

1  
00:00:00,000 --> 00:00:08,539  
our YouTube channel mr. grant justice

2  
00:00:02,339 --> 00:00:12,439  
give him a hand alright check this

3  
00:00:08,539 --> 00:00:12,439  
alright let's go ahead and get started

4  
00:00:14,990 --> 00:00:19,859  
good evening ladies and gentlemen and

5  
00:00:17,190 --> 00:00:22,800  
welcome to the Space Telescope public

6  
00:00:19,859 --> 00:00:25,109  
lecture series I am dr. Frank summers of

7  
00:00:22,800 --> 00:00:28,199  
the office of public outreach and it is

8  
00:00:25,109 --> 00:00:32,070  
my pleasure to be your host when you

9  
00:00:28,199 --> 00:00:34,020  
came in you came in early you might have

10  
00:00:32,070 --> 00:00:37,200  
gotten a picture of the star cluster

11  
00:00:34,020 --> 00:00:40,230  
westerlyn - if you came in a little bit

12  
00:00:37,200 --> 00:00:42,480  
later we ran out of westerlyn - and now

13  
00:00:40,229 --> 00:00:46,979  
we have the star-forming nebula and 90

14  
00:00:42,479 --> 00:00:48,869  
available if you get these the n 90s are

15  
00:00:46,979 --> 00:00:50,909  
still available if you want the

16  
00:00:48,869 --> 00:00:53,909  
westerlyn - well you might have to trade

17  
00:00:50,909 --> 00:00:56,459  
with somebody okay so do your best horse

18  
00:00:53,909 --> 00:00:57,869  
trading and you can get your wonderful

19  
00:00:56,460 --> 00:00:58,920  
pictures if you'd like to know more

20  
00:00:57,869 --> 00:01:00,718  
about them of course

21  
00:00:58,920 --> 00:01:03,629  
turn over on the back and we have a

22  
00:01:00,719 --> 00:01:07,228  
short essay telling you about them art

23  
00:01:03,628 --> 00:01:09,599  
its topic tonight a fun one mapping the

24  
00:01:07,228 --> 00:01:13,109  
United Federation of Planets and

25  
00:01:09,599 --> 00:01:14,609  
astronomers guide to the galaxy and of

26  
00:01:13,109 --> 00:01:16,319  
course everyone recognizes that the

27  
00:01:14,609 --> 00:01:19,618  
United Federation of Planets is a

28  
00:01:16,319 --> 00:01:21,779  
reference to Star Trek and mia has told

29

00:01:19,618 --> 00:01:27,379  
me that yes she will tell you where the

30  
00:01:21,780 --> 00:01:30,329  
Klingons are alright next month

31  
00:01:27,379 --> 00:01:37,259  
susannah days tua will be talking about

32  
00:01:30,328 --> 00:01:41,639  
the plumes of Europa ice water life find

33  
00:01:37,259 --> 00:01:42,989  
out next month April 3rd in May one of

34  
00:01:41,640 --> 00:01:46,399  
the talks we've been trying to get for a

35  
00:01:42,989 --> 00:01:50,359  
while recently won a Nobel Prize

36  
00:01:46,399 --> 00:01:53,070  
gravitational wave astronomy a new

37  
00:01:50,359 --> 00:01:54,959  
method for examining the universe that

38  
00:01:53,069 --> 00:01:55,618  
we can now finally detect gravitational

39  
00:01:54,959 --> 00:01:58,140  
waves

40  
00:01:55,618 --> 00:02:01,618  
we've only been trying for about 40 or

41  
00:01:58,140 --> 00:02:03,478  
50 years to see what we can do we can

42  
00:02:01,618 --> 00:02:05,159  
finally detect them and and 'if Richter

43  
00:02:03,478 --> 00:02:08,669

is our local expert who will tell you

44

00:02:05,159 --> 00:02:10,920  
about that on June we'll Fischer will

45

00:02:08,669 --> 00:02:13,789  
speak on one of my favorite nebula in

46

00:02:10,919 --> 00:02:16,878  
the entire universe the Orion Nebula

47

00:02:13,789 --> 00:02:19,188  
it is the nearest large star-forming

48

00:02:16,878 --> 00:02:21,348  
region is our template for understanding

49

00:02:19,188 --> 00:02:24,259  
star formation in the universe and the

50

00:02:21,348 --> 00:02:26,479  
guys here know so much about it he'll

51

00:02:24,259 --> 00:02:29,000  
give you all sorts of cool detail on how

52

00:02:26,479 --> 00:02:31,729  
stars are born actually not only stars

53

00:02:29,000 --> 00:02:35,419  
but also planetary systems all right

54

00:02:31,729 --> 00:02:38,119  
that will be in June the details are on

55

00:02:35,419 --> 00:02:40,280  
our website in your favorite search

56

00:02:38,120 --> 00:02:42,408  
engine type in Hubble public lectures

57

00:02:40,280 --> 00:02:44,209  
and you should find this webpage where

58  
00:02:42,408 --> 00:02:47,620  
we have the list of the upcoming talks

59  
00:02:44,209 --> 00:02:52,069  
oh by the way I see me above all is on

60  
00:02:47,620 --> 00:02:55,848  
undergrad from 2016 so she has spoken

61  
00:02:52,068 --> 00:02:59,179  
here before that was just a screengrab I

62  
00:02:55,848 --> 00:03:02,479  
did here we also have the online the

63  
00:02:59,180 --> 00:03:05,419  
live the YouTube and stsci webcasting as

64  
00:03:02,479 --> 00:03:08,780  
well as the archives the YouTube goes

65  
00:03:05,419 --> 00:03:12,609  
back to 2014 the webcast goes all the

66  
00:03:08,780 --> 00:03:15,769  
way back to 2005 that's a lot of

67  
00:03:12,609 --> 00:03:17,719  
astronaut astronomy topics I dare you to

68  
00:03:15,769 --> 00:03:21,229  
binge watch that in one weekend I don't

69  
00:03:17,719 --> 00:03:23,419  
think you can do it if you would like to

70  
00:03:21,229 --> 00:03:25,729  
be informed we have our sign up for our

71  
00:03:23,419 --> 00:03:29,750  
email list both subscribe and

72  
00:03:25,729 --> 00:03:31,549  
unsubscribe if you would like the

73  
00:03:29,750 --> 00:03:33,560  
announcements we say as I just told you

74  
00:03:31,549 --> 00:03:36,799  
sign up the website or if you can't

75  
00:03:33,560 --> 00:03:38,348  
possibly do that give me your email okay

76  
00:03:36,799 --> 00:03:40,879  
I'll write it down on a piece of paper

77  
00:03:38,348 --> 00:03:43,578  
hand it to me and I'll make sure you get

78  
00:03:40,878 --> 00:03:45,530  
on the list if you have comments or

79  
00:03:43,579 --> 00:03:48,739  
questions we have an email public

80  
00:03:45,530 --> 00:03:50,840  
lecture at STScI dot edu you can send

81  
00:03:48,739 --> 00:03:52,430  
email to that and we'll get to the

82  
00:03:50,840 --> 00:03:56,389  
answer all right

83  
00:03:52,430 --> 00:03:58,129  
social media Hubbell web and STScI have

84  
00:03:56,389 --> 00:04:01,489  
a variety of Facebook Twitter YouTube

85  
00:03:58,128 --> 00:04:04,219  
and Instagram I myself do a little bit

86

00:04:01,489 --> 00:04:06,079  
of Facebook Google+ and Twitter and some

87  
00:04:04,219 --> 00:04:09,400  
occasionally write some blog posts if

88  
00:04:06,079 --> 00:04:11,840  
you want to hear more from me

89  
00:04:09,400 --> 00:04:14,449  
unfortunately if you looked up you could

90  
00:04:11,840 --> 00:04:16,488  
not see any stars tonight it's cloudy

91  
00:04:14,449 --> 00:04:18,259  
it's actually he's gonna rain and

92  
00:04:16,488 --> 00:04:20,689  
possibly even snow a little bit tonight

93  
00:04:18,259 --> 00:04:23,569  
so ya know Maryland Space Grant

94  
00:04:20,689 --> 00:04:27,019  
Observatory tonight but if you go to MD

95  
00:04:23,569 --> 00:04:29,839  
dot space grant o RG you can find this

96  
00:04:27,019 --> 00:04:32,448  
and they have open houses every Friday

97  
00:04:29,839 --> 00:04:34,668  
you want to check this page for the

98  
00:04:32,449 --> 00:04:37,430  
observatory status right over here on

99  
00:04:34,668 --> 00:04:38,598  
the right-hand side and they'll tell you

100  
00:04:37,430 --> 00:04:43,400

whether or not they're going to be open

101

00:04:38,598 --> 00:04:47,019

on various Fridays okay and now the news

102

00:04:43,399 --> 00:04:49,969

from the universe for March 2018 and

103

00:04:47,019 --> 00:04:53,299

since our speaker has chosen a sort of

104

00:04:49,970 --> 00:04:54,770

Star Trek theme to her talk I decided I

105

00:04:53,300 --> 00:04:57,710

would add a little bit of Star Trek

106

00:04:54,769 --> 00:05:07,038

flavor to my news summary so our first

107

00:04:57,709 --> 00:05:09,408

topic is what factor 500 million when

108

00:05:07,038 --> 00:05:11,839

I'm talking about warp I'm actually not

109

00:05:09,408 --> 00:05:15,348

talking about the Star Trek warp I'm

110

00:05:11,839 --> 00:05:18,709

talking about warped images and this is

111

00:05:15,348 --> 00:05:21,918

Baltimore's Inner Harbor with a Saturn

112

00:05:18,709 --> 00:05:24,589

mass black hole passing over the Inner

113

00:05:21,918 --> 00:05:27,978

Harbor and you can see that the images

114

00:05:24,589 --> 00:05:30,529

of the background buildings are warped



115  
00:05:27,978 --> 00:05:34,430  
by the passage of that black hole

116  
00:05:30,529 --> 00:05:40,038  
because due to general relativity mass

117  
00:05:34,430 --> 00:05:43,038  
bends the mass bends space which changes

118  
00:05:40,038 --> 00:05:45,680  
the direction of light so as you look

119  
00:05:43,038 --> 00:05:47,360  
past a black hole think the light goes

120  
00:05:45,680 --> 00:05:49,280  
around in different directions and it

121  
00:05:47,360 --> 00:05:50,990  
warps the images of the background

122  
00:05:49,279 --> 00:05:52,339  
objects it doesn't actually warp the

123  
00:05:50,990 --> 00:05:54,978  
background objects but it warps those

124  
00:05:52,339 --> 00:05:56,418  
images now that cannot just happen here

125  
00:05:54,978 --> 00:05:58,788  
in Baltimore actually it's never

126  
00:05:56,418 --> 00:06:01,189  
happened here in Baltimore that's just

127  
00:05:58,788 --> 00:06:03,949  
an example but it can actually happen

128  
00:06:01,189 --> 00:06:06,860  
out in the universe in clusters of

129  
00:06:03,949 --> 00:06:09,919  
galaxies these clusters of galaxies have

130  
00:06:06,860 --> 00:06:13,069  
so much matter more mostly dark matter

131  
00:06:09,918 --> 00:06:15,799  
in them that they are massive enough to

132  
00:06:13,069 --> 00:06:17,810  
bend the space around them which

133  
00:06:15,800 --> 00:06:20,360  
actually changes the direction of the

134  
00:06:17,810 --> 00:06:24,199  
light passing through them we call this

135  
00:06:20,360 --> 00:06:26,210  
gravitational lensing gravity changes

136  
00:06:24,199 --> 00:06:28,788  
the direction of the light and it acts

137  
00:06:26,209 --> 00:06:31,129  
like a lens in space so if you've got

138  
00:06:28,788 --> 00:06:33,649  
this lens in space and you've got a

139  
00:06:31,129 --> 00:06:37,639  
telescope lens this actually acts as an

140  
00:06:33,649 --> 00:06:40,579  
extra lens to magnify and amplify the

141  
00:06:37,639 --> 00:06:43,250  
light of more distant objects

142  
00:06:40,579 --> 00:06:45,800  
using these gravitational lenses we can

143

00:06:43,250 --> 00:06:48,560  
see some of the most distant galaxies

144  
00:06:45,800 --> 00:06:53,000  
out there and so in this cluster called

145  
00:06:48,560 --> 00:06:55,189  
max Jo for 606 for seven plus seven oh

146  
00:06:53,000 --> 00:06:57,228  
one five they don't have any great names

147  
00:06:55,189 --> 00:07:00,409  
they're usually just phone numbers like

148  
00:06:57,228 --> 00:07:03,500  
that we actually found a really really

149  
00:07:00,408 --> 00:07:05,750  
distant galaxy and there are actually

150  
00:07:03,500 --> 00:07:07,968  
three images of it the light from this

151  
00:07:05,750 --> 00:07:12,199  
extremely distant galaxy passes three

152  
00:07:07,968 --> 00:07:14,598  
ways through this cluster and appear

153  
00:07:12,199 --> 00:07:18,020  
here here and here and you can see it's

154  
00:07:14,598 --> 00:07:20,689  
beautiful it's a red dot okay that's

155  
00:07:18,019 --> 00:07:23,299  
because it's a galaxy about thirteen

156  
00:07:20,689 --> 00:07:26,269  
billion light-years away one of the most

157  
00:07:23,300 --> 00:07:28,610

distant we've ever seen and when we do

158

00:07:26,269 --> 00:07:31,370

this that's what we usually get we get

159

00:07:28,610 --> 00:07:33,229

red dots because they're very small

160

00:07:31,370 --> 00:07:35,750

galaxies they're very distant and

161

00:07:33,228 --> 00:07:37,968

therefore they're seen in the early part

162

00:07:35,750 --> 00:07:39,889

of the universe okay if it's thirteen

163

00:07:37,968 --> 00:07:43,610

billion light-years away you're seeing

164

00:07:39,889 --> 00:07:46,908

that galaxy as it was 13 billion years

165

00:07:43,610 --> 00:07:49,968

ago okay that's only 800 million years

166

00:07:46,908 --> 00:07:53,990

after the Big Bang that's a really baby

167

00:07:49,968 --> 00:07:56,689

galaxy okay but this was something that

168

00:07:53,990 --> 00:08:00,769

was released a few years ago we have a

169

00:07:56,689 --> 00:08:04,788

new cluster that we looked at this one

170

00:08:00,769 --> 00:08:10,310

has the phone number SP T - CL jo6

171

00:08:04,788 --> 00:08:13,788

1 5 - 5 7 4 6 and in this one we do not

172  
00:08:10,310 --> 00:08:19,848  
have a red dot in this one we actually

173  
00:08:13,788 --> 00:08:23,778  
have a red streak we have a red smudge

174  
00:08:19,848 --> 00:08:26,538  
so this may not look like much to you ok

175  
00:08:23,778 --> 00:08:29,658  
so you got a it's a blur of red instead

176  
00:08:26,538 --> 00:08:33,049  
of a dot of red but actually by getting

177  
00:08:29,658 --> 00:08:35,299  
a red streak the gravitational lensing

178  
00:08:33,049 --> 00:08:38,870  
spreads it out turns it into a streak

179  
00:08:35,299 --> 00:08:40,370  
you can actually examine some of the

180  
00:08:38,870 --> 00:08:42,799  
internal characteristics you can

181  
00:08:40,370 --> 00:08:44,299  
estimate it alright this was found using

182  
00:08:42,799 --> 00:08:46,939  
the Hubble Space Telescope and the

183  
00:08:44,299 --> 00:08:49,759  
Spitzer Space Telescope using a program

184  
00:08:46,940 --> 00:08:53,240  
called relics when they're searched 41

185  
00:08:49,759 --> 00:08:54,088  
large clusters of galaxies looking

186  
00:08:53,240 --> 00:08:56,999  
specifically

187  
00:08:54,089 --> 00:09:00,660  
for these most distant objects and this

188  
00:08:56,999 --> 00:09:01,740  
object they can tell is only about 2,500

189  
00:09:00,659 --> 00:09:04,588  
light-years across

190  
00:09:01,740 --> 00:09:06,209  
now our galaxy is a hundred thousand

191  
00:09:04,589 --> 00:09:09,089  
light-years across so this is tiny

192  
00:09:06,208 --> 00:09:12,388  
compared to our galaxy our galaxy also

193  
00:09:09,089 --> 00:09:14,339  
has about 200 billion stars and the

194  
00:09:12,389 --> 00:09:17,490  
estimate on this is it's about less than

195  
00:09:14,339 --> 00:09:20,790  
three billion stars okay so it's very

196  
00:09:17,490 --> 00:09:22,799  
small it's a dwarf galaxy it's only half

197  
00:09:20,789 --> 00:09:25,049  
the size of what we call the small

198  
00:09:22,799 --> 00:09:27,628  
Magellanic Cloud which is a dwarf galaxy

199  
00:09:25,049 --> 00:09:29,729  
that's orbiting around our Milky Way but

200

00:09:27,629 --> 00:09:32,490  
you wouldn't expect it to be a large

201  
00:09:29,730 --> 00:09:35,039  
galaxy because this galaxy is estimated

202  
00:09:32,490 --> 00:09:38,399  
to be seen thirteen point three billion

203  
00:09:35,039 --> 00:09:42,240  
light-years away which makes we see it

204  
00:09:38,399 --> 00:09:46,889  
only 500 million years after the Big

205  
00:09:42,240 --> 00:09:50,568  
Bang and that's a crucial idea that

206  
00:09:46,889 --> 00:09:54,209  
galaxies of unorder a few billion stars

207  
00:09:50,568 --> 00:09:57,628  
can form within the first 500 million

208  
00:09:54,208 --> 00:10:00,088  
years how long after the Big Bang

209  
00:09:57,629 --> 00:10:02,039  
does it take four stars in galaxies to

210  
00:10:00,089 --> 00:10:04,529  
form that's one of the great questions

211  
00:10:02,039 --> 00:10:06,419  
in cosmology that we're pursuing this

212  
00:10:04,528 --> 00:10:08,730  
gives us evidence that at least you can

213  
00:10:06,419 --> 00:10:11,719  
get a few billion stars together in one

214  
00:10:08,730 --> 00:10:16,050

sort of clump 500 million years later

215

00:10:11,720 --> 00:10:17,759

now Hubble can't see the most

216

00:10:16,049 --> 00:10:20,248

distant galaxies because they're red

217

00:10:17,759 --> 00:10:22,589

shifted into the infrared so this is

218

00:10:20,249 --> 00:10:23,839

sort of a precursor for what we will see

219

00:10:22,589 --> 00:10:26,100

with the James Webb Space Telescope

220

00:10:23,839 --> 00:10:28,980

that's currently slated to launch in

221

00:10:26,100 --> 00:10:30,839

spring of 2019 so a little over a year

222

00:10:28,980 --> 00:10:33,089

from now the James Webb Space Telescope

223

00:10:30,839 --> 00:10:35,519

will launch and after it becomes

224

00:10:33,089 --> 00:10:37,649

observation operational we'll get more

225

00:10:35,519 --> 00:10:39,209

and more images like this and you can

226

00:10:37,649 --> 00:10:42,120

expect me to give you more and more

227

00:10:39,208 --> 00:10:44,969

stories looking at the first billion

228

00:10:42,120 --> 00:10:47,249

years of galaxy formation and having



229  
00:10:44,970 --> 00:10:49,470  
much greater statistics and getting an

230  
00:10:47,249 --> 00:10:51,659  
understanding of how galaxies initially

231  
00:10:49,470 --> 00:10:55,678  
formed in the universe so this is a

232  
00:10:51,659 --> 00:10:58,669  
great cool precursor and I named it warp

233  
00:10:55,678 --> 00:11:02,039  
factor 5 million because using the warp

234  
00:10:58,669 --> 00:11:04,708  
created by this galaxy cluster were able

235  
00:11:02,039 --> 00:11:07,480  
to see back to 500 million years after

236  
00:11:04,708 --> 00:11:10,989  
the Big Bang

237  
00:11:07,480 --> 00:11:13,289  
our second story lack of j-class

238  
00:11:10,990 --> 00:11:16,839  
atmospheres raises hopes of m-class

239  
00:11:13,289 --> 00:11:18,879  
planets alright so if you know your Star

240  
00:11:16,839 --> 00:11:21,279  
Trek okay you know that almost

241  
00:11:18,879 --> 00:11:23,169  
everything they visited was oh it's yet

242  
00:11:21,278 --> 00:11:25,750  
captain it's a nemesis m-class planet

243  
00:11:23,169 --> 00:11:27,939  
which means an earth-like planet okay

244  
00:11:25,750 --> 00:11:31,929  
I'm actually looked up on Wikipedia

245  
00:11:27,940 --> 00:11:36,190  
today they have 23 different classes of

246  
00:11:31,929 --> 00:11:37,088  
planets to find in Star Trek it's kind

247  
00:11:36,190 --> 00:11:40,329  
of blew my mind

248  
00:11:37,089 --> 00:11:42,579  
the specificity they had of these 23

249  
00:11:40,328 --> 00:11:44,859  
different classes of planets and it

250  
00:11:42,578 --> 00:11:47,679  
found out that the J class is the

251  
00:11:44,860 --> 00:11:49,778  
jupiter class Jupiter Saturn Uranus and

252  
00:11:47,679 --> 00:11:51,729  
Neptune gas giants although they aren't

253  
00:11:49,778 --> 00:11:53,350  
the only class of gas giants there's

254  
00:11:51,730 --> 00:11:55,539  
lots of several different classes out

255  
00:11:53,350 --> 00:11:57,190  
gassed gas giants I think the largest

256  
00:11:55,539 --> 00:11:59,049  
is the T class or something like that

257

00:11:57,190 --> 00:12:02,620  
I'm not a Trekkie so I don't know all

258  
00:11:59,049 --> 00:12:06,370  
this stuff but I'm using that to talk

259  
00:12:02,620 --> 00:12:10,539  
about the planets in the system Trappist

260  
00:12:06,370 --> 00:12:12,250  
one now this is an artistic presentation

261  
00:12:10,539 --> 00:12:14,528  
of the Trappist one system we talked

262  
00:12:12,250 --> 00:12:18,940  
about this before in which there are

263  
00:12:14,528 --> 00:12:21,338  
seven earth sized planets around a red

264  
00:12:18,940 --> 00:12:23,230  
dwarf star and this artistic

265  
00:12:21,339 --> 00:12:25,149  
presentation is supposed to show that

266  
00:12:23,230 --> 00:12:27,639  
okay here we have the red dwarf star and

267  
00:12:25,149 --> 00:12:31,028  
here we have steam to indicate it's hot

268  
00:12:27,639 --> 00:12:32,860  
water would be boiling away here we have

269  
00:12:31,028 --> 00:12:35,559  
water in its liquid form in the middle

270  
00:12:32,860 --> 00:12:39,159  
and out here we have water in ice form

271  
00:12:35,559 --> 00:12:41,169

where it's cold okay and several of

272

00:12:39,159 --> 00:12:44,769

these planets in the Trappist one system

273

00:12:41,169 --> 00:12:47,318

are in the region where liquid water

274

00:12:44,769 --> 00:12:50,709

would be liquid and that's what we call

275

00:12:47,318 --> 00:12:54,009

the habitable zone all right if you want

276

00:12:50,708 --> 00:12:55,509

a more didactic presentation of it here

277

00:12:54,009 --> 00:13:00,068

is the Travis one system with the red

278

00:12:55,509 --> 00:13:03,278

dwarf star here and the seven planets b

279

00:13:00,068 --> 00:13:06,278

c d e f h you've heard of Snow White

280

00:13:03,278 --> 00:13:09,429

and the Seven Dwarfs this is Red Dwarf

281

00:13:06,278 --> 00:13:14,429

and the Seven earth-sized planets in the

282

00:13:09,429 --> 00:13:17,049

Trappist one system now this is artistic

283

00:13:14,429 --> 00:13:20,649

interpretation okay do we know what

284

00:13:17,049 --> 00:13:23,979

these planets look like no not at all

285

00:13:20,649 --> 00:13:27,068

don't actually see the planets what we

286  
00:13:23,980 --> 00:13:29,170  
see is the planets pass in front of the

287  
00:13:27,068 --> 00:13:32,610  
star and block a little bit of the light

288  
00:13:29,169 --> 00:13:35,740  
so the light for that star drops and

289  
00:13:32,610 --> 00:13:38,409  
rises back up as the planet passes in

290  
00:13:35,740 --> 00:13:40,778  
front we call this the transit method of

291  
00:13:38,409 --> 00:13:43,838  
finding extrasolar planets and we found

292  
00:13:40,778 --> 00:13:48,730  
seven of these around this star so we

293  
00:13:43,839 --> 00:13:52,389  
don't actually see the planet but we

294  
00:13:48,730 --> 00:13:55,360  
could see its atmosphere because when a

295  
00:13:52,389 --> 00:13:57,249  
planet passes in front of a star some of

296  
00:13:55,360 --> 00:13:59,619  
the light of the star will go through

297  
00:13:57,249 --> 00:14:02,678  
that planet's atmosphere

298  
00:13:59,619 --> 00:14:05,889  
and the chemical elements in that

299  
00:14:02,678 --> 00:14:08,169  
planet's atmosphere will absorb some of

300  
00:14:05,889 --> 00:14:11,110  
the star's light so if you take a

301  
00:14:08,169 --> 00:14:12,818  
spectrum of the star and then you take

302  
00:14:11,110 --> 00:14:15,970  
another spectrum with the planet in

303  
00:14:12,818 --> 00:14:18,969  
front of the star subtract the two you

304  
00:14:15,970 --> 00:14:22,480  
get the spectrum of the planet's

305  
00:14:18,970 --> 00:14:24,879  
atmosphere how cool is that we can

306  
00:14:22,480 --> 00:14:28,058  
actually start to see the atmospheres of

307  
00:14:24,879 --> 00:14:30,928  
planets around other stars so we wanted

308  
00:14:28,058 --> 00:14:34,328  
to tell do these earth sized planets

309  
00:14:30,928 --> 00:14:36,639  
have earth-like atmospheres all right

310  
00:14:34,328 --> 00:14:39,669  
and so what we can tell here is if it

311  
00:14:36,639 --> 00:14:42,549  
has a big extended atmosphere we'll see

312  
00:14:39,669 --> 00:14:44,528  
a lot of absorption okay this big

313  
00:14:42,549 --> 00:14:47,528  
extended atmosphere we'd expect to be

314

00:14:44,528 --> 00:14:50,919  
hydrogen puffed up a poor primordial

315  
00:14:47,528 --> 00:14:54,009  
type atmosphere okay however if it has a

316  
00:14:50,919 --> 00:14:57,009  
thin atmosphere sort of like mercury I

317  
00:14:54,009 --> 00:14:58,870  
mean Venus Earth and Mars have today you

318  
00:14:57,009 --> 00:15:00,759  
know it's not primordial it's processed

319  
00:14:58,870 --> 00:15:02,499  
it has a good good amount of heavier

320  
00:15:00,759 --> 00:15:04,480  
elements in it well then it would have a

321  
00:15:02,499 --> 00:15:07,959  
thinner atmosphere and we'd see almost

322  
00:15:04,480 --> 00:15:09,670  
no absorption okay so if it has a big

323  
00:15:07,958 --> 00:15:11,828  
atmosphere we're gonna see absorption if

324  
00:15:09,669 --> 00:15:13,778  
it has a small atmosphere we're not

325  
00:15:11,828 --> 00:15:17,498  
going to see absorption all right here

326  
00:15:13,778 --> 00:15:19,899  
is the actual data ok presented in an

327  
00:15:17,499 --> 00:15:23,110  
artistic fashion the purple is what we

328  
00:15:19,899 --> 00:15:26,139

would expect if it had this large

329

00:15:23,110 --> 00:15:29,318

primordial atmosphere the yellow is the

330

00:15:26,139 --> 00:15:31,329

actual data and you can see that the

331

00:15:29,318 --> 00:15:34,009

actual data in the yellow it's

332

00:15:31,328 --> 00:15:37,609

consistent with basically a flat line

333

00:15:34,009 --> 00:15:40,939

not the big up-and-down that we see in

334

00:15:37,610 --> 00:15:44,690

the primordial atmosphere so for these

335

00:15:40,940 --> 00:15:48,230

four planets three of them D F and E all

336

00:15:44,690 --> 00:15:51,770

in habitable zone we do not see a large

337

00:15:48,230 --> 00:15:53,779

primordial atmosphere G we're not quite

338

00:15:51,769 --> 00:15:55,250

sure of okay then we need a little bit

339

00:15:53,779 --> 00:15:57,319

more we can't say with absolute

340

00:15:55,250 --> 00:15:59,690

certainty that G doesn't have a big

341

00:15:57,320 --> 00:16:01,790

atmosphere most likely it doesn't but

342

00:15:59,690 --> 00:16:03,680

you know we we have we have certain



343  
00:16:01,789 --> 00:16:07,819  
measures of this and this one's not good

344  
00:16:03,679 --> 00:16:11,449  
enough to say for sure so this lack of

345  
00:16:07,820 --> 00:16:14,420  
this j-class atmosphere indicates that

346  
00:16:11,450 --> 00:16:16,129  
it could have an m-class atmosphere but

347  
00:16:14,419 --> 00:16:19,370  
does it say it absolutely has an m-class

348  
00:16:16,129 --> 00:16:21,080  
atmosphere no it just says it doesn't

349  
00:16:19,370 --> 00:16:23,990  
have a doesn't have a large extended

350  
00:16:21,080 --> 00:16:26,389  
atmosphere which adds to the hope that

351  
00:16:23,990 --> 00:16:29,600  
these could actually be more earth-like

352  
00:16:26,389 --> 00:16:31,519  
they're not neptune like okay sometimes

353  
00:16:29,600 --> 00:16:33,740  
we think of these Earth's earth sized

354  
00:16:31,519 --> 00:16:35,210  
objects they could be super Earths that

355  
00:16:33,740 --> 00:16:37,070  
could be mini Neptune's these are not

356  
00:16:35,210 --> 00:16:39,980  
mini app tunes okay they don't have

357  
00:16:37,070 --> 00:16:42,470  
extended atmospheres like this so one

358  
00:16:39,980 --> 00:16:45,159  
checkmark yes in terms of moving forward

359  
00:16:42,470 --> 00:16:48,379  
in terms of trying to find earth-like

360  
00:16:45,159 --> 00:16:50,029  
planets we know their earth sized now

361  
00:16:48,379 --> 00:16:53,450  
we're continuing to try and find out if

362  
00:16:50,029 --> 00:16:54,289  
they're earth-like and this is a good as

363  
00:16:53,450 --> 00:16:56,920  
a good sign

364  
00:16:54,289 --> 00:16:59,959  
moving forward in that direction again

365  
00:16:56,919 --> 00:17:02,149  
we will find more out by when we have

366  
00:16:59,960 --> 00:17:03,110  
infrared observations of the James Webb

367  
00:17:02,149 --> 00:17:05,480  
Space Telescope

368  
00:17:03,110 --> 00:17:07,759  
because extrasolar planets actually

369  
00:17:05,480 --> 00:17:09,559  
shine in the infrared they're brighter

370  
00:17:07,759 --> 00:17:13,879  
in the infrared especially relative to

371

00:17:09,559 --> 00:17:15,799  
their host stars so again pointing to

372  
00:17:13,880 --> 00:17:17,350  
the future we're going to have a lot

373  
00:17:15,799 --> 00:17:20,480  
more of these type of stories as well

374  
00:17:17,349 --> 00:17:23,389  
when the infrared Space Telescope the

375  
00:17:20,480 --> 00:17:25,789  
JIT web is up there in next use next

376  
00:17:23,390 --> 00:17:28,250  
year and the year after us okay all

377  
00:17:25,789 --> 00:17:31,849  
right and so that is our news from the

378  
00:17:28,250 --> 00:17:35,569  
universe our featured speaker tonight is

379  
00:17:31,849 --> 00:17:38,349  
MIA boville who has this is like your

380  
00:17:35,569 --> 00:17:41,509  
third time talking here right she's

381  
00:17:38,349 --> 00:17:43,399  
coming she's wonderful because she comes

382  
00:17:41,509 --> 00:17:45,819  
and she volunteers for me every year

383  
00:17:43,400 --> 00:17:48,220  
okay there are

384  
00:17:45,819 --> 00:17:49,809  
number of speakers who you know I have

385  
00:17:48,220 --> 00:17:52,900

to with Trista arms to volunteer once

386

00:17:49,809 --> 00:17:55,809

every five or ten years okay but dia has

387

00:17:52,900 --> 00:17:59,350

come in and last time you talked on the

388

00:17:55,809 --> 00:18:00,460

the Harvard Harvard computers right

389

00:17:59,349 --> 00:18:03,549

that's what I would like to call them

390

00:18:00,460 --> 00:18:07,090

okay and tonight she is going to talk to

391

00:18:03,549 --> 00:18:10,119

you about the science of observing the

392

00:18:07,089 --> 00:18:14,669

galaxy with a wonderful Star Trek flare

393

00:18:10,119 --> 00:18:22,959

so ladies and gentlemen miss Mia Bobo I

394

00:18:14,670 --> 00:18:25,690

will call you doctor I missed you

395

00:18:22,960 --> 00:18:27,430

there we go so first off I'd like to

396

00:18:25,690 --> 00:18:33,820

apologize to every single person in this

397

00:18:27,430 --> 00:18:37,630

room in a red shirt all right now like a

398

00:18:33,819 --> 00:18:40,809

good scientist you cite your sources so

399

00:18:37,630 --> 00:18:43,690

for the science chunk of this talk I

400  
00:18:40,809 --> 00:18:46,799  
used galactic astronomy this is the one

401  
00:18:43,690 --> 00:18:49,090  
of the Bible's of our galaxy's course

402  
00:18:46,799 --> 00:18:51,399  
when I'm gonna cover the mapping of the

403  
00:18:49,089 --> 00:18:54,189  
Milky Way is a month in a graduate-level

404  
00:18:51,400 --> 00:18:57,100  
galaxies course and I'm going to attempt

405  
00:18:54,190 --> 00:19:02,019  
to do this in 40 minutes so I might lose

406  
00:18:57,099 --> 00:19:08,019  
leave a few things out and for the rest

407  
00:19:02,019 --> 00:19:09,759  
of it so this is the Star Trek Star Trek

408  
00:19:08,019 --> 00:19:11,740  
Atlas actually had to order this from

409  
00:19:09,759 --> 00:19:14,349  
San Luis Obispo California because

410  
00:19:11,740 --> 00:19:16,539  
apparently it's no longer in print but

411  
00:19:14,349 --> 00:19:19,179  
for is the act for the mapping of

412  
00:19:16,539 --> 00:19:21,369  
specific worlds to specific xual real

413  
00:19:19,180 --> 00:19:23,200  
stars which I'll get into towards the

414  
00:19:21,369 --> 00:19:25,359  
end of the talk this is what I used if

415  
00:19:23,200 --> 00:19:27,519  
anybody is a bigger Trekkie than me and

416  
00:19:25,359 --> 00:19:32,789  
wants to take issue with exactly what

417  
00:19:27,519 --> 00:19:32,789  
star I plotted just look at this first

418  
00:19:33,210 --> 00:19:40,380  
and I'd like to just point out that I do

419  
00:19:35,410 --> 00:19:43,240  
have a towel in my backpack

420  
00:19:40,380 --> 00:19:45,640  
all right so just to get this out of the

421  
00:19:43,240 --> 00:19:47,529  
way Star Trek is wonderful it does a lot

422  
00:19:45,640 --> 00:19:51,160  
of things really really well science is

423  
00:19:47,529 --> 00:19:52,930  
not one of them so this is a list of the

424  
00:19:51,160 --> 00:19:55,509  
things that Star Trek roughly speaking

425  
00:19:52,930 --> 00:19:58,269  
gets right we live in the Milky Way

426  
00:19:55,509 --> 00:19:59,440  
galaxy the Milky Way galaxy is about a

427  
00:19:58,269 --> 00:20:00,879  
hundred thousand light-years across

428

00:19:59,440 --> 00:20:02,170  
there how much of that is them getting

429  
00:20:00,880 --> 00:20:05,140  
it right and how much of that was dumb

430  
00:20:02,170 --> 00:20:07,810  
luck I'm not actually certain there are

431  
00:20:05,140 --> 00:20:09,840  
nebulae in the Milky Way they won't eat

432  
00:20:07,809 --> 00:20:12,579  
your ship they won't corrode your ship

433  
00:20:09,839 --> 00:20:14,259  
and they are significantly bigger than

434  
00:20:12,579 --> 00:20:20,069  
your ability to jot in and out at

435  
00:20:14,259 --> 00:20:20,069  
impulse there are stars in the Milky Way

436  
00:20:20,279 --> 00:20:25,930  
many of those stars have planets in fact

437  
00:20:23,319 --> 00:20:28,389  
we have been finding a lot of them this

438  
00:20:25,930 --> 00:20:30,310  
is as of December of 2017 and it

439  
00:20:28,390 --> 00:20:33,940  
probably needs to be updated

440  
00:20:30,309 --> 00:20:36,039  
the Kepler this is the full thing of the

441  
00:20:33,940 --> 00:20:38,799  
Kepler space telescope so this is all

442  
00:20:36,039 --> 00:20:41,710

the one planet systems two three four

443

00:20:38,799 --> 00:20:43,809

five six this is the Trappist one system

444

00:20:41,710 --> 00:20:48,069

that dr. Sommers was talking about our

445

00:20:43,809 --> 00:20:50,259

solar system and the Kepler 90 system so

446

00:20:48,069 --> 00:20:51,429

there are planets around stars in fact

447

00:20:50,259 --> 00:20:55,660

there were a lot more planets around

448

00:20:51,430 --> 00:20:57,279

stars and we thought there were some of

449

00:20:55,660 --> 00:20:59,440

these planets maybe in the habitable

450

00:20:57,279 --> 00:21:01,210

zone of their star and by habitable zone

451

00:20:59,440 --> 00:21:03,759

I do not mean m-class with the Vulcans

452

00:21:01,210 --> 00:21:05,289

on them I mean they are at the right

453

00:21:03,759 --> 00:21:07,299

distance from their star to have liquid

454

00:21:05,289 --> 00:21:09,099

water on their surface which means

455

00:21:07,299 --> 00:21:10,839

you've got a chance at actually having

456

00:21:09,099 --> 00:21:12,730

life whether that life becomes



457  
00:21:10,839 --> 00:21:15,389  
intelligent and develops warp drive well

458  
00:21:12,730 --> 00:21:19,539  
that's a complete other set of questions

459  
00:21:15,390 --> 00:21:22,660  
there are such things as neutron stars

460  
00:21:19,539 --> 00:21:25,029  
pulsars black holes dark matter and

461  
00:21:22,660 --> 00:21:26,710  
supernova explosions the statistical

462  
00:21:25,029 --> 00:21:30,839  
chance that they used these correctly in

463  
00:21:26,710 --> 00:21:30,840  
any given Star Trek episode is about 10%

464  
00:21:31,390 --> 00:21:36,070  
they do occasionally get this right but

465  
00:21:34,240 --> 00:21:38,859  
more likely than not they get it wrong

466  
00:21:36,069 --> 00:21:42,339  
and no you cannot punch your way through

467  
00:21:38,859 --> 00:21:46,240  
the event horizon of a black hole but

468  
00:21:42,339 --> 00:21:48,220  
primarily space is big however big you

469  
00:21:46,240 --> 00:21:50,529  
think space is it's bigger

470  
00:21:48,220 --> 00:21:55,059  
however weird do you think spaces it's

471  
00:21:50,529 --> 00:21:58,000  
weirder so now that we've gotten that

472  
00:21:55,059 --> 00:21:59,919  
out of the way before you the enterprise

473  
00:21:58,000 --> 00:22:02,440  
you can tell the enterprise or whichever

474  
00:21:59,920 --> 00:22:04,450  
particular starship you're on to go - I

475  
00:22:02,440 --> 00:22:06,940  
don't know insert techno babble here in

476  
00:22:04,450 --> 00:22:08,950  
the sector first you have to know where

477  
00:22:06,940 --> 00:22:11,920  
on earth that sector or in the galaxy

478  
00:22:08,950 --> 00:22:13,690  
that sector actually is and these are

479  
00:22:11,920 --> 00:22:15,940  
actually the only two good images I

480  
00:22:13,690 --> 00:22:17,410  
could find from Star Trek episodes of

481  
00:22:15,940 --> 00:22:24,940  
the various characters standing in front

482  
00:22:17,410 --> 00:22:26,560  
of a map but before you can start to say

483  
00:22:24,940 --> 00:22:29,380  
where did the enterprise go you first

484  
00:22:26,559 --> 00:22:31,359  
have to figure out where we are and that

485

00:22:29,380 --> 00:22:33,760  
starts with a very seemingly simple

486  
00:22:31,359 --> 00:22:37,539  
question where is the earth located in

487  
00:22:33,759 --> 00:22:39,190  
our solar system the planets will five

488  
00:22:37,539 --> 00:22:40,539  
of them are extremely bright they're

489  
00:22:39,190 --> 00:22:42,960  
very easy to measure in fact we've been

490  
00:22:40,539 --> 00:22:45,700  
measuring them for thousands of years

491  
00:22:42,960 --> 00:22:47,680  
but it's actually not so simple because

492  
00:22:45,700 --> 00:22:51,190  
we have to go even further back in time

493  
00:22:47,680 --> 00:22:56,710  
back to 270 BC and the Golden Age of

494  
00:22:51,190 --> 00:23:00,910  
Pericles as Athens this is Aristarchus

495  
00:22:56,710 --> 00:23:02,590  
of Samos and he went against the green a

496  
00:23:00,910 --> 00:23:04,710  
little bit he believed the Sun was at

497  
00:23:02,589 --> 00:23:08,230  
the center of the solar system that

498  
00:23:04,710 --> 00:23:10,329  
other stars were extremely far away and

499  
00:23:08,230 --> 00:23:13,630

that they there were other stars like

500

00:23:10,329 --> 00:23:15,639

our Sun and that's why as the earth

501

00:23:13,630 --> 00:23:19,630

moved around the Sun we didn't see those

502

00:23:15,640 --> 00:23:23,290

stars stars move against the sky however

503

00:23:19,630 --> 00:23:25,870

he was only one voice and at the same

504

00:23:23,289 --> 00:23:28,119

time there was some pretty big voices

505

00:23:25,869 --> 00:23:32,349

saying that no no no the Earth's at the

506

00:23:28,119 --> 00:23:37,149

center were stationary everything moves

507

00:23:32,349 --> 00:23:40,119

around us and this was Aristotle here

508

00:23:37,150 --> 00:23:42,340

and Ptolemy as in the Ptolemaic system

509

00:23:40,119 --> 00:23:42,969

he gets he's the poor schmuck that gets

510

00:23:42,339 --> 00:23:46,599

this name

511

00:23:42,970 --> 00:23:48,700

for him now you have the earth here at

512

00:23:46,599 --> 00:23:51,099

the center you have the moon going

513

00:23:48,700 --> 00:23:54,880

around and you have the Sun going around

514  
00:23:51,099 --> 00:23:56,349  
all in perfect circles however the

515  
00:23:54,880 --> 00:23:58,270  
problem is that if you actually look at

516  
00:23:56,349 --> 00:24:00,369  
the movement of a planet on the sky

517  
00:23:58,269 --> 00:24:01,779  
it'll kind of go this way a little bit

518  
00:24:00,369 --> 00:24:05,769  
and then it'll kind of go this way again

519  
00:24:01,779 --> 00:24:07,509  
and then I'll go back this way and the

520  
00:24:05,769 --> 00:24:09,579  
part where went backwards was retrograde

521  
00:24:07,509 --> 00:24:11,349  
motion and if everything's just orbiting

522  
00:24:09,579 --> 00:24:13,720  
the earth happy as you please you're not

523  
00:24:11,349 --> 00:24:17,379  
going to have retrograde motion so they

524  
00:24:13,720 --> 00:24:20,110  
inserted what they called epicycles onto

525  
00:24:17,380 --> 00:24:22,840  
each of these orbits depending on how

526  
00:24:20,109 --> 00:24:25,119  
much of the time the planet went

527  
00:24:22,839 --> 00:24:29,980  
backwards and how frequently it went

528  
00:24:25,119 --> 00:24:32,529  
backwards I'd and they and this worked

529  
00:24:29,980 --> 00:24:34,450  
they could predict with those circular

530  
00:24:32,529 --> 00:24:36,190  
orbits around the earth and epicycles

531  
00:24:34,450 --> 00:24:37,960  
they could roughly get the predict to

532  
00:24:36,190 --> 00:24:39,400  
the positions of the planets because

533  
00:24:37,960 --> 00:24:41,470  
that's your Holy Grail that's what you

534  
00:24:39,400 --> 00:24:43,690  
want to do you want to be able to

535  
00:24:41,470 --> 00:24:46,210  
predict where the planets are going to

536  
00:24:43,690 --> 00:24:50,710  
be the problem is that as you move

537  
00:24:46,210 --> 00:24:53,740  
forward in time the model kind of fell

538  
00:24:50,710 --> 00:24:56,259  
apart the predictions with just one MP

539  
00:24:53,740 --> 00:24:57,819  
cycle weren't working now if that's

540  
00:24:56,259 --> 00:24:59,288  
getting further and further off the

541  
00:24:57,819 --> 00:25:00,700  
actual position of the planet you would

542

00:24:59,288 --> 00:25:02,259  
think well maybe we should go back to

543  
00:25:00,700 --> 00:25:04,240  
what that other guy was saying and try

544  
00:25:02,259 --> 00:25:08,048  
heliocentric they just added more

545  
00:25:04,240 --> 00:25:09,460  
epicycles there's a principle in science

546  
00:25:08,048 --> 00:25:11,879  
called Occam's razor it's that the

547  
00:25:09,460 --> 00:25:16,298  
simplest solution is probably the best

548  
00:25:11,880 --> 00:25:18,039  
so we're gonna jump forward to 1609 this

549  
00:25:16,298 --> 00:25:20,168  
is about 30 years after Nicholas

550  
00:25:18,038 --> 00:25:21,819  
Copernicus once more resurrected the

551  
00:25:20,169 --> 00:25:25,830  
idea that yes the Sun is at the center

552  
00:25:21,819 --> 00:25:28,298  
of the solar system but like

553  
00:25:25,829 --> 00:25:30,849  
Aristophanes and aristotle and ptolemy

554  
00:25:28,298 --> 00:25:35,288  
he assumed the planets were on circular

555  
00:25:30,849 --> 00:25:38,589  
orbits perfect circles enter these two

556  
00:25:35,288 --> 00:25:40,298

gentlemen this is taco Brockie he was

557

00:25:38,589 --> 00:25:42,849

probably he was an incredibly fast

558

00:25:40,298 --> 00:25:44,589

talker he somehow convinced the King of

559

00:25:42,849 --> 00:25:45,519

Denmark to give him a castle and build

560

00:25:44,589 --> 00:25:48,490

him the most state-of-the-art

561

00:25:45,519 --> 00:25:49,599

observatory in Europe I really want to

562

00:25:48,490 --> 00:25:51,799

know how he did this because I've got

563

00:25:49,599 --> 00:25:56,219

grant proposals do

564

00:25:51,799 --> 00:25:58,440

for 30 years he puts together the most

565

00:25:56,220 --> 00:26:00,990

accurate set of measurements of the

566

00:25:58,440 --> 00:26:04,769

planets in existence he's able to do

567

00:26:00,990 --> 00:26:07,079

because he has these huge instruments

568

00:26:04,769 --> 00:26:09,139

this is a Sexton that allows him to

569

00:26:07,079 --> 00:26:11,579

measure very accurately the positions

570

00:26:09,140 --> 00:26:14,730

he's still going by naked-eye he's not



571  
00:26:11,579 --> 00:26:16,379  
using a telescope Galileo gali hasn't

572  
00:26:14,730 --> 00:26:18,150  
happened well he's alive but he hasn't

573  
00:26:16,380 --> 00:26:22,050  
actually aim to telescope at Jupiter yet

574  
00:26:18,150 --> 00:26:24,540  
and after 30 years of developing all of

575  
00:26:22,049 --> 00:26:27,269  
this data he passes that data off to you

576  
00:26:24,539 --> 00:26:28,529  
Hannes Kepler and that's a name that if

577  
00:26:27,269 --> 00:26:31,109  
you've been following all the planet

578  
00:26:28,529 --> 00:26:33,619  
formation we named a planet finding

579  
00:26:31,109 --> 00:26:36,689  
mission for him for a very good reason

580  
00:26:33,619 --> 00:26:39,029  
Brahe he tells him look at Mars Mars is

581  
00:26:36,690 --> 00:26:42,570  
the weird one if you can solve Mars you

582  
00:26:39,029 --> 00:26:44,160  
can solve all of it and Kepler keep in

583  
00:26:42,569 --> 00:26:46,139  
mind there's no slices there's no

584  
00:26:44,160 --> 00:26:48,900  
computers for the younger people in the

585  
00:26:46,140 --> 00:26:50,370  
room there's no scientific calculators

586  
00:26:48,900 --> 00:26:52,320  
for the slightly older people in the

587  
00:26:50,369 --> 00:26:56,579  
room and slide rules haven't been

588  
00:26:52,319 --> 00:27:00,929  
invented yet for the rest of the people

589  
00:26:56,579 --> 00:27:04,559  
in the room this is what Kepler figures

590  
00:27:00,930 --> 00:27:07,710  
out that the orbits of the planets are

591  
00:27:04,559 --> 00:27:09,179  
not circular there are ellipses now it

592  
00:27:07,710 --> 00:27:11,340  
just so happens for the orbit of the

593  
00:27:09,180 --> 00:27:13,230  
earth if I were to plot a circle on this

594  
00:27:11,339 --> 00:27:14,730  
slide and then plot the orbit of the

595  
00:27:13,230 --> 00:27:16,319  
earth on top of it you would not be able

596  
00:27:14,730 --> 00:27:19,140  
to tell the difference it's extremely

597  
00:27:16,319 --> 00:27:22,849  
close to a circle but for some planets

598  
00:27:19,140 --> 00:27:26,790  
this is the inner solar system like Mars

599

00:27:22,849 --> 00:27:29,759  
they're further off a circle the further

600  
00:27:26,789 --> 00:27:32,220  
off a circle the more elliptical or

601  
00:27:29,759 --> 00:27:33,450  
eccentric is the term we use the orbit

602  
00:27:32,220 --> 00:27:36,180  
is then we're clear

603  
00:27:33,450 --> 00:27:39,809  
this comes the more clearly this comes

604  
00:27:36,180 --> 00:27:43,350  
through so we have the Sun Mercury Venus

605  
00:27:39,809 --> 00:27:45,960  
Earth Mars the asteroid belt which we

606  
00:27:43,349 --> 00:27:50,659  
know is there but they didn't they knew

607  
00:27:45,960 --> 00:27:54,390  
about Jupiter which is here and Saturn

608  
00:27:50,660 --> 00:27:56,040  
that's it Uranus and Neptune we'll have

609  
00:27:54,390 --> 00:27:57,330  
to wait for telescopes to be discovered

610  
00:27:56,039 --> 00:28:01,889  
and there is no way they know about

611  
00:27:57,329 --> 00:28:03,539  
Pluto regardless of its status and just

612  
00:28:01,890 --> 00:28:05,009  
as a reminder that we are all already

613  
00:28:03,539 --> 00:28:08,849

very much in

614

00:28:05,009 --> 00:28:11,279

all of the green things on here our

615

00:28:08,849 --> 00:28:13,798

space missions which are currently out

616

00:28:11,279 --> 00:28:15,808

there that is the location of all of the

617

00:28:13,798 --> 00:28:21,210

space missions in our solar system as of

618

00:28:15,808 --> 00:28:23,369

this year this is pioneer ten pioneer 11

619

00:28:21,210 --> 00:28:26,179

and Voyager 1 and Voyager

620

00:28:23,369 --> 00:28:29,609

or I guess feature is what it ends up

621

00:28:26,179 --> 00:28:31,380

one and two are going off in different

622

00:28:29,609 --> 00:28:33,959

directions for the edge of our solar

623

00:28:31,380 --> 00:28:35,900

system so there's a reason we named a

624

00:28:33,960 --> 00:28:38,370

plan to find a mission for this guy so

625

00:28:35,900 --> 00:28:41,519

we now know that Earth is the third

626

00:28:38,369 --> 00:28:44,389

planet orbiting a relatively boring g2

627

00:28:41,519 --> 00:28:47,789

star we're actually lucky it's boring

628  
00:28:44,390 --> 00:28:50,190  
but how far away are those stars so we

629  
00:28:47,789 --> 00:28:53,279  
know they must be pretty far but how far

630  
00:28:50,190 --> 00:28:56,250  
are they actually and now we need some

631  
00:28:53,279 --> 00:28:58,440  
audience participation without hitting

632  
00:28:56,250 --> 00:29:00,990  
the person next to you or hit the person

633  
00:28:58,440 --> 00:29:02,548  
next to you if you don't like them hold

634  
00:29:00,990 --> 00:29:06,298  
your finger out in front of your face at

635  
00:29:02,548 --> 00:29:08,400  
arm's length all right if you can wink

636  
00:29:06,298 --> 00:29:13,319  
between one eye and the next do that

637  
00:29:08,400 --> 00:29:17,580  
otherwise use your hand does your finger

638  
00:29:13,319 --> 00:29:19,759  
move yes all right now stop using your

639  
00:29:17,579 --> 00:29:22,250  
finger and do the same thing with my arm

640  
00:29:19,759 --> 00:29:25,829  
now do this with my hand

641  
00:29:22,250 --> 00:29:31,048  
duck put your hand down and jump between

642  
00:29:25,829 --> 00:29:32,639  
and does my hand move a little for the

643  
00:29:31,048 --> 00:29:33,200  
people in the front a little for the

644  
00:29:32,640 --> 00:29:39,840  
back

645  
00:29:33,200 --> 00:29:41,880  
no that is parallax every single time

646  
00:29:39,839 --> 00:29:44,519  
you walk down the street and don't run

647  
00:29:41,880 --> 00:29:46,620  
into something you're using parallax and

648  
00:29:44,519 --> 00:29:49,019  
that's the fact that your eyes are

649  
00:29:46,619 --> 00:29:51,029  
separated is actually allowing you to

650  
00:29:49,019 --> 00:29:52,619  
have depth perception for those of you

651  
00:29:51,029 --> 00:29:56,308  
with glasses and I mean the people like

652  
00:29:52,619 --> 00:29:57,779  
me whose eyes just don't work if you've

653  
00:29:56,308 --> 00:30:02,970  
ever taken off your glasses you'll

654  
00:29:57,779 --> 00:30:04,798  
promptly run into a wall that's why so

655  
00:30:02,970 --> 00:30:06,509  
when you take this and instead of being

656

00:30:04,798 --> 00:30:08,700  
our eyes and our heads you actually talk

657  
00:30:06,509 --> 00:30:11,849  
about the earth you have the earth has

658  
00:30:08,700 --> 00:30:16,100  
an orbit it is one astronomical unit

659  
00:30:11,849 --> 00:30:18,359  
about 93 million miles from our Sun and

660  
00:30:16,099 --> 00:30:22,679  
if you look at us

661  
00:30:18,359 --> 00:30:26,099  
service star in January and observe that

662  
00:30:22,680 --> 00:30:30,029  
same star in July sir here's your star

663  
00:30:26,099 --> 00:30:33,299  
and you look at it if that star is close

664  
00:30:30,029 --> 00:30:39,750  
enough it'll appear to shift just like

665  
00:30:33,299 --> 00:30:42,659  
your finger did this is parallax the

666  
00:30:39,750 --> 00:30:43,230  
baseline that we have is 2 astronomical

667  
00:30:42,660 --> 00:30:46,440  
units

668  
00:30:43,230 --> 00:30:50,549  
that's how wide it is the wider the

669  
00:30:46,440 --> 00:30:53,509  
baseline the larger the angle the closer

670  
00:30:50,549 --> 00:30:56,659

the object the wider the angle and the

671

00:30:53,509 --> 00:30:59,250

further away an object is the smaller

672

00:30:56,660 --> 00:31:03,029

the pair the smaller the amount of

673

00:30:59,250 --> 00:31:04,799

parallax you will see and it turns out

674

00:31:03,029 --> 00:31:07,349

that there are not many formulas in

675

00:31:04,799 --> 00:31:10,680

astronomy that are this simple turns

676

00:31:07,349 --> 00:31:14,669

this is the distance to the object to a

677

00:31:10,680 --> 00:31:17,070

star this is the parallax in arc seconds

678

00:31:14,670 --> 00:31:19,050

so does everyone here have a sense of

679

00:31:17,069 --> 00:31:20,490

what a degree is on a circle if you were

680

00:31:19,049 --> 00:31:24,180

to draw a circle you have in a sense of

681

00:31:20,490 --> 00:31:26,519

how much of that circle is a degree now

682

00:31:24,180 --> 00:31:30,870

imagine at that degree is the equivalent

683

00:31:26,519 --> 00:31:35,009

of an hour of time an arc second is one

684

00:31:30,869 --> 00:31:38,699

second to that hour it is 136 hundredth



685  
00:31:35,009 --> 00:31:40,619  
of a degree I could try to draw that on

686  
00:31:38,700 --> 00:31:44,100  
an arc on this but you would list see an

687  
00:31:40,619 --> 00:31:47,539  
infinitesimal line if even that this is

688  
00:31:44,099 --> 00:31:49,769  
an incredibly small measure and it is at

689  
00:31:47,539 --> 00:31:52,109  
least two orders of magnitude smaller

690  
00:31:49,769 --> 00:31:54,329  
than what the person with the absolute

691  
00:31:52,109 --> 00:31:56,429  
best vision can see with our naked eye

692  
00:31:54,329 --> 00:32:01,559  
again those of us with glasses need not

693  
00:31:56,430 --> 00:32:04,170  
apply it turns out that one that if you

694  
00:32:01,559 --> 00:32:07,259  
if something has one arc second of

695  
00:32:04,170 --> 00:32:10,230  
parallax or if this shift is measured as

696  
00:32:07,259 --> 00:32:11,430  
one arc second it is three point two six

697  
00:32:10,230 --> 00:32:14,130  
light-years away

698  
00:32:11,430 --> 00:32:16,320  
we call that a parsec this is the

699  
00:32:14,130 --> 00:32:19,020  
primary unit astronomers use it has

700  
00:32:16,319 --> 00:32:24,869  
nothing to do with the Kessel run and it

701  
00:32:19,019 --> 00:32:26,609  
is not a unit of time so I didn't say

702  
00:32:24,869 --> 00:32:29,939  
Star Trek was the only science fiction

703  
00:32:26,609 --> 00:32:34,798  
universe that messes the science

704  
00:32:29,940 --> 00:32:37,980  
I don't think they were looking things

705  
00:32:34,798 --> 00:32:40,109  
up in dictionaries so they start they've

706  
00:32:37,980 --> 00:32:41,519  
known that this was gonna happen if the

707  
00:32:40,109 --> 00:32:43,349  
Sun was at the center and the earth is

708  
00:32:41,519 --> 00:32:45,089  
moving around it you know the stars are

709  
00:32:43,349 --> 00:32:47,898  
going to have parallax and they've been

710  
00:32:45,089 --> 00:32:53,428  
looking for this for about 2,000 years

711  
00:32:47,898 --> 00:32:57,388  
it takes until 1838 for us to have the

712  
00:32:53,429 --> 00:32:59,220  
technology to measure parallax and that

713

00:32:57,388 --> 00:33:04,519  
is because to measure parallax you have

714  
00:32:59,220 --> 00:33:04,519  
to measure one-tenth of an arc second

715  
00:33:06,259 --> 00:33:13,230  
in 1989 a catalog of extremely bright

716  
00:33:10,950 --> 00:33:16,048  
and star nearby stars was identified

717  
00:33:13,230 --> 00:33:17,639  
this was called Hipparchus it was one of

718  
00:33:16,048 --> 00:33:20,179  
the first attempts to do a large

719  
00:33:17,638 --> 00:33:21,750  
catalogue of these stars and to get

720  
00:33:20,179 --> 00:33:26,129  
parallax's for them

721  
00:33:21,750 --> 00:33:28,669  
in 2013 the Gaia space mission was

722  
00:33:26,128 --> 00:33:31,408  
launched by the European Space Agency

723  
00:33:28,669 --> 00:33:32,909  
just as an aside the process of mapping

724  
00:33:31,409 --> 00:33:37,860  
the Milky Way is very much an

725  
00:33:32,909 --> 00:33:39,509  
international endeavor this is the guy a

726  
00:33:37,859 --> 00:33:40,829  
spacecraft will an artist's rendition of

727  
00:33:39,509 --> 00:33:42,480

the guy spacecraft we're not out in

728

00:33:40,829 --> 00:33:47,158

space in the Milky Way isn't that pretty

729

00:33:42,480 --> 00:33:48,899

um this is a parkus so this is the

730

00:33:47,159 --> 00:33:51,899

amount of parallax the mission can

731

00:33:48,898 --> 00:33:56,758

measure in arcseconds all of these

732

00:33:51,898 --> 00:33:58,168

points so this is taco bra he actually

733

00:33:56,759 --> 00:33:59,759

like the taco bar he the guy that

734

00:33:58,169 --> 00:34:01,620

convinced the King of Denmark to build

735

00:33:59,759 --> 00:34:05,899

him an observatory it also got his nose

736

00:34:01,619 --> 00:34:08,578

cut off in a duel so this is about 1,600

737

00:34:05,898 --> 00:34:10,588

you have Hipparchus in ancient greece

738

00:34:08,579 --> 00:34:13,679

that attempted this with a thousand

739

00:34:10,588 --> 00:34:16,699

stars and then you can actually see the

740

00:34:13,679 --> 00:34:19,740

technology improving the blue line is

741

00:34:16,699 --> 00:34:21,689

how accurate your measurement has to be

742  
00:34:19,739 --> 00:34:25,799  
to be able to observe parallax around

743  
00:34:21,690 --> 00:34:27,389  
the nearest star to the Sun which also

744  
00:34:25,800 --> 00:34:30,990  
happens to be in the wrong hemisphere

745  
00:34:27,389 --> 00:34:33,659  
forever Greece its Alpha Centauri it's

746  
00:34:30,989 --> 00:34:35,309  
in the southern hemisphere so you

747  
00:34:33,659 --> 00:34:38,700  
finally get down to the apart cos

748  
00:34:35,309 --> 00:34:40,289  
mission this is 120,000 stars a little

749  
00:34:38,699 --> 00:34:42,638  
later there's a reason I'm explicitly

750  
00:34:40,289 --> 00:34:45,668  
mentioning this one and then

751  
00:34:42,639 --> 00:34:50,500  
2013 is the launch of Gaia which is a

752  
00:34:45,668 --> 00:34:57,788  
billion stars and Gaia is measuring

753  
00:34:50,500 --> 00:34:58,858  
parallax of 100 100 thousands of an

754  
00:34:57,789 --> 00:35:01,569  
arcsecond

755  
00:34:58,858 --> 00:35:03,670  
so if a degree is an hour this is a

756  
00:35:01,568 --> 00:35:07,480  
hundred thousandth of a second is how

757  
00:35:03,670 --> 00:35:09,730  
accurate Gaia is that kind of accuracy

758  
00:35:07,480 --> 00:35:11,619  
the increase in accuracy means increase

759  
00:35:09,730 --> 00:35:13,659  
distance to which we are able to measure

760  
00:35:11,619 --> 00:35:15,068  
parallax and Gaia for the brightest

761  
00:35:13,659 --> 00:35:22,480  
stars is going to get all the way to the

762  
00:35:15,068 --> 00:35:24,460  
galactic center so we have parallax we

763  
00:35:22,480 --> 00:35:27,190  
can start to observe stars right now we

764  
00:35:24,460 --> 00:35:29,019  
can go out to about a hundred to a

765  
00:35:27,190 --> 00:35:32,409  
thousand light-years depending on the

766  
00:35:29,018 --> 00:35:35,889  
star we're looking at and that is step

767  
00:35:32,409 --> 00:35:37,629  
one so determining distances the

768  
00:35:35,889 --> 00:35:39,278  
determining where something is on the

769  
00:35:37,630 --> 00:35:42,608  
sky we've actually gotten pretty good at

770

00:35:39,278 --> 00:35:44,670  
it's actually called astrometry that

771  
00:35:42,608 --> 00:35:47,170  
okay something else Star Trek covering

772  
00:35:44,670 --> 00:35:49,119  
pastrami tree is the location of things

773  
00:35:47,170 --> 00:35:51,909  
on the sky figuring out the distance is

774  
00:35:49,119 --> 00:35:54,579  
a whole different game and it is a we

775  
00:35:51,909 --> 00:35:57,190  
call it the distance ladder the first

776  
00:35:54,579 --> 00:35:59,769  
rung of that distance ladder is parallax

777  
00:35:57,190 --> 00:36:02,470  
is just is using the shift of the Stars

778  
00:35:59,768 --> 00:36:05,528  
second are things we call standard

779  
00:36:02,469 --> 00:36:07,629  
candles and they're not actually these

780  
00:36:05,528 --> 00:36:12,009  
kind of candles these are astronomical

781  
00:36:07,630 --> 00:36:13,838  
sources so you have a source that is a

782  
00:36:12,009 --> 00:36:15,309  
standard candle it can be a star it can

783  
00:36:13,838 --> 00:36:17,558  
be a supernova

784  
00:36:15,309 --> 00:36:19,480

whatever it is what's important is that

785

00:36:17,559 --> 00:36:22,539

you're able to get its absolute

786

00:36:19,480 --> 00:36:25,480

brightness its luminosity by a different

787

00:36:22,539 --> 00:36:28,750

means from physics from its period

788

00:36:25,480 --> 00:36:31,630

period different all of its brightness

789

00:36:28,750 --> 00:36:33,579

auscultation something and then some

790

00:36:31,630 --> 00:36:35,079

distance away you have the observer I

791

00:36:33,579 --> 00:36:36,460

thought about doing a cute picture of

792

00:36:35,079 --> 00:36:40,210

the enterprise but they're not always on

793

00:36:36,460 --> 00:36:43,269

earth and the way that this works is

794

00:36:40,210 --> 00:36:44,949

actually relatively simple you have the

795

00:36:43,268 --> 00:36:48,909

luminosity of the object which you're

796

00:36:44,949 --> 00:36:50,649

able to figure out by some means you

797

00:36:48,909 --> 00:36:53,259

have the apparent brightness that we

798

00:36:50,650 --> 00:36:56,019

measure on earth and the distance



799

00:36:53,259 --> 00:36:58,449  
between that object and us

800

00:36:56,019 --> 00:37:00,969  
is simply the luminosity over the

801

00:36:58,449 --> 00:37:02,649  
apparent brightness there's some

802

00:37:00,969 --> 00:37:04,359  
physical constants and things in there

803

00:37:02,650 --> 00:37:07,150  
and the distance is if this is actually

804

00:37:04,360 --> 00:37:08,890  
distance squared but this once again

805

00:37:07,150 --> 00:37:11,139  
this is very simple very very

806

00:37:08,889 --> 00:37:12,759  
straightforward in fact this is the same

807

00:37:11,139 --> 00:37:18,329  
one over R squared law that governs

808

00:37:12,760 --> 00:37:21,520  
gravity so we're gonna jump forward to

809

00:37:18,329 --> 00:37:26,559  
1900 Bell back actually I guess to 1908

810

00:37:21,519 --> 00:37:29,679  
and work by Henrietta Swan Leavitt she

811

00:37:26,559 --> 00:37:32,079  
worked with she was among 220 the

812

00:37:29,679 --> 00:37:34,089  
computers these actually were women that

813  
00:37:32,079 --> 00:37:36,340  
were doing computing again these things

814  
00:37:34,090 --> 00:37:37,930  
called computers apparently in 1950 they

815  
00:37:36,340 --> 00:37:42,460  
took up the size of a room or so my

816  
00:37:37,929 --> 00:37:44,049  
father tells me and Henrietta leave it

817  
00:37:42,460 --> 00:37:45,460  
was only one of them the work that they

818  
00:37:44,050 --> 00:37:47,800  
did actually forms the backbone of our

819  
00:37:45,460 --> 00:37:49,440  
understanding of the Stars and just as a

820  
00:37:47,800 --> 00:37:52,060  
note since it is Women's History Month

821  
00:37:49,440 --> 00:37:57,280  
140 of the names are known 80 of them

822  
00:37:52,059 --> 00:37:59,409  
are not we only have initials Henrietta

823  
00:37:57,280 --> 00:38:01,150  
Leavitt was she had an undergraduate

824  
00:37:59,409 --> 00:38:05,170  
degree in astronomy and she was given

825  
00:38:01,150 --> 00:38:06,670  
the task of looking for variables not go

826  
00:38:05,170 --> 00:38:08,500  
look at these specific variables just

827

00:38:06,670 --> 00:38:10,300  
here's some glass plates they were

828  
00:38:08,500 --> 00:38:13,570  
actually glass you can see a crack here

829  
00:38:10,300 --> 00:38:14,920  
these are actually glass plates some

830  
00:38:13,570 --> 00:38:18,240  
people in the room may remember remember

831  
00:38:14,920 --> 00:38:20,710  
film cameras I think some of you may not

832  
00:38:18,239 --> 00:38:22,059  
instead of film this actually wish you

833  
00:38:20,710 --> 00:38:26,199  
would take it on a silvered plate of

834  
00:38:22,059 --> 00:38:27,639  
glass this is the SMC in a much in a

835  
00:38:26,199 --> 00:38:31,269  
more modern image of the small

836  
00:38:27,639 --> 00:38:33,190  
Magellanic Cloud this is a image a

837  
00:38:31,269 --> 00:38:35,170  
period image of the small management

838  
00:38:33,190 --> 00:38:39,220  
club with her notations on it these are

839  
00:38:35,170 --> 00:38:41,230  
her notations and she noticed that there

840  
00:38:39,219 --> 00:38:42,549  
were class of variables in the small

841  
00:38:41,230 --> 00:38:44,740

magellanic cloud that were very

842

00:38:42,550 --> 00:38:45,940  
distinctive they rose in brightness

843

00:38:44,739 --> 00:38:47,139  
there were stars that rose and

844

00:38:45,940 --> 00:38:48,849  
brightness very quickly and then fell

845

00:38:47,139 --> 00:38:52,179  
off and then rose and brightness again

846

00:38:48,849 --> 00:38:55,599  
and then fell off these work they named

847

00:38:52,179 --> 00:38:58,500  
them sets for the prototype prototype

848

00:38:55,599 --> 00:39:01,000  
star for which they were identified and

849

00:38:58,500 --> 00:39:02,079  
since she had the SMC she had that she

850

00:39:01,000 --> 00:39:03,639  
knew they're all at the same distance

851

00:39:02,079 --> 00:39:05,679  
they're basically all at the same

852

00:39:03,639 --> 00:39:09,799  
distance and the brighter Sophia's had

853

00:39:05,679 --> 00:39:12,429  
longer periods as of 2009

854

00:39:09,800 --> 00:39:16,610  
we actually called us the leave it law

855

00:39:12,429 --> 00:39:19,359  
this is the first standard candle you

856  
00:39:16,610 --> 00:39:22,610  
now if you know the period of a Cepheid

857  
00:39:19,360 --> 00:39:25,130  
you go up you have its period you go up

858  
00:39:22,610 --> 00:39:28,130  
and you can read off its absolute

859  
00:39:25,130 --> 00:39:29,720  
brightness its luminosity if you have

860  
00:39:28,130 --> 00:39:31,099  
its luminosity you have its measured

861  
00:39:29,719 --> 00:39:34,009  
apparent brightness you have its

862  
00:39:31,099 --> 00:39:37,429  
distance and Cepheid Zarb right we can

863  
00:39:34,010 --> 00:39:40,070  
see these in external galaxies they also

864  
00:39:37,429 --> 00:39:42,019  
are not that rare and this is what you

865  
00:39:40,070 --> 00:39:43,340  
have to do to jump a rung of the

866  
00:39:42,019 --> 00:39:47,449  
distance ladder it's not as simple as

867  
00:39:43,340 --> 00:39:48,950  
doing this first off you find a Cepheid

868  
00:39:47,449 --> 00:39:52,099  
that's close enough to also have a

869  
00:39:48,949 --> 00:39:54,169  
parallax measurement then you calculate

870  
00:39:52,099 --> 00:39:56,150  
the distance to that Cepheid using

871  
00:39:54,170 --> 00:39:58,789  
parallax and using the distance modulus

872  
00:39:56,150 --> 00:40:01,789  
or using the relation between absolute

873  
00:39:58,789 --> 00:40:03,619  
luminosity apparent apparent brightness

874  
00:40:01,789 --> 00:40:05,500  
and distance you calculate the

875  
00:40:03,619 --> 00:40:09,319  
luminosity of that set

876  
00:40:05,500 --> 00:40:12,409  
you then use that luminosity to

877  
00:40:09,320 --> 00:40:14,510  
calibrate the leave it law to calibrate

878  
00:40:12,409 --> 00:40:18,199  
henriette leave its relation because you

879  
00:40:14,510 --> 00:40:21,020  
need to know where things sit on the

880  
00:40:18,199 --> 00:40:24,559  
luminosity axis does a Cepheid with a

881  
00:40:21,019 --> 00:40:27,320  
period of two days have a luminosity of

882  
00:40:24,559 --> 00:40:30,079  
10 times the luminosity of a Sun or a

883  
00:40:27,320 --> 00:40:32,360  
hundred that because that's a very very

884

00:40:30,079 --> 00:40:35,150  
that's a very large error that you're

885  
00:40:32,360 --> 00:40:36,950  
introducing in your distances you then

886  
00:40:35,150 --> 00:40:38,840  
use your calibrated leave it law to get

887  
00:40:36,949 --> 00:40:41,000  
the luminosities of Cepheid x'

888  
00:40:38,840 --> 00:40:44,510  
for which you know their period sapiens

889  
00:40:41,000 --> 00:40:47,239  
which are too far away for parallax you

890  
00:40:44,510 --> 00:40:48,440  
then use this except the Illuminati and

891  
00:40:47,239 --> 00:40:57,169  
the apparent brightness and you

892  
00:40:48,440 --> 00:40:59,539  
calculate the distance simple turns out

893  
00:40:57,170 --> 00:41:01,909  
there sophia's are not the only standard

894  
00:40:59,539 --> 00:41:03,440  
candle and focusing only on ones used to

895  
00:41:01,909 --> 00:41:06,589  
map the Milky Way there's a whole long

896  
00:41:03,440 --> 00:41:09,559  
list of these this is spectral class or

897  
00:41:06,590 --> 00:41:12,980  
color of a star from red to blue versus

898  
00:41:09,559 --> 00:41:15,289

its absolute brightness our Sun sits

899

00:41:12,980 --> 00:41:17,179

right here on the main sequence all

900

00:41:15,289 --> 00:41:19,159

these stars are burning hydrogen are

901

00:41:17,179 --> 00:41:21,169

fusing hydrogen to helium in their cores

902

00:41:19,159 --> 00:41:22,219

and this is where stars will spend the

903

00:41:21,170 --> 00:41:25,090

majority of their life

904

00:41:22,219 --> 00:41:27,980

and they're stable when they're on this

905

00:41:25,090 --> 00:41:30,470

however once they move on off it they

906

00:41:27,980 --> 00:41:32,420

become unstable and they move through

907

00:41:30,469 --> 00:41:34,159

something called an instability strip

908

00:41:32,420 --> 00:41:36,409

and these are where a lot of variable

909

00:41:34,159 --> 00:41:38,629

stars are you can see this is the

910

00:41:36,409 --> 00:41:40,759

prototype for the Cepheid archetype for

911

00:41:38,630 --> 00:41:43,329

the Cepheid x' and this is the archetype

912

00:41:40,760 --> 00:41:46,220

for another class called the RLI right



913  
00:41:43,329 --> 00:41:48,710  
like the Cepheid they have a relation

914  
00:41:46,219 --> 00:41:53,689  
between their luminosity and their

915  
00:41:48,710 --> 00:41:57,710  
period and um but unlike the Cepheid x'

916  
00:41:53,690 --> 00:42:00,050  
they are they are older so you can find

917  
00:41:57,710 --> 00:42:02,769  
these in evolved stellar systems and

918  
00:42:00,050 --> 00:42:05,480  
that's going to be important in a minute

919  
00:42:02,769 --> 00:42:09,019  
so we now know how far the stars are

920  
00:42:05,480 --> 00:42:11,030  
away and that is somewhere between 4

921  
00:42:09,019 --> 00:42:11,389  
light years and about a hundred thousand

922  
00:42:11,030 --> 00:42:18,019  
light years

923  
00:42:11,389 --> 00:42:21,529  
I warned you space was big now where is

924  
00:42:18,019 --> 00:42:25,699  
the solar system in our galaxy so we're

925  
00:42:21,530 --> 00:42:27,560  
going to jump back to 1772 to William

926  
00:42:25,699 --> 00:42:28,839  
and Carol and Herschel they were brother

927  
00:42:27,559 --> 00:42:31,489  
and sister

928  
00:42:28,840 --> 00:42:33,559  
astronomers living in England in the

929  
00:42:31,489 --> 00:42:37,639  
18th century I think something else was

930  
00:42:33,559 --> 00:42:40,489  
going on with England in 1772 but the

931  
00:42:37,639 --> 00:42:43,089  
you know just smoker falafel with you

932  
00:42:40,489 --> 00:42:44,989  
know some problematic colonies and

933  
00:42:43,090 --> 00:42:47,539  
really in her style based on

934  
00:42:44,989 --> 00:42:49,759  
observations of stars came up with a

935  
00:42:47,539 --> 00:42:52,369  
model of the Milky Way which you can see

936  
00:42:49,760 --> 00:42:54,500  
here he notices that when you look up

937  
00:42:52,369 --> 00:42:57,079  
haven't has anyone here seen the Milky

938  
00:42:54,500 --> 00:42:58,639  
Way at a dark night all right you see

939  
00:42:57,079 --> 00:43:00,769  
the Ark of it so there's a high density

940  
00:42:58,639 --> 00:43:03,829  
area of stars and fewer stars above and

941

00:43:00,769 --> 00:43:05,179  
below so he has that here you can see

942  
00:43:03,829 --> 00:43:07,400  
that there's definitely a direction in

943  
00:43:05,179 --> 00:43:07,879  
which there are more stars this is where

944  
00:43:07,400 --> 00:43:11,840  
the Sun is

945  
00:43:07,880 --> 00:43:17,000  
I just want wild guess about whether or

946  
00:43:11,840 --> 00:43:18,230  
not this is right no anytime we're at

947  
00:43:17,000 --> 00:43:22,760  
the center of the universe you have a

948  
00:43:18,230 --> 00:43:24,590  
problem it's actually called the

949  
00:43:22,760 --> 00:43:26,810  
Copernican principle never put the earth

950  
00:43:24,590 --> 00:43:29,110  
at the center of the universe or in a

951  
00:43:26,809 --> 00:43:29,110  
corner

952  
00:43:29,500 --> 00:43:34,869  
so but to fully solve this problem you

953  
00:43:32,989 --> 00:43:37,639  
had to wait a hundred and fifty years

954  
00:43:34,869 --> 00:43:39,230  
this is how well shapely he was actually

955  
00:43:37,639 --> 00:43:42,559

the second director of the Harvard

956

00:43:39,230 --> 00:43:44,449

Observatory and he used our alive I

957

00:43:42,559 --> 00:43:46,309

variables remember that second standard

958

00:43:44,449 --> 00:43:50,029

candle and was able to get the distance

959

00:43:46,309 --> 00:43:51,469

to globular clusters and unfortunately

960

00:43:50,030 --> 00:43:54,200

the telescope's not working but

961

00:43:51,469 --> 00:43:56,089

globulars are very dense massive

962

00:43:54,199 --> 00:43:59,480

clusters of stars that orbit our Milky

963

00:43:56,090 --> 00:44:01,250

Way and if these are things that are in

964

00:43:59,480 --> 00:44:03,349

the halo and the outskirts of our galaxy

965

00:44:01,250 --> 00:44:05,329

and you look at the you can measure the

966

00:44:03,349 --> 00:44:07,250

distribution if the Sun is at the center

967

00:44:05,329 --> 00:44:11,210

of the galaxy then the globular clusters

968

00:44:07,250 --> 00:44:12,650

should be centered around us if we're

969

00:44:11,210 --> 00:44:14,659

not at the center of the galaxy the

970  
00:44:12,650 --> 00:44:17,599  
globular clusters shouldn't be centred

971  
00:44:14,659 --> 00:44:20,599  
around us and he plotted the

972  
00:44:17,599 --> 00:44:23,299  
distribution of the globular clusters in

973  
00:44:20,599 --> 00:44:26,480  
physical space so this is in kiloparsec

974  
00:44:23,300 --> 00:44:30,769  
so thousands of parsecs or about 3,000

975  
00:44:26,480 --> 00:44:32,900  
light years per unit versus this is up

976  
00:44:30,769 --> 00:44:36,139  
and down in the plane so this is the

977  
00:44:32,900 --> 00:44:37,730  
plane of our galaxy right here and he

978  
00:44:36,139 --> 00:44:40,279  
found out that lo and behold the Sun is

979  
00:44:37,730 --> 00:44:42,349  
not at the center of the galaxy I mean

980  
00:44:40,280 --> 00:44:44,480  
like this I'm sure this was shocking but

981  
00:44:42,349 --> 00:44:46,309  
the Sun is not at the center of a galaxy

982  
00:44:44,480 --> 00:44:47,690  
in fact the center point is in the

983  
00:44:46,309 --> 00:44:50,329  
direction of the constellation of

984  
00:44:47,690 --> 00:44:52,760  
Sagittarius he believed it was about

985  
00:44:50,329 --> 00:44:55,250  
fourteen kiloparsecs away he was off by

986  
00:44:52,760 --> 00:45:00,140  
about a factor of two in astronomy we

987  
00:44:55,250 --> 00:45:02,690  
call that an error bar this is the

988  
00:45:00,139 --> 00:45:04,250  
diagram of our Milky Way edge-on you

989  
00:45:02,690 --> 00:45:06,170  
have the disk of our galaxy and the

990  
00:45:04,250 --> 00:45:09,199  
Bulge for the record the Bulge is not

991  
00:45:06,170 --> 00:45:12,170  
that pretty the Sun is here about

992  
00:45:09,199 --> 00:45:13,519  
halfway out on the disk the whole disk

993  
00:45:12,170 --> 00:45:16,250  
is a hundred thousand light-years across

994  
00:45:13,519 --> 00:45:21,230  
with the globular clusters orbiting the

995  
00:45:16,250 --> 00:45:24,650  
entire system so we are not in the

996  
00:45:21,230 --> 00:45:26,829  
middle of things we are in Loudoun

997  
00:45:24,650 --> 00:45:26,829  
County

998

00:45:28,239 --> 00:45:35,358  
not on the complete edge of things but

999  
00:45:30,858 --> 00:45:37,608  
you know relatively far out so we know

1000  
00:45:35,358 --> 00:45:39,409  
where we are that we're out on the edge

1001  
00:45:37,608 --> 00:45:41,358  
that we're in the disk of our Milky Way

1002  
00:45:39,409 --> 00:45:43,219  
that the earth is not at the center of

1003  
00:45:41,358 --> 00:45:47,449  
our solar system and that the stars are

1004  
00:45:43,219 --> 00:45:53,269  
very very far away but what does our

1005  
00:45:47,449 --> 00:45:55,458  
galaxy actually look like this is an

1006  
00:45:53,268 --> 00:45:57,798  
image this is a composite image taken by

1007  
00:45:55,458 --> 00:45:59,629  
the European Southern Observatory so

1008  
00:45:57,798 --> 00:46:01,038  
this is you cannot telescope cannot take

1009  
00:45:59,630 --> 00:46:03,950  
this in one image this is actually an

1010  
00:46:01,039 --> 00:46:05,839  
all-sky image it's beautiful absolutely

1011  
00:46:03,949 --> 00:46:09,558  
beautiful the center of the galaxy is

1012  
00:46:05,838 --> 00:46:13,728

right here but there's something in the

1013

00:46:09,559 --> 00:46:19,660

way so this is the disc and there's all

1014

00:46:13,728 --> 00:46:22,518

these dark spots these are dust clouds

1015

00:46:19,659 --> 00:46:25,998

now this is not the kind of dusty out to

1016

00:46:22,518 --> 00:46:28,129

sweep off your floor it's actually good

1017

00:46:25,998 --> 00:46:29,298

that you have it these dust tends to

1018

00:46:28,130 --> 00:46:31,009

form in areas where there is a lot of

1019

00:46:29,298 --> 00:46:34,429

star formation we are actually on a

1020

00:46:31,009 --> 00:46:35,659

sitting on a dust aggregate right now in

1021

00:46:34,429 --> 00:46:37,639

the early days of our planet the

1022

00:46:35,659 --> 00:46:41,420

planetary nebula dust particles started

1023

00:46:37,639 --> 00:46:42,798

to clump together and then they become

1024

00:46:41,420 --> 00:46:44,209

rocks and then the rocks are banging

1025

00:46:42,798 --> 00:46:45,650

into each other and then they become

1026

00:46:44,208 --> 00:46:50,149

asteroids and the next thing you know



1027  
00:46:45,650 --> 00:46:52,430  
you have earth but they are a problem

1028  
00:46:50,150 --> 00:46:54,798  
because visible light the light we see

1029  
00:46:52,429 --> 00:46:57,919  
with our eyes cannot penetrate that dust

1030  
00:46:54,798 --> 00:46:59,809  
the dust blocks it so if you want to

1031  
00:46:57,920 --> 00:47:01,190  
observe the center of the galaxy if you

1032  
00:46:59,809 --> 00:47:03,109  
want to observe really anywhere in the

1033  
00:47:01,190 --> 00:47:06,229  
galaxy beyond our little region you've

1034  
00:47:03,108 --> 00:47:07,759  
got a problem the good news is that

1035  
00:47:06,228 --> 00:47:10,308  
there's more light than just visible

1036  
00:47:07,759 --> 00:47:12,048  
light this is the Eagle Nebula the

1037  
00:47:10,309 --> 00:47:14,390  
pillars of creation in the Eagle Nebula

1038  
00:47:12,048 --> 00:47:15,619  
for those of you that remember this was

1039  
00:47:14,389 --> 00:47:19,068  
on the front page of the Washington Post

1040  
00:47:15,619 --> 00:47:21,108  
when the original image came out this is

1041  
00:47:19,068 --> 00:47:22,929  
in visible light this beautiful

1042  
00:47:21,108 --> 00:47:27,889  
multicolored image and visible light

1043  
00:47:22,929 --> 00:47:29,899  
this is the same shot in the infrared so

1044  
00:47:27,889 --> 00:47:31,578  
infrared light has a slightly longer

1045  
00:47:29,900 --> 00:47:34,219  
wavelength that's slightly redder than

1046  
00:47:31,579 --> 00:47:35,479  
visible light it's how your cat knows

1047  
00:47:34,219 --> 00:47:38,150  
where the food bowl is in the middle of

1048  
00:47:35,478 --> 00:47:39,318  
the night and if you have ever used

1049  
00:47:38,150 --> 00:47:40,800  
night-vision goggles

1050  
00:47:39,318 --> 00:47:44,909  
that's what it

1051  
00:47:40,800 --> 00:47:46,769  
those are using infrared it's also we we

1052  
00:47:44,909 --> 00:47:48,809  
perceive it as heat our bodies are

1053  
00:47:46,769 --> 00:47:53,179  
giving off infrared radiation in the

1054  
00:47:48,809 --> 00:47:56,730  
form of heat but what's incredible is

1055

00:47:53,179 --> 00:47:58,319  
these stores are here in this image we

1056  
00:47:56,730 --> 00:48:01,289  
didn't just ship them in special for the

1057  
00:47:58,320 --> 00:48:04,200  
infrared exposure it's just in the

1058  
00:48:01,289 --> 00:48:06,119  
infrared light you can look through the

1059  
00:48:04,199 --> 00:48:09,149  
dust and the gas of the pillars to the

1060  
00:48:06,119 --> 00:48:11,250  
Stars behind them and when you do that

1061  
00:48:09,150 --> 00:48:14,280  
for the entire Milky Way things look a

1062  
00:48:11,250 --> 00:48:15,989  
little different this is the Milky Way

1063  
00:48:14,280 --> 00:48:18,810  
this is a composite image in

1064  
00:48:15,989 --> 00:48:21,329  
near-infrared and the near infrared part

1065  
00:48:18,809 --> 00:48:24,059  
of the spectrum you can now see the

1066  
00:48:21,329 --> 00:48:27,329  
stellar disk of the Milky Way and the

1067  
00:48:24,059 --> 00:48:29,119  
stellar bulge the dust lanes that we're

1068  
00:48:27,329 --> 00:48:34,860  
blocking our view have faded completely

1069  
00:48:29,119 --> 00:48:36,829

into the background and when we start

1070

00:48:34,860 --> 00:48:40,680

looking towards the galactic center

1071

00:48:36,829 --> 00:48:43,739

which is about 8.5 kiloparsecs or 25,000

1072

00:48:40,679 --> 00:48:45,750

light-years away when we looked in we

1073

00:48:43,739 --> 00:48:49,079

find that there is an extremely bright

1074

00:48:45,750 --> 00:48:50,789

radio source called sad a star right at

1075

00:48:49,079 --> 00:48:52,889

the supposed location of the center of

1076

00:48:50,789 --> 00:48:54,779

our galaxy and when we zoom in further

1077

00:48:52,889 --> 00:48:56,400

we see that the galactic center isn't

1078

00:48:54,780 --> 00:48:58,320

just some stars moving around it's

1079

00:48:56,400 --> 00:49:02,400

actually a very complex region and

1080

00:48:58,320 --> 00:49:05,010

there's this incredibly bright source at

1081

00:49:02,400 --> 00:49:10,079

the center and when you zoom even

1082

00:49:05,010 --> 00:49:12,990

further in I hope this works and you

1083

00:49:10,079 --> 00:49:16,170

look these are this is the center these

1084  
00:49:12,989 --> 00:49:20,189  
are stars this is not a movie or an

1085  
00:49:16,170 --> 00:49:22,829  
artist's conception this is data this is

1086  
00:49:20,190 --> 00:49:25,409  
data taken over a period of about 10

1087  
00:49:22,829 --> 00:49:29,130  
years for comparison it will take them

1088  
00:49:25,409 --> 00:49:31,589  
some 250 million years to orbit the

1089  
00:49:29,130 --> 00:49:37,260  
Milky Way these stars are moving

1090  
00:49:31,590 --> 00:49:39,210  
incredibly fast it turns out that using

1091  
00:49:37,260 --> 00:49:40,920  
Kepler's laws using the laws you're

1092  
00:49:39,210 --> 00:49:43,769  
honest Kepler determined for our solar

1093  
00:49:40,920 --> 00:49:45,269  
system you can take one of these orbits

1094  
00:49:43,769 --> 00:49:48,750  
and figure out how much mass is in the

1095  
00:49:45,269 --> 00:49:52,889  
middle there it's not emitting any light

1096  
00:49:48,750 --> 00:49:53,760  
it's very compact and it's 3 million

1097  
00:49:52,889 --> 00:49:56,849  
times the mass

1098  
00:49:53,760 --> 00:49:58,350  
versa this is the supermassive black

1099  
00:49:56,849 --> 00:49:59,608  
hole at the center of the Milky Way so

1100  
00:49:58,349 --> 00:50:03,710  
if you want an over the center of the

1101  
00:49:59,608 --> 00:50:03,710  
Milky Way is that's it right there

1102  
00:50:04,429 --> 00:50:10,230  
here's the and we and again this is

1103  
00:50:08,670 --> 00:50:12,300  
where I have to take what we do in a

1104  
00:50:10,230 --> 00:50:15,449  
month and graduate galaxies and compress

1105  
00:50:12,300 --> 00:50:17,310  
it this is the optical Milky Way disk

1106  
00:50:15,449 --> 00:50:20,429  
and optical this is the near-infrared

1107  
00:50:17,309 --> 00:50:22,199  
image that I showed you before when you

1108  
00:50:20,429 --> 00:50:24,539  
look in the mid infrared further to

1109  
00:50:22,199 --> 00:50:26,579  
longer wavelengths you're now seeing the

1110  
00:50:24,539 --> 00:50:28,079  
dust heating up all those dust clouds

1111  
00:50:26,579 --> 00:50:31,349  
heating up that's what you're seeing

1112

00:50:28,079 --> 00:50:32,159  
here when you start looking at molecular

1113  
00:50:31,349 --> 00:50:34,529  
hydrogen

1114  
00:50:32,159 --> 00:50:36,779  
this is hydrogen that's bonded so it's

1115  
00:50:34,530 --> 00:50:38,850  
h2 it's two atoms of hydrogen bound

1116  
00:50:36,780 --> 00:50:41,100  
together this is right this is

1117  
00:50:38,849 --> 00:50:42,868  
relatively cool gas so this is where

1118  
00:50:41,099 --> 00:50:45,389  
stars are forming right here

1119  
00:50:42,869 --> 00:50:47,340  
concentrated in the disk we know that

1120  
00:50:45,389 --> 00:50:48,929  
tells us that stars are forming in the

1121  
00:50:47,340 --> 00:50:53,850  
disk of our galaxy they're not forming

1122  
00:50:48,929 --> 00:50:55,799  
everywhere you start in addition the

1123  
00:50:53,849 --> 00:50:57,809  
atomic hydrogen which is measuring

1124  
00:50:55,800 --> 00:51:00,330  
warmer hydrogen and the molecular

1125  
00:50:57,809 --> 00:51:03,108  
hydrogen together actually we from them

1126  
00:51:00,329 --> 00:51:06,809

we find out we have an extra spiral arm

1127

00:51:03,108 --> 00:51:08,849

apparently we lost it I don't know we

1128

00:51:06,809 --> 00:51:14,940

have an extra spiral arm that we only

1129

00:51:08,849 --> 00:51:16,559

found in gas and this and in the radio

1130

00:51:14,940 --> 00:51:19,230

wavelengths the same wavelengths that

1131

00:51:16,559 --> 00:51:21,150

you use to tune your car for the radio

1132

00:51:19,230 --> 00:51:25,199

in your car for I'm assuming some people

1133

00:51:21,150 --> 00:51:27,059

still use radios in their cars it turns

1134

00:51:25,199 --> 00:51:30,029

out that there is yet another distance

1135

00:51:27,059 --> 00:51:32,099

indicator our Sun will become a will

1136

00:51:30,030 --> 00:51:33,780

stay in the main sequence eventually we

1137

00:51:32,099 --> 00:51:35,849

become a red giant will become a

1138

00:51:33,780 --> 00:51:39,630

planetary nebula which are very pretty

1139

00:51:35,849 --> 00:51:41,579

and eventually die as a white dwarf in

1140

00:51:39,630 --> 00:51:46,200

stellar evolution terms this is called



1141  
00:51:41,579 --> 00:51:47,789  
going out with a whimper a massive star

1142  
00:51:46,199 --> 00:51:50,129  
and by massive I mean something eight

1143  
00:51:47,789 --> 00:51:52,980  
times the mass of our Sun or even bigger

1144  
00:51:50,130 --> 00:51:55,260  
will become a red supergiant it'll move

1145  
00:51:52,980 --> 00:51:57,329  
around a bunch and then it will undergo

1146  
00:51:55,260 --> 00:51:58,680  
a supernova explosion these are some of

1147  
00:51:57,329 --> 00:52:02,219  
the most energetic events in the

1148  
00:51:58,679 --> 00:52:05,519  
universe and some of these will form a

1149  
00:52:02,219 --> 00:52:07,409  
neutron star these are the neutron star

1150  
00:52:05,519 --> 00:52:09,869  
was two neutron stars

1151  
00:52:07,409 --> 00:52:13,049  
colliding with each other that was the

1152  
00:52:09,869 --> 00:52:16,079  
recent subject of the first both LIGO

1153  
00:52:13,050 --> 00:52:20,010  
and optical detection for gravity waves

1154  
00:52:16,079 --> 00:52:22,079  
and it turns out that neutron stars in

1155  
00:52:20,010 --> 00:52:24,540  
addition to being the size of a stew

1156  
00:52:22,079 --> 00:52:28,980  
being our mass of our Sun it combined to

1157  
00:52:24,539 --> 00:52:31,559  
the size of Washington DC spin this is

1158  
00:52:28,980 --> 00:52:34,740  
Jocelyn Bell Burnell as a graduate

1159  
00:52:31,559 --> 00:52:38,309  
student she detected a signal each of

1160  
00:52:34,739 --> 00:52:41,729  
these little dips is a pulse from a

1161  
00:52:38,309 --> 00:52:43,380  
neutron star what's happening is you

1162  
00:52:41,730 --> 00:52:49,019  
have the neutron star here remember this

1163  
00:52:43,380 --> 00:52:50,369  
is this is the DC Beltway or the wall or

1164  
00:52:49,019 --> 00:52:54,179  
the Baltimore Beltway since we are in

1165  
00:52:50,369 --> 00:52:57,569  
Baltimore this is the rotation access to

1166  
00:52:54,179 --> 00:53:00,569  
the star spinning this is the magnetic

1167  
00:52:57,570 --> 00:53:04,559  
field on earth our magnetic field lines

1168  
00:53:00,570 --> 00:53:07,550  
up with our pole in reality a neutron

1169

00:53:04,559 --> 00:53:10,259  
stars it doesn't so this is the axis

1170  
00:53:07,550 --> 00:53:12,210  
every time you sweep you get a signal

1171  
00:53:10,260 --> 00:53:16,020  
and I'm not doing that anymore because

1172  
00:53:12,210 --> 00:53:18,420  
I'm dizzy this is a cleaner image where

1173  
00:53:16,019 --> 00:53:22,530  
you can see the period and every pulsar

1174  
00:53:18,420 --> 00:53:24,960  
has a unique period and it turns out

1175  
00:53:22,530 --> 00:53:26,820  
that in addition to this the pulses if

1176  
00:53:24,960 --> 00:53:28,590  
there's three electrons or just

1177  
00:53:26,820 --> 00:53:31,740  
electrons flying around in space because

1178  
00:53:28,590 --> 00:53:35,460  
of course there are pulsars tend to

1179  
00:53:31,739 --> 00:53:38,549  
spread out the signal of the Pulsar will

1180  
00:53:35,460 --> 00:53:40,199  
spread out or disperse if you have a

1181  
00:53:38,550 --> 00:53:41,940  
pulsar where you independently know the

1182  
00:53:40,199 --> 00:53:44,189  
distances because why is this going to

1183  
00:53:41,940 --> 00:53:46,500

be the straight forward you can map the

1184

00:53:44,190 --> 00:53:48,300

electron density of the galaxy if you

1185

00:53:46,500 --> 00:53:50,099

know the electron density of the galaxy

1186

00:53:48,300 --> 00:53:52,350

and you can measure the dispersion for

1187

00:53:50,099 --> 00:53:55,230

other pulsars suddenly you know where

1188

00:53:52,349 --> 00:53:56,969

all the pulsars are in the galaxy this

1189

00:53:55,230 --> 00:53:58,559

is the disk of the galaxy this is a

1190

00:53:56,969 --> 00:54:01,289

hundred thousand light-years across

1191

00:53:58,559 --> 00:54:03,869

and these are the note these are the

1192

00:54:01,289 --> 00:54:07,590

known positions of pulsars in our galaxy

1193

00:54:03,869 --> 00:54:10,469

so unlike the Cepheid unlike many other

1194

00:54:07,590 --> 00:54:12,450

things this is one of the only tools we

1195

00:54:10,469 --> 00:54:16,379

have to really map the far edge of the

1196

00:54:12,449 --> 00:54:18,569

galaxy in addition this is something

1197

00:54:16,380 --> 00:54:20,190

once in a while Star Trek actually gets

1198  
00:54:18,570 --> 00:54:20,480  
something right I don't remember whether

1199  
00:54:20,190 --> 00:54:21,858  
we're

1200  
00:54:20,480 --> 00:54:23,659  
q with the traveler that flung the

1201  
00:54:21,858 --> 00:54:25,279  
enterprise somewhere but they're trying

1202  
00:54:23,659 --> 00:54:28,000  
to figure out where they are and they

1203  
00:54:25,280 --> 00:54:31,420  
explicitly say check the pulsars and

1204  
00:54:28,000 --> 00:54:34,639  
that is because each pulsar has a unique

1205  
00:54:31,420 --> 00:54:36,619  
period so if you identify this pulsar

1206  
00:54:34,639 --> 00:54:38,868  
this pulsar and that pulsar you now know

1207  
00:54:36,619 --> 00:54:39,858  
where you are and since we I didn't know

1208  
00:54:38,869 --> 00:54:41,720  
if they're gonna be kids in the audience

1209  
00:54:39,858 --> 00:54:46,340  
hence the editing of the of the

1210  
00:54:41,719 --> 00:54:50,059  
pioneered the pioneer plaque this is

1211  
00:54:46,340 --> 00:54:51,950  
this is not a Hubble image this is an

1212  
00:54:50,059 --> 00:54:57,139  
artist's conception but this is based on

1213  
00:54:51,949 --> 00:55:01,250  
data this is the Milky Way the centre

1214  
00:54:57,139 --> 00:55:03,079  
here with a bar we know this based on

1215  
00:55:01,250 --> 00:55:04,608  
kinematics the the velocity and the

1216  
00:55:03,079 --> 00:55:07,730  
movements of the stars in the centre of

1217  
00:55:04,608 --> 00:55:12,949  
our galaxy we have two major arms coming

1218  
00:55:07,730 --> 00:55:17,000  
off either side smaller arms here more

1219  
00:55:12,949 --> 00:55:18,469  
minor arms and then there's this

1220  
00:55:17,000 --> 00:55:20,150  
additional arm here this is the one that

1221  
00:55:18,469 --> 00:55:23,299  
we figured out from radio observations

1222  
00:55:20,150 --> 00:55:29,119  
of hydrogen this is what we call the

1223  
00:55:23,300 --> 00:55:31,880  
Orion spur that's Orion this is the

1224  
00:55:29,119 --> 00:55:35,930  
earth roughly speaking not to scale by

1225  
00:55:31,880 --> 00:55:38,480  
the way this is the farthest measurement

1226

00:55:35,929 --> 00:55:40,669  
we have in our galaxy this is 667

1227  
00:55:38,480 --> 00:55:42,050  
thousand light-years away if you

1228  
00:55:40,670 --> 00:55:44,059  
remember I told you Star Trek out the

1229  
00:55:42,050 --> 00:55:45,200  
scale the galaxy wrong accidentally if

1230  
00:55:44,059 --> 00:55:46,190  
we had your gun like another ten

1231  
00:55:45,199 --> 00:55:48,769  
thousand light-years that would have

1232  
00:55:46,190 --> 00:55:50,059  
been out of the disk just to give you a

1233  
00:55:48,769 --> 00:55:52,280  
sense of this that's what I mean by good

1234  
00:55:50,059 --> 00:55:54,170  
I got it right accidentally this is the

1235  
00:55:52,280 --> 00:55:56,210  
earth this is sixty seven thousand

1236  
00:55:54,170 --> 00:55:57,950  
light-years away there's about another

1237  
00:55:56,210 --> 00:56:01,820  
twenty thousand light-years between us

1238  
00:55:57,949 --> 00:56:04,159  
and the edge of the disk and since

1239  
00:56:01,820 --> 00:56:05,539  
you've been so good I promised you that

1240  
00:56:04,159 --> 00:56:08,750

I would tell you what the Klingons were

1241

00:56:05,539 --> 00:56:10,909

at the end of this I believe it turns

1242

00:56:08,750 --> 00:56:13,309

out that the planet Vulcan is orbiting

1243

00:56:10,909 --> 00:56:16,039

an actual star

1244

00:56:13,309 --> 00:56:17,420

it's called forty Eridani for the nearby

1245

00:56:16,039 --> 00:56:18,590

stars we actually have something a

1246

00:56:17,420 --> 00:56:21,530

little more interesting than phone

1247

00:56:18,590 --> 00:56:24,140

numbers it is in the constellation of

1248

00:56:21,530 --> 00:56:26,780

air adonis the river which is right here

1249

00:56:24,139 --> 00:56:29,569

this is a ryan so if you want to

1250

00:56:26,780 --> 00:56:33,250

actually find where Vulcan is in the sky

1251

00:56:29,570 --> 00:56:34,720

it's right around here and I had to put

1252

00:56:33,250 --> 00:56:40,119

sort of Star Trek Discovery reference in

1253

00:56:34,719 --> 00:56:41,799

here this is literally what I did in the

1254

00:56:40,119 --> 00:56:44,079

Star Trek Star charts there is a list of



1255  
00:56:41,800 --> 00:56:45,760  
about will actually not list its maps

1256  
00:56:44,079 --> 00:56:47,199  
that have things written in two type

1257  
00:56:45,760 --> 00:56:49,750  
font that wasn't particularly easy to

1258  
00:56:47,199 --> 00:56:52,329  
read but you have a whole bunch of stars

1259  
00:56:49,750 --> 00:56:53,559  
this is for 40 Eridani which is Vulcan

1260  
00:56:52,329 --> 00:56:56,500  
in Star Trek

1261  
00:56:53,559 --> 00:56:58,299  
you have the Galactic coordinates so

1262  
00:56:56,500 --> 00:57:01,360  
this is basically latitude and longitude

1263  
00:56:58,300 --> 00:57:04,870  
for our galaxy and this is the parallax

1264  
00:57:01,360 --> 00:57:07,329  
this is how much Epsilon Eridani is

1265  
00:57:04,869 --> 00:57:09,789  
moving if you measure in January and

1266  
00:57:07,329 --> 00:57:12,670  
June the larger this number is the

1267  
00:57:09,789 --> 00:57:15,550  
closer something is an Epsilon Eridani

1268  
00:57:12,670 --> 00:57:19,869  
or Vulcan is about 16 and a quarter

1269  
00:57:15,550 --> 00:57:22,480  
light-years away so on cosmic terms

1270  
00:57:19,869 --> 00:57:24,960  
extremely close by in absolute terms it

1271  
00:57:22,480 --> 00:57:30,329  
would take us 17 years to say hi and

1272  
00:57:24,960 --> 00:57:30,329  
another 17 years for them to say oh god

1273  
00:57:31,440 --> 00:57:40,119  
this is the Federation every single star

1274  
00:57:36,250 --> 00:57:43,960  
in the in Star Trek star charts that was

1275  
00:57:40,119 --> 00:57:47,079  
in Federation space I plugged into the

1276  
00:57:43,960 --> 00:57:49,659  
Sinbad database which is this right

1277  
00:57:47,079 --> 00:57:51,340  
there and pulled out the Galactica

1278  
00:57:49,659 --> 00:57:54,429  
latitude the Galactic longitude and the

1279  
00:57:51,340 --> 00:57:56,950  
parallax which gave me the distances the

1280  
00:57:54,429 --> 00:58:00,549  
Federation can be measured with parallax

1281  
00:57:56,949 --> 00:58:03,429  
that is how small it is the entire

1282  
00:58:00,550 --> 00:58:05,110  
Federation is about to 300 light-years

1283

00:58:03,429 --> 00:58:06,460  
across depending on if you switch I'll

1284  
00:58:05,110 --> 00:58:08,349  
give them four hundred because you've

1285  
00:58:06,460 --> 00:58:11,710  
got some sort of weird squiggly bits

1286  
00:58:08,349 --> 00:58:13,509  
that go off to the side I think this is

1287  
00:58:11,710 --> 00:58:15,010  
if you were looking down into the plane

1288  
00:58:13,510 --> 00:58:16,600  
of our galaxy that's what it would look

1289  
00:58:15,010 --> 00:58:19,240  
like so you have sort of a tail going

1290  
00:58:16,599 --> 00:58:22,829  
off here and this is looking into the

1291  
00:58:19,239 --> 00:58:25,659  
disk towards the center of our galaxy so

1292  
00:58:22,829 --> 00:58:27,219  
if Kirk is on the enterprise on the edge

1293  
00:58:25,659 --> 00:58:29,170  
of the Federation and looks back at

1294  
00:58:27,219 --> 00:58:31,869  
Earth with a powerful enough telescope

1295  
00:58:29,170 --> 00:58:34,750  
he could watch his Efrain Cochrane take

1296  
00:58:31,869 --> 00:58:37,059  
off on the first work play he couldn't

1297  
00:58:34,750 --> 00:58:39,039

watch us the Federation isn't big enough

1298

00:58:37,059 --> 00:58:44,559

for him to be able to go far enough away

1299

00:58:39,039 --> 00:58:47,489

to look 300 years back in time I told

1300

00:58:44,559 --> 00:58:47,489

you I was gonna nerd out

1301

00:58:49,099 --> 00:58:56,068

um turns out the Klingons are closer

1302

00:58:52,768 --> 00:58:58,229

than we think they are this is the

1303

00:58:56,068 --> 00:59:00,449

distance to all the systems notice

1304

00:58:58,230 --> 00:59:01,769

Klingon systems the closest ones are

1305

00:59:00,449 --> 00:59:06,659

actually less than a hundred light years

1306

00:59:01,768 --> 00:59:08,159

away and if you want to look for the

1307

00:59:06,659 --> 00:59:12,118

Klingon Empire look in the

1308

00:59:08,159 --> 00:59:14,368

constellations of Leo and Gemini that's

1309

00:59:12,119 --> 00:59:16,470

if you want to look towards the the

1310

00:59:14,369 --> 00:59:18,240

Klingon Empire there in Leo it's Leo and

1311

00:59:16,469 --> 00:59:22,288

Gemini about a hundred light years away

1312  
00:59:18,239 --> 00:59:23,848  
and I couldn't and I didn't know which

1313  
00:59:22,289 --> 00:59:27,089  
Klingons to use by the way for that

1314  
00:59:23,849 --> 00:59:29,789  
picture I think this is just we got

1315  
00:59:27,088 --> 00:59:34,409  
better at makeup over the course of 50

1316  
00:59:29,789 --> 00:59:36,839  
years the Romulans and of course I had

1317  
00:59:34,409 --> 00:59:38,818  
to use green the black here is the

1318  
00:59:36,838 --> 00:59:40,440  
Romulan neutral zone that's actually

1319  
00:59:38,818 --> 00:59:41,969  
only about 30 light years away they're

1320  
00:59:40,440 --> 00:59:46,048  
actually closer than the Klingons and

1321  
00:59:41,969 --> 00:59:50,909  
the Romulans Empire is at is big it goes

1322  
00:59:46,048 --> 00:59:53,579  
out to about 150 light-years away if you

1323  
00:59:50,909 --> 00:59:54,598  
to see to look towards the Romulans you

1324  
00:59:53,579 --> 00:59:56,849  
actually have to be in the southern

1325  
00:59:54,599 --> 00:59:58,680  
hemisphere in the constellation of

1326  
00:59:56,849 --> 01:00:04,910  
Centaurus in the southern hemisphere and

1327  
00:59:58,679 --> 01:00:04,909  
we have the oops wrong Cardassian sorry

1328  
01:00:05,748 --> 01:00:13,259  
the Kardashians are actually in if you

1329  
01:00:09,208 --> 01:00:14,818  
look towards the Big Dipper they are if

1330  
01:00:13,259 --> 01:00:16,440  
you look towards the Big Dipper tonight

1331  
01:00:14,818 --> 01:00:20,489  
you were looking in the direction of the

1332  
01:00:16,440 --> 01:00:22,559  
Kardashians what is it something and

1333  
01:00:20,489 --> 01:00:24,568  
these are the distances this is actually

1334  
01:00:22,559 --> 01:00:26,519  
aren't distances - these are distances

1335  
01:00:24,568 --> 01:00:30,420  
the edge of Cardassian space because

1336  
01:00:26,518 --> 01:00:33,778  
that's all I could find so the answer is

1337  
01:00:30,420 --> 01:00:35,519  
that yes this stuff is a lot closer than

1338  
01:00:33,778 --> 01:00:37,259  
you think they're not 3,000 light years

1339  
01:00:35,518 --> 01:00:39,268  
away but the chance that you could

1340

01:00:37,259 --> 01:00:48,630  
actually get across 100 that 100 light

1341  
01:00:39,268 --> 01:00:51,778  
years to come and say hi questionable so

1342  
01:00:48,630 --> 01:00:55,079  
just to put this into perspective I told

1343  
01:00:51,778 --> 01:00:59,009  
you space was big this is the Federation

1344  
01:00:55,079 --> 01:01:01,499  
and the Klingon Empire and the Romulans

1345  
01:00:59,009 --> 01:01:03,900  
and the Cardassian this is all of Star

1346  
01:01:01,498 --> 01:01:05,458  
Trek with the exception of the bit that

1347  
01:01:03,900 --> 01:01:08,548  
happened over here and the kind of

1348  
01:01:05,458 --> 01:01:10,649  
happened over here but to give you a

1349  
01:01:08,548 --> 01:01:13,199  
sense of how difficult it is to see

1350  
01:01:10,650 --> 01:01:14,940  
through this massive stuff because

1351  
01:01:13,199 --> 01:01:17,068  
remember we're stuck in the disc we're

1352  
01:01:14,940 --> 01:01:19,858  
stuck right here on earth looking at our

1353  
01:01:17,068 --> 01:01:22,380  
galaxy through its disk we know less

1354  
01:01:19,858 --> 01:01:24,420

about Star Trek's Delta Quadrant than we

1355

01:01:22,380 --> 01:01:25,910

do about galaxies a billion light-years

1356

01:01:24,420 --> 01:01:28,170

away

1357

01:01:25,909 --> 01:01:29,879

it's easier for us to find an

1358

01:01:28,170 --> 01:01:31,559

information about galaxies on the near

1359

01:01:29,880 --> 01:01:32,880

the edge of the universe than it is to

1360

01:01:31,559 --> 01:01:37,619

figure out what's going on on the other

1361

01:01:32,880 --> 01:01:40,048

side of our own galaxy and it's sort of

1362

01:01:37,619 --> 01:01:41,729

as a closing note the Orion Nebula is

1363

01:01:40,048 --> 01:01:43,108

the closest major star for me and to our

1364

01:01:41,728 --> 01:01:45,108

that was by the way thank you so much

1365

01:01:43,108 --> 01:01:48,420

for mentioning Orion that was a perfect

1366

01:01:45,108 --> 01:01:51,598

it's about 1,400 light-years away this

1367

01:01:48,420 --> 01:01:53,309

is at least a five-year mission this is

1368

01:01:51,599 --> 01:01:56,880

not let's go check out the Orion Nebula



1369  
01:01:53,309 --> 01:01:59,069  
and we'll be home next week and to give

1370  
01:01:56,880 --> 01:02:02,369  
you a sense of scale remember we're here

1371  
01:01:59,068 --> 01:02:07,130  
in Orion's here on galactic scales this

1372  
01:02:02,369 --> 01:02:09,930  
is extremely extremely close by as such

1373  
01:02:07,130 --> 01:02:11,548  
even in whatever future we end up in

1374  
01:02:09,929 --> 01:02:14,208  
assuming that we don't accidentally blow

1375  
01:02:11,548 --> 01:02:16,650  
ourselves up in the next 10 years

1376  
01:02:14,208 --> 01:02:18,690  
astronomers are still going to be

1377  
01:02:16,650 --> 01:02:20,309  
studying the universe largely study

1378  
01:02:18,690 --> 01:02:21,568  
the universe the same way that they have

1379  
01:02:20,309 --> 01:02:25,250  
been for the better part of three

1380  
01:02:21,568 --> 01:02:28,380  
thousand years with photons with light

1381  
01:02:25,250 --> 01:02:32,980  
physics and hopefully really awesome

1382  
01:02:28,380 --> 01:02:44,660  
Space Telescope's thank you

1383  
01:02:32,980 --> 01:02:48,449  
[Applause]

1384  
01:02:44,659 --> 01:02:50,098  
all right so um if I rid read that

1385  
01:02:48,449 --> 01:02:52,078  
correctly if we're 1,400 light-years

1386  
01:02:50,099 --> 01:02:53,759  
away to the Orion Nebula the Orion

1387  
01:02:52,079 --> 01:03:00,329  
Nebula is technically not in Federation

1388  
01:02:53,759 --> 01:03:02,009  
space then yeah Federation space it's

1389  
01:03:00,329 --> 01:03:07,559  
like it's a it's a 1,200 light-years

1390  
01:03:02,009 --> 01:03:09,960  
beyond Federation space okay I think the

1391  
01:03:07,559 --> 01:03:11,759  
Federation had better annex the Orion

1392  
01:03:09,960 --> 01:03:14,909  
Nebula it is that is one of the most

1393  
01:03:11,759 --> 01:03:19,528  
gorgeous places in our galaxy okay so I

1394  
01:03:14,909 --> 01:03:21,719  
think we'll have together well look III

1395  
01:03:19,528 --> 01:03:23,159  
just you know we got a call paramount

1396  
01:03:21,719 --> 01:03:26,129  
and get their writers to get get the

1397

01:03:23,159 --> 01:03:27,690  
rhein Nebula inside Federation in Star

1398  
01:03:26,130 --> 01:03:29,369  
Trek if you haven't noticed they tend to

1399  
01:03:27,690 --> 01:03:34,559  
move the enterprise moves at the speed

1400  
01:03:29,369 --> 01:03:36,599  
of plot so it's actually very difficult

1401  
01:03:34,559 --> 01:03:38,039  
to figure out how fast are they actually

1402  
01:03:36,599 --> 01:03:40,890  
going and how far are they actually

1403  
01:03:38,039 --> 01:03:45,319  
going all right do we have any questions

1404  
01:03:40,889 --> 01:03:45,318  
for the for our speaker here tonight

1405  
01:03:45,739 --> 01:04:12,119  
yes orange jacket I don't know the

1406  
01:04:10,289 --> 01:04:14,729  
numbers but it is and we repeat the

1407  
01:04:12,119 --> 01:04:16,729  
question for the question is how fast

1408  
01:04:14,728 --> 01:04:20,248  
are the stars are moving

1409  
01:04:16,728 --> 01:04:22,439  
periapsis that their closest approach to

1410  
01:04:20,248 --> 01:04:26,728  
the black hole I don't have a number for

1411  
01:04:22,440 --> 01:04:29,009

you it is extremely fast it is fast

1412

01:04:26,728 --> 01:04:30,598

enough that when the one of the ones

1413

01:04:29,009 --> 01:04:32,009

that goes close enough approaches the

1414

01:04:30,599 --> 01:04:34,289

black hole they weren't sure it was

1415

01:04:32,009 --> 01:04:36,150

going to come out the other side so

1416

01:04:34,289 --> 01:04:37,528

they're orbiting it's a basically I

1417

01:04:36,150 --> 01:04:40,229

think it's pretty much as fast as you

1418

01:04:37,528 --> 01:04:43,349

can go but I don't have an actual number

1419

01:04:40,228 --> 01:04:45,598

in meters per second right I mean for

1420

01:04:43,349 --> 01:04:51,180

reference you know the Sun is moving at

1421

01:04:45,599 --> 01:04:52,130

what 250 222 US km/s 250 kilometers per

1422

01:04:51,179 --> 01:04:54,879

second this is

1423

01:04:52,130 --> 01:04:59,660

100 times faster yeah so but 200 comma

1424

01:04:54,880 --> 01:05:01,670

second times 3600 is what like a hundred

1425

01:04:59,659 --> 01:05:03,649

and a hundred thousand miles per hour or

1426  
01:05:01,670 --> 01:05:08,019  
something like that if a kilometers per

1427  
01:05:03,650 --> 01:05:08,019  
hour right just to give it something

1428  
01:05:08,199 --> 01:05:12,769  
these are moving so fast in space we

1429  
01:05:10,610 --> 01:05:14,480  
talk about kilometers per second not

1430  
01:05:12,769 --> 01:05:16,369  
kilometers per hour okay

1431  
01:05:14,480 --> 01:05:18,559  
um so we always have to translate from

1432  
01:05:16,369 --> 01:05:20,389  
the numbers that we know we memorize the

1433  
01:05:18,559 --> 01:05:22,429  
numbers we can explain

1434  
01:05:20,389 --> 01:05:24,529  
yes question there yes you mentioned

1435  
01:05:22,429 --> 01:05:27,440  
that astrology is one of the things that

1436  
01:05:24,530 --> 01:05:29,810  
Star Trek has done correctly I recall

1437  
01:05:27,440 --> 01:05:32,750  
there were some episodes with a travel

1438  
01:05:29,809 --> 01:05:34,880  
back a time an astronomer tree tells

1439  
01:05:32,750 --> 01:05:41,150  
them what their time that he have

1440  
01:05:34,880 --> 01:05:43,099  
arrived in his mission so the question

1441  
01:05:41,150 --> 01:05:45,349  
was in some Star Trek episodes they

1442  
01:05:43,099 --> 01:05:47,230  
travel back in time and the astrology of

1443  
01:05:45,349 --> 01:05:51,769  
the stars tells them what time it is

1444  
01:05:47,230 --> 01:05:54,050  
comment on that and parallax parallax is

1445  
01:05:51,769 --> 01:05:55,759  
the star moving the Stars actually

1446  
01:05:54,050 --> 01:05:58,730  
moving with parallax that's automatic

1447  
01:05:55,760 --> 01:06:01,910  
the stars are actually moving relative

1448  
01:05:58,730 --> 01:06:04,519  
to the Sun proper motions are if we're

1449  
01:06:01,909 --> 01:06:08,809  
sitting here and a star is moving like

1450  
01:06:04,519 --> 01:06:10,759  
this this the amount it comes across so

1451  
01:06:08,809 --> 01:06:13,699  
not along our line of sight but across

1452  
01:06:10,760 --> 01:06:15,290  
that is its proper motion you would

1453  
01:06:13,699 --> 01:06:17,089  
assume that by the time you got to the

1454

01:06:15,289 --> 01:06:19,309  
world of Star Trek they would have we

1455  
01:06:17,090 --> 01:06:20,809  
were actually already well into having

1456  
01:06:19,309 --> 01:06:23,150  
that mapped and knowing the proper

1457  
01:06:20,809 --> 01:06:24,320  
motions of the nearby stars you would

1458  
01:06:23,150 --> 01:06:27,050  
assume by the time you got to Star Trek

1459  
01:06:24,320 --> 01:06:29,420  
they would have that for a much larger

1460  
01:06:27,050 --> 01:06:33,620  
volume and so you would be able to say

1461  
01:06:29,420 --> 01:06:36,380  
you know Epsilon Eridani is here but

1462  
01:06:33,619 --> 01:06:41,269  
should be here but it's here so it must

1463  
01:06:36,380 --> 01:06:58,190  
be 300 years ago okay all the way in the

1464  
01:06:41,269 --> 01:06:59,989  
back and the redshirt when galaxies

1465  
01:06:58,190 --> 01:07:01,789  
rotate do they all rotate in the same

1466  
01:06:59,989 --> 01:07:04,250  
direction or what direction do they

1467  
01:07:01,789 --> 01:07:06,630  
rotate in it depends on what direction

1468  
01:07:04,250 --> 01:07:09,780

you're looking at them

1469

01:07:06,630 --> 01:07:14,559

and I'm actually not being entirely for

1470

01:07:09,780 --> 01:07:16,390

being in in when we talk about things it

1471

01:07:14,559 --> 01:07:17,980

depends on what direction is up it

1472

01:07:16,389 --> 01:07:20,529

actually depends from what you define is

1473

01:07:17,980 --> 01:07:22,389

up and usually what we say is if is we

1474

01:07:20,530 --> 01:07:23,980

use the right hand rule and we say if

1475

01:07:22,389 --> 01:07:26,500

you take your hand your right hand like

1476

01:07:23,980 --> 01:07:27,909

this feel free to do this if you without

1477

01:07:26,500 --> 01:07:30,489

preferably without hitting your neighbor

1478

01:07:27,909 --> 01:07:32,649

again and if you curl your hands like

1479

01:07:30,489 --> 01:07:35,769

this in a counterclockwise direction

1480

01:07:32,650 --> 01:07:37,269

your thumb points up so we define if you

1481

01:07:35,769 --> 01:07:38,710

have something rotating and you have it

1482

01:07:37,269 --> 01:07:43,269

in the counterclockwise direction we



1483  
01:07:38,710 --> 01:07:45,099  
defined this as up and so if you were to

1484  
01:07:43,269 --> 01:07:47,019  
take that same object and instead of

1485  
01:07:45,099 --> 01:07:48,699  
looking at it from above you look at it

1486  
01:07:47,019 --> 01:07:52,300  
from below you're now going to have

1487  
01:07:48,699 --> 01:07:55,779  
clockwise rotation and so the direction

1488  
01:07:52,300 --> 01:07:57,250  
of the rotation is very dependent on how

1489  
01:07:55,780 --> 01:07:59,350  
you look but if you show the Milky Way

1490  
01:07:57,250 --> 01:08:03,219  
the picture the Robert Hertz diagram in

1491  
01:07:59,349 --> 01:08:05,349  
the Milky Way there we go we can say

1492  
01:08:03,219 --> 01:08:09,429  
about this that they tend to rotate with

1493  
01:08:05,349 --> 01:08:11,650  
the trailing spiral arms we don't know I

1494  
01:08:09,429 --> 01:08:13,989  
think I know of like one galaxy that

1495  
01:08:11,650 --> 01:08:15,760  
might have leading spiral arms which

1496  
01:08:13,989 --> 01:08:20,019  
means that for this galaxy it would be

1497  
01:08:15,760 --> 01:08:22,119  
rotating clockwise okay and from the

1498  
01:08:20,020 --> 01:08:24,460  
direction you're looking at it okay of

1499  
01:08:22,119 --> 01:08:26,710  
course right just because that the

1500  
01:08:24,460 --> 01:08:36,609  
spiral arms trail okay they're called

1501  
01:08:26,710 --> 01:08:38,890  
trailing spiral arms looking at the same

1502  
01:08:36,609 --> 01:08:40,000  
image from the other side of the disk it

1503  
01:08:38,890 --> 01:08:43,720  
would look like it was rotating

1504  
01:08:40,000 --> 01:08:45,310  
counterclockwise right you know we have

1505  
01:08:43,720 --> 01:08:46,869  
one we have we we can agree on one

1506  
01:08:45,310 --> 01:08:50,080  
perspective here right for this to this

1507  
01:08:46,869 --> 01:08:52,420  
diagram we can also agree that I I know

1508  
01:08:50,079 --> 01:08:54,100  
of like one galaxy where was some it was

1509  
01:08:52,420 --> 01:08:56,500  
puff possible that it might have a

1510  
01:08:54,100 --> 01:08:59,380  
leading spiral arm but I didn't believe

1511

01:08:56,500 --> 01:09:00,640  
it actually so it's all the spiral arms

1512  
01:08:59,380 --> 01:09:04,600  
I know of our trailing do you know of

1513  
01:09:00,640 --> 01:09:06,490  
any okay good all right in the purple

1514  
01:09:04,600 --> 01:09:07,990  
down here so you're not in a red shirt

1515  
01:09:06,489 --> 01:09:18,239  
or a blue shirt you're in a purple shirt

1516  
01:09:07,989 --> 01:09:18,239  
so I guess you're kind of safe Star Trek

1517  
01:09:18,659 --> 01:09:28,139  
so what happened the universe that we

1518  
01:09:24,569 --> 01:09:28,889  
know they're trying to return where did

1519  
01:09:28,140 --> 01:09:31,250  
they go

1520  
01:09:28,890 --> 01:09:33,930  
are you talking about Star Trek Voyager

1521  
01:09:31,250 --> 01:09:39,960  
okay so where did Star Trek Voyager go

1522  
01:09:33,930 --> 01:09:41,430  
here I told you the 67 that I put this

1523  
01:09:39,960 --> 01:09:45,480  
up for a reason

1524  
01:09:41,430 --> 01:09:49,590  
Voyager is here they're they're barely

1525  
01:09:45,479 --> 01:09:51,529

still in the galaxy because they keep

1526

01:09:49,590 --> 01:09:53,909

running into people every other planet

1527

01:09:51,529 --> 01:09:55,229

there they're barely there they're

1528

01:09:53,909 --> 01:10:01,170

barely and they they're like they're up

1529

01:09:55,229 --> 01:10:04,319

here okay over there yes the stars

1530

01:10:01,170 --> 01:10:07,920

toward the center of the galaxy versus

1531

01:10:04,319 --> 01:10:10,319

on the edge are the ones more toward the

1532

01:10:07,920 --> 01:10:13,380

center are they traveling faster or

1533

01:10:10,319 --> 01:10:15,599

slower so what are the speed of the

1534

01:10:13,380 --> 01:10:16,920

stars in the galaxies going from the

1535

01:10:15,600 --> 01:10:21,900

center to the edge or slow relative

1536

01:10:16,920 --> 01:10:24,029

speeds of those a rotation curve the

1537

01:10:21,899 --> 01:10:25,679

motivationally rotation curve of the

1538

01:10:24,029 --> 01:10:29,670

Milky Way the rotation speed of the

1539

01:10:25,680 --> 01:10:31,920

stars is actually relatively constant

1540  
01:10:29,670 --> 01:10:35,279  
with distance from the center of the

1541  
01:10:31,920 --> 01:10:37,289  
galaxy and so that means that the stars

1542  
01:10:35,279 --> 01:10:40,679  
in here are actually going at about the

1543  
01:10:37,289 --> 01:10:43,319  
same speed as the stars out here this is

1544  
01:10:40,680 --> 01:10:46,260  
one of the major pieces of evidence for

1545  
01:10:43,319 --> 01:10:49,829  
dark matter actually I told you Dark

1546  
01:10:46,260 --> 01:10:51,060  
Matter exists it just piano doesn't

1547  
01:10:49,829 --> 01:10:54,420  
exist the way that you would think it

1548  
01:10:51,060 --> 01:10:55,950  
would Star Trek there is right at the

1549  
01:10:54,420 --> 01:10:57,840  
center of our galaxy as you start moving

1550  
01:10:55,949 --> 01:10:59,939  
out there is an increase in speed as you

1551  
01:10:57,840 --> 01:11:02,430  
go further out but once you get certain

1552  
01:10:59,939 --> 01:11:05,819  
about to the orbit of our Sun which is

1553  
01:11:02,430 --> 01:11:07,380  
about 25,000 light years out the speed

1554  
01:11:05,819 --> 01:11:12,259  
of rotation is is flattened and is

1555  
01:11:07,380 --> 01:11:18,630  
constant okay in the black jacket there

1556  
01:11:12,260 --> 01:11:20,250  
so how our solar system can be to the

1557  
01:11:18,630 --> 01:11:25,079  
center of the galaxy before it becomes

1558  
01:11:20,250 --> 01:11:27,479  
on alright so if our galaxy were closer

1559  
01:11:25,079 --> 01:11:29,279  
to the center of the Milky Way would it

1560  
01:11:27,479 --> 01:11:31,889  
be come back our Sun yes

1561  
01:11:29,279 --> 01:11:34,439  
would the solar system be come in

1562  
01:11:31,890 --> 01:11:38,850  
habitable I wouldn't want to be right on

1563  
01:11:34,439 --> 01:11:42,139  
top of Sagittarius a then you might have

1564  
01:11:38,850 --> 01:11:46,950  
a problem but we could be a good ways in

1565  
01:11:42,140 --> 01:11:48,329  
because remember space is really big we

1566  
01:11:46,949 --> 01:11:50,250  
would actually have more trouble at the

1567  
01:11:48,329 --> 01:11:53,039  
center of a globular cluster because of

1568

01:11:50,250 --> 01:11:55,020  
how crowded things are then we would in

1569  
01:11:53,039 --> 01:11:56,579  
the center of our galaxy so really until

1570  
01:11:55,020 --> 01:11:58,980  
you get to the really close in to the

1571  
01:11:56,579 --> 01:12:01,829  
galactic center you would be we'd be

1572  
01:11:58,979 --> 01:12:03,149  
fine yeah and just to amplify her point

1573  
01:12:01,829 --> 01:12:05,250  
about globular clusters globular

1574  
01:12:03,149 --> 01:12:06,960  
clusters are the only place that we know

1575  
01:12:05,250 --> 01:12:09,449  
of where stars can actually dense enough

1576  
01:12:06,960 --> 01:12:10,859  
that stars can actually collide so I

1577  
01:12:09,449 --> 01:12:14,369  
mean that actually causes that would

1578  
01:12:10,859 --> 01:12:16,679  
cause a lot more problems than billion

1579  
01:12:14,369 --> 01:12:19,829  
years Andromeda is going to slam into

1580  
01:12:16,680 --> 01:12:21,600  
the Milky Way when that happens none of

1581  
01:12:19,829 --> 01:12:23,130  
the stars are going to collide that is

1582  
01:12:21,600 --> 01:12:25,230

how much space there is between the

1583

01:12:23,130 --> 01:12:28,409

stars the stars are actually going to

1584

01:12:25,229 --> 01:12:32,849

just move past each other but we got

1585

01:12:28,409 --> 01:12:34,559

four billion years to wait for that that

1586

01:12:32,850 --> 01:12:49,170

makes for a lot of sequels before that

1587

01:12:34,560 --> 01:12:50,970

happens all the way in the far corner it

1588

01:12:49,170 --> 01:12:52,500

looks very bright in the center of the

1589

01:12:50,970 --> 01:12:53,940

galaxy you know we have an issue with

1590

01:12:52,500 --> 01:12:55,979

light pollution

1591

01:12:53,939 --> 01:12:59,879

I think we'd have even more issue seen

1592

01:12:55,979 --> 01:13:01,739

through it I mean right now we because

1593

01:12:59,880 --> 01:13:03,449

we're in the disc so the Milky Way

1594

01:13:01,739 --> 01:13:05,279

across is about a hundred thousand light

1595

01:13:03,449 --> 01:13:07,250

years the disc is only a thousand light

1596

01:13:05,279 --> 01:13:09,689

years thick you can think of it as a



1597  
01:13:07,250 --> 01:13:12,720  
laser disc it's about the right

1598  
01:13:09,689 --> 01:13:14,489  
dimensions if you're in the center if

1599  
01:13:12,720 --> 01:13:16,710  
you're sort of in the Bulge area here

1600  
01:13:14,489 --> 01:13:19,139  
right now if we look up out of the disk

1601  
01:13:16,710 --> 01:13:21,119  
or down out of the disk we have a

1602  
01:13:19,140 --> 01:13:24,930  
relatively clear view of what's outside

1603  
01:13:21,119 --> 01:13:27,630  
the Milky Way if we're in the middle in

1604  
01:13:24,930 --> 01:13:30,329  
the Bulge you're gonna have to look this

1605  
01:13:27,630 --> 01:13:31,680  
way this way up down you know whichever

1606  
01:13:30,329 --> 01:13:33,149  
direction you choose to look you're

1607  
01:13:31,680 --> 01:13:36,300  
gonna be looking through a whole lot of

1608  
01:13:33,149 --> 01:13:37,529  
stars and so it's actually gonna it's

1609  
01:13:36,300 --> 01:13:39,090  
not so much that you're gonna have light

1610  
01:13:37,529 --> 01:13:40,829  
pollution as it's gonna be almost

1611  
01:13:39,090 --> 01:13:43,110  
impossible to see anything beyond the

1612  
01:13:40,829 --> 01:13:44,819  
Milky Way right and the same is true in

1613  
01:13:43,109 --> 01:13:45,469  
a globular cluster you get in the center

1614  
01:13:44,819 --> 01:13:47,389  
of globby

1615  
01:13:45,469 --> 01:13:50,328  
cluster of a million stars you can do

1616  
01:13:47,389 --> 01:13:52,699  
incredible stellar astronomy but extra

1617  
01:13:50,328 --> 01:13:55,460  
galactic astronomy really kind of

1618  
01:13:52,698 --> 01:13:56,899  
difficult okay so yeah we're actually

1619  
01:13:55,460 --> 01:13:59,630  
kind of lucky being out in the boondocks

1620  
01:13:56,899 --> 01:14:03,138  
we have a nice clear skies and in one

1621  
01:13:59,630 --> 01:14:06,739  
sense like that okay in the blue shirt

1622  
01:14:03,139 --> 01:14:09,440  
right there this this spiral structure

1623  
01:14:06,738 --> 01:14:13,879  
makes me think that the galaxy is

1624  
01:14:09,439 --> 01:14:18,198  
turning is rotating if it's rotating how

1625

01:14:13,880 --> 01:14:22,998  
can the hour be moving at the same speed

1626  
01:14:18,198 --> 01:14:25,219  
as further okay so if the galaxy is

1627  
01:14:22,998 --> 01:14:26,840  
rotating how can the outers objects be

1628  
01:14:25,219 --> 01:14:29,748  
moving at the same speed is the inner

1629  
01:14:26,840 --> 01:14:33,710  
objects um the answer is actually dark

1630  
01:14:29,748 --> 01:14:37,399  
matter is what dark matter so everything

1631  
01:14:33,710 --> 01:14:42,880  
we see this visible all the stars the

1632  
01:14:37,399 --> 01:14:46,308  
gas the dust starships whatever

1633  
01:14:42,880 --> 01:14:48,078  
starships hapless bipedal species all of

1634  
01:14:46,309 --> 01:14:49,670  
that is made up of something called

1635  
01:14:48,078 --> 01:14:52,009  
baryonic matter and all of that

1636  
01:14:49,670 --> 01:14:54,828  
interacts with light it either absorbs

1637  
01:14:52,010 --> 01:14:57,010  
light or emits light all of that is

1638  
01:14:54,828 --> 01:15:00,488  
about 10% of the matter in the universe

1639  
01:14:57,010 --> 01:15:03,199

the other 90% is dark matter and dark

1640

01:15:00,488 --> 01:15:06,288

matter we only see dark matter because

1641

01:15:03,198 --> 01:15:08,118

of gravity because we know it's there we

1642

01:15:06,288 --> 01:15:10,158

know that there if the stars on the

1643

01:15:08,118 --> 01:15:12,368

outer edge of the disk are orbiting just

1644

01:15:10,158 --> 01:15:16,339

as fast as the stars in the inner edge

1645

01:15:12,368 --> 01:15:18,498

then we and we know that the mass of the

1646

01:15:16,340 --> 01:15:21,828

Milky Way the enclose the mass inside

1647

01:15:18,498 --> 01:15:23,179

those orbits is basically the same once

1648

01:15:21,828 --> 01:15:24,859

you get out here so it should be falling

1649

01:15:23,179 --> 01:15:27,288

off like you see like the fact that

1650

01:15:24,859 --> 01:15:29,179

Neptune orbits slower than Jupiter which

1651

01:15:27,288 --> 01:15:32,689

orbits slower than mercury that's called

1652

01:15:29,179 --> 01:15:35,929

Keplerian rotation the fact that we see

1653

01:15:32,689 --> 01:15:38,118

this flat rotation constant rotation as

1654  
01:15:35,929 --> 01:15:39,889  
far out as we can observe means that

1655  
01:15:38,118 --> 01:15:42,109  
there must be an additional mass

1656  
01:15:39,889 --> 01:15:43,760  
component which ends up being about 90%

1657  
01:15:42,109 --> 01:15:45,469  
of the mass of the galaxy that just

1658  
01:15:43,760 --> 01:15:46,820  
isn't interacting with light it's not

1659  
01:15:45,469 --> 01:15:49,340  
absorbing light it's not emitting light

1660  
01:15:46,819 --> 01:15:51,630  
and that is dark matter and that's about

1661  
01:15:49,340 --> 01:15:54,050  
90 percent of the

1662  
01:15:51,630 --> 01:15:57,720  
and I'll add one more comment that the

1663  
01:15:54,050 --> 01:15:59,670  
pattern speed of the spiral structure is

1664  
01:15:57,720 --> 01:16:02,159  
different from the orbital speed of the

1665  
01:15:59,670 --> 01:16:04,350  
stars within it stars go into these

1666  
01:16:02,159 --> 01:16:06,689  
spiral arms and move out of these spiral

1667  
01:16:04,350 --> 01:16:08,670  
arms so the patterns speed the density

1668  
01:16:06,689 --> 01:16:10,979  
wave of the spirals actually is a

1669  
01:16:08,670 --> 01:16:13,020  
different rotational speed than the

1670  
01:16:10,979 --> 01:16:15,719  
stars that are moving through them okay

1671  
01:16:13,020 --> 01:16:17,430  
so that's another thing to process it

1672  
01:16:15,720 --> 01:16:18,690  
but the arms

1673  
01:16:17,430 --> 01:16:21,510  
[Music]

1674  
01:16:18,689 --> 01:16:25,500  
well we can't watch getting we can't

1675  
01:16:21,510 --> 01:16:28,140  
watch a galaxy for that long to confirm

1676  
01:16:25,500 --> 01:16:31,140  
that but our simulations do show that

1677  
01:16:28,140 --> 01:16:32,970  
the that the pattern that the pattern

1678  
01:16:31,140 --> 01:16:35,190  
stays roughly constant for a while but

1679  
01:16:32,970 --> 01:16:38,940  
they can they can stretch out and reform

1680  
01:16:35,189 --> 01:16:40,619  
and break up in for instance when the LM

1681  
01:16:38,939 --> 01:16:42,199  
if the LMC in the essence you come too

1682

01:16:40,619 --> 01:16:44,909  
close to the disk they will actually

1683  
01:16:42,199 --> 01:16:49,289  
modify this pattern okay we got a couple

1684  
01:16:44,909 --> 01:16:50,970  
questions from online at warp 9.9 how

1685  
01:16:49,289 --> 01:17:06,119  
long would it take for the enterprise to

1686  
01:16:50,970 --> 01:17:09,570  
cross the Milky Way if they'd asked me

1687  
01:17:06,119 --> 01:17:11,369  
warp six I would have been going at

1688  
01:17:09,569 --> 01:17:14,219  
maximum warp it takes a hundred years to

1689  
01:17:11,369 --> 01:17:16,019  
cross the Milky Way maximum warp 9.9

1690  
01:17:14,220 --> 01:17:17,760  
depending on what maximum orb is it's

1691  
01:17:16,020 --> 01:17:19,770  
about a thousand light years per year

1692  
01:17:17,760 --> 01:17:23,130  
hence the reason that Orion is more than

1693  
01:17:19,770 --> 01:17:25,050  
a five year mission okay and let's see

1694  
01:17:23,130 --> 01:17:27,720  
there was a good question what do you

1695  
01:17:25,050 --> 01:17:30,119  
think is the most interesting unanswered

1696  
01:17:27,720 --> 01:17:32,850

question you have relating to your work

1697

01:17:30,119 --> 01:17:35,069

your studies of things well I don't

1698

01:17:32,850 --> 01:17:39,300

actually work on the Milky Way yes I

1699

01:17:35,069 --> 01:17:44,189

work on extremely tiny galaxies that are

1700

01:17:39,300 --> 01:17:45,840

orbiting the Milky Way and I would

1701

01:17:44,189 --> 01:17:49,019

actually say that you know going back to

1702

01:17:45,840 --> 01:17:53,250

your first news from the universe point

1703

01:17:49,020 --> 01:17:56,190

we don't I work on galaxies very small

1704

01:17:53,250 --> 01:17:58,619

galaxies at today in the local universe

1705

01:17:56,189 --> 01:18:01,649

oh and their counterparts in the first

1706

01:17:58,619 --> 01:18:03,930

billion years of the universe and how

1707

01:18:01,649 --> 01:18:05,129

that happened how different physical

1708

01:18:03,930 --> 01:18:07,990

mechanism

1709

01:18:05,130 --> 01:18:09,940

regulated an interplay to form those

1710

01:18:07,989 --> 01:18:11,829

first galaxies I think is for me one of



1711  
01:18:09,939 --> 01:18:14,769  
the most interesting problems and we are

1712  
01:18:11,829 --> 01:18:18,550  
nowhere near solving it Webb's gonna

1713  
01:18:14,770 --> 01:18:21,310  
help but we need W first as well okay

1714  
01:18:18,550 --> 01:18:28,510  
and one last question from the audience

1715  
01:18:21,310 --> 01:18:47,580  
what's a laserdisc we just got a couple

1716  
01:18:28,510 --> 01:18:50,860  
more minutes Yeah right there okay so

1717  
01:18:47,579 --> 01:18:52,899  
what is the fastest we've sent we we've

1718  
01:18:50,859 --> 01:18:55,149  
created is not aizen's that's the

1719  
01:18:52,899 --> 01:18:56,829  
fastest chip we've launched and how fast

1720  
01:18:55,149 --> 01:19:00,939  
do you think we possibly can go do you

1721  
01:18:56,829 --> 01:19:10,000  
know how fast it's going no we can call

1722  
01:19:00,939 --> 01:19:11,439  
Alan Stern right now we can only the

1723  
01:19:10,000 --> 01:19:12,880  
main way that we get things moving fast

1724  
01:19:11,439 --> 01:19:14,889  
this is true for New Horizons which

1725  
01:19:12,880 --> 01:19:16,810  
recently flew by Pluto this is true for

1726  
01:19:14,890 --> 01:19:19,000  
the Pioneer missions and for the two

1727  
01:19:16,810 --> 01:19:21,550  
Voyager missions is that as we go out

1728  
01:19:19,000 --> 01:19:23,229  
through the solar system we go by the

1729  
01:19:21,550 --> 01:19:24,159  
giant planets and actually the reason we

1730  
01:19:23,229 --> 01:19:26,559  
could do the Pioneer and Voyager

1731  
01:19:24,159 --> 01:19:29,130  
missions when we did is because all the

1732  
01:19:26,560 --> 01:19:31,450  
giant planets were lined up perfectly

1733  
01:19:29,130 --> 01:19:33,039  
right when we had the technology to do

1734  
01:19:31,449 --> 01:19:34,510  
it they just happen to be lined up

1735  
01:19:33,039 --> 01:19:39,069  
perfectly and this does not happen that

1736  
01:19:34,510 --> 01:19:40,720  
often as the planets and so you swing by

1737  
01:19:39,069 --> 01:19:42,369  
Jupiter you get a gravity assist and you

1738  
01:19:40,720 --> 01:19:44,860  
speed up then you swing by Saturn

1739

01:19:42,369 --> 01:19:48,519  
Neptune Uranus and then Neptune on the

1740  
01:19:44,859 --> 01:19:51,639  
way out doing that we are nowhere near

1741  
01:19:48,520 --> 01:19:55,260  
the speed of light New Horizons is

1742  
01:19:51,640 --> 01:19:58,780  
moving at 16 kilometers a second or

1743  
01:19:55,260 --> 01:20:00,940  
36,000 miles per hour so 16 to give you

1744  
01:19:58,779 --> 01:20:03,369  
a sense 16 kilometers per second is New

1745  
01:20:00,939 --> 01:20:05,109  
Horizons and the speed of light is a

1746  
01:20:03,369 --> 01:20:08,170  
hundred thousand kilometers per second

1747  
01:20:05,109 --> 01:20:10,599  
as we approach the speed of light

1748  
01:20:08,170 --> 01:20:12,190  
because of relativity as you start

1749  
01:20:10,600 --> 01:20:13,900  
approaching the speed of light the mass

1750  
01:20:12,189 --> 01:20:16,779  
of whatever you're sending approaches

1751  
01:20:13,899 --> 01:20:18,849  
infinity so we could

1752  
01:20:16,779 --> 01:20:20,109  
something near the speed of light or as

1753  
01:20:18,850 --> 01:20:21,510

close to the speed of light as we

1754

01:20:20,109 --> 01:20:24,819

possibly could

1755

01:20:21,510 --> 01:20:28,480

but even if we got something to half the

1756

01:20:24,819 --> 01:20:33,639

speed of light it would take eight years

1757

01:20:28,479 --> 01:20:36,969

to get to Alpha Centauri and it would

1758

01:20:33,640 --> 01:20:41,770

take thirty-two years to get to forty

1759

01:20:36,970 --> 01:20:44,710

Eridani so unless unless there's a way

1760

01:20:41,770 --> 01:20:46,780

around this the speed of light is the

1761

01:20:44,710 --> 01:20:48,579

speed limit of the universe unless

1762

01:20:46,779 --> 01:20:50,739

there's a way around it of course it's

1763

01:20:48,579 --> 01:20:52,239

no fun in you know you can't have Star

1764

01:20:50,739 --> 01:20:57,189

Trek if it's like well we'll get there

1765

01:20:52,239 --> 01:20:57,909

and about you know seventy years yeah no

1766

01:20:57,189 --> 01:21:02,589

that wouldn't make for a very

1767

01:20:57,909 --> 01:21:04,269

entertaining show yeah we scientists are

1768  
01:21:02,590 --> 01:21:06,670  
a little bit dampers on Hollywood script

1769  
01:21:04,270 --> 01:21:08,140  
writers that come around I've gotten a

1770  
01:21:06,670 --> 01:21:10,180  
couple of scripts past me and got like I

1771  
01:21:08,140 --> 01:21:13,480  
yeah this is it and none of this is

1772  
01:21:10,180 --> 01:21:16,119  
possible they don't listen because they

1773  
01:21:13,479 --> 01:21:18,069  
need it to work for their story but you

1774  
01:21:16,119 --> 01:21:24,430  
know we can give them our best advice

1775  
01:21:18,069 --> 01:21:26,099  
all right here what's on the other side

1776  
01:21:24,430 --> 01:21:30,220  
of a black hole

1777  
01:21:26,100 --> 01:21:34,180  
we don't know physics actually breaks

1778  
01:21:30,220 --> 01:21:35,860  
down inside of black holes so we

1779  
01:21:34,180 --> 01:21:37,780  
understand how things work on quantum

1780  
01:21:35,859 --> 01:21:39,250  
scales we understand our quantum

1781  
01:21:37,779 --> 01:21:42,269  
mechanics works and we've been able to

1782  
01:21:39,250 --> 01:21:45,699  
make quantum forces work with

1783  
01:21:42,270 --> 01:21:48,520  
electromagnetic physics but when you try

1784  
01:21:45,699 --> 01:21:50,949  
to combine those with general relativity

1785  
01:21:48,520 --> 01:21:52,990  
with our understanding of gravity the

1786  
01:21:50,949 --> 01:21:56,079  
equations don't agree and the

1787  
01:21:52,989 --> 01:21:58,090  
predictions don't agree at all and so we

1788  
01:21:56,079 --> 01:22:01,000  
don't actually know what's going on

1789  
01:21:58,090 --> 01:22:03,190  
inside of a black hole because our two

1790  
01:22:01,000 --> 01:22:05,649  
understandings of the universe are

1791  
01:22:03,189 --> 01:22:07,929  
giving us completely contradictory

1792  
01:22:05,649 --> 01:22:09,909  
answers it's actually called the to

1793  
01:22:07,930 --> 01:22:11,860  
unify those to make them work inside a

1794  
01:22:09,909 --> 01:22:18,340  
black hole is one of the Holy Grails of

1795  
01:22:11,859 --> 01:22:19,839  
theoretical physics right now I mean it

1796

01:22:18,340 --> 01:22:22,500  
could be a wormhole to the Gamma

1797  
01:22:19,840 --> 01:22:22,500  
Quadrant but

1798  
01:22:22,639 --> 01:22:27,538  
well you know we the scientific answer

1799  
01:22:25,738 --> 01:22:30,238  
is that we once you're past the event

1800  
01:22:27,538 --> 01:22:32,668  
horizon we don't know okay we have an

1801  
01:22:30,238 --> 01:22:37,259  
update from somebody online who looked

1802  
01:22:32,668 --> 01:22:39,569  
it up and NASA's Juno was accelerated by

1803  
01:22:37,260 --> 01:22:43,199  
Jupiter and they they quote one hundred

1804  
01:22:39,569 --> 01:22:44,578  
sixty-five thousand miles per hour that

1805  
01:22:43,198 --> 01:22:47,759  
makes you know the fastest moving

1806  
01:22:44,578 --> 01:22:49,288  
human-made object in history okay I

1807  
01:22:47,760 --> 01:22:52,019  
didn't know that Juno had gotten up to

1808  
01:22:49,288 --> 01:22:53,578  
that speed the Juno probe that's

1809  
01:22:52,019 --> 01:22:56,489  
measuring the magnetosphere of jupiter

1810  
01:22:53,578 --> 01:22:58,708

right now was accelerated when it came

1811

01:22:56,488 --> 01:23:01,108

past Jupiter is in this big huge looping

1812

01:22:58,708 --> 01:23:02,819

orbit around Jupiter and somebody online

1813

01:23:01,109 --> 01:23:06,780

says it's it's now the fastest

1814

01:23:02,819 --> 01:23:08,819

human-made object in history okay it's

1815

01:23:06,779 --> 01:23:10,828

9:20 for all I give you the honor of the

1816

01:23:08,819 --> 01:23:14,268

last question in the back here net speed

1817

01:23:10,828 --> 01:23:17,069

is strictly gravitational is responsible

1818

01:23:14,269 --> 01:23:19,619

well it it would have approached Jupiter

1819

01:23:17,069 --> 01:23:22,858

with similar tens of kilometers per

1820

01:23:19,618 --> 01:23:25,618

second speed as is moving out but then

1821

01:23:22,859 --> 01:23:28,349

because it came so deep into Jupiter's

1822

01:23:25,618 --> 01:23:30,118

gravity well it gotten an acceleration

1823

01:23:28,349 --> 01:23:32,550

as it came through Jupiter's gravity

1824

01:23:30,118 --> 01:23:34,768

well that increased its speed so it's



1825  
01:23:32,550 --> 01:23:38,939  
orbiting Jupiter with that speed okay

1826  
01:23:34,769 --> 01:23:41,010  
all right so understanding that meal

1827  
01:23:38,939 --> 01:23:45,119  
we'll be back next year where she's

1828  
01:23:41,010 --> 01:23:46,708  
going to disprove shine Holt's theory of

1829  
01:23:45,118 --> 01:23:50,128  
multiple you do realize I'm applying to

1830  
01:23:46,708 --> 01:23:54,538  
jobs in California right I'm making a

1831  
01:23:50,128 --> 01:23:56,340  
Star Trek reference here okay wine holds

1832  
01:23:54,538 --> 01:23:57,779  
your theory of multiple Big Bang's which

1833  
01:23:56,340 --> 01:23:59,609  
is dependent upon Wang's second

1834  
01:23:57,779 --> 01:24:02,878  
postulate okay and so you have to get

1835  
01:23:59,609 --> 01:24:07,129  
past there's no observables yes we all

1836  
01:24:02,878 --> 01:24:07,128  
know that Wang as Captain Janeway said

1837  
01:24:20,420 --> 01:24:24,590  
but next month

1838  
01:24:28,130 --> 01:24:33,480  
Suzanne adduced wha and in the meantime

1839

01:24:31,020 --> 01:24:33,800

let's give a warm thank you to me above

1840

01:24:33,479 --> 01:24:48,328

Oh

1841

01:24:33,800 --> 01:24:48,329

[Applause]