:06:37,629 --> 00:06:33,650

telescope lens this actually acts as an

139
00:06:40,570 --> 00:06:37,639
extra lens to magnify and amplify the

140
00:06:43,240 --> 00:06:40,580
light of more distant objects

141
00:06:45,790 --> 00:06:43,250
using these gravitational lenses we can

142
00:06:48,550 --> 00:06:45,800
see some of the most distant galaxies

143
00:06:52,990 --> 00:06:48,560
out there and so in this cluster called

144
00:06:55,179 --> 00:06:53,000
max Jo for 606 for seven plus seven oh

145
00:06:57,219 --> 00:06:55,189
one five they don't have any great names

146
00:07:00,399 --> 00:06:57,229
they're usually just phone numbers like

147
00:07:03,490 --> 00:07:00,409
that we actually found a really really

148
00:07:05,740 --> 00:07:03,500
distant galaxy and there are actually

149
00:07:07,959 --> 00:07:05,750
three images of it the light from this

150
00:07:12,189 --> 00:07:07,969
extremely distant galaxy passes three

151
00:07:14,589 --> 00:07:12,199
ways through this cluster and appear

152
00:07:18,010 --> 00:07:14,599
here here and here and you can see it's

153
00:07:20,680 --> 00:07:18,020
beautiful it's a red dot okay that's

154
00:07:23,290 --> 00:07:20,690
because it's a galaxy about thirteen

155
00:07:26,260 --> 00:07:23,300
billion light-years away one of the most

156
00:07:28,600 --> 00:07:26,270
distant we've ever seen and when we do

157
00:07:31,360 --> 00:07:28,610
this that's what we usually get we get

158
00:07:33,219 --> 00:07:31,370
red dots because they're very small

159
00:07:35,740 --> 00:07:33,229
galaxies they're very distant and

160
00:07:37,959 --> 00:07:35,750
therefore they're seen in the early part

161
00:07:39,879 --> 00:07:37,969
of the universe okay if it's thirteen

162
00:07:43,600 --> 00:07:39,889
billion light-years away you're seeing

163
00:07:46,899 --> 00:07:43,610

that galaxy as it was 13 billion years

164
00:07:49,959 --> 00:07:46,909
ago okay that's only 800 million years

165
00:07:53,980 --> 00:07:49,969
after the Big Bang that's a really baby

166
00:07:56,680 --> 00:07:53,990
galaxy okay but this was something that

167
00:08:00,760 --> 00:07:56,690
was released a few years ago we have a

168
00:08:04,779 --> 00:08:00,770
new cluster that we looked at this one

169
00:08:10,300 --> 00:08:04,789
has the phone number SP T - CL jo6

170
00:08:13,779 --> 00:08:10,310
1 5 - 5 7 4 6 and in this one we do not

171
00:08:19,839 --> 00:08:13,789
have a red dot in this one we actually

172
00:08:23,769 --> 00:08:19,849
have a red streak we have a red smudge

173
00:08:26,529 --> 00:08:23,779
so this may not look like much to you ok

174
00:08:29,649 --> 00:08:26,539
so you got a it's a blur of red instead

175
00:08:33,040 --> 00:08:29,659
of a dot of red but actually by getting

176
00:08:35,290 --> 00:08:33,050
a red streak the gravitational lensing

177
00:08:38,860 --> 00:08:35,300
spreads it out turns it into a streak

178
00:08:40,360 --> 00:08:38,870
you can actually examine some of the

179
00:08:42,790 --> 00:08:40,370
internal characteristics you can

180
00:08:44,290 --> 00:08:42,800
estimate it alright this was found using

181
00:08:46,930 --> 00:08:44,300
the Hubble Space Telescope and the

182
00:08:49,750 --> 00:08:46,940
Spitzer Space Telescope using a program

183
00:08:53,230 --> 00:08:49,760
called relics when they're searched 41

184
00:08:54,079 --> 00:08:53,240
large clusters of galaxies looking

185
00:08:56,989 --> 00:08:54,089
specifically

186
00:09:00,650 --> 00:08:56,999
for these most distant objects and this

187
00:09:01,730 --> 00:09:00,660
object they can tell is only about 2,500

188
00:09:04,579 --> 00:09:01,740

light-years across

189
00:09:06,199 --> 00:09:04,589
now our galaxy is a hundred thousand

190
00:09:09,079 --> 00:09:06,209
light-years across so this is tiny

191
00:09:12,379 --> 00:09:09,089
compared to our galaxy our galaxy also

192
00:09:14,329 --> 00:09:12,389
has about 200 billion stars and the

193
00:09:17,480 --> 00:09:14,339
estimate on this is it's about less than

194
00:09:20,780 --> 00:09:17,490
three billion stars okay so it's very

195
00:09:22,790 --> 00:09:20,790
small it's a dwarf galaxy it's only half

196
00:09:25,040 --> 00:09:22,800
the size of what we call the small

197
00:09:27,619 --> 00:09:25,050
Magellanic Cloud which is a dwarf galaxy

198
00:09:29,720 --> 00:09:27,629
that's orbiting around our Milky Way but

199
00:09:32,480 --> 00:09:29,730
you wouldn't expect it to be a large

200
00:09:35,030 --> 00:09:32,490
galaxy because this galaxy is estimated

201
00:09:38,389 --> 00:09:35,040
to be seen thirteen point three billion

202
00:09:42,230 --> 00:09:38,399
light-years away which makes we see it

203
00:09:46,879 --> 00:09:42,240
only 500 million years after the Big

204
00:09:50,559 --> 00:09:46,889
Bang and that's a crucial idea that

205
00:09:54,199 --> 00:09:50,569
galaxies of unorder a few billion stars

206
00:09:57,619 --> 00:09:54,209
can form within the first 500 million

207
00:10:00,079 --> 00:09:57,629
years how long after the Big Bang

208
00:10:02,030 --> 00:10:00,089
does it take four stars in galaxies to

209
00:10:04,519 --> 00:10:02,040
form that's one of the great questions

210
00:10:06,410 --> 00:10:04,529
in cosmology that we're pursuing this

211
00:10:08,720 --> 00:10:06,420
gives us evidence that at least you can

212
00:10:11,710 --> 00:10:08,730
get a few billion stars together in one

213
00:10:16,040 --> 00:10:11,720

sort of clump 500 million years later

214
00:10:17,749 --> 00:10:16,050
now Hubble can't can't see the most

215
00:10:20,239 --> 00:10:17,759
distant galaxies because they're red

216
00:10:22,579 --> 00:10:20,249
shifted into the infrared so this is

217
00:10:23,829 --> 00:10:22,589
sort of a precursor for what we will see

218
00:10:26,090 --> 00:10:23,839
with the James Webb Space Telescope

219
00:10:28,970 --> 00:10:26,100
that's currently slated to launch in

220
00:10:30,829 --> 00:10:28,980
spring of 2019 so a little over a year

221
00:10:33,079 --> 00:10:30,839
from now the James Webb Space Telescope

222
00:10:35,509 --> 00:10:33,089
will launch and after it becomes

223
00:10:37,639 --> 00:10:35,519
observation operational we'll get more

224
00:10:39,199 --> 00:10:37,649
and more images like this and you can

225
00:10:42,110 --> 00:10:39,209
expect me to give you more and more

226
00:10:44,960 --> 00:10:42,120
stories looking at the first billion

227
00:10:47,239 --> 00:10:44,970
years of galaxy formation and having

228
00:10:49,460 --> 00:10:47,249
much greater statistics and getting an

229
00:10:51,650 --> 00:10:49,470
understanding of how galaxies initially

230
00:10:55,669 --> 00:10:51,660
formed in the universe so this is a

231
00:10:58,660 --> 00:10:55,679
great cool precursor and I named it warp

232
00:11:02,030 --> 00:10:58,670
factor 5 million because using the warp

233
00:11:04,699 --> 00:11:02,040
created by this galaxy cluster were able

234
00:11:07,470 --> 00:11:04,709
to see back to 500 million years after

235
00:11:10,980 --> 00:11:07,480
the Big Bang

236
00:11:13,280 --> 00:11:10,990
our second story lack of j-class

237
00:11:16,829 --> 00:11:13,290
atmospheres raises hopes of m-class

238
00:11:18,870 --> 00:11:16,839

planets alright so if you know your Star

239
00:11:21,269 --> 00:11:18,880
Trek okay you know that almost

240
00:11:23,160 --> 00:11:21,279
everything they visited was oh it's yet

241
00:11:25,740 --> 00:11:23,170
captain it's a nemesis m-class planet

242
00:11:27,930 --> 00:11:25,750
which means an earth-like planet okay

243
00:11:31,920 --> 00:11:27,940
I'm actually looked up on Wikipedia

244
00:11:36,180 --> 00:11:31,930
today they have 23 different classes of

245
00:11:37,079 --> 00:11:36,190
planets to find in Star Trek it's kind

246
00:11:40,319 --> 00:11:37,089
of blew my mind

247
00:11:42,569 --> 00:11:40,329
the specificity they had of these 23

248
00:11:44,850 --> 00:11:42,579
different classes of planets and it

249
00:11:47,670 --> 00:11:44,860
found out that the J class is the

250
00:11:49,769 --> 00:11:47,680
jupiter class Jupiter Saturn Uranus and

251
00:11:51,720 --> 00:11:49,779
Neptune gas giants although they aren't

252
00:11:53,340 --> 00:11:51,730
the only class of gas giants there's

253
00:11:55,530 --> 00:11:53,350
lots of several different classes out

254
00:11:57,180 --> 00:11:55,540
glassed gas giants I think the largest

255
00:11:59,040 --> 00:11:57,190
is the T class or something like that

256
00:12:02,610 --> 00:11:59,050
I'm not a Trekkie so I don't know all

257
00:12:06,360 --> 00:12:02,620
this stuff but I'm using that to talk

258
00:12:10,530 --> 00:12:06,370
about the planets in the system Trappist

259
00:12:12,240 --> 00:12:10,540
one now this is an artistic presentation

260
00:12:14,519 --> 00:12:12,250
of the Trappist one system we talked

261
00:12:18,930 --> 00:12:14,529
about this before in which there are

262
00:12:21,329 --> 00:12:18,940
seven earth sized planets around a red

263
00:12:23,220 --> 00:12:21,339

dwarf star and this artistic

264
00:12:25,139 --> 00:12:23,230
presentation is supposed to show that

265
00:12:27,629 --> 00:12:25,149
okay here we have the red dwarf star and

266
00:12:31,019 --> 00:12:27,639
here we have steam to indicate it's hot

267
00:12:32,850 --> 00:12:31,029
water would be boiling away here we have

268
00:12:35,550 --> 00:12:32,860
water in its liquid form in the middle

269
00:12:39,150 --> 00:12:35,560
and out here we have water in ice form

270
00:12:41,160 --> 00:12:39,160
where it's cold okay and several of

271
00:12:44,759 --> 00:12:41,170
these planets in the Trappist one system

272
00:12:47,309 --> 00:12:44,769
are in the region where liquid water

273
00:12:50,699 --> 00:12:47,319
would be liquid and that's what we call

274
00:12:54,000 --> 00:12:50,709
the habitable zone all right if you want

275
00:12:55,500 --> 00:12:54,010
a more didactic presentation of it here

276
00:13:00,059 --> 00:12:55,510
is the Travis one system with the red

277
00:13:03,269 --> 00:13:00,069
dwarf star here and the seven planets b

278
00:13:06,269 --> 00:13:03,279
c d e f g h you've heard of Snow White

279
00:13:09,420 --> 00:13:06,279
and the Seven Dwarfs this is Red Dwarf

280
00:13:14,420 --> 00:13:09,430
and the Seven earth-sized planets in the

281
00:13:17,040 --> 00:13:14,430
Trappist one system now this is artistic

282
00:13:20,639 --> 00:13:17,050
interpretation okay do we know what

283
00:13:23,970 --> 00:13:20,649
these planets look like no not at all

284
00:13:27,059 --> 00:13:23,980
don't actually see the planets what we

285
00:13:29,160 --> 00:13:27,069
see is the planets pass in front of the

286
00:13:32,600 --> 00:13:29,170
star and block a little bit of the light

287
00:13:35,730 --> 00:13:32,610
so the light for that star drops and

288
00:13:38,400 --> 00:13:35,740

rises back up as the planet passes in

289
00:13:40,769 --> 00:13:38,410
front we call this the transit method of

290
00:13:43,829 --> 00:13:40,779
finding extrasolar planets and we found

291
00:13:48,720 --> 00:13:43,839
seven of these around this star so we

292
00:13:52,379 --> 00:13:48,730
don't actually see the planet but we

293
00:13:55,350 --> 00:13:52,389
could see its atmosphere because when a

294
00:13:57,239 --> 00:13:55,360
planet passes in front of a star some of

295
00:13:59,609 --> 00:13:57,249
the light of the star will go through

296
00:14:02,669 --> 00:13:59,619
that planet's atmosphere

297
00:14:05,879 --> 00:14:02,679
and the chemical elements in that

298
00:14:08,160 --> 00:14:05,889
planet's atmosphere will absorb some of

299
00:14:11,100 --> 00:14:08,170
the star's light so if you take a

300
00:14:12,809 --> 00:14:11,110
spectrum of the star and then you take

301
00:14:15,960 --> 00:14:12,819
another spectrum with the planet in

302
00:14:18,960 --> 00:14:15,970
front of the star subtract the two you

303
00:14:22,470 --> 00:14:18,970
get the spectrum of the planet's

304
00:14:24,869 --> 00:14:22,480
atmosphere how cool is that we can

305
00:14:28,049 --> 00:14:24,879
actually start to see the atmospheres of

306
00:14:30,919 --> 00:14:28,059
planets around other stars so we wanted

307
00:14:34,319 --> 00:14:30,929
to tell do these earth sized planets

308
00:14:36,629 --> 00:14:34,329
have earth-like atmospheres all right

309
00:14:39,660 --> 00:14:36,639
and so what we can tell here is if it

310
00:14:42,540 --> 00:14:39,670
has a big extended atmosphere we'll see

311
00:14:44,519 --> 00:14:42,550
a lot of absorption okay this big

312
00:14:47,519 --> 00:14:44,529
extended atmosphere we'd expect to be

313
00:14:50,910 --> 00:14:47,529

hydrogen puffed up a poor primordial

314
00:14:53,999 --> 00:14:50,920
type atmosphere okay however if it has a

315
00:14:56,999 --> 00:14:54,009
thin atmosphere sort of like mercury I

316
00:14:58,860 --> 00:14:57,009
mean Venus Earth and Mars have today you

317
00:15:00,749 --> 00:14:58,870
know it's not primordial it's processed

318
00:15:02,489 --> 00:15:00,759
it has a good good amount of heavier

319
00:15:04,470 --> 00:15:02,499
elements in it well then it would have a

320
00:15:07,949 --> 00:15:04,480
thinner atmosphere and we'd see almost

321
00:15:09,660 --> 00:15:07,959
no absorption okay so if it has a big

322
00:15:11,819 --> 00:15:09,670
atmosphere we're gonna see absorption if

323
00:15:13,769 --> 00:15:11,829
it has a small atmosphere we're not

324
00:15:17,489 --> 00:15:13,779
going to see absorption all right here

325
00:15:19,889 --> 00:15:17,499
is the actual data ok presented in an

326
00:15:23,100 --> 00:15:19,899
artistic fashion the purple is what we

327
00:15:26,129 --> 00:15:23,110
would expect if it had this large

328
00:15:29,309 --> 00:15:26,139
primordial atmosphere the yellow is the

329
00:15:31,319 --> 00:15:29,319
actual data and you can see that the

330
00:15:34,000 --> 00:15:31,329
actual data in the yellow it's

331
00:15:37,600 --> 00:15:34,010
consistent with basically a flat line

332
00:15:40,930 --> 00:15:37,610
not the big up-and-down that we see in

333
00:15:44,680 --> 00:15:40,940
the primordial atmosphere so for these

334
00:15:48,220 --> 00:15:44,690
four planets three of them D F and E all

335
00:15:51,760 --> 00:15:48,230
in habitable zone we do not see a large

336
00:15:53,770 --> 00:15:51,770
primordial atmosphere G we're not quite

337
00:15:55,240 --> 00:15:53,780
sure of okay then we need a little bit

338
00:15:57,310 --> 00:15:55,250

more we can't say with absolute

339
00:15:59,680 --> 00:15:57,320
certainty that G doesn't have a big

340
00:16:01,780 --> 00:15:59,690
atmosphere most likely it doesn't but

341
00:16:03,670 --> 00:16:01,790
you know we we have we have certain

342
00:16:07,810 --> 00:16:03,680
measures of this and this one's not good

343
00:16:11,440 --> 00:16:07,820
enough to say for sure so this lack of

344
00:16:14,410 --> 00:16:11,450
this j-class atmosphere indicates that

345
00:16:16,120 --> 00:16:14,420
it could have an m-class atmosphere but

346
00:16:19,360 --> 00:16:16,130
does it say it absolutely has an m-class

347
00:16:21,070 --> 00:16:19,370
atmosphere no it just says it doesn't

348
00:16:23,980 --> 00:16:21,080
have a doesn't have a large extended

349
00:16:26,380 --> 00:16:23,990
atmosphere which adds to the hope that

350
00:16:29,590 --> 00:16:26,390
these could actually be more earth-like

351
00:16:31,510 --> 00:16:29,600
they're not neptune like okay sometimes

352
00:16:33,730 --> 00:16:31,520
we think of these Earth's earth sized

353
00:16:35,200 --> 00:16:33,740
objects they could be super Earths that

354
00:16:37,060 --> 00:16:35,210
could be mini Neptune's these are not

355
00:16:39,970 --> 00:16:37,070
mini app tunes okay they don't have

356
00:16:42,460 --> 00:16:39,980
extended atmospheres like this so one

357
00:16:45,150 --> 00:16:42,470
checkmark yes in terms of moving forward

358
00:16:48,370 --> 00:16:45,160
in terms of trying to find earth-like

359
00:16:50,020 --> 00:16:48,380
planets we know their earth sized now

360
00:16:53,440 --> 00:16:50,030
we're continuing to try and find out if

361
00:16:54,280 --> 00:16:53,450
they're earth-like and this is a good as

362
00:16:56,910 --> 00:16:54,290
a good sign

363
00:16:59,950 --> 00:16:56,920

moving forward in that direction again

364
00:17:02,140 --> 00:16:59,960
we will find more out by when we have

365
00:17:03,100 --> 00:17:02,150
infrared observations of the James Webb

366
00:17:05,470 --> 00:17:03,110
Space Telescope

367
00:17:07,750 --> 00:17:05,480
because extrasolar planets actually

368
00:17:09,550 --> 00:17:07,760
shine in the infrared they're brighter

369
00:17:13,870 --> 00:17:09,560
in the infrared especially relative to

370
00:17:15,790 --> 00:17:13,880
their host stars so again pointing to

371
00:17:17,340 --> 00:17:15,800
the future we're going to have a lot

372
00:17:20,470 --> 00:17:17,350
more of these type of stories as well

373
00:17:23,380 --> 00:17:20,480
when the infrared Space Telescope the

374
00:17:25,780 --> 00:17:23,390
JIT web is up there in next use next

375
00:17:28,240 --> 00:17:25,790
year and the year after us okay all

376
00:17:31,840 --> 00:17:28,250
right and so that is our news from the

377
00:17:35,560 --> 00:17:31,850
universe our featured speaker tonight is

378
00:17:38,340 --> 00:17:35,570
MIA boville who has this is like your

379
00:17:41,500 --> 00:17:38,350
third time talking here right she's

380
00:17:43,390 --> 00:17:41,510
coming she's wonderful because she comes

381
00:17:45,810 --> 00:17:43,400
and she volunteers for me every year

382
00:17:48,210 --> 00:17:45,820
okay there are

383
00:17:49,800 --> 00:17:48,220
number of speakers who you know I have

384
00:17:52,890 --> 00:17:49,810
to with Trista arms to volunteer once

385
00:17:55,800 --> 00:17:52,900
every five or ten years okay but dia has

386
00:17:59,340 --> 00:17:55,810
come in and last time you talked on the

387
00:18:00,450 --> 00:17:59,350
the Harvard Harvard computers right

388
00:18:03,540 --> 00:18:00,460

that's what I would like to call them

389
00:18:07,080 --> 00:18:03,550
okay and tonight she is going to talk to

390
00:18:10,110 --> 00:18:07,090
you about the science of observing the

391
00:18:14,660 --> 00:18:10,120
galaxy with a wonderful Star Trek flare

392
00:18:22,950 --> 00:18:14,670
so ladies and gentlemen miss Mia Bobo I

393
00:18:25,680 --> 00:18:22,960
will call you doctor I missed you

394
00:18:27,420 --> 00:18:25,690
there we go so first off I'd like to

395
00:18:33,810 --> 00:18:27,430
apologize to every single person in this

396
00:18:37,620 --> 00:18:33,820
room in a red shirt all right now like a

397
00:18:40,800 --> 00:18:37,630
good scientist you cite your sources so

398
00:18:43,680 --> 00:18:40,810
for the science chunk of this talk I

399
00:18:46,790 --> 00:18:43,690
used galactic astronomy this is the one

400
00:18:49,080 --> 00:18:46,800
of the Bible's of our galaxy's course

401
00:18:51,390 --> 00:18:49,090
when I'm gonna cover the mapping of the

402
00:18:54,180 --> 00:18:51,400
Milky Way is a month in a graduate-level

403
00:18:57,090 --> 00:18:54,190
galaxies course and I'm going to attempt

404
00:19:02,010 --> 00:18:57,100
to do this in 40 minutes so I might lose

405
00:19:08,010 --> 00:19:02,020
leave a few things out and for the rest

406
00:19:09,750 --> 00:19:08,020
of it so this is the Star Trek Star Trek

407
00:19:11,730 --> 00:19:09,760
Atlas actually had to order this from

408
00:19:14,340 --> 00:19:11,740
San Luis Obispo California because

409
00:19:16,530 --> 00:19:14,350
apparently it's no longer in print but

410
00:19:19,170 --> 00:19:16,540
for is the act for the mapping of

411
00:19:21,360 --> 00:19:19,180
specific worlds to specific xual real

412
00:19:23,190 --> 00:19:21,370
stars which I'll get into towards the

413
00:19:25,350 --> 00:19:23,200

end of the talk this is what I used if

414
00:19:27,510 --> 00:19:25,360
anybody is a bigger Trekkie than me and

415
00:19:33,200 --> 00:19:27,520
wants to take issue with exactly what

416
00:19:40,370 --> 00:19:35,400
and I'd like to just point out that I do

417
00:19:43,230 --> 00:19:40,380
have a towel in my backpack

418
00:19:45,630 --> 00:19:43,240
all right so just to get this out of the

419
00:19:47,520 --> 00:19:45,640
way Star Trek is wonderful it does a lot

420
00:19:51,150 --> 00:19:47,530
of things really really well science is

421
00:19:52,920 --> 00:19:51,160
not one of them so this is a list of the

422
00:19:55,500 --> 00:19:52,930
things that Star Trek roughly speaking

423
00:19:58,260 --> 00:19:55,510
gets right we live in the Milky Way

424
00:19:59,430 --> 00:19:58,270
galaxy the Milky Way galaxy is about a

425
00:20:00,870 --> 00:19:59,440
hundred thousand light-years across

426
00:20:02,160 --> 00:20:00,880
there how much of that is them getting

427
00:20:05,130 --> 00:20:02,170
it right and how much of that was dumb

428
00:20:07,800 --> 00:20:05,140
luck I'm not actually certain there are

429
00:20:09,830 --> 00:20:07,810
nebulae in the Milky Way they won't eat

430
00:20:12,570 --> 00:20:09,840
your ship they won't corrode your ship

431
00:20:14,250 --> 00:20:12,580
and they are significantly bigger than

432
00:20:20,270 --> 00:20:14,260
your ability to jot in and out at

433
00:20:25,920 --> 00:20:23,310
many of those stars have planets in fact

434
00:20:28,380 --> 00:20:25,930
we have been finding a lot of them this

435
00:20:30,300 --> 00:20:28,390
is as of December of 2017 and it

436
00:20:33,930 --> 00:20:30,310
probably needs to be updated

437
00:20:36,030 --> 00:20:33,940
the Kepler this is the full thing of the

438
00:20:38,790 --> 00:20:36,040

Kepler space telescope so this is all

439
00:20:41,700 --> 00:20:38,800
the one planet systems two three four

440
00:20:43,800 --> 00:20:41,710
five six this is the Trappist one system

441
00:20:48,060 --> 00:20:43,810
that dr. Sommers was talking about our

442
00:20:50,250 --> 00:20:48,070
solar system and the Kepler 90 system so

443
00:20:51,420 --> 00:20:50,260
there are planets around stars in fact

444
00:20:55,650 --> 00:20:51,430
there were a lot more planets around

445
00:20:57,270 --> 00:20:55,660
stars and we thought there were some of

446
00:20:59,430 --> 00:20:57,280
these planets maybe in the habitable

447
00:21:01,200 --> 00:20:59,440
zone of their star and by habitable zone

448
00:21:03,750 --> 00:21:01,210
I do not mean m-class with the Vulcans

449
00:21:05,280 --> 00:21:03,760
on them I mean they are at the right

450
00:21:07,290 --> 00:21:05,290
distance from their star to have liquid

451
00:21:09,090 --> 00:21:07,300
water on their surface which means

452
00:21:10,830 --> 00:21:09,100
you've got a chance at actually having

453
00:21:12,720 --> 00:21:10,840
life whether that life becomes

454
00:21:15,380 --> 00:21:12,730
intelligent and develops warp drive well

455
00:21:19,530 --> 00:21:15,390
that's a complete other set of questions

456
00:21:22,650 --> 00:21:19,540
there are such things as neutron stars

457
00:21:25,020 --> 00:21:22,660
pulsars black holes dark matter and

458
00:21:26,700 --> 00:21:25,030
supernova explosions the statistical

459
00:21:31,380 --> 00:21:26,710
chance that they used these correctly in

460
00:21:36,060 --> 00:21:34,230
they do occasionally get this right but

461
00:21:38,850 --> 00:21:36,070
more likely than not they get it wrong

462
00:21:42,330 --> 00:21:38,860
and no you cannot punch your way through

463
00:21:46,230 --> 00:21:42,340

the event horizon of a black hole but

464
00:21:48,210 --> 00:21:46,240
primarily space is big however big you

465
00:21:50,520 --> 00:21:48,220
think space is it's bigger

466
00:21:55,050 --> 00:21:50,530
however weird do you think spaces it's

467
00:21:57,990 --> 00:21:55,060
weirder so now that we've gotten that

468
00:21:59,910 --> 00:21:58,000
out of the way before you the enterprise

469
00:22:02,430 --> 00:21:59,920
you can tell the enterprise or whichever

470
00:22:04,440 --> 00:22:02,440
particular starship you're on to go - I

471
00:22:06,930 --> 00:22:04,450
don't know insert techno babble here in

472
00:22:08,940 --> 00:22:06,940
the sector first you have to know where

473
00:22:11,910 --> 00:22:08,950
on earth that sector or in the galaxy

474
00:22:13,680 --> 00:22:11,920
that sector actually is and these are

475
00:22:15,930 --> 00:22:13,690
actually the only two good images I

476
00:22:17,400 --> 00:22:15,940
could find from Star Trek episodes of

477
00:22:24,930 --> 00:22:17,410
the various characters standing in front

478
00:22:26,550 --> 00:22:24,940
of a map but before you can start to say

479
00:22:29,370 --> 00:22:26,560
where did the enterprise go you first

480
00:22:31,350 --> 00:22:29,380
have to figure out where we are and that

481
00:22:33,750 --> 00:22:31,360
starts with a very seemingly simple

482
00:22:37,530 --> 00:22:33,760
question where is the earth located in

483
00:22:39,180 --> 00:22:37,540
our solar system the planets will five

484
00:22:40,530 --> 00:22:39,190
of them are extremely bright they're

485
00:22:42,950 --> 00:22:40,540
very easy to measure in fact we've been

486
00:22:45,690 --> 00:22:42,960
measuring them for thousands of years

487
00:22:47,670 --> 00:22:45,700
but it's actually not so simple because

488
00:22:51,180 --> 00:22:47,680

we have to go even further back in time

489
00:22:56,700 --> 00:22:51,190
back to 270 BC and the Golden Age of

490
00:23:00,900 --> 00:22:56,710
Pericles as Athens this is Aristarchus

491
00:23:02,580 --> 00:23:00,910
of Samos and he went against the green a

492
00:23:04,700 --> 00:23:02,590
little bit he believed the Sun was at

493
00:23:08,220 --> 00:23:04,710
the center of the solar system that

494
00:23:10,320 --> 00:23:08,230
other stars were extremely far away and

495
00:23:13,620 --> 00:23:10,330
that they there were other stars like

496
00:23:15,630 --> 00:23:13,630
our Sun and that's why as the earth

497
00:23:19,620 --> 00:23:15,640
moved around the Sun we didn't see those

498
00:23:23,280 --> 00:23:19,630
stars stars move against the sky however

499
00:23:25,860 --> 00:23:23,290
he was only one voice and at the same

500
00:23:28,110 --> 00:23:25,870
time there was some pretty big voices

501
00:23:32,340 --> 00:23:28,120
saying that no no no the Earth's at the

502
00:23:37,140 --> 00:23:32,350
center were stationary everything moves

503
00:23:40,110 --> 00:23:37,150
around us and this was Aristotle here

504
00:23:42,330 --> 00:23:40,120
and Ptolemy as in the Ptolemaic system

505
00:23:42,960 --> 00:23:42,340
he gets he's the poor schmuck that gets

506
00:23:46,590 --> 00:23:42,970
this name

507
00:23:48,690 --> 00:23:46,600
for him now you have the earth here at

508
00:23:51,090 --> 00:23:48,700
the center you have the moon going

509
00:23:54,870 --> 00:23:51,100
around and you have the Sun going around

510
00:23:56,340 --> 00:23:54,880
all in perfect circles however the

511
00:23:58,260 --> 00:23:56,350
problem is that if you actually look at

512
00:24:00,360 --> 00:23:58,270
the movement of a planet on the sky

513
00:24:01,770 --> 00:24:00,370

it'll kind of go this way a little bit

514
00:24:05,760 --> 00:24:01,780
and then it'll kind of go this way again

515
00:24:07,500 --> 00:24:05,770
and then I'll go back this way and the

516
00:24:09,570 --> 00:24:07,510
part where went backwards was retrograde

517
00:24:11,340 --> 00:24:09,580
motion and if everything's just orbiting

518
00:24:13,710 --> 00:24:11,350
the earth happy as you please you're not

519
00:24:17,370 --> 00:24:13,720
going to have retrograde motion so they

520
00:24:20,100 --> 00:24:17,380
inserted what they called epicycles onto

521
00:24:22,830 --> 00:24:20,110
each of these orbits depending on how

522
00:24:25,110 --> 00:24:22,840
much of the time the planet went

523
00:24:29,970 --> 00:24:25,120
backwards and how frequently it went

524
00:24:32,520 --> 00:24:29,980
backwards I'd and they and this worked

525
00:24:34,440 --> 00:24:32,530
they could predict with those circular

526
00:24:36,180 --> 00:24:34,450
orbits around the earth and epicycles

527
00:24:37,950 --> 00:24:36,190
they could roughly get the predict to

528
00:24:39,390 --> 00:24:37,960
the positions of the planets because

529
00:24:41,460 --> 00:24:39,400
that's your Holy Grail that's what you

530
00:24:43,680 --> 00:24:41,470
want to do you want to be able to

531
00:24:46,200 --> 00:24:43,690
predict where the planets are going to

532
00:24:50,700 --> 00:24:46,210
be the problem is that as you move

533
00:24:53,730 --> 00:24:50,710
forward in time the model kind of fell

534
00:24:56,250 --> 00:24:53,740
apart the predictions with just one MP

535
00:24:57,810 --> 00:24:56,260
cycle weren't working now if that's

536
00:24:59,279 --> 00:24:57,820
getting further and further off the

537
00:25:00,690 --> 00:24:59,289
actual position of the planet you would

538
00:25:02,250 --> 00:25:00,700

think well maybe we should go back to

539
00:25:04,230 --> 00:25:02,260
what that other guy was saying and try

540
00:25:08,039 --> 00:25:04,240
heliocentric they just added more

541
00:25:09,450 --> 00:25:08,049
epicycles there's a principle in science

542
00:25:11,870 --> 00:25:09,460
called Occam's razor it's that the

543
00:25:16,289 --> 00:25:11,880
simplest solution is probably the best

544
00:25:18,029 --> 00:25:16,299
so we're gonna jump forward to 1609 this

545
00:25:20,159 --> 00:25:18,039
is about 30 years after Nicholas

546
00:25:21,810 --> 00:25:20,169
Copernicus once more resurrected the

547
00:25:25,820 --> 00:25:21,820
idea that yes the Sun is at the center

548
00:25:28,289 --> 00:25:25,830
of the solar system but like

549
00:25:30,840 --> 00:25:28,299
Aristophanes and aristotle and ptolemy

550
00:25:35,279 --> 00:25:30,850
he assumed the planets were on circular

551
00:25:38,580 --> 00:25:35,289
orbits perfect circles enter these two

552
00:25:40,289 --> 00:25:38,590
gentlemen this is taco Brockie he was

553
00:25:42,840 --> 00:25:40,299
probably he was an incredibly fast

554
00:25:44,580 --> 00:25:42,850
talker he somehow convinced the King of

555
00:25:45,510 --> 00:25:44,590
Denmark to give him a castle and build

556
00:25:48,480 --> 00:25:45,520
him the most state-of-the-art

557
00:25:49,590 --> 00:25:48,490
observatory in Europe I really want to

558
00:25:51,790 --> 00:25:49,600
know how he did this because I've got

559
00:25:56,210 --> 00:25:51,800
grant proposals do

560
00:25:58,430 --> 00:25:56,220
for 30 years he puts together the most

561
00:26:00,980 --> 00:25:58,440
accurate set of measurements of the

562
00:26:04,760 --> 00:26:00,990
planets in existence he's able to do

563
00:26:07,070 --> 00:26:04,770

because he has these huge instruments

564
00:26:09,130 --> 00:26:07,080
this is a Sexton that allows him to

565
00:26:11,570 --> 00:26:09,140
measure very accurately the positions

566
00:26:14,720 --> 00:26:11,580
he's still going by naked-eye he's not

567
00:26:16,370 --> 00:26:14,730
using a telescope Galileo gali hasn't

568
00:26:18,140 --> 00:26:16,380
happened well he's alive but he hasn't

569
00:26:22,040 --> 00:26:18,150
actually aim to telescope at Jupiter yet

570
00:26:24,530 --> 00:26:22,050
and after 30 years of developing all of

571
00:26:27,260 --> 00:26:24,540
this data he passes that data off to you

572
00:26:28,520 --> 00:26:27,270
Hannes Kepler and that's a name that if

573
00:26:31,100 --> 00:26:28,530
you've been following all the planet

574
00:26:33,610 --> 00:26:31,110
formation we named a planet finding

575
00:26:36,680 --> 00:26:33,620
mission for him for a very good reason

576
00:26:39,020 --> 00:26:36,690
Brahe he tells him look at Mars Mars is

577
00:26:42,560 --> 00:26:39,030
the weird one if you can solve Mars you

578
00:26:44,150 --> 00:26:42,570
can solve all of it and Kepler keep in

579
00:26:46,130 --> 00:26:44,160
mind there's no slices there's no

580
00:26:48,890 --> 00:26:46,140
computers for the younger people in the

581
00:26:50,360 --> 00:26:48,900
room there's no scientific calculators

582
00:26:52,310 --> 00:26:50,370
for the slightly older people in the

583
00:26:56,570 --> 00:26:52,320
room and slide rules haven't been

584
00:27:00,920 --> 00:26:56,580
invented yet for the rest of the people

585
00:27:04,550 --> 00:27:00,930
in the room this is what Kepler figures

586
00:27:07,700 --> 00:27:04,560
out that the orbits of the planets are

587
00:27:09,170 --> 00:27:07,710
not circular there are ellipses now it

588
00:27:11,330 --> 00:27:09,180

just so happens for the orbit of the

589
00:27:13,220 --> 00:27:11,340
earth if I were to plot a circle on this

590
00:27:14,720 --> 00:27:13,230
slide and then plot the orbit of the

591
00:27:16,310 --> 00:27:14,730
earth on top of it you would not be able

592
00:27:19,130 --> 00:27:16,320
to tell the difference it's extremely

593
00:27:22,840 --> 00:27:19,140
close to a circle but for some planets

594
00:27:26,780 --> 00:27:22,850
this is the inner solar system like Mars

595
00:27:29,750 --> 00:27:26,790
they're further off a circle the further

596
00:27:32,210 --> 00:27:29,760
off a circle the more elliptical or

597
00:27:33,440 --> 00:27:32,220
eccentric is the term we use the orbit

598
00:27:36,170 --> 00:27:33,450
is then we're clear

599
00:27:39,800 --> 00:27:36,180
this comes the more clearly this comes

600
00:27:43,340 --> 00:27:39,810
through so we have the Sun Mercury Venus

601
00:27:45,950 --> 00:27:43,350
Earth Mars the asteroid belt which we

602
00:27:50,650 --> 00:27:45,960
know is there but they didn't they knew

603
00:27:54,380 --> 00:27:50,660
about Jupiter which is here and Saturn

604
00:27:56,030 --> 00:27:54,390
that's it Uranus and Neptune we'll have

605
00:27:57,320 --> 00:27:56,040
to wait for telescopes to be discovered

606
00:28:01,880 --> 00:27:57,330
and there is no way they know about

607
00:28:03,530 --> 00:28:01,890
Pluto regardless of its status and just

608
00:28:05,000 --> 00:28:03,540
as a reminder that we are all already

609
00:28:08,840 --> 00:28:05,010
very much in

610
00:28:11,270 --> 00:28:08,850
all of the green things on here our

611
00:28:13,789 --> 00:28:11,280
space missions which are currently out

612
00:28:15,799 --> 00:28:13,799
there that is the location of all of the

613
00:28:21,200 --> 00:28:15,809

space missions in our solar system as of

614
00:28:23,360 --> 00:28:21,210
this year this is pioneer ten pioneer 11

615
00:28:26,169 --> 00:28:23,370
and Voyager 1 and Voyager

616
00:28:29,600 --> 00:28:26,179
or I guess feature is what it ends up

617
00:28:31,370 --> 00:28:29,610
one and two are going off in different

618
00:28:33,950 --> 00:28:31,380
directions for the edge of our solar

619
00:28:35,890 --> 00:28:33,960
system so there's a reason we named a

620
00:28:38,360 --> 00:28:35,900
plan to find a mission for this guy so

621
00:28:41,510 --> 00:28:38,370
we now know that Earth is the third

622
00:28:44,380 --> 00:28:41,520
planet orbiting a relatively boring g2

623
00:28:47,780 --> 00:28:44,390
star we're actually lucky it's boring

624
00:28:50,180 --> 00:28:47,790
but how far away are those stars so we

625
00:28:53,270 --> 00:28:50,190
know they must be pretty far but how far

626
00:28:56,240 --> 00:28:53,280
are they actually and now we need some

627
00:28:58,430 --> 00:28:56,250
audience participation without hitting

628
00:29:00,980 --> 00:28:58,440
the person next to you or hit the person

629
00:29:02,539 --> 00:29:00,990
next to you if you don't like them hold

630
00:29:06,289 --> 00:29:02,549
your finger out in front of your face at

631
00:29:08,390 --> 00:29:06,299
arm's length all right if you can wink

632
00:29:13,310 --> 00:29:08,400
between one eye and the next do that

633
00:29:17,570 --> 00:29:13,320
otherwise use your hand does your finger

634
00:29:19,750 --> 00:29:17,580
move yes all right now stop using your

635
00:29:22,240 --> 00:29:19,760
finger and do the same thing with my arm

636
00:29:25,820 --> 00:29:22,250
now do this with my hand

637
00:29:31,039 --> 00:29:25,830
duck put your hand down and jump between

638
00:29:32,630 --> 00:29:31,049

and does my hand move a little for the

639
00:29:33,190 --> 00:29:32,640
people in the front a little for the

640
00:29:39,830 --> 00:29:33,200
back

641
00:29:41,870 --> 00:29:39,840
no that is parallax every single time

642
00:29:44,510 --> 00:29:41,880
you walk down the street and don't run

643
00:29:46,610 --> 00:29:44,520
into something you're using parallax and

644
00:29:49,010 --> 00:29:46,620
that's the fact that your eyes are

645
00:29:51,020 --> 00:29:49,020
separated is actually allowing you to

646
00:29:52,610 --> 00:29:51,030
have depth perception for those of you

647
00:29:56,299 --> 00:29:52,620
with glasses and I mean the people like

648
00:29:57,770 --> 00:29:56,309
me whose eyes just don't work if you've

649
00:30:02,960 --> 00:29:57,780
ever taken off your glasses you'll

650
00:30:04,789 --> 00:30:02,970
promptly run into a wall that's why so

651
00:30:06,500 --> 00:30:04,799
when you take this and instead of being

652
00:30:08,690 --> 00:30:06,510
our eyes and our heads you actually talk

653
00:30:11,840 --> 00:30:08,700
about the earth you have the earth has

654
00:30:16,090 --> 00:30:11,850
an orbit it is one astronomical unit

655
00:30:18,350 --> 00:30:16,100
about 93 million miles from our Sun and

656
00:30:22,670 --> 00:30:18,360
if you look at us

657
00:30:26,090 --> 00:30:22,680
service star in January and observe that

658
00:30:30,020 --> 00:30:26,100
same star in July sir here's your star

659
00:30:33,290 --> 00:30:30,030
and you look at it if that star is close

660
00:30:39,740 --> 00:30:33,300
enough it'll appear to shift just like

661
00:30:42,650 --> 00:30:39,750
your finger did this is parallax the

662
00:30:43,220 --> 00:30:42,660
baseline that we have is 2 astronomical

663
00:30:46,430 --> 00:30:43,230

units

664
00:30:50,540 --> 00:30:46,440
that's how wide it is the wider the

665
00:30:53,500 --> 00:30:50,550
baseline the larger the angle the closer

666
00:30:56,650 --> 00:30:53,510
the object the wider the angle and the

667
00:30:59,240 --> 00:30:56,660
further away an object is the smaller

668
00:31:03,020 --> 00:30:59,250
the pair the smaller the amount of

669
00:31:04,790 --> 00:31:03,030
parallax you will see and it turns out

670
00:31:07,340 --> 00:31:04,800
that there are not many formulas in

671
00:31:10,670 --> 00:31:07,350
astronomy that are this simple turns

672
00:31:14,660 --> 00:31:10,680
this is the distance to the object to a

673
00:31:17,060 --> 00:31:14,670
star this is the parallax in arc seconds

674
00:31:19,040 --> 00:31:17,070
so does everyone here have a sense of

675
00:31:20,480 --> 00:31:19,050
what a degree is on a circle if you were

676
00:31:24,170 --> 00:31:20,490
to draw a circle you have in a sense of

677
00:31:26,510 --> 00:31:24,180
how much of that circle is a degree now

678
00:31:30,860 --> 00:31:26,520
imagine at that degree is the equivalent

679
00:31:35,000 --> 00:31:30,870
of an hour of time an arc second is one

680
00:31:38,690 --> 00:31:35,010
second to that hour it is 136 hundredth

681
00:31:40,610 --> 00:31:38,700
of a degree I could try to draw that on

682
00:31:44,090 --> 00:31:40,620
an arc on this but you would list see an

683
00:31:47,530 --> 00:31:44,100
infinitesimal line if even that this is

684
00:31:49,760 --> 00:31:47,540
an incredibly small measure and it is at

685
00:31:52,100 --> 00:31:49,770
least two orders of magnitude smaller

686
00:31:54,320 --> 00:31:52,110
than what the person with the absolute

687
00:31:56,420 --> 00:31:54,330
best vision can see with our naked eye

688
00:32:01,550 --> 00:31:56,430

again those of us with glasses need not

689
00:32:04,160 --> 00:32:01,560
apply it turns out that one that if you

690
00:32:07,250 --> 00:32:04,170
if something has one arc second of

691
00:32:10,220 --> 00:32:07,260
parallax or if this shift is measured as

692
00:32:11,420 --> 00:32:10,230
one arc second it is three point two six

693
00:32:14,120 --> 00:32:11,430
light-years away

694
00:32:16,310 --> 00:32:14,130
we call that a parsec this is the

695
00:32:19,010 --> 00:32:16,320
primary unit astronomers use it has

696
00:32:24,860 --> 00:32:19,020
nothing to do with the Kessel run and it

697
00:32:26,600 --> 00:32:24,870
is not a unit of time so I didn't say

698
00:32:29,930 --> 00:32:26,610
Star Trek was the only science fiction

699
00:32:34,789 --> 00:32:29,940
universe that messes the science

700
00:32:37,970 --> 00:32:34,799
I don't think they were looking things

701
00:32:40,100 --> 00:32:37,980
up in dictionaries so they start they've

702
00:32:41,509 --> 00:32:40,110
known that this was gonna happen if the

703
00:32:43,340 --> 00:32:41,519
Sun was at the center and the earth is

704
00:32:45,080 --> 00:32:43,350
moving around it you know the stars are

705
00:32:47,889 --> 00:32:45,090
going to have parallax and they've been

706
00:32:53,419 --> 00:32:47,899
looking for this for about 2,000 years

707
00:32:57,379 --> 00:32:53,429
it takes until 1838 for us to have the

708
00:32:59,210 --> 00:32:57,389
technology to measure parallax and that

709
00:33:06,249 --> 00:32:59,220
is because to measure parallax you have

710
00:33:13,220 --> 00:33:10,940
in 1989 a catalog of extremely bright

711
00:33:16,039 --> 00:33:13,230
and sedan nearby stars was identified

712
00:33:17,629 --> 00:33:16,049
this was called Hipparchus it was one of

713
00:33:20,169 --> 00:33:17,639

the first attempts to do a large

714
00:33:21,740 --> 00:33:20,179
catalogue of these stars and to get

715
00:33:26,119 --> 00:33:21,750
parallax's for them

716
00:33:28,659 --> 00:33:26,129
in 2013 the Gaia space mission was

717
00:33:31,399 --> 00:33:28,669
launched by the European Space Agency

718
00:33:32,899 --> 00:33:31,409
just as an aside the process of mapping

719
00:33:37,850 --> 00:33:32,909
the Milky Way is very much an

720
00:33:39,499 --> 00:33:37,860
international endeavor this is the guy a

721
00:33:40,820 --> 00:33:39,509
spacecraft will an artist's rendition of

722
00:33:42,470 --> 00:33:40,830
the guy spacecraft we're not out in

723
00:33:47,149 --> 00:33:42,480
space in the Milky Way isn't that pretty

724
00:33:48,889 --> 00:33:47,159
um this is a parkus so this is the

725
00:33:51,889 --> 00:33:48,899
amount of parallax the mission can

726
00:33:56,749 --> 00:33:51,899
measure in arcseconds all of these

727
00:33:58,159 --> 00:33:56,759
points so this is taco bra he actually

728
00:33:59,749 --> 00:33:58,169
like the taco bar he the guy that

729
00:34:01,610 --> 00:33:59,759
convinced the King of Denmark to build

730
00:34:05,889 --> 00:34:01,620
him an observatory it also got his nose

731
00:34:08,569 --> 00:34:05,899
cut off in a duel so this is about 1,600

732
00:34:10,579 --> 00:34:08,579
you have Hipparchus in ancient greece

733
00:34:13,669 --> 00:34:10,589
that attempted this with a thousand

734
00:34:16,690 --> 00:34:13,679
stars and then you can actually see the

735
00:34:19,730 --> 00:34:16,700
technology improving the blue line is

736
00:34:21,680 --> 00:34:19,740
how accurate your measurement has to be

737
00:34:25,790 --> 00:34:21,690
to be able to observe parallax around

738
00:34:27,379 --> 00:34:25,800

the nearest star to the Sun which also

739
00:34:30,980 --> 00:34:27,389
happens to be in the wrong hemisphere

740
00:34:33,649 --> 00:34:30,990
forever Greece its Alpha Centauri it's

741
00:34:35,300 --> 00:34:33,659
in the southern hemisphere so you

742
00:34:38,690 --> 00:34:35,310
finally get down to the apart cos

743
00:34:40,280 --> 00:34:38,700
mission this is 120,000 stars a little

744
00:34:42,629 --> 00:34:40,290
later there's a reason I'm explicitly

745
00:34:45,659 --> 00:34:42,639
mentioning this one and then

746
00:34:50,490 --> 00:34:45,669
2013 is the launch of Gaia which is a

747
00:34:57,779 --> 00:34:50,500
billion stars and Gaia is measuring

748
00:34:58,849 --> 00:34:57,789
parallax of 100 100 thousands of an

749
00:35:01,559 --> 00:34:58,859
arcsecond

750
00:35:03,660 --> 00:35:01,569
so if a degree is an hour this is a

751
00:35:07,470 --> 00:35:03,670
hundred thousandth of a second is how

752
00:35:09,720 --> 00:35:07,480
accurate Gaia is that kind of accuracy

753
00:35:11,609 --> 00:35:09,730
the increase in accuracy means increase

754
00:35:13,650 --> 00:35:11,619
distance to which we are able to measure

755
00:35:15,059 --> 00:35:13,660
parallax and Gaia for the brightest

756
00:35:22,470 --> 00:35:15,069
stars is going to get all the way to the

757
00:35:24,450 --> 00:35:22,480
galactic center so we have parallax we

758
00:35:27,180 --> 00:35:24,460
can start to observe stars right now we

759
00:35:29,009 --> 00:35:27,190
can go out to about a hundred to a

760
00:35:32,400 --> 00:35:29,019
thousand light-years depending on the

761
00:35:35,880 --> 00:35:32,410
star we're looking at and that is step

762
00:35:37,620 --> 00:35:35,890
one so determining distances the

763
00:35:39,269 --> 00:35:37,630

determining where something is on the

764
00:35:42,599 --> 00:35:39,279
sky we've actually gotten pretty good at

765
00:35:44,660 --> 00:35:42,609
it's actually called astrometry that

766
00:35:47,160 --> 00:35:44,670
okay something else Star Trek covering

767
00:35:49,109 --> 00:35:47,170
pastrami tree is the location of things

768
00:35:51,900 --> 00:35:49,119
on the sky figuring out the distance is

769
00:35:54,569 --> 00:35:51,910
a whole different game and it is a we

770
00:35:57,180 --> 00:35:54,579
call it the distance ladder the first

771
00:35:59,759 --> 00:35:57,190
rung of that distance ladder is parallax

772
00:36:02,460 --> 00:35:59,769
is just is using the shift of the Stars

773
00:36:05,519 --> 00:36:02,470
second are things we call standard

774
00:36:07,620 --> 00:36:05,529
candles and they're not actually these

775
00:36:11,999 --> 00:36:07,630
kind of candles these are astronomical

776
00:36:13,829 --> 00:36:12,009
sources so you have a source that is a

777
00:36:15,299 --> 00:36:13,839
standard candle it can be a star it can

778
00:36:17,549 --> 00:36:15,309
be a supernova

779
00:36:19,470 --> 00:36:17,559
whatever it is what's important is that

780
00:36:22,529 --> 00:36:19,480
you're able to get its absolute

781
00:36:25,470 --> 00:36:22,539
brightness its luminosity by a different

782
00:36:28,740 --> 00:36:25,480
means from physics from its period

783
00:36:31,620 --> 00:36:28,750
period different all of its brightness

784
00:36:33,569 --> 00:36:31,630
auscultation something and then some

785
00:36:35,069 --> 00:36:33,579
distance away you have the observer I

786
00:36:36,450 --> 00:36:35,079
thought about doing a cute picture of

787
00:36:40,200 --> 00:36:36,460
the enterprise but they're not always on

788
00:36:43,259 --> 00:36:40,210

earth and the way that this works is

789
00:36:44,940 --> 00:36:43,269
actually relatively simple you have the

790
00:36:48,900 --> 00:36:44,950
luminosity of the object which you're

791
00:36:50,640 --> 00:36:48,910
able to figure out by some means you

792
00:36:53,249 --> 00:36:50,650
have the apparent brightness that we

793
00:36:56,010 --> 00:36:53,259
measure on earth and the distance

794
00:36:58,440 --> 00:36:56,020
between that object and us

795
00:37:00,960 --> 00:36:58,450
is simply the luminosity over the

796
00:37:02,640 --> 00:37:00,970
apparent brightness there's some

797
00:37:04,350 --> 00:37:02,650
physical constants and things in there

798
00:37:07,140 --> 00:37:04,360
and the distance is if this is actually

799
00:37:08,880 --> 00:37:07,150
distance squared but this once again

800
00:37:11,130 --> 00:37:08,890
this is very simple very very

801
00:37:12,750 --> 00:37:11,140
straightforward in fact this is the same

802
00:37:18,320 --> 00:37:12,760
one over R squared law that governs

803
00:37:21,510 --> 00:37:18,330
gravity so we're gonna jump forward to

804
00:37:26,550 --> 00:37:21,520
1900 Bell back actually I guess to 1908

805
00:37:29,670 --> 00:37:26,560
and work by Henrietta Swan Leavitt she

806
00:37:32,070 --> 00:37:29,680
worked with she was among 220 the

807
00:37:34,080 --> 00:37:32,080
computers these actually were women that

808
00:37:36,330 --> 00:37:34,090
were doing computing again these things

809
00:37:37,920 --> 00:37:36,340
called computers apparently in 1950 they

810
00:37:42,450 --> 00:37:37,930
took up the size of a room or so my

811
00:37:44,040 --> 00:37:42,460
father tells me and Henrietta leave it

812
00:37:45,450 --> 00:37:44,050
was only one of them the work that they

813
00:37:47,790 --> 00:37:45,460

did actually forms the backbone of our

814
00:37:49,430 --> 00:37:47,800
understanding of the Stars and just as a

815
00:37:52,050 --> 00:37:49,440
note since it is Women's History Month

816
00:37:57,270 --> 00:37:52,060
140 of the names are known 80 of them

817
00:37:59,400 --> 00:37:57,280
are not we only have initials Henrietta

818
00:38:01,140 --> 00:37:59,410
Leavitt was she had an undergraduate

819
00:38:05,160 --> 00:38:01,150
degree in astronomy and she was given

820
00:38:06,660 --> 00:38:05,170
the task of looking for variables not go

821
00:38:08,490 --> 00:38:06,670
look at these specific variables just

822
00:38:10,290 --> 00:38:08,500
here's some glass plates they were

823
00:38:13,560 --> 00:38:10,300
actually glass you can see a crack here

824
00:38:14,910 --> 00:38:13,570
these are actually glass plates some

825
00:38:18,230 --> 00:38:14,920
people in the room may remember remember

826
00:38:20,700 --> 00:38:18,240
film cameras I think some of you may not

827
00:38:22,050 --> 00:38:20,710
instead of film this actually wish you

828
00:38:26,190 --> 00:38:22,060
would take it on a silvered plate of

829
00:38:27,630 --> 00:38:26,200
glass this is the SMC in a much in a

830
00:38:31,260 --> 00:38:27,640
more modern image of the small

831
00:38:33,180 --> 00:38:31,270
Magellanic Cloud this is a image a

832
00:38:35,160 --> 00:38:33,190
period image of the small management

833
00:38:39,210 --> 00:38:35,170
club with her notations on it these are

834
00:38:41,220 --> 00:38:39,220
her notations and she noticed that there

835
00:38:42,540 --> 00:38:41,230
were class of variables in the small

836
00:38:44,730 --> 00:38:42,550
magellanic cloud that were very

837
00:38:45,930 --> 00:38:44,740
distinctive they rose in brightness

838
00:38:47,130 --> 00:38:45,940

there were stars that rose and

839
00:38:48,840 --> 00:38:47,140
brightness very quickly and then fell

840
00:38:52,170 --> 00:38:48,850
off and then rose and brightness again

841
00:38:55,590 --> 00:38:52,180
and then fell off these work they named

842
00:38:58,490 --> 00:38:55,600
them sets for the prototype prototype

843
00:39:00,990 --> 00:38:58,500
star for which they were identified and

844
00:39:02,070 --> 00:39:01,000
since she had the SMC she had that she

845
00:39:03,630 --> 00:39:02,080
knew they're all at the same distance

846
00:39:05,670 --> 00:39:03,640
they're basically all at the same

847
00:39:09,790 --> 00:39:05,680
distance and the brighter Sophia's had

848
00:39:12,420 --> 00:39:09,800
longer periods as of 2009

849
00:39:16,600 --> 00:39:12,430
we actually called us the leave it law

850
00:39:19,350 --> 00:39:16,610
this is the first standard candle you

851
00:39:22,600 --> 00:39:19,360
now if you know the period of a Cepheid

852
00:39:25,120 --> 00:39:22,610
you go up you have its period you go up

853
00:39:28,120 --> 00:39:25,130
and you can read off its absolute

854
00:39:29,710 --> 00:39:28,130
brightness its luminosity if you have

855
00:39:31,090 --> 00:39:29,720
its luminosity you have its measured

856
00:39:34,000 --> 00:39:31,100
apparent brightness you have its

857
00:39:37,420 --> 00:39:34,010
distance and Cepheid Zarb right we can

858
00:39:40,060 --> 00:39:37,430
see these in external galaxies they also

859
00:39:42,010 --> 00:39:40,070
are not that rare and this is what you

860
00:39:43,330 --> 00:39:42,020
have to do to jump a rung of the

861
00:39:47,440 --> 00:39:43,340
distance ladder it's not as simple as

862
00:39:48,940 --> 00:39:47,450
doing this first off you find a Cepheid

863
00:39:52,090 --> 00:39:48,950

that's close enough to also have a

864
00:39:54,160 --> 00:39:52,100
parallax measurement then you calculate

865
00:39:56,140 --> 00:39:54,170
the distance to that Cepheid using

866
00:39:58,780 --> 00:39:56,150
parallax and using the distance modulus

867
00:40:01,780 --> 00:39:58,790
or using the relation between absolute

868
00:40:03,610 --> 00:40:01,790
luminosity apparent apparent brightness

869
00:40:05,490 --> 00:40:03,620
and distance you calculate the

870
00:40:09,310 --> 00:40:05,500
luminosity of that set

871
00:40:12,400 --> 00:40:09,320
you then use that luminosity to

872
00:40:14,500 --> 00:40:12,410
calibrate the leave it law to calibrate

873
00:40:18,190 --> 00:40:14,510
henriette leave its relation because you

874
00:40:21,010 --> 00:40:18,200
need to know where things sit on the

875
00:40:24,550 --> 00:40:21,020
luminosity axis does a Cepheid with a

876
00:40:27,310 --> 00:40:24,560
period of two days have a luminosity of

877
00:40:30,070 --> 00:40:27,320
10 times the luminosity of a Sun or a

878
00:40:32,350 --> 00:40:30,080
hundred that because that's a very very

879
00:40:35,140 --> 00:40:32,360
that's a very large error that you're

880
00:40:36,940 --> 00:40:35,150
introducing in your distances you then

881
00:40:38,830 --> 00:40:36,950
use your calibrated leave it law to get

882
00:40:40,990 --> 00:40:38,840
the luminosities of Cepheid x'

883
00:40:44,500 --> 00:40:41,000
for which you know their period sapiens

884
00:40:47,230 --> 00:40:44,510
which are too far away for parallax you

885
00:40:48,430 --> 00:40:47,240
then use this except the Illuminati and

886
00:40:57,160 --> 00:40:48,440
the apparent brightness and you

887
00:40:59,530 --> 00:40:57,170
calculate the distance simple turns out

888
00:41:01,900 --> 00:40:59,540

there sophia's are not the only standard

889
00:41:03,430 --> 00:41:01,910
candle and focusing only on ones used to

890
00:41:06,580 --> 00:41:03,440
map the Milky Way there's a whole long

891
00:41:09,550 --> 00:41:06,590
list of these this is spectral class or

892
00:41:12,970 --> 00:41:09,560
color of a star from red to blue versus

893
00:41:15,280 --> 00:41:12,980
its absolute brightness our Sun sits

894
00:41:17,170 --> 00:41:15,290
right here on the main sequence all

895
00:41:19,150 --> 00:41:17,180
these stars are burning hydrogen are

896
00:41:21,160 --> 00:41:19,160
fusing hydrogen to helium in their cores

897
00:41:22,210 --> 00:41:21,170
and this is where stars will spend the

898
00:41:25,080 --> 00:41:22,220
majority of their life

899
00:41:27,970 --> 00:41:25,090
and they're stable when they're on this

900
00:41:30,460 --> 00:41:27,980
however once they move on off it they

901
00:41:32,410 --> 00:41:30,470
become unstable and they move through

902
00:41:34,150 --> 00:41:32,420
something called an instability strip

903
00:41:36,400 --> 00:41:34,160
and these are where a lot of variable

904
00:41:38,620 --> 00:41:36,410
stars are you can see this is the

905
00:41:40,750 --> 00:41:38,630
prototype for the Cepheid archetype for

906
00:41:43,320 --> 00:41:40,760
the Cepheid x' and this is the archetype

907
00:41:46,210 --> 00:41:43,330
for another class called the RLI right

908
00:41:48,700 --> 00:41:46,220
like the Cepheid they have a relation

909
00:41:53,680 --> 00:41:48,710
between their luminosity and their

910
00:41:57,700 --> 00:41:53,690
period and um but unlike the Cepheid x'

911
00:42:00,040 --> 00:41:57,710
they are they are older so you can find

912
00:42:02,760 --> 00:42:00,050
these in evolved stellar systems and

913
00:42:05,470 --> 00:42:02,770

that's going to be important in a minute

914
00:42:09,010 --> 00:42:05,480
so we now know how far the stars are

915
00:42:11,020 --> 00:42:09,020
away and that is somewhere between 4

916
00:42:11,380 --> 00:42:11,030
light years and about a hundred thousand

917
00:42:18,010 --> 00:42:11,390
light years

918
00:42:21,520 --> 00:42:18,020
I warned you space was big now where is

919
00:42:25,690 --> 00:42:21,530
the solar system in our galaxy so we're

920
00:42:27,550 --> 00:42:25,700
going to jump back to 1772 to William

921
00:42:28,830 --> 00:42:27,560
and Carol and Herschel they were brother

922
00:42:31,480 --> 00:42:28,840
and sister

923
00:42:33,550 --> 00:42:31,490
astronomers living in England in the

924
00:42:37,630 --> 00:42:33,560
18th century I think something else was

925
00:42:40,480 --> 00:42:37,640
going on with England in 1772 but the

926
00:42:43,080 --> 00:42:40,490
you know just smoker falafel with you

927
00:42:44,980 --> 00:42:43,090
know some problematic colonies and

928
00:42:47,530 --> 00:42:44,990
really in her style based on

929
00:42:49,750 --> 00:42:47,540
observations of stars came up with a

930
00:42:52,360 --> 00:42:49,760
model of the Milky Way which you can see

931
00:42:54,490 --> 00:42:52,370
here he notices that when you look up

932
00:42:57,070 --> 00:42:54,500
haven't has anyone here seen the Milky

933
00:42:58,630 --> 00:42:57,080
Way at a dark night all right you see

934
00:43:00,760 --> 00:42:58,640
the Ark of it so there's a high density

935
00:43:03,820 --> 00:43:00,770
area of stars and fewer stars above and

936
00:43:05,170 --> 00:43:03,830
below so he has that here you can see

937
00:43:07,390 --> 00:43:05,180
that there's definitely a direction in

938
00:43:07,870 --> 00:43:07,400

which there are more stars this is where

939
00:43:11,830 --> 00:43:07,880
the Sun is

940
00:43:16,990 --> 00:43:11,840
I just want wild guess about whether or

941
00:43:18,220 --> 00:43:17,000
not this is right no anytime we're at

942
00:43:22,750 --> 00:43:18,230
the center of the universe you have a

943
00:43:24,580 --> 00:43:22,760
problem it's actually called the

944
00:43:26,800 --> 00:43:24,590
Copernican principle never put the earth

945
00:43:29,490 --> 00:43:26,810
at the center of the universe or in a

946
00:43:34,860 --> 00:43:32,980
so but to fully solve this problem you

947
00:43:37,630 --> 00:43:34,870
had to wait a hundred and fifty years

948
00:43:39,220 --> 00:43:37,640
this is how well shapely he was actually

949
00:43:42,550 --> 00:43:39,230
the second director of the Harvard

950
00:43:44,440 --> 00:43:42,560
Observatory and he used our alive I

951
00:43:46,300 --> 00:43:44,450
variables remember that second standard

952
00:43:50,020 --> 00:43:46,310
candle and was able to get the distance

953
00:43:51,460 --> 00:43:50,030
to globular clusters and unfortunately

954
00:43:54,190 --> 00:43:51,470
the telescope's not working but

955
00:43:56,080 --> 00:43:54,200
globulars are very dense massive

956
00:43:59,470 --> 00:43:56,090
clusters of stars that orbit our Milky

957
00:44:01,240 --> 00:43:59,480
Way and if these are things that are in

958
00:44:03,340 --> 00:44:01,250
the halo and the outskirts of our galaxy

959
00:44:05,320 --> 00:44:03,350
and you look at the you can measure the

960
00:44:07,240 --> 00:44:05,330
distribution if the Sun is at the center

961
00:44:11,200 --> 00:44:07,250
of the galaxy then the globular clusters

962
00:44:12,640 --> 00:44:11,210
should be centered around us if we're

963
00:44:14,650 --> 00:44:12,650

not at the center of the galaxy the

964
00:44:17,590 --> 00:44:14,660
globular clusters shouldn't be centred

965
00:44:20,590 --> 00:44:17,600
around us and he plotted the

966
00:44:23,290 --> 00:44:20,600
distribution of the globular clusters in

967
00:44:26,470 --> 00:44:23,300
physical space so this is in kiloparsec

968
00:44:30,760 --> 00:44:26,480
so thousands of parsecs or about 3,000

969
00:44:32,890 --> 00:44:30,770
light years per unit versus this is up

970
00:44:36,130 --> 00:44:32,900
and down in the plane so this is the

971
00:44:37,720 --> 00:44:36,140
plane of our galaxy right here and he

972
00:44:40,270 --> 00:44:37,730
found out that lo and behold the Sun is

973
00:44:42,340 --> 00:44:40,280
not at the center of the galaxy I mean

974
00:44:44,470 --> 00:44:42,350
like this I'm sure this was shocking but

975
00:44:46,300 --> 00:44:44,480
the Sun is not at the center of a galaxy

976
00:44:47,680 --> 00:44:46,310
in fact the center point is in the

977
00:44:50,320 --> 00:44:47,690
direction of the constellation of

978
00:44:52,750 --> 00:44:50,330
Sagittarius he believed it was about

979
00:44:55,240 --> 00:44:52,760
fourteen kiloparsecs away he was off by

980
00:45:00,130 --> 00:44:55,250
about a factor of two in astronomy we

981
00:45:02,680 --> 00:45:00,140
call that an error bar this is the

982
00:45:04,240 --> 00:45:02,690
diagram of our Milky Way edge-on you

983
00:45:06,160 --> 00:45:04,250
have the disk of our galaxy and the

984
00:45:09,190 --> 00:45:06,170
Bulge for the record the Bulge is not

985
00:45:12,160 --> 00:45:09,200
that pretty the Sun is here about

986
00:45:13,510 --> 00:45:12,170
halfway out on the disk the whole disk

987
00:45:16,240 --> 00:45:13,520
is a hundred thousand light-years across

988
00:45:21,220 --> 00:45:16,250

with the globular clusters orbiting the

989
00:45:24,640 --> 00:45:21,230
entire system so we are not in the

990
00:45:28,229 --> 00:45:24,650
middle of things we are in Loudoun

991
00:45:35,349 --> 00:45:30,849
not on the complete edge of things but

992
00:45:37,599 --> 00:45:35,359
you know relatively far out so we know

993
00:45:39,400 --> 00:45:37,609
where we are that we're out on the edge

994
00:45:41,349 --> 00:45:39,410
that we're in the disk of our Milky Way

995
00:45:43,209 --> 00:45:41,359
that the earth is not at the center of

996
00:45:47,440 --> 00:45:43,219
our solar system and that the stars are

997
00:45:53,259 --> 00:45:47,450
very very far away but what does our

998
00:45:55,449 --> 00:45:53,269
galaxy actually look like this is an

999
00:45:57,789 --> 00:45:55,459
image this is a composite image taken by

1000
00:45:59,620 --> 00:45:57,799
the European Southern Observatory so

1001
00:46:01,029 --> 00:45:59,630
this is you cannot telescope cannot take

1002
00:46:03,940 --> 00:46:01,039
this in one image this is actually an

1003
00:46:05,829 --> 00:46:03,950
all-sky image it's beautiful absolutely

1004
00:46:09,549 --> 00:46:05,839
beautiful the center of the galaxy is

1005
00:46:13,719 --> 00:46:09,559
right here but there's something in the

1006
00:46:19,650 --> 00:46:13,729
way so this is the disc and there's all

1007
00:46:22,509 --> 00:46:19,660
these dark spots these are dust clouds

1008
00:46:25,989 --> 00:46:22,519
now this is not the kind of dusty out to

1009
00:46:28,120 --> 00:46:25,999
sweep off your floor it's actually good

1010
00:46:29,289 --> 00:46:28,130
that you have it these dust tends to

1011
00:46:30,999 --> 00:46:29,299
form in areas where there is a lot of

1012
00:46:34,420 --> 00:46:31,009
star formation we are actually on a

1013
00:46:35,650 --> 00:46:34,430

sitting on a dust aggregate right now in

1014
00:46:37,630 --> 00:46:35,660
the early days of our planet the

1015
00:46:41,410 --> 00:46:37,640
planetary nebula dust particles started

1016
00:46:42,789 --> 00:46:41,420
to clump together and then they become

1017
00:46:44,199 --> 00:46:42,799
rocks and then the rocks are banging

1018
00:46:45,640 --> 00:46:44,209
into each other and then they become

1019
00:46:50,140 --> 00:46:45,650
asteroids and the next thing you know

1020
00:46:52,420 --> 00:46:50,150
you have earth but they are a problem

1021
00:46:54,789 --> 00:46:52,430
because visible light the light we see

1022
00:46:57,910 --> 00:46:54,799
with our eyes cannot penetrate that dust

1023
00:46:59,799 --> 00:46:57,920
the dust blocks it so if you want to

1024
00:47:01,180 --> 00:46:59,809
observe the center of the galaxy if you

1025
00:47:03,099 --> 00:47:01,190
want to observe really anywhere in the

1026
00:47:06,219 --> 00:47:03,109
galaxy beyond our little region you've

1027
00:47:07,749 --> 00:47:06,229
got a problem the good news is that

1028
00:47:10,299 --> 00:47:07,759
there's more light than just visible

1029
00:47:12,039 --> 00:47:10,309
light this is the Eagle Nebula the

1030
00:47:14,380 --> 00:47:12,049
pillars of creation in the Eagle Nebula

1031
00:47:15,609 --> 00:47:14,390
for those of you that remember this was

1032
00:47:19,059 --> 00:47:15,619
on the front page of the Washington Post

1033
00:47:21,099 --> 00:47:19,069
when the original image came out this is

1034
00:47:22,920 --> 00:47:21,109
in visible light this beautiful

1035
00:47:27,880 --> 00:47:22,930
multicolored image and visible light

1036
00:47:29,890 --> 00:47:27,890
this is the same shot in the infrared so

1037
00:47:31,569 --> 00:47:29,900
infrared light has a slightly longer

1038
00:47:34,209 --> 00:47:31,579

wavelength that's slightly redder than

1039
00:47:35,469 --> 00:47:34,219
visible light it's how your cat knows

1040
00:47:38,140 --> 00:47:35,479
where the food bowl is in the middle of

1041
00:47:39,309 --> 00:47:38,150
the night and if you have ever used

1042
00:47:40,790 --> 00:47:39,319
night-vision goggles

1043
00:47:44,900 --> 00:47:40,800
that's what it

1044
00:47:46,760 --> 00:47:44,910
those are using infrared it's also we we

1045
00:47:48,800 --> 00:47:46,770
perceive it as heat our bodies are

1046
00:47:53,170 --> 00:47:48,810
giving off infrared radiation in the

1047
00:47:56,720 --> 00:47:53,180
form of heat but what's incredible is

1048
00:47:58,310 --> 00:47:56,730
these stores are here in this image we

1049
00:48:01,280 --> 00:47:58,320
didn't just ship them in special for the

1050
00:48:04,190 --> 00:48:01,290
infrared exposure it's just in the

1051
00:48:06,110 --> 00:48:04,200
infrared light you can look through the

1052
00:48:09,140 --> 00:48:06,120
dust and the gas of the pillars to the

1053
00:48:11,240 --> 00:48:09,150
Stars behind them and when you do that

1054
00:48:14,270 --> 00:48:11,250
for the entire Milky Way things look a

1055
00:48:15,980 --> 00:48:14,280
little different this is the Milky Way

1056
00:48:18,800 --> 00:48:15,990
this is a composite image in

1057
00:48:21,320 --> 00:48:18,810
near-infrared and the near infrared part

1058
00:48:24,050 --> 00:48:21,330
of the spectrum you can now see the

1059
00:48:27,320 --> 00:48:24,060
stellar disk of the Milky Way and the

1060
00:48:29,110 --> 00:48:27,330
stellar bulge the dust lanes that we're

1061
00:48:34,850 --> 00:48:29,120
blocking our view have faded completely

1062
00:48:36,820 --> 00:48:34,860
into the background and when we start

1063
00:48:40,670 --> 00:48:36,830

looking towards the galactic center

1064
00:48:43,730 --> 00:48:40,680
which is about 8.5 kiloparsecs or 25,000

1065
00:48:45,740 --> 00:48:43,740
light-years away when we looked in we

1066
00:48:49,070 --> 00:48:45,750
find that there is an extremely bright

1067
00:48:50,780 --> 00:48:49,080
radio source called sad a star right at

1068
00:48:52,880 --> 00:48:50,790
the supposed location of the center of

1069
00:48:54,770 --> 00:48:52,890
our galaxy and when we zoom in further

1070
00:48:56,390 --> 00:48:54,780
we see that the galactic center isn't

1071
00:48:58,310 --> 00:48:56,400
just some stars moving around it's

1072
00:49:02,390 --> 00:48:58,320
actually a very complex region and

1073
00:49:05,000 --> 00:49:02,400
there's this incredibly bright source at

1074
00:49:10,070 --> 00:49:05,010
the center and when you zoom even

1075
00:49:12,980 --> 00:49:10,080
further in I hope this works and you

1076
00:49:16,160 --> 00:49:12,990
look these are this is the center these

1077
00:49:20,180 --> 00:49:16,170
are stars this is not a movie or an

1078
00:49:22,820 --> 00:49:20,190
artist's conception this is data this is

1079
00:49:25,400 --> 00:49:22,830
data taken over a period of about 10

1080
00:49:29,120 --> 00:49:25,410
years for comparison it will take them

1081
00:49:31,580 --> 00:49:29,130
some 250 million years to orbit the

1082
00:49:37,250 --> 00:49:31,590
Milky Way these stars are moving

1083
00:49:39,200 --> 00:49:37,260
incredibly fast it turns out that using

1084
00:49:40,910 --> 00:49:39,210
Kepler's laws using the laws you're

1085
00:49:43,760 --> 00:49:40,920
honest Kepler determined for our solar

1086
00:49:45,260 --> 00:49:43,770
system you can take one of these orbits

1087
00:49:48,740 --> 00:49:45,270
and figure out how much mass is in the

1088
00:49:52,880 --> 00:49:48,750

middle there it's not emitting any light

1089
00:49:53,750 --> 00:49:52,890
it's very compact and it's 3 million

1090
00:49:56,840 --> 00:49:53,760
times the mass

1091
00:49:58,340 --> 00:49:56,850
versa this is the supermassive black

1092
00:49:59,599 --> 00:49:58,350
hole at the center of the Milky Way so

1093
00:50:04,420 --> 00:49:59,609
if you want an over the center of the

1094
00:50:10,220 --> 00:50:08,660
here's the and we and again this is

1095
00:50:12,290 --> 00:50:10,230
where I have to take what we do in a

1096
00:50:15,440 --> 00:50:12,300
month and graduate galaxies and compress

1097
00:50:17,300 --> 00:50:15,450
it this is the optical Milky Way disk

1098
00:50:20,420 --> 00:50:17,310
and optical this is the near-infrared

1099
00:50:22,190 --> 00:50:20,430
image that I showed you before when you

1100
00:50:24,530 --> 00:50:22,200
look in the mid infrared further to

1101
00:50:26,570 --> 00:50:24,540
longer wavelengths you're now seeing the

1102
00:50:28,070 --> 00:50:26,580
dust heating up all those dust clouds

1103
00:50:31,340 --> 00:50:28,080
heating up that's what you're seeing

1104
00:50:32,150 --> 00:50:31,350
here when you start looking at molecular

1105
00:50:38,840 --> 00:50:32,160
hydrogen

1106
00:50:41,090 --> 00:50:38,850
together this is right this is

1107
00:50:42,859 --> 00:50:41,100
relatively cool gas so this is where

1108
00:50:45,380 --> 00:50:42,869
stars are forming right here

1109
00:50:47,330 --> 00:50:45,390
concentrated in the disk we know that

1110
00:50:48,920 --> 00:50:47,340
tells us that stars are forming in the

1111
00:50:53,840 --> 00:50:48,930
disk of our galaxy they're not forming

1112
00:50:55,790 --> 00:50:53,850
everywhere you start in addition the

1113
00:50:57,800 --> 00:50:55,800

atomic hydrogen which is measuring

1114
00:51:00,320 --> 00:50:57,810
warmer hydrogen and the molecular

1115
00:51:03,099 --> 00:51:00,330
hydrogen together actually we from them

1116
00:51:06,800 --> 00:51:03,109
we find out we have an extra spiral arm

1117
00:51:08,840 --> 00:51:06,810
apparently we lost it I don't know we

1118
00:51:14,930 --> 00:51:08,850
have an extra spiral arm that we only

1119
00:51:16,550 --> 00:51:14,940
found in gas and this and in the radio

1120
00:51:19,220 --> 00:51:16,560
wavelengths the same wavelengths that

1121
00:51:21,140 --> 00:51:19,230
you use to tune your car for the radio

1122
00:51:25,190 --> 00:51:21,150
in your car for I'm assuming some people

1123
00:51:27,050 --> 00:51:25,200
still use radios in their cars it turns

1124
00:51:30,020 --> 00:51:27,060
out that there is yet another distance

1125
00:51:32,090 --> 00:51:30,030
indicator our Sun will become a will

1126
00:51:33,770 --> 00:51:32,100
stay in the main sequence eventually we

1127
00:51:35,840 --> 00:51:33,780
become a red giant will become a

1128
00:51:39,620 --> 00:51:35,850
planetary nebula which are very pretty

1129
00:51:41,570 --> 00:51:39,630
and eventually die as a white dwarf in

1130
00:51:46,190 --> 00:51:41,580
stellar evolution terms this is called

1131
00:51:47,780 --> 00:51:46,200
going out with a whimper a massive star

1132
00:51:50,120 --> 00:51:47,790
and by massive I mean something eight

1133
00:51:52,970 --> 00:51:50,130
times the mass of our Sun or even bigger

1134
00:51:55,250 --> 00:51:52,980
will become a red supergiant it'll move

1135
00:51:57,320 --> 00:51:55,260
around a bunch and then it will undergo

1136
00:51:58,670 --> 00:51:57,330
a supernova explosion these are some of

1137
00:52:02,210 --> 00:51:58,680
the most energetic events in the

1138
00:52:05,510 --> 00:52:02,220

universe and some of these will form a

1139
00:52:07,400 --> 00:52:05,520
neutron star these are the neutron star

1140
00:52:09,860 --> 00:52:07,410
was two neutron stars

1141
00:52:13,040 --> 00:52:09,870
colliding with each other that was the

1142
00:52:16,070 --> 00:52:13,050
recent subject of the first both LIGO

1143
00:52:20,000 --> 00:52:16,080
and optical detection for gravity waves

1144
00:52:22,070 --> 00:52:20,010
and it turns out that neutron stars in

1145
00:52:24,530 --> 00:52:22,080
addition to being the size of a stew

1146
00:52:28,970 --> 00:52:24,540
being our mass of our Sun it combined to

1147
00:52:31,550 --> 00:52:28,980
the size of Washington DC spin this is

1148
00:52:34,730 --> 00:52:31,560
Jocelyn Bell Burnell as a graduate

1149
00:52:38,300 --> 00:52:34,740
student she detected a signal each of

1150
00:52:41,720 --> 00:52:38,310
these little dips is a pulse from a

1151
00:52:43,370 --> 00:52:41,730
neutron star what's happening is you

1152
00:52:49,010 --> 00:52:43,380
have the neutron star here remember this

1153
00:52:50,360 --> 00:52:49,020
is this is the DC Beltway or the wall or

1154
00:52:54,170 --> 00:52:50,370
the Baltimore Beltway since we are in

1155
00:52:57,560 --> 00:52:54,180
Baltimore this is the rotation access to

1156
00:53:00,560 --> 00:52:57,570
the star spinning this is the magnetic

1157
00:53:04,550 --> 00:53:00,570
field on earth our magnetic field lines

1158
00:53:07,540 --> 00:53:04,560
up with our pole in reality a neutron

1159
00:53:10,250 --> 00:53:07,550
stars it doesn't so this is the axis

1160
00:53:12,200 --> 00:53:10,260
every time you sweep you get a signal

1161
00:53:16,010 --> 00:53:12,210
and I'm not doing that anymore because

1162
00:53:18,410 --> 00:53:16,020
I'm dizzy this is a cleaner image where

1163
00:53:22,520 --> 00:53:18,420

you can see the period and every pulsar

1164
00:53:24,950 --> 00:53:22,530
has a unique period and it turns out

1165
00:53:26,810 --> 00:53:24,960
that in addition to this the pulses if

1166
00:53:28,580 --> 00:53:26,820
there's three electrons or just

1167
00:53:31,730 --> 00:53:28,590
electrons flying around in space because

1168
00:53:35,450 --> 00:53:31,740
of course there are pulsars tend to

1169
00:53:38,540 --> 00:53:35,460
spread out the signal of the Pulsar will

1170
00:53:40,190 --> 00:53:38,550
spread out or disperse if you have a

1171
00:53:41,930 --> 00:53:40,200
pulsar where you independently know the

1172
00:53:44,180 --> 00:53:41,940
distances because why is this going to

1173
00:53:46,490 --> 00:53:44,190
be the straight forward you can map the

1174
00:53:48,290 --> 00:53:46,500
electron density of the galaxy if you

1175
00:53:50,090 --> 00:53:48,300
know the electron density of the galaxy

1176
00:53:52,340 --> 00:53:50,100
and you can measure the dispersion for

1177
00:53:55,220 --> 00:53:52,350
other pulsars suddenly you know where

1178
00:53:56,960 --> 00:53:55,230
all the pulsars are in the galaxy this

1179
00:53:58,550 --> 00:53:56,970
is the disk of the galaxy this is a

1180
00:54:01,280 --> 00:53:58,560
hundred thousand light-years across

1181
00:54:03,860 --> 00:54:01,290
and these are the note these are the

1182
00:54:07,580 --> 00:54:03,870
known positions of pulsars in our galaxy

1183
00:54:10,460 --> 00:54:07,590
so unlike the Cepheid unlike many other

1184
00:54:12,440 --> 00:54:10,470
things this is one of the only tools we

1185
00:54:16,370 --> 00:54:12,450
have to really map the far edge of the

1186
00:54:18,560 --> 00:54:16,380
galaxy in addition this is something

1187
00:54:20,180 --> 00:54:18,570
once in a while Star Trek actually gets

1188
00:54:20,470 --> 00:54:20,190

something right I don't remember whether

1189
00:54:21,849 --> 00:54:20,480
we're

1190
00:54:23,650 --> 00:54:21,859
q with the traveler that flung the

1191
00:54:25,270 --> 00:54:23,660
enterprise somewhere but they're trying

1192
00:54:27,990 --> 00:54:25,280
to figure out where they are and they

1193
00:54:31,410 --> 00:54:28,000
explicitly say check the pulsars and

1194
00:54:34,630 --> 00:54:31,420
that is because each pulsar has a unique

1195
00:54:36,609 --> 00:54:34,640
period so if you identify this pulsar

1196
00:54:38,859 --> 00:54:36,619
this pulsar and that pulsar you now know

1197
00:54:39,849 --> 00:54:38,869
where you are and since we I didn't know

1198
00:54:41,710 --> 00:54:39,859
if they're gonna be kids in the audience

1199
00:54:46,330 --> 00:54:41,720
hence the editing of the of the

1200
00:54:50,050 --> 00:54:46,340
pioneered the pioneer plaque this is

1201
00:54:51,940 --> 00:54:50,060
this is not a Hubble image this is an

1202
00:54:57,130 --> 00:54:51,950
artist's conception but this is based on

1203
00:55:01,240 --> 00:54:57,140
data this is the Milky Way the centre

1204
00:55:03,070 --> 00:55:01,250
here with a bar we know this based on

1205
00:55:04,599 --> 00:55:03,080
kinematics the the velocity and the

1206
00:55:07,720 --> 00:55:04,609
movements of the stars in the centre of

1207
00:55:12,940 --> 00:55:07,730
our galaxy we have two major arms coming

1208
00:55:16,990 --> 00:55:12,950
off either side smaller arms here more

1209
00:55:18,460 --> 00:55:17,000
minor arms and then there's this

1210
00:55:20,140 --> 00:55:18,470
additional arm here this is the one that

1211
00:55:23,290 --> 00:55:20,150
we figured out from radio observations

1212
00:55:29,109 --> 00:55:23,300
of hydrogen this is what we call the

1213
00:55:31,870 --> 00:55:29,119

Orion spur that's Orion this is the

1214
00:55:35,920 --> 00:55:31,880
earth roughly speaking not to scale by

1215
00:55:38,470 --> 00:55:35,930
the way this is the farthest measurement

1216
00:55:40,660 --> 00:55:38,480
we have in our galaxy this is 667

1217
00:55:42,040 --> 00:55:40,670
thousand light-years away if you

1218
00:55:44,050 --> 00:55:42,050
remember I told you Star Trek out the

1219
00:55:45,190 --> 00:55:44,060
scale the galaxy wrong accidentally if

1220
00:55:46,180 --> 00:55:45,200
we had your gun like another ten

1221
00:55:48,760 --> 00:55:46,190
thousand light-years that would have

1222
00:55:50,050 --> 00:55:48,770
been out of the disk just to give you a

1223
00:55:52,270 --> 00:55:50,060
sense of this that's what I mean by good

1224
00:55:54,160 --> 00:55:52,280
I got it right accidentally this is the

1225
00:55:56,200 --> 00:55:54,170
earth this is sixty seven thousand

1226
00:55:57,940 --> 00:55:56,210
light-years away there's about another

1227
00:56:01,810 --> 00:55:57,950
twenty thousand light-years between us

1228
00:56:04,150 --> 00:56:01,820
and the edge of the disk and since

1229
00:56:05,530 --> 00:56:04,160
you've been so good I promised you that

1230
00:56:08,740 --> 00:56:05,540
I would tell you what the Klingons were

1231
00:56:10,900 --> 00:56:08,750
at the end of this I believe it turns

1232
00:56:13,300 --> 00:56:10,910
out that the planet Vulcan is orbiting

1233
00:56:16,030 --> 00:56:13,310
an actual star

1234
00:56:17,410 --> 00:56:16,040
it's called forty Eridani for the nearby

1235
00:56:18,580 --> 00:56:17,420
stars we actually have something a

1236
00:56:21,520 --> 00:56:18,590
little more interesting than phone

1237
00:56:24,130 --> 00:56:21,530
numbers it is in the constellation of

1238
00:56:26,770 --> 00:56:24,140

air adonis the river which is right here

1239
00:56:29,560 --> 00:56:26,780
this is a ryan so if you want to

1240
00:56:33,240 --> 00:56:29,570
actually find where Vulcan is in the sky

1241
00:56:34,710 --> 00:56:33,250
it's right around here and I had to put

1242
00:56:40,110 --> 00:56:34,720
sort of Star Trek Discovery reference in

1243
00:56:41,790 --> 00:56:40,120
here this is literally what I did in the

1244
00:56:44,070 --> 00:56:41,800
Star Trek Star charts there is a list of

1245
00:56:45,750 --> 00:56:44,080
about will actually not list its maps

1246
00:56:47,190 --> 00:56:45,760
that have things written in two type

1247
00:56:49,740 --> 00:56:47,200
font that wasn't particularly easy to

1248
00:56:52,320 --> 00:56:49,750
read but you have a whole bunch of stars

1249
00:56:53,550 --> 00:56:52,330
this is for 40 Eridani which is Vulcan

1250
00:56:56,490 --> 00:56:53,560
in Star Trek

1251
00:56:58,290 --> 00:56:56,500
you have the Galactic coordinates so

1252
00:57:01,350 --> 00:56:58,300
this is basically latitude and longitude

1253
00:57:04,860 --> 00:57:01,360
for our galaxy and this is the parallax

1254
00:57:07,320 --> 00:57:04,870
this is how much Epsilon Eridani is

1255
00:57:09,780 --> 00:57:07,330
moving if you measure in January and

1256
00:57:12,660 --> 00:57:09,790
June the larger this number is the

1257
00:57:15,540 --> 00:57:12,670
closer something is an Epsilon Eridani

1258
00:57:19,860 --> 00:57:15,550
or Vulcan is about 16 and a quarter

1259
00:57:22,470 --> 00:57:19,870
light-years away so on cosmic terms

1260
00:57:24,950 --> 00:57:22,480
extremely close by in absolute terms it

1261
00:57:31,430 --> 00:57:24,960
would take us 17 years to say hi and

1262
00:57:40,110 --> 00:57:36,240
this is the Federation every single star

1263
00:57:43,950 --> 00:57:40,120

in the in Star Trek star charts that was

1264
00:57:47,070 --> 00:57:43,960
in Federation space I plugged into the

1265
00:57:49,650 --> 00:57:47,080
Sinbad database which is this right

1266
00:57:51,330 --> 00:57:49,660
there and pulled out the Galactica

1267
00:57:54,420 --> 00:57:51,340
latitude the Galactic longitude and the

1268
00:57:56,940 --> 00:57:54,430
parallax which gave me the distances the

1269
00:58:00,540 --> 00:57:56,950
Federation can be measured with parallax

1270
00:58:03,420 --> 00:58:00,550
that is how small it is the entire

1271
00:58:05,100 --> 00:58:03,430
Federation is about to 300 light-years

1272
00:58:06,450 --> 00:58:05,110
across depending on if you switch I'll

1273
00:58:08,340 --> 00:58:06,460
give them four hundred because you've

1274
00:58:11,700 --> 00:58:08,350
got some sort of weird squiggly bits

1275
00:58:13,500 --> 00:58:11,710
that go off to the side I think this is

1276
00:58:15,000 --> 00:58:13,510
if you were looking down into the plane

1277
00:58:16,590 --> 00:58:15,010
of our galaxy that's what it would look

1278
00:58:19,230 --> 00:58:16,600
like so you have sort of a tail going

1279
00:58:22,820 --> 00:58:19,240
off here and this is looking into the

1280
00:58:25,650 --> 00:58:22,830
disk towards the center of our galaxy so

1281
00:58:27,210 --> 00:58:25,660
if Kirk is on the enterprise on the edge

1282
00:58:29,160 --> 00:58:27,220
of the Federation and looks back at

1283
00:58:31,860 --> 00:58:29,170
Earth with a powerful enough telescope

1284
00:58:34,740 --> 00:58:31,870
he could watch his Efrain Cochrane take

1285
00:58:37,050 --> 00:58:34,750
off on the first work play he couldn't

1286
00:58:39,030 --> 00:58:37,060
watch us the Federation isn't big enough

1287
00:58:44,550 --> 00:58:39,040
for him to be able to go far enough away

1288
00:58:49,089 --> 00:58:44,560

to look 300 years back in time I told

1289
00:58:56,059 --> 00:58:52,759
um turns out the Klingons are closer

1290
00:58:58,220 --> 00:58:56,069
than we think they are this is the

1291
00:59:00,440 --> 00:58:58,230
distance to all the systems notice

1292
00:59:01,759 --> 00:59:00,450
Klingon systems the closest ones are

1293
00:59:06,650 --> 00:59:01,769
actually less than a hundred light years

1294
00:59:08,150 --> 00:59:06,660
away and if you want to look for the

1295
00:59:12,109 --> 00:59:08,160
Klingon Empire look in the

1296
00:59:14,359 --> 00:59:12,119
constellations of Leo and Gemini that's

1297
00:59:16,460 --> 00:59:14,369
if you want to look towards the the

1298
00:59:18,230 --> 00:59:16,470
Klingon Empire there in Leo it's Leo and

1299
00:59:22,279 --> 00:59:18,240
Gemini about a hundred light years away

1300
00:59:23,839 --> 00:59:22,289
and I couldn't and I didn't know which

1301
00:59:27,079 --> 00:59:23,849
Klingons to use by the way for that

1302
00:59:29,779 --> 00:59:27,089
picture I think this is just we got

1303
00:59:34,400 --> 00:59:29,789
better at makeup over the course of 50

1304
00:59:36,829 --> 00:59:34,410
years the Romulans and of course I had

1305
00:59:38,809 --> 00:59:36,839
to use green the black here is the

1306
00:59:40,430 --> 00:59:38,819
Romulan neutral zone that's actually

1307
00:59:41,960 --> 00:59:40,440
only about 30 light years away they're

1308
00:59:46,039 --> 00:59:41,970
actually closer than the Klingons and

1309
00:59:50,900 --> 00:59:46,049
the Romulans Empire is at is big it goes

1310
00:59:53,569 --> 00:59:50,910
out to about 150 light-years away if you

1311
00:59:54,589 --> 00:59:53,579
to see to look towards the Romulans you

1312
00:59:56,839 --> 00:59:54,599
actually have to be in the southern

1313
00:59:58,670 --> 00:59:56,849

hemisphere in the constellation of

1314
01:00:05,739 --> 00:59:58,680
Centaurus in the southern hemisphere and

1315
01:00:13,249 --> 01:00:09,199
the Kardashians are actually in if you

1316
01:00:14,809 --> 01:00:13,259
look towards the Big Dipper they are if

1317
01:00:16,430 --> 01:00:14,819
you look towards the Big Dipper tonight

1318
01:00:20,479 --> 01:00:16,440
you were looking in the direction of the

1319
01:00:22,549 --> 01:00:20,489
Kardashians what is it something and

1320
01:00:24,559 --> 01:00:22,559
these are the distances this is actually

1321
01:00:26,509 --> 01:00:24,569
aren't distances - these are distances

1322
01:00:30,410 --> 01:00:26,519
the edge of Cardassian space because

1323
01:00:33,769 --> 01:00:30,420
that's all I could find so the answer is

1324
01:00:35,509 --> 01:00:33,779
that yes this stuff is a lot closer than

1325
01:00:37,249 --> 01:00:35,519
you think they're not 3,000 light years

1326
01:00:39,259 --> 01:00:37,259
away but the chance that you could

1327
01:00:48,620 --> 01:00:39,269
actually get across 100 that 100 light

1328
01:00:51,769 --> 01:00:48,630
years to come and say hi questionable so

1329
01:00:55,069 --> 01:00:51,779
just to put this into perspective I told

1330
01:00:58,999 --> 01:00:55,079
you space was big this is the Federation

1331
01:01:01,489 --> 01:00:59,009
and the Klingon Empire and the Romulans

1332
01:01:03,890 --> 01:01:01,499
and the Cardassian this is all of Star

1333
01:01:05,449 --> 01:01:03,900
Trek with the exception of the bit that

1334
01:01:08,539 --> 01:01:05,459
happened over here and the kind of

1335
01:01:10,640 --> 01:01:08,549
happened over here but to give you a

1336
01:01:13,189 --> 01:01:10,650
sense of how difficult it is to see

1337
01:01:14,930 --> 01:01:13,199
through this massive stuff because

1338
01:01:17,059 --> 01:01:14,940

remember we're stuck in the disc we're

1339
01:01:19,849 --> 01:01:17,069
stuck right here on earth looking at our

1340
01:01:22,370 --> 01:01:19,859
galaxy through its disk we know less

1341
01:01:24,410 --> 01:01:22,380
about Star Trek's Delta Quadrant than we

1342
01:01:25,900 --> 01:01:24,420
do about galaxies a billion light-years

1343
01:01:28,160 --> 01:01:25,910
away

1344
01:01:29,870 --> 01:01:28,170
it's easier for us to find an

1345
01:01:31,549 --> 01:01:29,880
information about galaxies on the near

1346
01:01:32,870 --> 01:01:31,559
the edge of the universe than it is to

1347
01:01:37,609 --> 01:01:32,880
figure out what's going on on the other

1348
01:01:40,039 --> 01:01:37,619
side of our own galaxy and it's sort of

1349
01:01:41,719 --> 01:01:40,049
as a closing note the Orion Nebula is

1350
01:01:43,099 --> 01:01:41,729
the closest major star for me and to our

1351
01:01:45,099 --> 01:01:43,109
that was by the way thank you so much

1352
01:01:48,410 --> 01:01:45,109
for mentioning Orion that was a perfect

1353
01:01:51,589 --> 01:01:48,420
it's about 1,400 light-years away this

1354
01:01:53,299 --> 01:01:51,599
is at least a five-year mission this is

1355
01:01:56,870 --> 01:01:53,309
not let's go check out the Orion Nebula

1356
01:01:59,059 --> 01:01:56,880
and we'll be home next week and to give

1357
01:02:02,359 --> 01:01:59,069
you a sense of scale remember we're here

1358
01:02:07,120 --> 01:02:02,369
in Orion's here on galactic scales this

1359
01:02:09,920 --> 01:02:07,130
is extremely extremely close by as such

1360
01:02:11,539 --> 01:02:09,930
even in whatever future we end up in

1361
01:02:14,199 --> 01:02:11,549
assuming that we don't accidentally blow

1362
01:02:16,640 --> 01:02:14,209
ourselves up in the next 10 years

1363
01:02:18,680 --> 01:02:16,650

astronomers are still going to be

1364
01:02:20,300 --> 01:02:18,690
studying the universe largely study

1365
01:02:21,559 --> 01:02:20,310
the universe the same way that they have

1366
01:02:25,240 --> 01:02:21,569
been for the better part of three

1367
01:02:28,370 --> 01:02:25,250
thousand years with photons with light

1368
01:02:32,970 --> 01:02:28,380
physics and hopefully really awesome

1369
01:02:44,650 --> 01:02:32,980
Space Telescope's thank you

1370
01:02:48,440 --> 01:02:44,660
[Applause]

1371
01:02:50,089 --> 01:02:48,450
all right so um if I rid read that

1372
01:02:52,069 --> 01:02:50,099
correctly if we're 1,400 light-years

1373
01:02:53,749 --> 01:02:52,079
away to the Orion Nebula the Orion

1374
01:03:00,319 --> 01:02:53,759
Nebula is technically not in Federation

1375
01:03:01,999 --> 01:03:00,329
space then yeah Federation space it's

1376
01:03:07,549 --> 01:03:02,009
like it's a it's a 1,200 light-years

1377
01:03:09,950 --> 01:03:07,559
beyond Federation space okay I think the

1378
01:03:11,749 --> 01:03:09,960
Federation had better annex the Orion

1379
01:03:14,900 --> 01:03:11,759
Nebula it is that is one of the most

1380
01:03:19,519 --> 01:03:14,910
gorgeous places in our galaxy okay so I

1381
01:03:21,710 --> 01:03:19,529
think we'll have together well look III

1382
01:03:23,150 --> 01:03:21,720
just you know we got a call paramount

1383
01:03:26,120 --> 01:03:23,160
and get their writers to get get the

1384
01:03:27,680 --> 01:03:26,130
rhein Nebula inside Federation in Star

1385
01:03:29,359 --> 01:03:27,690
Trek if you haven't noticed they tend to

1386
01:03:34,549 --> 01:03:29,369
move the enterprise moves at the speed

1387
01:03:36,589 --> 01:03:34,559
of plot so it's actually very difficult

1388
01:03:38,029 --> 01:03:36,599

to figure out how fast are they actually

1389
01:03:40,880 --> 01:03:38,039
going and how far are they actually

1390
01:03:45,729 --> 01:03:40,890
going all right do we have any questions

1391
01:04:12,109 --> 01:04:10,279
yes orange jacket I don't know the

1392
01:04:14,719 --> 01:04:12,119
numbers but it is and we repeat the

1393
01:04:16,719 --> 01:04:14,729
question for the question is how fast

1394
01:04:20,239 --> 01:04:16,729
are the stars are moving

1395
01:04:22,430 --> 01:04:20,249
periapsis that their closest approach to

1396
01:04:26,719 --> 01:04:22,440
the black hole I don't have a number for

1397
01:04:28,999 --> 01:04:26,729
you it is extremely fast it is fast

1398
01:04:30,589 --> 01:04:29,009
enough that when the one of the ones

1399
01:04:31,999 --> 01:04:30,599
that goes close enough approaches the

1400
01:04:34,279 --> 01:04:32,009
black hole they weren't sure it was

1401
01:04:36,140 --> 01:04:34,289
going to come out the other side so

1402
01:04:37,519 --> 01:04:36,150
they're orbiting it's a basically I

1403
01:04:40,219 --> 01:04:37,529
think it's pretty much as fast as you

1404
01:04:43,339 --> 01:04:40,229
can go but I don't have an actual number

1405
01:04:45,589 --> 01:04:43,349
in meters per second right I mean for

1406
01:04:51,170 --> 01:04:45,599
reference you know the Sun is moving at

1407
01:04:52,120 --> 01:04:51,180
what 250 222 US km/s 250 kilometers per

1408
01:04:54,870 --> 01:04:52,130
second this is

1409
01:04:59,650 --> 01:04:54,880
100 times faster yeah so but 200 comma

1410
01:05:01,660 --> 01:04:59,660
second times 3600 is what like a hundred

1411
01:05:03,640 --> 01:05:01,670
and a hundred thousand miles per hour or

1412
01:05:08,190 --> 01:05:03,650
something like that if a kilometers per

1413
01:05:12,760 --> 01:05:10,600

these are moving so fast in space we

1414
01:05:14,470 --> 01:05:12,770
talk about kilometers per second not

1415
01:05:16,360 --> 01:05:14,480
kilometers per hour okay

1416
01:05:18,550 --> 01:05:16,370
um so we always have to translate from

1417
01:05:20,380 --> 01:05:18,560
the numbers that we know we memorize the

1418
01:05:22,420 --> 01:05:20,390
numbers we can explain

1419
01:05:24,520 --> 01:05:22,430
yes question there yes you mentioned

1420
01:05:27,430 --> 01:05:24,530
that astrology is one of the things that

1421
01:05:29,800 --> 01:05:27,440
Star Trek has done correctly I recall

1422
01:05:32,740 --> 01:05:29,810
there were some episodes with a travel

1423
01:05:34,870 --> 01:05:32,750
back a time an astronomer tree tells

1424
01:05:41,140 --> 01:05:34,880
them what their time that he have

1425
01:05:43,090 --> 01:05:41,150
arrived in his mission so the question

1426
01:05:45,340 --> 01:05:43,100
was in some Star Trek episodes they

1427
01:05:47,220 --> 01:05:45,350
travel back in time and the astrology of

1428
01:05:51,760 --> 01:05:47,230
the stars tells them what time it is

1429
01:05:54,040 --> 01:05:51,770
comment on that and parallax parallax is

1430
01:05:55,750 --> 01:05:54,050
the star moving the Stars actually

1431
01:05:58,720 --> 01:05:55,760
moving with parallax that's automatic

1432
01:06:01,900 --> 01:05:58,730
the stars are actually moving relative

1433
01:06:04,510 --> 01:06:01,910
to the Sun proper motions are if we're

1434
01:06:08,800 --> 01:06:04,520
sitting here and a star is moving like

1435
01:06:10,750 --> 01:06:08,810
this this the amount it comes across so

1436
01:06:13,690 --> 01:06:10,760
not along our line of sight but across

1437
01:06:15,280 --> 01:06:13,700
that is its proper motion you would

1438
01:06:17,080 --> 01:06:15,290

assume that by the time you got to the

1439
01:06:19,300 --> 01:06:17,090
world of Star Trek they would have we

1440
01:06:20,800 --> 01:06:19,310
were actually already well into having

1441
01:06:23,140 --> 01:06:20,810
that mapped and knowing the proper

1442
01:06:24,310 --> 01:06:23,150
motions of the nearby stars you would

1443
01:06:27,040 --> 01:06:24,320
assume by the time you got to Star Trek

1444
01:06:29,410 --> 01:06:27,050
they would have that for a much larger

1445
01:06:33,610 --> 01:06:29,420
volume and so you would be able to say

1446
01:06:36,370 --> 01:06:33,620
you know Epsilon Eridani is here but

1447
01:06:41,260 --> 01:06:36,380
should be here but it's here so it must

1448
01:06:58,180 --> 01:06:41,270
be 300 years ago okay all the way in the

1449
01:06:59,980 --> 01:06:58,190
back and the redshirt when galaxies

1450
01:07:01,780 --> 01:06:59,990
rotate do they all rotate in the same

1451
01:07:04,240 --> 01:07:01,790
direction or what direction do they

1452
01:07:06,620 --> 01:07:04,250
rotate in it depends on what direction

1453
01:07:09,770 --> 01:07:06,630
you're looking at them

1454
01:07:14,550 --> 01:07:09,780
and I'm actually not being entirely for

1455
01:07:16,380 --> 01:07:14,560
being in in when we talk about things it

1456
01:07:17,970 --> 01:07:16,390
depends on what direction is up it

1457
01:07:20,520 --> 01:07:17,980
actually depends from what you define is

1458
01:07:22,380 --> 01:07:20,530
up and usually what we say is if is we

1459
01:07:23,970 --> 01:07:22,390
use the right hand rule and we say if

1460
01:07:26,490 --> 01:07:23,980
you take your hand your right hand like

1461
01:07:27,900 --> 01:07:26,500
this feel free to do this if you without

1462
01:07:30,480 --> 01:07:27,910
preferably without hitting your neighbor

1463
01:07:32,640 --> 01:07:30,490

again and if you curl your hands like

1464
01:07:35,760 --> 01:07:32,650
this in a counterclockwise direction

1465
01:07:37,260 --> 01:07:35,770
your thumb points up so we define if you

1466
01:07:38,700 --> 01:07:37,270
have something rotating and you have it

1467
01:07:43,260 --> 01:07:38,710
in the counterclockwise direction we

1468
01:07:45,090 --> 01:07:43,270
defined this as up and so if you were to

1469
01:07:47,010 --> 01:07:45,100
take that same object and instead of

1470
01:07:48,690 --> 01:07:47,020
looking at it from above you look at it

1471
01:07:52,290 --> 01:07:48,700
from below you're now going to have

1472
01:07:55,770 --> 01:07:52,300
clockwise rotation and so the direction

1473
01:07:57,240 --> 01:07:55,780
of the rotation is very dependent on how

1474
01:07:59,340 --> 01:07:57,250
you look but if you show the Milky Way

1475
01:08:03,210 --> 01:07:59,350
the picture the Robert Hertz diagram in

1476
01:08:05,340 --> 01:08:03,220
the Milky Way there we go we can say

1477
01:08:09,420 --> 01:08:05,350
about this that they tend to rotate with

1478
01:08:11,640 --> 01:08:09,430
the trailing spiral arms we don't know I

1479
01:08:13,980 --> 01:08:11,650
think I know of like one galaxy that

1480
01:08:15,750 --> 01:08:13,990
might have leading spiral arms which

1481
01:08:20,010 --> 01:08:15,760
means that for this galaxy it would be

1482
01:08:22,110 --> 01:08:20,020
rotating clockwise okay and from the

1483
01:08:24,450 --> 01:08:22,120
direction you're looking at it okay of

1484
01:08:26,700 --> 01:08:24,460
course right just because that the

1485
01:08:36,599 --> 01:08:26,710
spiral arms trail okay they're called

1486
01:08:38,880 --> 01:08:36,609
trailing spiral arms looking at the same

1487
01:08:39,990 --> 01:08:38,890
image from the other side of the disk it

1488
01:08:43,710 --> 01:08:40,000

would look like it was rotating

1489
01:08:45,300 --> 01:08:43,720
counterclockwise right you know we have

1490
01:08:46,860 --> 01:08:45,310
one we have we we can agree on one

1491
01:08:50,070 --> 01:08:46,870
perspective here right for this to this

1492
01:08:52,410 --> 01:08:50,080
diagram we can also agree that I I know

1493
01:08:54,090 --> 01:08:52,420
of like one galaxy where was some it was

1494
01:08:56,490 --> 01:08:54,100
puff possible that it might have a

1495
01:08:59,370 --> 01:08:56,500
leading spiral arm but I didn't believe

1496
01:09:00,630 --> 01:08:59,380
it actually so it's all the spiral arms

1497
01:09:04,590 --> 01:09:00,640
I know of our trailing do you know of

1498
01:09:06,480 --> 01:09:04,600
any okay good all right in the purple

1499
01:09:07,980 --> 01:09:06,490
down here so you're not in a red shirt

1500
01:09:18,650 --> 01:09:07,990
or a blue shirt you're in a purple shirt

1501
01:09:28,130 --> 01:09:24,560
so what happened the universe that we

1502
01:09:28,880 --> 01:09:28,140
know they're trying to return where did

1503
01:09:31,240 --> 01:09:28,890
they go

1504
01:09:33,920 --> 01:09:31,250
are you talking about Star Trek Voyager

1505
01:09:39,950 --> 01:09:33,930
okay so where did Star Trek Voyager go

1506
01:09:41,420 --> 01:09:39,960
here I told you the 67 that I put this

1507
01:09:45,470 --> 01:09:41,430
up for a reason

1508
01:09:49,580 --> 01:09:45,480
Voyager is here they're they're barely

1509
01:09:51,520 --> 01:09:49,590
still in the galaxy because they keep

1510
01:09:53,900 --> 01:09:51,530
running into people every other planet

1511
01:09:55,220 --> 01:09:53,910
there they're barely there they're

1512
01:10:01,160 --> 01:09:55,230
barely and they they're like they're up

1513
01:10:04,310 --> 01:10:01,170

here okay over there yes the stars

1514
01:10:07,910 --> 01:10:04,320
toward the center of the galaxy versus

1515
01:10:10,310 --> 01:10:07,920
on the edge are the ones more toward the

1516
01:10:13,370 --> 01:10:10,320
center are they traveling faster or

1517
01:10:15,590 --> 01:10:13,380
slower so what are the speed of the

1518
01:10:16,910 --> 01:10:15,600
stars in the galaxies going from the

1519
01:10:21,890 --> 01:10:16,920
center to the edge or slow relative

1520
01:10:24,020 --> 01:10:21,900
speeds of those a rotation curve the

1521
01:10:25,670 --> 01:10:24,030
motivationally rotation curve of the

1522
01:10:29,660 --> 01:10:25,680
Milky Way the rotation speed of the

1523
01:10:31,910 --> 01:10:29,670
stars is actually relatively constant

1524
01:10:35,270 --> 01:10:31,920
with distance from the center of the

1525
01:10:37,280 --> 01:10:35,280
galaxy and so that means that the stars

1526
01:10:40,670 --> 01:10:37,290
in here are actually going at about the

1527
01:10:43,310 --> 01:10:40,680
same speed as the stars out here this is

1528
01:10:46,250 --> 01:10:43,320
one of the major pieces of evidence for

1529
01:10:49,820 --> 01:10:46,260
dark matter actually I told you Dark

1530
01:10:51,050 --> 01:10:49,830
Matter exists it just piano doesn't

1531
01:10:54,410 --> 01:10:51,060
exist the way that you would think it

1532
01:10:55,940 --> 01:10:54,420
would Star Trek there is right at the

1533
01:10:57,830 --> 01:10:55,950
center of our galaxy as you start moving

1534
01:10:59,930 --> 01:10:57,840
out there is an increase in speed as you

1535
01:11:02,420 --> 01:10:59,940
go further out but once you get certain

1536
01:11:05,810 --> 01:11:02,430
about to the orbit of our Sun which is

1537
01:11:07,370 --> 01:11:05,820
about 25,000 light years out the speed

1538
01:11:12,250 --> 01:11:07,380

of rotation is is flattened and is

1539
01:11:18,620 --> 01:11:12,260
constant okay in the black jacket there

1540
01:11:20,240 --> 01:11:18,630
so how our solar system can be to the

1541
01:11:25,070 --> 01:11:20,250
center of the galaxy before it becomes

1542
01:11:27,470 --> 01:11:25,080
on alright so if our galaxy were closer

1543
01:11:29,270 --> 01:11:27,480
to the center of the Milky Way would it

1544
01:11:31,880 --> 01:11:29,280
be come back our Sun yes

1545
01:11:34,430 --> 01:11:31,890
would the solar system be come in

1546
01:11:38,840 --> 01:11:34,440
habitable I wouldn't want to be right on

1547
01:11:42,130 --> 01:11:38,850
top of Sagittarius a then you might have

1548
01:11:46,940 --> 01:11:42,140
a problem but we could be a good ways in

1549
01:11:48,320 --> 01:11:46,950
because remember space is really big we

1550
01:11:50,240 --> 01:11:48,330
would actually have more trouble at the

1551
01:11:53,030 --> 01:11:50,250
center of a globular cluster because of

1552
01:11:55,010 --> 01:11:53,040
how crowded things are then we would in

1553
01:11:56,570 --> 01:11:55,020
the center of our galaxy so really until

1554
01:11:58,970 --> 01:11:56,580
you get to the really close in to the

1555
01:12:01,820 --> 01:11:58,980
galactic center you would be we'd be

1556
01:12:03,140 --> 01:12:01,830
fine yeah and just to amplify her point

1557
01:12:05,240 --> 01:12:03,150
about globular clusters globular

1558
01:12:06,950 --> 01:12:05,250
clusters are the only place that we know

1559
01:12:09,440 --> 01:12:06,960
of where stars can actually dense enough

1560
01:12:10,850 --> 01:12:09,450
that stars can actually collide so I

1561
01:12:14,360 --> 01:12:10,860
mean that actually causes that would

1562
01:12:16,670 --> 01:12:14,370
cause a lot more problems than billion

1563
01:12:19,820 --> 01:12:16,680

years Andromeda is going to slam into

1564
01:12:21,590 --> 01:12:19,830
the Milky Way when that happens none of

1565
01:12:23,120 --> 01:12:21,600
the stars are going to collide that is

1566
01:12:25,220 --> 01:12:23,130
how much space there is between the

1567
01:12:28,400 --> 01:12:25,230
stars the stars are actually going to

1568
01:12:32,840 --> 01:12:28,410
just move past each other but we got

1569
01:12:34,550 --> 01:12:32,850
four billion years to wait for that that

1570
01:12:49,160 --> 01:12:34,560
makes for a lot of sequels before that

1571
01:12:50,960 --> 01:12:49,170
happens all the way in the far corner it

1572
01:12:52,490 --> 01:12:50,970
looks very bright in the center of the

1573
01:12:53,930 --> 01:12:52,500
galaxy you know we have an issue with

1574
01:12:55,970 --> 01:12:53,940
light pollution

1575
01:12:59,870 --> 01:12:55,980
I think we'd have even more issue seen

1576
01:13:01,730 --> 01:12:59,880
through it I mean right now we because

1577
01:13:03,440 --> 01:13:01,740
we're in the disc so the Milky Way

1578
01:13:05,270 --> 01:13:03,450
across is about a hundred thousand light

1579
01:13:07,240 --> 01:13:05,280
years the disc is only a thousand light

1580
01:13:09,680 --> 01:13:07,250
years thick you can think of it as a

1581
01:13:12,710 --> 01:13:09,690
laser disc it's about the right

1582
01:13:14,480 --> 01:13:12,720
dimensions if you're in the center if

1583
01:13:16,700 --> 01:13:14,490
you're sort of in the Bulge area here

1584
01:13:19,130 --> 01:13:16,710
right now if we look up out of the disk

1585
01:13:21,110 --> 01:13:19,140
or down out of the disk we have a

1586
01:13:24,920 --> 01:13:21,120
relatively clear view of what's outside

1587
01:13:27,620 --> 01:13:24,930
the Milky Way if we're in the middle in

1588
01:13:30,320 --> 01:13:27,630

the Bulge you're gonna have to look this

1589
01:13:31,670 --> 01:13:30,330
way this way up down you know whichever

1590
01:13:33,140 --> 01:13:31,680
direction you choose to look you're

1591
01:13:36,290 --> 01:13:33,150
gonna be looking through a whole lot of

1592
01:13:37,520 --> 01:13:36,300
stars and so it's actually gonna it's

1593
01:13:39,080 --> 01:13:37,530
not so much that you're gonna have light

1594
01:13:40,820 --> 01:13:39,090
pollution as it's gonna be almost

1595
01:13:43,100 --> 01:13:40,830
impossible to see anything beyond the

1596
01:13:44,810 --> 01:13:43,110
Milky Way right and the same is true in

1597
01:13:45,459 --> 01:13:44,820
a globular cluster you get in the center

1598
01:13:47,379 --> 01:13:45,469
of globby

1599
01:13:50,319 --> 01:13:47,389
cluster of a million stars you can do

1600
01:13:52,689 --> 01:13:50,329
incredible stellar astronomy but extra

1601
01:13:55,450 --> 01:13:52,699
galactic astronomy really kind of

1602
01:13:56,890 --> 01:13:55,460
difficult okay so yeah we're actually

1603
01:13:59,620 --> 01:13:56,900
kind of lucky being out in the boondocks

1604
01:14:03,129 --> 01:13:59,630
we have a nice clear skies and in one

1605
01:14:06,729 --> 01:14:03,139
sense like that okay in the blue shirt

1606
01:14:09,430 --> 01:14:06,739
right there this this spiral structure

1607
01:14:13,870 --> 01:14:09,440
makes me think that the galaxy is

1608
01:14:18,189 --> 01:14:13,880
turning is rotating if it's rotating how

1609
01:14:22,989 --> 01:14:18,199
can the hour be moving at the same speed

1610
01:14:25,209 --> 01:14:22,999
as further okay so if the galaxy is

1611
01:14:26,830 --> 01:14:25,219
rotating how can the outers objects be

1612
01:14:29,739 --> 01:14:26,840
moving at the same speed is the inner

1613
01:14:33,700 --> 01:14:29,749

objects um the answer is actually dark

1614
01:14:37,390 --> 01:14:33,710
matter is what dark matter so everything

1615
01:14:42,870 --> 01:14:37,400
we see this visible all the stars the

1616
01:14:46,299 --> 01:14:42,880
gas the dust starships whatever

1617
01:14:48,069 --> 01:14:46,309
starships hapless bipedal species all of

1618
01:14:49,660 --> 01:14:48,079
that is made up of something called

1619
01:14:52,000 --> 01:14:49,670
baryonic matter and all of that

1620
01:14:54,819 --> 01:14:52,010
interacts with light it either absorbs

1621
01:14:57,000 --> 01:14:54,829
light or emits light all of that is

1622
01:15:00,479 --> 01:14:57,010
about 10% of the matter in the universe

1623
01:15:03,189 --> 01:15:00,489
the other 90% is dark matter and dark

1624
01:15:06,279 --> 01:15:03,199
matter we only see dark matter because

1625
01:15:08,109 --> 01:15:06,289
of gravity because we know it's there we

1626
01:15:10,149 --> 01:15:08,119
know that there if the stars on the

1627
01:15:12,359 --> 01:15:10,159
outer edge of the disk are orbiting just

1628
01:15:16,330 --> 01:15:12,369
as fast as the stars in the inner edge

1629
01:15:18,489 --> 01:15:16,340
then we and we know that the mass of the

1630
01:15:21,819 --> 01:15:18,499
Milky Way the enclose the mass inside

1631
01:15:23,169 --> 01:15:21,829
those orbits is basically the same once

1632
01:15:24,850 --> 01:15:23,179
you get out here so it should be falling

1633
01:15:27,279 --> 01:15:24,860
off like you see like the fact that

1634
01:15:29,169 --> 01:15:27,289
Neptune orbits slower than Jupiter which

1635
01:15:32,680 --> 01:15:29,179
orbits slower than mercury that's called

1636
01:15:35,919 --> 01:15:32,690
Keplerian rotation the fact that we see

1637
01:15:38,109 --> 01:15:35,929
this flat rotation constant rotation as

1638
01:15:39,879 --> 01:15:38,119

far out as we can observe means that

1639
01:15:42,100 --> 01:15:39,889
there must be an additional mass

1640
01:15:43,750 --> 01:15:42,110
component which ends up being about 90%

1641
01:15:45,459 --> 01:15:43,760
of the mass of the galaxy that just

1642
01:15:46,810 --> 01:15:45,469
isn't interacting with light it's not

1643
01:15:49,330 --> 01:15:46,820
absorbing light it's not emitting light

1644
01:15:51,620 --> 01:15:49,340
and that is dark matter and that's about

1645
01:15:54,040 --> 01:15:51,630
90 percent of the

1646
01:15:57,710 --> 01:15:54,050
and I'll add one more comment that the

1647
01:15:59,660 --> 01:15:57,720
pattern speed of the spiral structure is

1648
01:16:02,150 --> 01:15:59,670
different from the orbital speed of the

1649
01:16:04,340 --> 01:16:02,160
stars within it stars go into these

1650
01:16:06,680 --> 01:16:04,350
spiral arms and move out of these spiral

1651
01:16:08,660 --> 01:16:06,690
arms so the patterns speed the density

1652
01:16:10,970 --> 01:16:08,670
wave of the spirals actually is a

1653
01:16:13,010 --> 01:16:10,980
different rotational speed than the

1654
01:16:15,710 --> 01:16:13,020
stars that are moving through them okay

1655
01:16:17,420 --> 01:16:15,720
so that's another thing to process it

1656
01:16:18,680 --> 01:16:17,430
but the arms

1657
01:16:21,500 --> 01:16:18,690
[Music]

1658
01:16:25,490 --> 01:16:21,510
well we can't watch getting we can't

1659
01:16:28,130 --> 01:16:25,500
watch a galaxy for that long to confirm

1660
01:16:31,130 --> 01:16:28,140
that but our simulations do show that

1661
01:16:32,960 --> 01:16:31,140
the that the pattern that the pattern

1662
01:16:35,180 --> 01:16:32,970
stays roughly constant for a while but

1663
01:16:38,930 --> 01:16:35,190

they can they can stretch out and reform

1664
01:16:40,610 --> 01:16:38,940
and break up in for instance when the LM

1665
01:16:42,190 --> 01:16:40,620
if the LMC in the essence you come too

1666
01:16:44,900 --> 01:16:42,200
close to the disk they will actually

1667
01:16:49,280 --> 01:16:44,910
modify this pattern okay we got a couple

1668
01:16:50,960 --> 01:16:49,290
questions from online at warp 9.9 how

1669
01:17:06,110 --> 01:16:50,970
long would it take for the enterprise to

1670
01:17:09,560 --> 01:17:06,120
cross the Milky Way if they'd asked me

1671
01:17:11,360 --> 01:17:09,570
warp six I would have been going at

1672
01:17:14,210 --> 01:17:11,370
maximum warp it takes a hundred years to

1673
01:17:16,010 --> 01:17:14,220
cross the Milky Way maximum warp 9.9

1674
01:17:17,750 --> 01:17:16,020
depending on what maximum orb is it's

1675
01:17:19,760 --> 01:17:17,760
about a thousand light years per year

1676
01:17:23,120 --> 01:17:19,770
hence the reason that Orion is more than

1677
01:17:25,040 --> 01:17:23,130
a five year mission okay and let's see

1678
01:17:27,710 --> 01:17:25,050
there was a good question what do you

1679
01:17:30,110 --> 01:17:27,720
think is the most interesting unanswered

1680
01:17:32,840 --> 01:17:30,120
question you have relating to your work

1681
01:17:35,060 --> 01:17:32,850
your studies of things well I don't

1682
01:17:39,290 --> 01:17:35,070
actually work on the Milky Way yes I

1683
01:17:44,180 --> 01:17:39,300
work on extremely tiny galaxies that are

1684
01:17:45,830 --> 01:17:44,190
orbiting the Milky Way and I would

1685
01:17:49,010 --> 01:17:45,840
actually say that you know going back to

1686
01:17:53,240 --> 01:17:49,020
your first news from the universe point

1687
01:17:56,180 --> 01:17:53,250
we don't I work on galaxies very small

1688
01:17:58,610 --> 01:17:56,190

galaxies at today in the local universe

1689
01:18:01,640 --> 01:17:58,620
oh and their counterparts in the first

1690
01:18:03,920 --> 01:18:01,650
billion years of the universe and how

1691
01:18:05,120 --> 01:18:03,930
that happened how different physical

1692
01:18:07,980 --> 01:18:05,130
mechanism

1693
01:18:09,930 --> 01:18:07,990
regulated an interplay to form those

1694
01:18:11,820 --> 01:18:09,940
first galaxies I think is for me one of

1695
01:18:14,760 --> 01:18:11,830
the most interesting problems and we are

1696
01:18:18,540 --> 01:18:14,770
nowhere near solving it Webb's gonna

1697
01:18:21,300 --> 01:18:18,550
help but we need W first as well okay

1698
01:18:28,500 --> 01:18:21,310
and one last question from the audience

1699
01:18:47,570 --> 01:18:28,510
what's a laserdisc we just got a couple

1700
01:18:50,850 --> 01:18:47,580
more minutes Yeah right there okay so

1701
01:18:52,890 --> 01:18:50,860
what is the fastest we've sent we we've

1702
01:18:55,140 --> 01:18:52,900
created is not aizen's that's the

1703
01:18:56,820 --> 01:18:55,150
fastest chip we've launched and how fast

1704
01:19:00,930 --> 01:18:56,830
do you think we possibly can go do you

1705
01:19:09,990 --> 01:19:00,940
know how fast it's going no we can call

1706
01:19:11,430 --> 01:19:10,000
Alan Stern right now we can only the

1707
01:19:12,870 --> 01:19:11,440
main way that we get things moving fast

1708
01:19:14,880 --> 01:19:12,880
this is true for New Horizons which

1709
01:19:16,800 --> 01:19:14,890
recently flew by Pluto this is true for

1710
01:19:18,990 --> 01:19:16,810
the Pioneer missions and for the two

1711
01:19:21,540 --> 01:19:19,000
Voyager missions is that as we go out

1712
01:19:23,220 --> 01:19:21,550
through the solar system we go by the

1713
01:19:24,150 --> 01:19:23,230

giant planets and actually the reason we

1714
01:19:26,550 --> 01:19:24,160
could do the Pioneer and Voyager

1715
01:19:29,120 --> 01:19:26,560
missions when we did is because all the

1716
01:19:31,440 --> 01:19:29,130
giant planets were lined up perfectly

1717
01:19:33,030 --> 01:19:31,450
right when we had the technology to do

1718
01:19:34,500 --> 01:19:33,040
it they just happen to be lined up

1719
01:19:39,060 --> 01:19:34,510
perfectly and this does not happen that

1720
01:19:40,710 --> 01:19:39,070
often as the planets and so you swing by

1721
01:19:42,360 --> 01:19:40,720
Jupiter you get a gravity assist and you

1722
01:19:44,850 --> 01:19:42,370
speed up then you swing by Saturn

1723
01:19:48,510 --> 01:19:44,860
Neptune Uranus and then Neptune on the

1724
01:19:51,630 --> 01:19:48,520
way out doing that we are nowhere near

1725
01:19:55,250 --> 01:19:51,640
the speed of light New Horizons is

1726
01:19:58,770 --> 01:19:55,260
moving at 16 kilometers a second or

1727
01:20:00,930 --> 01:19:58,780
36,000 miles per hour so 16 to give you

1728
01:20:03,360 --> 01:20:00,940
a sense 16 kilometers per second is New

1729
01:20:05,100 --> 01:20:03,370
Horizons and the speed of light is a

1730
01:20:08,160 --> 01:20:05,110
hundred thousand kilometers per second

1731
01:20:10,590 --> 01:20:08,170
as we approach the speed of light

1732
01:20:12,180 --> 01:20:10,600
because of relativity as you start

1733
01:20:13,890 --> 01:20:12,190
approaching the speed of light the mass

1734
01:20:16,770 --> 01:20:13,900
of whatever you're sending approaches

1735
01:20:18,840 --> 01:20:16,780
infinity so we could

1736
01:20:20,100 --> 01:20:18,850
something near the speed of light or as

1737
01:20:21,500 --> 01:20:20,110
close to the speed of light as we

1738
01:20:24,810 --> 01:20:21,510

possibly could

1739
01:20:28,470 --> 01:20:24,820
but even if we got something to half the

1740
01:20:33,630 --> 01:20:28,480
speed of light it would take eight years

1741
01:20:36,960 --> 01:20:33,640
to get to Alpha Centauri and it would

1742
01:20:41,760 --> 01:20:36,970
take thirty-two years to get to forty

1743
01:20:44,700 --> 01:20:41,770
Eridani so unless unless there's a way

1744
01:20:46,770 --> 01:20:44,710
around this the speed of light is the

1745
01:20:48,570 --> 01:20:46,780
speed limit of the universe unless

1746
01:20:50,730 --> 01:20:48,580
there's a way around it of course it's

1747
01:20:52,230 --> 01:20:50,740
no fun in you know you can't have Star

1748
01:20:57,180 --> 01:20:52,240
Trek if it's like well we'll get there

1749
01:20:57,900 --> 01:20:57,190
and about you know seventy years yeah no

1750
01:21:02,580 --> 01:20:57,910
that wouldn't make for a very

1751
01:21:04,260 --> 01:21:02,590
entertaining show yeah we scientists are

1752
01:21:06,660 --> 01:21:04,270
a little bit dampers on Hollywood script

1753
01:21:08,130 --> 01:21:06,670
writers that come around I've gotten a

1754
01:21:10,170 --> 01:21:08,140
couple of scripts past me and got like I

1755
01:21:13,470 --> 01:21:10,180
yeah this is it and none of this is

1756
01:21:16,110 --> 01:21:13,480
possible they don't listen because they

1757
01:21:18,060 --> 01:21:16,120
need it to work for their story but you

1758
01:21:24,420 --> 01:21:18,070
know we can give them our best advice

1759
01:21:26,090 --> 01:21:24,430
all right here what's on the other side

1760
01:21:30,210 --> 01:21:26,100
of a black hole

1761
01:21:34,170 --> 01:21:30,220
we don't know physics actually breaks

1762
01:21:35,850 --> 01:21:34,180
down inside of black holes so we

1763
01:21:37,770 --> 01:21:35,860

understand how things work on quantum

1764
01:21:39,240 --> 01:21:37,780
scales we understand our quantum

1765
01:21:42,260 --> 01:21:39,250
mechanics works and we've been able to

1766
01:21:45,690 --> 01:21:42,270
make quantum forces work with

1767
01:21:48,510 --> 01:21:45,700
electromagnetic physics but when you try

1768
01:21:50,940 --> 01:21:48,520
to combine those with general relativity

1769
01:21:52,980 --> 01:21:50,950
with our understanding of gravity the

1770
01:21:56,070 --> 01:21:52,990
equations don't agree and the

1771
01:21:58,080 --> 01:21:56,080
predictions don't agree at all and so we

1772
01:22:00,990 --> 01:21:58,090
don't actually know what's going on

1773
01:22:03,180 --> 01:22:01,000
inside of a black hole because our two

1774
01:22:05,640 --> 01:22:03,190
understandings of the universe are

1775
01:22:07,920 --> 01:22:05,650
giving us completely contradictory

1776
01:22:09,900 --> 01:22:07,930
answers it's actually called the to

1777
01:22:11,850 --> 01:22:09,910
unify those to make them work inside a

1778
01:22:18,330 --> 01:22:11,860
black hole is one of the Holy Grails of

1779
01:22:19,830 --> 01:22:18,340
theoretical physics right now I mean it

1780
01:22:22,629 --> 01:22:19,840
could be a wormhole to the Gamma

1781
01:22:27,529 --> 01:22:25,729
well you know we the scientific answer

1782
01:22:30,229 --> 01:22:27,539
is that we once you're past the event

1783
01:22:32,659 --> 01:22:30,239
horizon we don't know okay we have an

1784
01:22:37,250 --> 01:22:32,669
update from somebody online who looked

1785
01:22:39,560 --> 01:22:37,260
it up and NASA's Juno was accelerated by

1786
01:22:43,189 --> 01:22:39,570
Jupiter and they they quote one hundred

1787
01:22:44,569 --> 01:22:43,199
sixty-five thousand miles per hour that

1788
01:22:47,750 --> 01:22:44,579

makes you know the fastest moving

1789
01:22:49,279 --> 01:22:47,760
human-made object in history okay I

1790
01:22:52,009 --> 01:22:49,289
didn't know that Juno had gotten up to

1791
01:22:53,569 --> 01:22:52,019
that speed the Juno probe that's

1792
01:22:56,479 --> 01:22:53,579
measuring the magnetosphere of jupiter

1793
01:22:58,699 --> 01:22:56,489
right now was accelerated when it came

1794
01:23:01,099 --> 01:22:58,709
past Jupiter is in this big huge looping

1795
01:23:02,810 --> 01:23:01,109
orbit around Jupiter and somebody online

1796
01:23:06,770 --> 01:23:02,820
says it's it's now the fastest

1797
01:23:08,810 --> 01:23:06,780
human-made object in history okay it's

1798
01:23:10,819 --> 01:23:08,820
9:20 for all I give you the honor of the

1799
01:23:14,259 --> 01:23:10,829
last question in the back here net speed

1800
01:23:17,060 --> 01:23:14,269
is strictly gravitational is responsible

1801
01:23:19,609 --> 01:23:17,070
well it it would have approached Jupiter

1802
01:23:22,849 --> 01:23:19,619
with similar tens of kilometers per

1803
01:23:25,609 --> 01:23:22,859
second speed as is moving out but then

1804
01:23:28,339 --> 01:23:25,619
because it came so deep into Jupiter's

1805
01:23:30,109 --> 01:23:28,349
gravity well it gotten an acceleration

1806
01:23:32,540 --> 01:23:30,119
as it came through Jupiter's gravity

1807
01:23:34,759 --> 01:23:32,550
well that increased its speed so it's

1808
01:23:38,929 --> 01:23:34,769
orbiting Jupiter with that speed okay

1809
01:23:41,000 --> 01:23:38,939
all right so understanding that meal

1810
01:23:45,109 --> 01:23:41,010
we'll be back next year where she's

1811
01:23:46,699 --> 01:23:45,119
going to disprove shine Holt's theory of

1812
01:23:50,119 --> 01:23:46,709
multiple you do realize I'm applying to

1813
01:23:54,529 --> 01:23:50,129

jobs in California right I'm making a

1814
01:23:56,330 --> 01:23:54,539
Star Trek reference here okay wine holds

1815
01:23:57,770 --> 01:23:56,340
your theory of multiple Big Bang's which

1816
01:23:59,599 --> 01:23:57,780
is dependent upon Wang's second

1817
01:24:02,869 --> 01:23:59,609
postulate okay and so you have to get

1818
01:24:20,410 --> 01:24:02,879
past there's no observables yes we all

1819
01:24:20,420 --> 01:24:28,120
but next month

1820
01:24:33,470 --> 01:24:31,010
Suzanne adduced wha and in the meantime

1821
01:24:33,790 --> 01:24:33,480
let's give a warm thank you to me above