Hubble Public Lecture Series

Topic: Planetary Tales from the Stellar Crypt: Exoplanets Surviving the Death of their Host Star

Speaker: John Debes,
Space Telescope Science Institute

1
00:00:25,790 --> 00:00:17,990
yeah we got that okay let's take the

2
00:00:31,490 --> 00:00:25,800
house lights down and we shall begin no

3
00:00:33,290 --> 00:00:31,500
need these laser pointer works okay good

4
00:00:34,720 --> 00:00:33,300
evening ladies and gentlemen and welcome

5
00:00:37,940 --> 00:00:34,730
to the space telescope science

6
00:00:40,040 --> 00:00:37,950
Institute's public lecture series it is

7
00:00:41,780 --> 00:00:40,050
by joy and pleasure to be your host i am

8
00:00:44,479 --> 00:00:41,790
dr. Frank summers of the office of

9
00:00:46,340 --> 00:00:44,489
public outreach for the gentleman who

10
00:00:49,340 --> 00:00:46,350
just came in late you didn't get a

11
00:00:51,439 --> 00:00:49,350
pretty picture yet pretty are

12
00:00:53,420 --> 00:00:51,449
down there on the corner and today

13
00:00:59,720 --> 00:00:53,430

tights pretty picture is the butterfly

14
00:01:02,750 --> 00:00:59,730
nebulae also known as NGC 6302 this is a

15
00:01:05,000 --> 00:01:02,760
dying star which is of significance for

16
00:01:07,789 --> 00:01:05,010
our speakers talk tonight because he's

17
00:01:10,219 --> 00:01:07,799
talking about you talking about I'll

18
00:01:12,859 --> 00:01:10,229
just go straight to it planetary tales

19
00:01:16,420 --> 00:01:12,869
from the stellar crypt exoplanets

20
00:01:19,880 --> 00:01:16,430
surviving the death of their host star

21
00:01:21,320 --> 00:01:19,890
this is John devas who has spoken to us

22
00:01:23,690 --> 00:01:21,330
before with all sorts of interesting

23
00:01:29,240 --> 00:01:23,700
titles but I got to see John your title

24
00:01:33,080 --> 00:01:29,250
is so long that you get a small font on

25
00:01:35,929 --> 00:01:33,090
slide here next month we have Rachel

26
00:01:38,060 --> 00:01:35,939
Austin talking about why we need to

27
00:01:41,480 --> 00:01:38,070
understand stars to find the next earth

28
00:01:43,999 --> 00:01:41,490
and in May we have time Brown talking

29
00:01:46,069 --> 00:01:44,009
about on the table is analyses the

30
00:01:48,050 --> 00:01:46,079
oldest stars in the neighborhood and

31
00:01:50,450 --> 00:01:48,060
you'll see that both of them will also

32
00:01:53,270 --> 00:01:50,460
get similarly small fonts on their title

33
00:01:55,190 --> 00:01:53,280
slide but Nicole Lewis in June we

34
00:01:57,319 --> 00:01:55,200
talking about probing worlds beyond our

35
00:01:58,730 --> 00:01:57,329
solar system she'll get a little bit of

36
00:02:01,940 --> 00:01:58,740
a bigger font because she uses the

37
00:02:04,190 --> 00:02:01,950
shorter title there all right and if you

38
00:02:05,430 --> 00:02:04,200

are going to come to those talks as

39
00:02:07,680 --> 00:02:05,440
those of you

40
00:02:09,719 --> 00:02:07,690
you're found out tonight those are you

41
00:02:13,050 --> 00:02:09,729
on the web might find out if you come

42
00:02:15,030 --> 00:02:13,060
that the san martin drive south of the

43
00:02:17,330 --> 00:02:15,040
Space Telescope Science Institute will

44
00:02:20,970 --> 00:02:17,340
be closed until approximately September

45
00:02:22,950 --> 00:02:20,980
2016 if you come to visit us come to the

46
00:02:25,890 --> 00:02:22,960
auditorium you must approach from the

47
00:02:28,200 --> 00:02:25,900
north from the university parkway okay

48
00:02:31,590 --> 00:02:28,210
all the details are available at this

49
00:02:33,240 --> 00:02:31,600
web web address from Johns Hopkins but

50
00:02:35,070 --> 00:02:33,250
all you really no need to know is what's

51
00:02:37,590 --> 00:02:35,080
what's here just come come at us from

52
00:02:39,600 --> 00:02:37,600
the north all right you can find out

53
00:02:44,130 --> 00:02:39,610
information about our upcoming lectures

54
00:02:45,510 --> 00:02:44,140
on our webpage if you just put Hubble

55
00:02:46,920 --> 00:02:45,520
public talks into your favorite search

56
00:02:49,560 --> 00:02:46,930
engine you should come up with this web

57
00:02:53,340 --> 00:02:49,570
page this web page was redesigned last

58
00:02:57,330 --> 00:02:53,350
month excuse me it has links to the

59
00:02:59,070 --> 00:02:57,340
online a lot of it so that we can so

60
00:03:01,320 --> 00:02:59,080
that those of you who want to watch at

61
00:03:03,720 --> 00:03:01,330
home if you are sick and next month you

62
00:03:06,810 --> 00:03:03,730
can watch live online both on YouTube

63
00:03:09,479 --> 00:03:06,820

and on the stsci webcasting site we had

64
00:03:12,420 --> 00:03:09,489
the archives of stuff that's on youtube

65
00:03:15,000 --> 00:03:12,430
or in the stsci webcast archive we go

66
00:03:17,550 --> 00:03:15,010
all the way back to 2005 so that's like

67
00:03:20,280 --> 00:03:17,560
10 years of astronomical goodness for

68
00:03:23,040 --> 00:03:20,290
you to enjoy we also added to our

69
00:03:25,500 --> 00:03:23,050
website web page an easy way to

70
00:03:28,170 --> 00:03:25,510
subscribe to our announcements emailing

71
00:03:30,390 --> 00:03:28,180
list the one or two emails that I send

72
00:03:32,760 --> 00:03:30,400
every month reminding people of the neck

73
00:03:35,640 --> 00:03:32,770
upcoming lectures as well as telling you

74
00:03:37,170 --> 00:03:35,650
when the webcasts have been posted and

75
00:03:39,750 --> 00:03:37,180
where you can find those webcasts which

76
00:03:42,080 --> 00:03:39,760
is useful also on the right hand side

77
00:03:46,140 --> 00:03:42,090
you can see the links to the upcoming

78
00:03:48,030 --> 00:03:46,150
lectures about that email list if you

79
00:03:50,640 --> 00:03:48,040
don't want to use the easy way you want

80
00:03:54,000 --> 00:03:50,650
to do it the hard way you can buy going

81
00:03:56,160 --> 00:03:54,010
to mail list at stsci edu clicking on

82
00:03:58,380 --> 00:03:56,170
public lecture announced and providing

83
00:04:00,509 --> 00:03:58,390
your email address there or if you

84
00:04:01,770 --> 00:04:00,519
really want to be lazy just write it

85
00:04:03,750 --> 00:04:01,780
down on a piece of paper and hand it to

86
00:04:05,550 --> 00:04:03,760
me at the end of the talk okay and I'll

87
00:04:08,370 --> 00:04:05,560
make sure you get added to the email

88
00:04:10,930 --> 00:04:08,380

list if you would like to give us other

89
00:04:14,140 --> 00:04:10,940
contact us in other ways we have the

90
00:04:16,090 --> 00:04:14,150
public lecture at stsci edu comments

91
00:04:18,280 --> 00:04:16,100
questions and yet another way to sign up

92
00:04:22,120 --> 00:04:18,290
for announcements we got way too many

93
00:04:23,350 --> 00:04:22,130
ways in that right social media if you

94
00:04:26,530 --> 00:04:23,360
would like to follow us on social media

95
00:04:28,390 --> 00:04:26,540
Hubble has facebook to twitter accounts

96
00:04:32,350 --> 00:04:28,400
we're on google+ we're on pinterest and

97
00:04:33,850 --> 00:04:32,360
maybe a few more i myself have a blog

98
00:04:35,530 --> 00:04:33,860
Hubble's universe unfiltered on the

99
00:04:38,230 --> 00:04:35,540
Hubble site I'll have a new posting on

100
00:04:39,610 --> 00:04:38,240
Friday ok I don't post very often but I

101
00:04:42,400 --> 00:04:39,620
got there's a new one coming up on

102
00:04:45,250 --> 00:04:42,410
friday i'm on facebook google+ and on

103
00:04:47,710 --> 00:04:45,260
twitter but i'm only occasionally on

104
00:04:50,490 --> 00:04:47,720
those devices because social media can

105
00:04:52,780 --> 00:04:50,500
just eat up way too much of your time

106
00:04:55,360 --> 00:04:52,790
unfortunately this guy is not clear

107
00:04:58,630 --> 00:04:55,370
tonight so we will yet again not have

108
00:05:00,220 --> 00:04:58,640
observatory after the talk this is like

109
00:05:02,350 --> 00:05:00,230
three or four months in a row that we

110
00:05:05,050 --> 00:05:02,360
haven't had this I apologize I don't

111
00:05:06,580 --> 00:05:05,060
control the weather alright people may

112
00:05:09,220 --> 00:05:06,590
call me the master of the universe but I

113
00:05:12,700 --> 00:05:09,230

cannot control the weather for you so

114
00:05:14,860 --> 00:05:12,710
but if you go to maryland md dot space

115
00:05:17,380 --> 00:05:14,870
grant o RG the maryland space grant

116
00:05:20,080 --> 00:05:17,390
observatory you will find their webpage

117
00:05:22,480 --> 00:05:20,090
and their information about their open

118
00:05:25,000 --> 00:05:22,490
nights on friday nights I believe every

119
00:05:26,800 --> 00:05:25,010
Friday night that's clear again subject

120
00:05:28,390 --> 00:05:26,810
to the weather they will let you look

121
00:05:30,880 --> 00:05:28,400
through their wonderful telescope there

122
00:05:33,760 --> 00:05:30,890
ok so go to their website page and find

123
00:05:36,900 --> 00:05:33,770
out about that let's take it to our new

124
00:05:41,800 --> 00:05:36,910
summary news from the universe for march

125
00:05:46,120 --> 00:05:41,810
2016 our first story tonight when'd this

126
00:05:48,640 --> 00:05:46,130
galaxy cluster grow so big I mean every

127
00:05:51,580 --> 00:05:48,650
time my kids see their grandmothers like

128
00:05:54,790 --> 00:05:51,590
oh you've gotten so big when did this

129
00:05:57,820 --> 00:05:54,800
happen right well we astronomers do the

130
00:06:01,300 --> 00:05:57,830
same things but this time for galaxy

131
00:06:02,920 --> 00:06:01,310
clusters okay so here is a galaxy

132
00:06:05,800 --> 00:06:02,930
cluster in the nearby universe it's

133
00:06:07,060 --> 00:06:05,810
called the coma cluster okay and the

134
00:06:09,040 --> 00:06:07,070
coma cluster is one of the largest

135
00:06:11,860 --> 00:06:09,050
galaxies ocean it's got thousands of

136
00:06:13,930 --> 00:06:11,870
galaxies in it right and we have

137
00:06:18,120 --> 00:06:13,940
estimated the mass of the coma cluster

138
00:06:20,290 --> 00:06:18,130

and it's two quadrillion solar masses

139
00:06:22,960 --> 00:06:20,300
now I know some of you think I just made

140
00:06:24,310 --> 00:06:22,970
that up all right but I didn't okay it

141
00:06:28,330 --> 00:06:24,320
goes million

142
00:06:30,430 --> 00:06:28,340
billion trillion quadrillion okay and

143
00:06:33,130 --> 00:06:30,440
that math assessment here is actually

144
00:06:35,470 --> 00:06:33,140
two quadrillion all right it's two times

145
00:06:37,360 --> 00:06:35,480
ten to the fifteenth solar masses just a

146
00:06:39,490 --> 00:06:37,370
really big number but it's a number that

147
00:06:41,980 --> 00:06:39,500
I'm going to need later on and later on

148
00:06:43,570 --> 00:06:41,990
in this to it to F for comparison okay

149
00:06:45,340 --> 00:06:43,580
so two times ten to the fifteenth is

150
00:06:47,890 --> 00:06:45,350
your comparison number remember that

151
00:06:49,750 --> 00:06:47,900
we'll get back to it so as the galaxy

152
00:06:56,070 --> 00:06:49,760
cluster we're going to talk about is not

153
00:06:59,650 --> 00:06:56,080
coma it's this one called I dcs 1426 ok

154
00:07:01,210 --> 00:06:59,660
and this galaxy cluster looks kind of

155
00:07:04,960 --> 00:07:01,220
similar to coma lots and lots of

156
00:07:07,390 --> 00:07:04,970
galaxies but there's a clue when we look

157
00:07:10,450 --> 00:07:07,400
at the wavelengths in which Hubble

158
00:07:13,480 --> 00:07:10,460
observed this galaxy cluster because you

159
00:07:17,170 --> 00:07:13,490
can see the blue in this image is 606

160
00:07:20,200 --> 00:07:17,180
and 814 nanometers blue in visible light

161
00:07:22,450 --> 00:07:20,210
is actually around 400 to 450 nanometers

162
00:07:26,500 --> 00:07:22,460
right the blue in this image is actually

163
00:07:30,220 --> 00:07:26,510

read the green and the red in this image

164
00:07:32,920 --> 00:07:30,230
is actually the near-infrared so all of

165
00:07:35,970 --> 00:07:32,930
the filters use to observe this cluster

166
00:07:39,430 --> 00:07:35,980
I'll go from the red into the infrared

167
00:07:43,000 --> 00:07:39,440
why do we do that well because this is a

168
00:07:44,860 --> 00:07:43,010
high redshift cluster all right the

169
00:07:47,140 --> 00:07:44,870
galaxy is so far away that it's light

170
00:07:50,140 --> 00:07:47,150
has been red shifted from visible light

171
00:07:52,150 --> 00:07:50,150
toward the infrared light so it's better

172
00:07:55,300 --> 00:07:52,160
to see this galaxy cluster using

173
00:07:58,420 --> 00:07:55,310
infrared light okay this galaxy cluster

174
00:08:02,020 --> 00:07:58,430
is measured to be about 10 billion light

175
00:08:04,300 --> 00:08:02,030
years away okay it's 10 billion

176
00:08:08,710 --> 00:08:04,310
light-years away which means it's seen

177
00:08:10,540 --> 00:08:08,720
as it was 10 billion years ago so the

178
00:08:12,820 --> 00:08:10,550
question is all right this is about 4

179
00:08:15,070 --> 00:08:12,830
billion years after the Big Bang the

180
00:08:18,630 --> 00:08:15,080
question is how large of a galaxy

181
00:08:21,730 --> 00:08:18,640
cluster can you grow in 4 billion years

182
00:08:23,170 --> 00:08:21,740
let's find out so we're going to take

183
00:08:25,030 --> 00:08:23,180
that Hubble image and we're going to

184
00:08:26,800 --> 00:08:25,040
color it yellow all right we're going to

185
00:08:28,150 --> 00:08:26,810
do a composite image all right we're

186
00:08:29,860 --> 00:08:28,160
going to take all that that Hubble image

187
00:08:31,450 --> 00:08:29,870
and we're just going to call it visible

188
00:08:33,130 --> 00:08:31,460

even though between you and me it's

189
00:08:35,830 --> 00:08:33,140
really more infrared than visible light

190
00:08:38,240 --> 00:08:35,840
in this Hubble image okay we're going to

191
00:08:40,370 --> 00:08:38,250
use the Spitzer Space Telescope

192
00:08:42,709 --> 00:08:40,380
to observe it in deeper into the

193
00:08:44,300 --> 00:08:42,719
infrared okay Spitzer is an infrared

194
00:08:45,950 --> 00:08:44,310
telescope doesn't have the resolution of

195
00:08:48,050 --> 00:08:45,960
Hubble but it can see further into

196
00:08:49,880 --> 00:08:48,060
infrared which is better for seeing

197
00:08:52,130 --> 00:08:49,890
these higher redshift clusters in order

198
00:08:54,170 --> 00:08:52,140
to see the infrared emission from them

199
00:08:56,540 --> 00:08:54,180
and this is going to tell us a bit about

200
00:08:59,060 --> 00:08:56,550
these higher redshift galaxies but to

201
00:09:01,280 --> 00:08:59,070
really get great information about it to

202
00:09:03,470 --> 00:09:01,290
try and measure clusters of galaxies we

203
00:09:06,380 --> 00:09:03,480
want to go to the x-rays using the

204
00:09:08,390 --> 00:09:06,390
Chandra x-ray Observatory now these

205
00:09:11,150 --> 00:09:08,400
clusters of galaxies formed by the

206
00:09:13,970 --> 00:09:11,160
mergers of smaller clusters and the gas

207
00:09:16,610 --> 00:09:13,980
in between the galaxies as the clusters

208
00:09:19,520 --> 00:09:16,620
as the clusters merged together gets

209
00:09:23,350 --> 00:09:19,530
heated up heat it up until it's millions

210
00:09:27,190 --> 00:09:23,360
of degrees and glows in x-rays and

211
00:09:29,270 --> 00:09:27,200
because the energy put into that gas is

212
00:09:30,710 --> 00:09:29,280
indicative of the amount of energy of

213
00:09:33,890 --> 00:09:30,720

the kinetic energy of the galaxies

214
00:09:36,110 --> 00:09:33,900
colliding in the amount of x-ray

215
00:09:39,920 --> 00:09:36,120
emission is proportional to the amount

216
00:09:41,990 --> 00:09:39,930
of mass in the cluster okay from the

217
00:09:44,150 --> 00:09:42,000
amount of x-ray emission of the gas

218
00:09:46,730 --> 00:09:44,160
inside the cluster you could make a good

219
00:09:49,190 --> 00:09:46,740
estimate of the total amount of mass in

220
00:09:51,620 --> 00:09:49,200
the cluster all right so here's that

221
00:09:55,630 --> 00:09:51,630
composite image we were building here is

222
00:09:58,190 --> 00:09:55,640
the x-rays from Chandra and blue the

223
00:10:00,350 --> 00:09:58,200
visible flash near-infrared from Hubble

224
00:10:03,320 --> 00:10:00,360
and yellow and the infrared from Spitzer

225
00:10:06,829 --> 00:10:03,330
in red okay and this shows you the

226
00:10:08,860 --> 00:10:06,839
extent of the cluster of galaxies of the

227
00:10:11,690 --> 00:10:08,870
gas between the cluster and galaxies and

228
00:10:13,520 --> 00:10:11,700
using these we can make the estimate of

229
00:10:16,880 --> 00:10:13,530
the mass of this cluster of galaxies and

230
00:10:21,590 --> 00:10:16,890
the mass estimate is 500 trillion solar

231
00:10:24,110 --> 00:10:21,600
masses or 5 times 10 to the 14th okay

232
00:10:25,550 --> 00:10:24,120
now if you remember two times ten to the

233
00:10:28,400 --> 00:10:25,560
fifteenth was your reference number

234
00:10:31,850 --> 00:10:28,410
right this is about one-quarter the mass

235
00:10:35,210 --> 00:10:31,860
that's in the coma cluster however the

236
00:10:39,590 --> 00:10:35,220
coma cluster has had 10 billion more

237
00:10:43,310 --> 00:10:39,600
years to develop and grow that mass the

238
00:10:46,640 --> 00:10:43,320

question is can you really grow such a

239
00:10:50,150 --> 00:10:46,650
big galaxy cluster oh you know a half a

240
00:10:51,470 --> 00:10:50,160
half a quadrillion solar masses in four

241
00:10:54,290 --> 00:10:51,480
billion years

242
00:10:56,840 --> 00:10:54,300
for reference the Milky Way galaxy had

243
00:10:59,210 --> 00:10:56,850
just formed 10 billion years ago so in

244
00:11:02,090 --> 00:10:59,220
our part of the universe we just gotten

245
00:11:04,189 --> 00:11:02,100
one galaxy here we've got hundreds to

246
00:11:07,009 --> 00:11:04,199
thousands of galaxies together in the

247
00:11:09,889 --> 00:11:07,019
first four billion years obviously it

248
00:11:13,519 --> 00:11:09,899
can be done but it puts constraints on

249
00:11:15,650 --> 00:11:13,529
our hypothesis of how quickly things can

250
00:11:18,650 --> 00:11:15,660
grow in the universe and it appears that

251
00:11:22,819 --> 00:11:18,660
galaxy clusters you know they grow up so

252
00:11:24,829 --> 00:11:22,829
fast all right we can get a large galaxy

253
00:11:27,110 --> 00:11:24,839
cluster very early on in the universe

254
00:11:30,920 --> 00:11:27,120
and this is one of our Hubble press

255
00:11:33,920 --> 00:11:30,930
releases from last month all right okay

256
00:11:36,470 --> 00:11:33,930
our second story is not a Hubble story

257
00:11:39,290 --> 00:11:36,480
but it's too important to overlook a

258
00:11:44,740 --> 00:11:39,300
century later general relativity is

259
00:11:47,810 --> 00:11:44,750
still making waves all right so 1915

260
00:11:50,990 --> 00:11:47,820
Albert Einstein produces his general

261
00:11:54,199 --> 00:11:51,000
theory of relativity all right and we

262
00:11:57,410 --> 00:11:54,209
have celebrated its centennial last year

263
00:12:00,410 --> 00:11:57,420

ok now how many of you have been here to

264
00:12:01,550 --> 00:12:00,420
the public lecture series before ok how

265
00:12:04,460 --> 00:12:01,560
many of you have heard me talk about

266
00:12:06,110 --> 00:12:04,470
gravitational lensing how many of you

267
00:12:09,620 --> 00:12:06,120
have heard my three word summary of

268
00:12:14,509 --> 00:12:09,630
general relativity can anybody quote it

269
00:12:17,750 --> 00:12:14,519
back to me mass warps space or bends

270
00:12:19,970 --> 00:12:17,760
space as you said yes ok so what I've

271
00:12:23,329 --> 00:12:19,980
mostly told you about general relativity

272
00:12:26,870 --> 00:12:23,339
is described by this this image ok that

273
00:12:31,009 --> 00:12:26,880
the presence of mass puts a bend a warp

274
00:12:33,290 --> 00:12:31,019
in space ok and that light traveling

275
00:12:36,650 --> 00:12:33,300
through that warp space takes a curved

276
00:12:40,420 --> 00:12:36,660
path ok because it follows the contours

277
00:12:43,100 --> 00:12:40,430
of that curved space this is how we get

278
00:12:46,160 --> 00:12:43,110
gravitational lensing these giant

279
00:12:48,980 --> 00:12:46,170
clusters of galaxies warp space so much

280
00:12:50,329 --> 00:12:48,990
that the galaxies on the far side their

281
00:12:52,699 --> 00:12:50,339
light comes through and gums stretched

282
00:12:55,790 --> 00:12:52,709
and becomes the streaky our key things

283
00:12:58,280 --> 00:12:55,800
along here gravitational lensing ok and

284
00:13:00,800 --> 00:12:58,290
I have sometimes called this visual

285
00:13:02,449 --> 00:13:00,810
proof of general relativity because

286
00:13:04,880 --> 00:13:02,459
Newton's theory of gravity doesn't

287
00:13:05,300 --> 00:13:04,890
produce gravitational lensing Einstein's

288
00:13:08,960 --> 00:13:05,310

theory

289
00:13:11,450 --> 00:13:08,970
does however there are many other proofs

290
00:13:14,230 --> 00:13:11,460
of general relativity all right between

291
00:13:17,600 --> 00:13:14,240
the the time delays and and other things

292
00:13:19,790 --> 00:13:17,610
there is however one prediction of

293
00:13:25,040 --> 00:13:19,800
general relativity that had never been

294
00:13:28,400 --> 00:13:25,050
verified okay if you can warp space you

295
00:13:30,950 --> 00:13:28,410
can also send a ripple across space okay

296
00:13:33,769 --> 00:13:30,960
so making a warping space can actually

297
00:13:38,420 --> 00:13:33,779
send a ripple across space called

298
00:13:41,600 --> 00:13:38,430
gravitational waves okay so they set up

299
00:13:43,820 --> 00:13:41,610
detectors observatories to try and

300
00:13:45,500 --> 00:13:43,830
observe them and this is the laser

301
00:13:47,840 --> 00:13:45,510
interferometer gravitational-wave

302
00:13:49,730 --> 00:13:47,850
Observatory which everyone just calls

303
00:13:52,670 --> 00:13:49,740
LIGO because it's a lot less of a

304
00:13:55,370 --> 00:13:52,680
mouthful and in hanford washington and

305
00:13:57,829 --> 00:13:55,380
Livingston Louisiana they have two

306
00:13:59,390 --> 00:13:57,839
detectors set up I'm not going to get

307
00:14:03,100 --> 00:13:59,400
into the details of how it works but let

308
00:14:06,010 --> 00:14:03,110
me just give you the basics each arm of

309
00:14:09,980 --> 00:14:06,020
these detectors is four kilometers long

310
00:14:13,490 --> 00:14:09,990
they take a laser beam split it and send

311
00:14:15,290 --> 00:14:13,500
it down both arms and back when it comes

312
00:14:18,470 --> 00:14:15,300
back together they cause it to interfere

313
00:14:23,270 --> 00:14:18,480

with itself and in doing so they can

314
00:14:24,710 --> 00:14:23,280
measure extremely precise distances okay

315
00:14:29,300 --> 00:14:24,720
they can measure the distance along

316
00:14:31,460 --> 00:14:29,310
those arms extremely precisely now if a

317
00:14:34,700 --> 00:14:31,470
gravitational wave was coming through

318
00:14:36,470 --> 00:14:34,710
and stretching space well then one

319
00:14:39,200 --> 00:14:36,480
direction would get stretched just a

320
00:14:41,840 --> 00:14:39,210
tiny tiny bit and the other one would

321
00:14:43,690 --> 00:14:41,850
get shortened just a tiny tiny bit okay

322
00:14:48,079 --> 00:14:43,700
all right in the perpendicular direction

323
00:14:50,750 --> 00:14:48,089
so by measuring the distance deviation

324
00:14:53,570 --> 00:14:50,760
on between these two arms they could

325
00:14:58,329 --> 00:14:53,580
actually measure the idea of a

326
00:15:01,699 --> 00:14:58,339
gravitational wave going past okay so

327
00:15:05,120 --> 00:15:01,709
they measured something September 14

328
00:15:09,680 --> 00:15:05,130
2015 they got this signal which is

329
00:15:11,990 --> 00:15:09,690
dubbed GW 15 09 14 all right and it was

330
00:15:13,850 --> 00:15:12,000
measured in the hanford data shown in

331
00:15:16,699 --> 00:15:13,860
this orange color and the Livingston

332
00:15:18,980 --> 00:15:16,709
data shown in this blue color now it's

333
00:15:21,350 --> 00:15:18,990
important that you measure it in two

334
00:15:23,630 --> 00:15:21,360
replaces because a signal like this

335
00:15:25,460 --> 00:15:23,640
could be caused by you know some

336
00:15:27,920 --> 00:15:25,470
technician dropping a hammer next to the

337
00:15:30,800 --> 00:15:27,930
instrument okay all right but a hammer

338
00:15:33,410 --> 00:15:30,810

in Washington state is not going to be

339
00:15:35,420 --> 00:15:33,420
measured in Louisiana and vice versa so

340
00:15:37,820 --> 00:15:35,430
if you're measuring the same signal in

341
00:15:38,930 --> 00:15:37,830
both places that tells you hey it's

342
00:15:41,240 --> 00:15:38,940
pretty much coming from the universe

343
00:15:44,780 --> 00:15:41,250
maybe it's Thor's hammer you know or

344
00:15:47,300 --> 00:15:44,790
something like that excuse me all right

345
00:15:48,800 --> 00:15:47,310
and you can also see from this plot that

346
00:15:52,100 --> 00:15:48,810
they measured pretty much the same

347
00:15:58,160 --> 00:15:52,110
signal both in Washington State and in

348
00:16:01,790 --> 00:15:58,170
Louisiana what would it be ok well the

349
00:16:05,870 --> 00:16:01,800
hypothesis would be that it is two black

350
00:16:07,760 --> 00:16:05,880
holes merging together ok two black

351
00:16:10,790 --> 00:16:07,770
holes caught in orbit around each other

352
00:16:13,040 --> 00:16:10,800
giving off energy as they spiral in and

353
00:16:16,940 --> 00:16:13,050
then merge together to form one black

354
00:16:19,930 --> 00:16:16,950
hole right we're talking about to really

355
00:16:22,730 --> 00:16:19,940
really massive gravitational distortions

356
00:16:25,460 --> 00:16:22,740
merging together creating a

357
00:16:28,699 --> 00:16:25,470
gravitational wave big enough to be

358
00:16:31,730 --> 00:16:28,709
observed across the universe all right

359
00:16:35,329 --> 00:16:31,740
how big does it need to be well they did

360
00:16:37,819 --> 00:16:35,339
simulations and here is the hanford data

361
00:16:39,680 --> 00:16:37,829
and this yellow line going through it is

362
00:16:42,170 --> 00:16:39,690
the prediction of the simulation and

363
00:16:43,670 --> 00:16:42,180

there's the Livingston data and again

364
00:16:44,780 --> 00:16:43,680
the blue line light blue line going

365
00:16:47,030 --> 00:16:44,790
through it is prediction of that data

366
00:16:49,850 --> 00:16:47,040
and you can see how wonderfully this

367
00:16:51,650 --> 00:16:49,860
this matches so in doing the various

368
00:16:53,930 --> 00:16:51,660
Suites of simulations to try and figure

369
00:16:58,550 --> 00:16:53,940
out what this is they determined that

370
00:17:01,280 --> 00:16:58,560
it's a 36 solar mass black hole and a 29

371
00:17:05,270 --> 00:17:01,290
solar mass black hole merging together

372
00:17:08,900 --> 00:17:05,280
to form a 62 solar mass black hole and

373
00:17:10,910 --> 00:17:08,910
that would produce that signal which the

374
00:17:14,419 --> 00:17:10,920
signal that they observed in Washington

375
00:17:16,760 --> 00:17:14,429
and in Louisiana from the amplitude of

376
00:17:20,110 --> 00:17:16,770
that signal they can detect they can

377
00:17:24,230 --> 00:17:20,120
tell that the merger would have happened

378
00:17:27,079 --> 00:17:24,240
1.3 billion light-years away that's

379
00:17:30,260 --> 00:17:27,089
billion with ab e 1.3 billion so in a

380
00:17:32,690 --> 00:17:30,270
distant galaxy okay ten percent of the

381
00:17:36,170 --> 00:17:32,700
way across the observable

382
00:17:40,190 --> 00:17:36,180
and if you do the math you heard that I

383
00:17:43,790 --> 00:17:40,200
said 36 and 29 makes 62 no they don't

384
00:17:47,240 --> 00:17:43,800
there's three solar masses missing where

385
00:17:50,950 --> 00:17:47,250
did that three solar masses go into the

386
00:17:54,050 --> 00:17:50,960
fabric of space that three solar masses

387
00:17:56,510 --> 00:17:54,060
was put into the fabric of space to

388
00:18:00,710 --> 00:17:56,520

create a gravitational waves such an

389
00:18:04,190 --> 00:18:00,720
amazing event okay an amazing event that

390
00:18:06,020 --> 00:18:04,200
lasted you know less than a second

391
00:18:08,000 --> 00:18:06,030
actually about two-tenths of a second

392
00:18:10,190 --> 00:18:08,010
you can see from the graph okay well

393
00:18:12,170 --> 00:18:10,200
we'll be generous with ya we'll call it

394
00:18:14,170 --> 00:18:12,180
full two tenths of a second and they say

395
00:18:16,670 --> 00:18:14,180
I have to quote this the peak wattage

396
00:18:18,410 --> 00:18:16,680
for that tiny little fraction of a

397
00:18:21,200 --> 00:18:18,420
second was greater than the combined

398
00:18:27,530 --> 00:18:21,210
light of all the stars in the observable

399
00:18:31,430 --> 00:18:27,540
universe but still still all that energy

400
00:18:35,780 --> 00:18:31,440
going into it only stretch the fabric of

401
00:18:41,060 --> 00:18:35,790
space by one one thousandth the diameter

402
00:18:44,330 --> 00:18:41,070
of a proton that much energy what they

403
00:18:46,430 --> 00:18:44,340
measured was space being stretched by

404
00:18:48,410 --> 00:18:46,440
one one thousandth the diameter of

405
00:18:50,090 --> 00:18:48,420
proton first of all the fact that we

406
00:18:53,000 --> 00:18:50,100
could measure that is absolutely amazing

407
00:18:55,750 --> 00:18:53,010
right but so much energy to create such

408
00:18:58,910 --> 00:18:55,760
a tiny little deviation in space okay

409
00:19:02,360 --> 00:18:58,920
gravitational waves are really really

410
00:19:03,830 --> 00:19:02,370
really small okay and we talk about

411
00:19:06,020 --> 00:19:03,840
gravity being the weakest of the four

412
00:19:08,030 --> 00:19:06,030
fundamental forces here's your evidence

413
00:19:10,160 --> 00:19:08,040

that you have to destroy three solar

414
00:19:13,790 --> 00:19:10,170
masses three times the mass of the Sun

415
00:19:19,280 --> 00:19:13,800
just to stretch space by less than the

416
00:19:21,950 --> 00:19:19,290
width of a proton yes the amplitude of

417
00:19:24,170 --> 00:19:21,960
course of changes with it Goes Down Goes

418
00:19:25,880 --> 00:19:24,180
Down linearly with distance okay in this

419
00:19:27,320 --> 00:19:25,890
case I'm not exactly sure why it doesn't

420
00:19:29,680 --> 00:19:27,330
goes down linearly instead of by the

421
00:19:33,770 --> 00:19:29,690
square I couldn't figure that out today

422
00:19:37,670 --> 00:19:33,780
but i'm not i'm not a gr physicist on

423
00:19:40,580 --> 00:19:37,680
that okay so here is the paper that they

424
00:19:43,130 --> 00:19:40,590
released last month okay on the first

425
00:19:45,560 --> 00:19:43,140
observation of gravitational waves from

426
00:19:46,100 --> 00:19:45,570
a binary black hole merger first of all

427
00:19:49,270 --> 00:19:46,110
the result

428
00:19:52,100 --> 00:19:49,280
health is that black holes do merge okay

429
00:19:54,169 --> 00:19:52,110
we had thought that they would we had

430
00:19:57,169 --> 00:19:54,179
guessed that they would but there was no

431
00:20:00,080 --> 00:19:57,179
evidence for it until this paper was

432
00:20:02,180 --> 00:20:00,090
released second thing gravitational

433
00:20:04,820 --> 00:20:02,190
waves exist this is a fundamental

434
00:20:06,830 --> 00:20:04,830
prediction of general relativity that

435
00:20:08,870 --> 00:20:06,840
had never been tested before some call

436
00:20:10,419 --> 00:20:08,880
it the final prediction of general

437
00:20:13,760 --> 00:20:10,429
relativity that needed to be tested

438
00:20:16,760 --> 00:20:13,770

gravitational waves do exist the third

439
00:20:18,950 --> 00:20:16,770
thing due to the time delay between when

440
00:20:20,440 --> 00:20:18,960
it was observed in Washington and when

441
00:20:22,640 --> 00:20:20,450
it was deserved in Louisiana

442
00:20:24,890 --> 00:20:22,650
gravitational waves as predicted by

443
00:20:28,370 --> 00:20:24,900
general relativity travel at the speed

444
00:20:31,070 --> 00:20:28,380
of light there was no evidence to allow

445
00:20:32,840 --> 00:20:31,080
for any deviation from the speed of

446
00:20:35,690 --> 00:20:32,850
light for this gravitational wave

447
00:20:37,520 --> 00:20:35,700
disturbance they said it was oh I forget

448
00:20:39,260 --> 00:20:37,530
what the the number of milliseconds was

449
00:20:42,400 --> 00:20:39,270
like six milliseconds differential

450
00:20:44,630 --> 00:20:42,410
between the two sites and finally

451
00:20:48,200 --> 00:20:44,640
general relativity has been proved

452
00:20:50,270 --> 00:20:48,210
correct yet again all right so now we

453
00:20:52,900 --> 00:20:50,280
have a brand-new window on the universe

454
00:20:56,390 --> 00:20:52,910
we can observe the stretching of space

455
00:20:58,640 --> 00:20:56,400
to see these really high energy events

456
00:21:00,440 --> 00:20:58,650
and you're saying well like it was 1.3

457
00:21:04,520 --> 00:21:00,450
billion light-years away is just one

458
00:21:07,039 --> 00:21:04,530
event however LIGO wasn't even in

459
00:21:09,200 --> 00:21:07,049
production mode at the time when they

460
00:21:13,539 --> 00:21:09,210
saw this it was in its pre production

461
00:21:17,120 --> 00:21:13,549
mode okay LIGO we have the hanford and

462
00:21:18,980 --> 00:21:17,130
Livingston ones here in the US under

463
00:21:21,919 --> 00:21:18,990

construction we have Virgo in Europe on

464
00:21:23,810 --> 00:21:21,929
the Geo 600 is online LIGO India's

465
00:21:27,049 --> 00:21:23,820
planned we have CAG are coming along and

466
00:21:30,650 --> 00:21:27,059
in Japan when we get the full suite of

467
00:21:31,640 --> 00:21:30,660
them as well as the planned upgrades to

468
00:21:33,320 --> 00:21:31,650
them which will increase their

469
00:21:36,830 --> 00:21:33,330
sensitivity by another factor of ten or

470
00:21:39,950 --> 00:21:36,840
two all right we will be able to see the

471
00:21:43,280 --> 00:21:39,960
prediction is dozens to thousands of

472
00:21:45,350 --> 00:21:43,290
these events over the next decade so we

473
00:21:47,659 --> 00:21:45,360
have started I feel like this is like

474
00:21:49,460 --> 00:21:47,669
the exoplanets I think where we were in

475
00:21:50,990 --> 00:21:49,470
the 1990s with exoplanets we just saw

476
00:21:52,880 --> 00:21:51,000
the first exoplanets around start

477
00:21:55,620 --> 00:21:52,890
planets around other stars we're now

478
00:21:58,710 --> 00:21:55,630
being able to see the first of these

479
00:22:00,180 --> 00:21:58,720
really massive events black hole mergers

480
00:22:02,700 --> 00:22:00,190
we should be able to see neutron star

481
00:22:05,190 --> 00:22:02,710
neutron star mergers will be able to

482
00:22:07,110 --> 00:22:05,200
characterize them and understand what

483
00:22:09,090 --> 00:22:07,120
their prevalence is out there in the

484
00:22:12,060 --> 00:22:09,100
universe so we're at a really cool place

485
00:22:13,650 --> 00:22:12,070
and yes your answer to the question

486
00:22:16,050 --> 00:22:13,660
that's always asked this will probably

487
00:22:19,170 --> 00:22:16,060
produce a Nobel Prize maybe about 15

488
00:22:21,060 --> 00:22:19,180

years from now okay Nobel Prizes aren't

489
00:22:22,590 --> 00:22:21,070
given immediately they definitely gotta

490
00:22:24,900 --> 00:22:22,600
wait until make sure that everything

491
00:22:26,880 --> 00:22:24,910
everything everything holds together but

492
00:22:29,280 --> 00:22:26,890
yeah I can easily see this producing a

493
00:22:35,210 --> 00:22:29,290
Nobel Prize in about 15 years all right

494
00:22:37,080 --> 00:22:35,220
question well we have a small

495
00:22:38,190 --> 00:22:37,090
localization on the sky that's actually

496
00:22:40,620 --> 00:22:38,200
something I thank glad you mentioned

497
00:22:43,320 --> 00:22:40,630
that because by having more detectors

498
00:22:45,180 --> 00:22:43,330
around the world will be able to reduce

499
00:22:47,370 --> 00:22:45,190
the angular size of it there was a swath

500
00:22:49,110 --> 00:22:47,380
because I the only two we could say all

501
00:22:51,690 --> 00:22:49,120
right here's a swath of the sky because

502
00:22:53,610 --> 00:22:51,700
you're observing basically the sky above

503
00:22:55,050 --> 00:22:53,620
you when you do when you with the gender

504
00:22:57,180 --> 00:22:55,060
of a gravitational wave detector right

505
00:22:59,340 --> 00:22:57,190
and if you have them all around the

506
00:23:00,930 --> 00:22:59,350
world whoever sees it or doesn't see it

507
00:23:03,090 --> 00:23:00,940
and when they see it gives you

508
00:23:05,750 --> 00:23:03,100
triangulation all right in order to be

509
00:23:09,840 --> 00:23:05,760
able to pick a finer point on the sky

510
00:23:11,940 --> 00:23:09,850
folks have looked in the region where it

511
00:23:15,000 --> 00:23:11,950
was whereas determined it could have

512
00:23:17,280 --> 00:23:15,010
come from and nobody's found anything of

513
00:23:20,100 --> 00:23:17,290

any significance yet for that for that

514
00:23:21,990 --> 00:23:20,110
region but with more detectors online

515
00:23:23,940 --> 00:23:22,000
we'll be able to do it and now people

516
00:23:25,440 --> 00:23:23,950
will actually believe them okay if they

517
00:23:26,850 --> 00:23:25,450
set out a telegram boy we thought no

518
00:23:28,350 --> 00:23:26,860
gravitational wave go look at people

519
00:23:30,570 --> 00:23:28,360
like yeah my going to waste my telus

520
00:23:31,920 --> 00:23:30,580
telescope time on that right now they

521
00:23:34,590 --> 00:23:31,930
will believe them they will do the

522
00:23:37,260 --> 00:23:34,600
follow-up so that will be a that'll be a

523
00:23:39,270 --> 00:23:37,270
hot topic to better than that does it

524
00:23:42,450 --> 00:23:39,280
make sense to talk about frequency and

525
00:23:47,310 --> 00:23:42,460
amplitude of these gravitational waves

526
00:23:48,990 --> 00:23:47,320
or are you just a really miniscule that

527
00:23:51,060 --> 00:23:49,000
the miniscule is the amp and think that

528
00:23:54,450 --> 00:23:51,070
the amount of motion is very very small

529
00:23:58,590 --> 00:23:54,460
but the frequencies are in Hertz to two

530
00:24:00,780 --> 00:23:58,600
kilohertz okay and the detectors are

531
00:24:03,540 --> 00:24:00,790
only sensitive over a certain range of

532
00:24:04,440 --> 00:24:03,550
frequencies and that was it actually

533
00:24:09,210 --> 00:24:04,450
another

534
00:24:12,240 --> 00:24:09,220
reason why they built that they believe

535
00:24:14,430 --> 00:24:12,250
the graviton has no mass and then

536
00:24:16,560 --> 00:24:14,440
travels at the speed of light is that if

537
00:24:18,120 --> 00:24:16,570
it had massed there would be deviation

538
00:24:19,620 --> 00:24:18,130

along the frequencies the frequencies

539
00:24:22,020 --> 00:24:19,630
would arrive just slightly different

540
00:24:24,390 --> 00:24:22,030
flex slightly slightly different times

541
00:24:28,950 --> 00:24:24,400
and there was no deviation and frequency

542
00:24:31,410 --> 00:24:28,960
of scene okay all right let go and go

543
00:24:35,190 --> 00:24:31,420
down here so more gravitational waves

544
00:24:37,320 --> 00:24:35,200
the same thing is graviton no gravitons

545
00:24:40,050 --> 00:24:37,330
are the particle that would carry the

546
00:24:41,730 --> 00:24:40,060
gravitational force but the way there's

547
00:24:43,920 --> 00:24:41,740
a particle wave duality that we talk

548
00:24:46,230 --> 00:24:43,930
about like the photon is the particle

549
00:24:47,790 --> 00:24:46,240
that carries light whereas light is also

550
00:24:49,860 --> 00:24:47,800
considered an electromagnetic wave in

551
00:24:52,770 --> 00:24:49,870
the same way you have gravitational

552
00:24:55,650 --> 00:24:52,780
waves you also have a graviton to carry

553
00:24:58,890 --> 00:24:55,660
gravitational forces okay yeah it's it's

554
00:25:00,510 --> 00:24:58,900
it's this particle wave dualities it's

555
00:25:03,840 --> 00:25:00,520
fuzzy even for us professionals to do it

556
00:25:06,210 --> 00:25:03,850
okay question here Oh 600 didn't pick

557
00:25:07,470 --> 00:25:06,220
anything up as far as I know Gio 600 did

558
00:25:10,770 --> 00:25:07,480
not pick anything up it was not in the

559
00:25:12,750 --> 00:25:10,780
paper that I read one other question in

560
00:25:15,210 --> 00:25:12,760
the back oh yeah plans underway right

561
00:25:17,340 --> 00:25:15,220
now to put detectors in space so they'll

562
00:25:20,910 --> 00:25:17,350
be 3 billion miles apart and therefore

563
00:25:23,040 --> 00:25:20,920

much more accurate there is the ELISA

564
00:25:26,220 --> 00:25:23,050
project which is the laser

565
00:25:27,570 --> 00:25:26,230
interferometer or interferometry Space

566
00:25:30,510 --> 00:25:27,580
Observatory or something like that I

567
00:25:31,950 --> 00:25:30,520
don't know much about that but yes there

568
00:25:33,570 --> 00:25:31,960
are plans to try and put laser

569
00:25:37,020 --> 00:25:33,580
interferometers in space to measure

570
00:25:39,420 --> 00:25:37,030
gravitational waves from space I say I'm

571
00:25:41,640 --> 00:25:39,430
not an expert on all right don't want to

572
00:25:42,870 --> 00:25:41,650
pull up John's talk and any birth you

573
00:25:45,600 --> 00:25:42,880
get more question about gravitation

574
00:25:47,540 --> 00:25:45,610
waste come see me afterwards right now

575
00:25:50,430 --> 00:25:47,550
let me introduce our featured speaker

576
00:25:52,350 --> 00:25:50,440
john davis got his bachelor's degree

577
00:25:57,970 --> 00:25:52,360
from across the street at johns hopkins

578
00:26:04,799 --> 00:26:02,110
or med state on a decade ago and did

579
00:26:06,940 --> 00:26:04,809
post arcs postdoc down at Carnegie

580
00:26:11,080 --> 00:26:06,950
Department of terrestrial magnetism down

581
00:26:14,700 --> 00:26:11,090
in DC they he was at Goddard Space

582
00:26:16,810 --> 00:26:14,710
Flight Center what does NPP stand for ah

583
00:26:17,919 --> 00:26:16,820
suppose doctoral programs trying to

584
00:26:20,260 --> 00:26:17,929
figure that out when you gave this to a

585
00:26:22,659 --> 00:26:20,270
dispatcher dude I've down a Goddard for

586
00:26:26,080 --> 00:26:22,669
three years and then he came up to us in

587
00:26:27,580 --> 00:26:26,090
2011 here at the Space Telescope Science

588
00:26:30,400 --> 00:26:27,590

Institute besides being a wonderful

589
00:26:33,310 --> 00:26:30,410
communicator of science he is the lead

590
00:26:35,440 --> 00:26:33,320
for the space telescope imaging

591
00:26:44,320 --> 00:26:35,450
spectrograph so ladies and gentlemen

592
00:26:50,840 --> 00:26:47,660
right so we're going to have a little

593
00:26:53,210 --> 00:26:50,850
death and destruction tonight the last

594
00:26:56,150 --> 00:26:53,220
time I gave the talk I talked about a

595
00:26:57,410 --> 00:26:56,160
zombie planet around filmer hut and this

596
00:26:59,480 --> 00:26:57,420
time we're going to be talking about a

597
00:27:03,170 --> 00:26:59,490
whole bunch of dead stars and the sort

598
00:27:06,460 --> 00:27:03,180
of leftover debris that might be in

599
00:27:09,830 --> 00:27:06,470
orbit around them so when we talk about

600
00:27:12,110 --> 00:27:09,840
planets these days planets are

601
00:27:14,570 --> 00:27:12,120
everywhere it used to be whenever

602
00:27:16,460 --> 00:27:14,580
someone had an idea that some observable

603
00:27:18,440 --> 00:27:16,470
signature was due to planets people

604
00:27:19,820 --> 00:27:18,450
would kind of laugh at them because oh

605
00:27:21,380 --> 00:27:19,830
there haven't been that many planets

606
00:27:24,200 --> 00:27:21,390
found we don't know where planets exist

607
00:27:25,850 --> 00:27:24,210
that kind of thing but now we're in an

608
00:27:27,710 --> 00:27:25,860
era where we have thousands of

609
00:27:31,730 --> 00:27:27,720
exoplanets that have been discovered and

610
00:27:34,850 --> 00:27:31,740
this is a plot from EXO planet zorg just

611
00:27:37,040 --> 00:27:34,860
the other day where I took all the

612
00:27:40,820 --> 00:27:37,050
observed planets both from radial

613
00:27:42,590 --> 00:27:40,830

velocity surveys Kepler direct imaging

614
00:27:44,930 --> 00:27:42,600
and I plotted them up in a sort of a

615
00:27:47,300 --> 00:27:44,940
weird way I plotted them as a function

616
00:27:50,000 --> 00:27:47,310
of the effective temperature of the star

617
00:27:53,060 --> 00:27:50,010
that they were orbiting around their

618
00:27:55,940 --> 00:27:53,070
mass the simple size gives you the mass

619
00:28:00,230 --> 00:27:55,950
of the star and the color bar gives you

620
00:28:03,770 --> 00:28:00,240
how big the star is so most of the

621
00:28:06,440 --> 00:28:03,780
planets we have seen are around sun-like

622
00:28:09,050 --> 00:28:06,450
temperature stars they have a large

623
00:28:11,210 --> 00:28:09,060
range now in planet mass thanks to

624
00:28:13,520 --> 00:28:11,220
things like Kepler and very precise

625
00:28:16,190 --> 00:28:13,530
radial velocity surveys but we're also

626
00:28:18,560 --> 00:28:16,200
starting to probe stars of very

627
00:28:20,270 --> 00:28:18,570
different radii as well and what that's

628
00:28:22,220 --> 00:28:20,280
telling us is that we're seeing star

629
00:28:24,530 --> 00:28:22,230
we're seeing planets in orbit around

630
00:28:27,380 --> 00:28:24,540
stars of many different kinds of

631
00:28:29,860 --> 00:28:27,390
evolutionary states for Barry from

632
00:28:32,300 --> 00:28:29,870
somewhat young stars all the way up to

633
00:28:33,950 --> 00:28:32,310
giant stars which are sort of sun-like

634
00:28:37,100 --> 00:28:33,960
stars that are going through their end

635
00:28:40,520 --> 00:28:37,110
phases of life and so when I was a wee

636
00:28:43,850 --> 00:28:40,530
grad student back in the early 2000s my

637
00:28:45,950 --> 00:28:43,860
advisor talked to me and he said you

638
00:28:48,200 --> 00:28:45,960

know you should take a look and see what

639
00:28:51,380 --> 00:28:48,210
happens to a planetary system when its

640
00:28:53,540 --> 00:28:51,390
star dies and that was my fault in my

641
00:28:56,420 --> 00:28:53,550
second year of grad school and it became

642
00:28:57,110 --> 00:28:56,430
eventually my most cited paper on dead

643
00:28:59,360 --> 00:28:57,120
planet

644
00:29:03,860 --> 00:28:59,370
systems so we'll talk a little bit about

645
00:29:06,920 --> 00:29:03,870
that so the end point for most stars is

646
00:29:08,620 --> 00:29:06,930
the white dwarf white dwarfs are also

647
00:29:11,720 --> 00:29:08,630
known as gin degenerate stars

648
00:29:15,770 --> 00:29:11,730
degenerates right so not 2016

649
00:29:19,010 --> 00:29:15,780
presidential candidates but what's

650
00:29:21,410 --> 00:29:19,020
happening here is basically the star as

651
00:29:24,980 --> 00:29:21,420
it's burning it's hydrogen fusing it

652
00:29:28,070 --> 00:29:24,990
into helium it's creating this core of

653
00:29:30,380 --> 00:29:28,080
fusion ash at it's at the center of the

654
00:29:33,740 --> 00:29:30,390
star and over time it exhausts all

655
00:29:36,290 --> 00:29:33,750
that's heal hydrogen and it puffs up to

656
00:29:38,900 --> 00:29:36,300
a giant and eventually starts burning

657
00:29:41,840 --> 00:29:38,910
helium into carbon and other things and

658
00:29:44,630 --> 00:29:41,850
eventually that runs out and it puffs

659
00:29:47,360 --> 00:29:44,640
again into a bigger giant and eventually

660
00:29:48,919 --> 00:29:47,370
loses most of its mass about a half if

661
00:29:51,380 --> 00:29:48,929
we're talking about a solar type star

662
00:29:53,090 --> 00:29:51,390
and so you're left with this sort of

663
00:29:55,610 --> 00:29:53,100

corpse of the star called a white dwarf

664
00:29:59,210 --> 00:29:55,620
which is basically just the degenerate

665
00:30:02,270 --> 00:29:59,220
core of that star and it's so dense that

666
00:30:04,160 --> 00:30:02,280
the electrons are sort of bouncing

667
00:30:06,440 --> 00:30:04,170
together and they're providing the

668
00:30:08,930 --> 00:30:06,450
pressure support against the gravity of

669
00:30:11,030 --> 00:30:08,940
the mass so a typical white dwarf is

670
00:30:13,100 --> 00:30:11,040
about six-tenths of the solar mass and

671
00:30:15,380 --> 00:30:13,110
its radius is similar to that of the

672
00:30:17,480 --> 00:30:15,390
earth so these are very dense objects

673
00:30:20,180 --> 00:30:17,490
they're the endpoint to stellar

674
00:30:23,090 --> 00:30:20,190
evolution for any kind of star that's

675
00:30:24,860 --> 00:30:23,100
not going to explode and for the longest

676
00:30:27,620 --> 00:30:24,870
time people thought that this process

677
00:30:30,140 --> 00:30:27,630
losing more than half of its mass during

678
00:30:31,990 --> 00:30:30,150
this evolution from being a normal star

679
00:30:34,910 --> 00:30:32,000
to a giant eventually to a white dwarf

680
00:30:35,960 --> 00:30:34,920
meant that any planetary system that

681
00:30:38,270 --> 00:30:35,970
must be around it must be destroyed

682
00:30:40,220 --> 00:30:38,280
instantly from this process if you do

683
00:30:42,950 --> 00:30:40,230
sort of a simple gravitational

684
00:30:45,169 --> 00:30:42,960
calculation you think okay if I suddenly

685
00:30:47,210 --> 00:30:45,179
remove half the mass from a star all

686
00:30:48,799 --> 00:30:47,220
your planet's just go flying out right

687
00:30:51,650 --> 00:30:48,809
because they suddenly have way too much

688
00:30:53,500 --> 00:30:51,660

energy for the gravity of the star but

689
00:30:56,480 --> 00:30:53,510
it turns out that's not what's happening

690
00:30:58,220 --> 00:30:56,490
and then I'll just point out and i'll

691
00:31:00,290 --> 00:30:58,230
get to more of that story later but i'll

692
00:31:03,530 --> 00:31:00,300
just point out if you just take a census

693
00:31:05,630 --> 00:31:03,540
of the the nearest 10 parsecs or 32

694
00:31:07,280 --> 00:31:05,640
light-years we have you know sort of

695
00:31:10,010 --> 00:31:07,290
estimates for the numbers of different

696
00:31:11,210 --> 00:31:10,020
exoplanets and m dwarfs brown dwarfs all

697
00:31:14,419 --> 00:31:11,220
the way up to a star

698
00:31:16,340 --> 00:31:14,429
ours and it unfortunately they didn't

699
00:31:20,240 --> 00:31:16,350
include white dwarfs my favorite star

700
00:31:23,570 --> 00:31:20,250
but white dwarfs are about as numerous

701
00:31:24,980 --> 00:31:23,580
in local space as sun-like stars so you

702
00:31:26,570 --> 00:31:24,990
just want to keep that in the back your

703
00:31:29,570 --> 00:31:26,580
head and I'll get back to that by the

704
00:31:31,640 --> 00:31:29,580
end of our talk okay so we can do a

705
00:31:33,320 --> 00:31:31,650
thought experiment about what happens to

706
00:31:35,270 --> 00:31:33,330
planetary systems by thinking about our

707
00:31:36,590 --> 00:31:35,280
own solar system now we're definitely in

708
00:31:38,060 --> 00:31:36,600
an age where we shouldn't only be

709
00:31:41,659 --> 00:31:38,070
thinking of our solar system as a

710
00:31:43,549 --> 00:31:41,669
prototypical or archetypal planetary

711
00:31:45,409 --> 00:31:43,559
system but the solar system is always a

712
00:31:47,120 --> 00:31:45,419
good place to start right we shouldn't

713
00:31:49,039 --> 00:31:47,130

be limited by what our solar system

714
00:31:50,450 --> 00:31:49,049
tells us but it's always a good place to

715
00:31:52,010 --> 00:31:50,460
do thought experiments and stuff like

716
00:31:55,399 --> 00:31:52,020
that so if we have a little picture of

717
00:31:57,950 --> 00:31:55,409
the sort of inner solar system including

718
00:31:59,870 --> 00:31:57,960
Jupiter and Saturn our asteroid belt and

719
00:32:01,399 --> 00:31:59,880
then all the terrestrial planets we're

720
00:32:05,360 --> 00:32:01,409
sitting here four and a half billion

721
00:32:07,340 --> 00:32:05,370
years don't argue with me about that and

722
00:32:10,310 --> 00:32:07,350
and we're in it you know we're in a nice

723
00:32:12,649 --> 00:32:10,320
stable kind of happy place nothing's

724
00:32:14,779 --> 00:32:12,659
going to happen for a while I do have to

725
00:32:18,080 --> 00:32:14,789
say unfortunately in a billion years

726
00:32:20,390 --> 00:32:18,090
we're hosed that's when the Sun due to

727
00:32:21,500 --> 00:32:20,400
its fusion keeps getting a little bit

728
00:32:24,140 --> 00:32:21,510
hotter a little bit hotter and we'll

729
00:32:26,120 --> 00:32:24,150
have runaway greenhouse gas effect you

730
00:32:30,169 --> 00:32:26,130
know global warming on a much more

731
00:32:33,380 --> 00:32:30,179
severe scale okay so that's fine about

732
00:32:35,570 --> 00:32:33,390
maybe there and then eventually we're

733
00:32:39,380 --> 00:32:35,580
going to be in the red giant phase right

734
00:32:42,440 --> 00:32:39,390
our son is going to puff up i also have

735
00:32:44,480 --> 00:32:42,450
bad news if the heat doesn't get us the

736
00:32:48,310 --> 00:32:44,490
stellar surface will because it's going

737
00:32:50,899 --> 00:32:48,320
to puff up to the to greater than an au

738
00:32:53,000 --> 00:32:50,909

and a couple things are happening right

739
00:32:54,770 --> 00:32:53,010
it's so big it has thi it's really

740
00:32:58,279 --> 00:32:54,780
strong tide so anything close to the

741
00:32:59,960 --> 00:32:58,289
star gets eaten and once we once it goes

742
00:33:03,500 --> 00:32:59,970
in the stellar envelope we think that's

743
00:33:06,740 --> 00:33:03,510
pretty much the end but Mars seems to

744
00:33:08,870 --> 00:33:06,750
survive this process maybe and part of

745
00:33:11,060 --> 00:33:08,880
the asteroid belt might survive and I'll

746
00:33:12,860 --> 00:33:11,070
go more into that later and Jupiter's

747
00:33:14,779 --> 00:33:12,870
all the way out here now by this point

748
00:33:17,419 --> 00:33:14,789
the Sun actually hasn't lost a whole lot

749
00:33:21,230 --> 00:33:17,429
of mass maybe a tenth or two tenths of a

750
00:33:22,990 --> 00:33:21,240
solar mass so you'll notice if we go

751
00:33:25,810 --> 00:33:23,000
back if I can figure out yeah

752
00:33:28,840 --> 00:33:25,820
hey that worked where's Jupiter is it in

753
00:33:30,670 --> 00:33:28,850
the same place no it's getting a little

754
00:33:33,580 --> 00:33:30,680
bigger it's further out so what's

755
00:33:37,000 --> 00:33:33,590
happening here is the star is losing

756
00:33:40,240 --> 00:33:37,010
mass but its losing mass pretty slowly

757
00:33:41,560 --> 00:33:40,250
so that the orbit is not perturbed vary

758
00:33:43,990 --> 00:33:41,570
greatly we call this an adiabatic

759
00:33:47,320 --> 00:33:44,000
process this is like boiling the Frog

760
00:33:50,500 --> 00:33:47,330
you put the frog in the pot you slowly

761
00:33:52,150 --> 00:33:50,510
turn up the heat frogs fine slowly turn

762
00:33:54,340 --> 00:33:52,160
up the heat a little more frogs still

763
00:33:57,220 --> 00:33:54,350

fine then you keep going until suddenly

764
00:33:59,860 --> 00:33:57,230
the fog is dead right so we're basically

765
00:34:01,630 --> 00:33:59,870
boiling the frog with Jupiter here it

766
00:34:04,450 --> 00:34:01,640
doesn't really care that the Sun is

767
00:34:07,060 --> 00:34:04,460
losing mass its orbit to conserve

768
00:34:09,310 --> 00:34:07,070
angular momentum just slowly expands a

769
00:34:11,680 --> 00:34:09,320
little bit and it expands by a

770
00:34:14,919 --> 00:34:11,690
predictable amount so if the Sun has

771
00:34:18,070 --> 00:34:14,929
lost two you know it has eighty percent

772
00:34:19,659 --> 00:34:18,080
of its mass jupiter has moved to an

773
00:34:22,570 --> 00:34:19,669
orbital separation that's one over

774
00:34:24,430 --> 00:34:22,580
eighty percent right a little over one

775
00:34:29,440 --> 00:34:24,440
point whatever i can't do math in front

776
00:34:32,800 --> 00:34:29,450
of people anyway eventually the star

777
00:34:35,590 --> 00:34:32,810
loses mass a bit more quickly and we're

778
00:34:37,869 --> 00:34:35,600
left with the remnant white dwarf but it

779
00:34:41,889 --> 00:34:37,879
hasn't lost still has not lost mass too

780
00:34:44,200 --> 00:34:41,899
quickly for the orbits not to react to

781
00:34:46,600 --> 00:34:44,210
it and the other thing that i want you

782
00:34:48,550 --> 00:34:46,610
to remember is that now we have instead

783
00:34:51,369 --> 00:34:48,560
of a solar mass we have like a half four

784
00:34:53,350 --> 00:34:51,379
of six tenths of a solar mass object at

785
00:34:55,240 --> 00:34:53,360
the center of this planetary system that

786
00:34:57,010 --> 00:34:55,250
for all intents and purposes i'm going

787
00:35:00,190 --> 00:34:57,020
to claim to you survives and then i will

788
00:35:03,310 --> 00:35:00,200

prove it to you in some way later but

789
00:35:07,570 --> 00:35:03,320
basically everything now is much more

790
00:35:09,490 --> 00:35:07,580
powerful right so in dynamics we often

791
00:35:13,750 --> 00:35:09,500
care about the mass ratio between a

792
00:35:17,050 --> 00:35:13,760
planet and its central object ok so when

793
00:35:20,170 --> 00:35:17,060
jupiter tugs on anything we think about

794
00:35:22,990 --> 00:35:20,180
how much that happens by the ratio of

795
00:35:25,660 --> 00:35:23,000
Jupiter's mass to the central mass so

796
00:35:28,900 --> 00:35:25,670
now the central mass has gotten smaller

797
00:35:31,480 --> 00:35:28,910
Jupiter is already kind of a beefy fella

798
00:35:32,980 --> 00:35:31,490
he's now even more beefy with gravity

799
00:35:36,080 --> 00:35:32,990
because he's more of an influential

800
00:35:37,760 --> 00:35:36,090
player in this gravitational system

801
00:35:41,870 --> 00:35:37,770
that will become important later but

802
00:35:44,090 --> 00:35:41,880
again not right now okay so now a little

803
00:35:47,300 --> 00:35:44,100
detour so five years after Einstein

804
00:35:49,790 --> 00:35:47,310
predicted gravitational waves van Manon

805
00:35:53,360 --> 00:35:49,800
was at the Mount Wilson Observatory and

806
00:35:56,360 --> 00:35:53,370
he found a curious faint star and he

807
00:35:58,730 --> 00:35:56,370
noted when he took the spectrum this is

808
00:36:01,760 --> 00:35:58,740
by far the faintest f-type star known at

809
00:36:05,690 --> 00:36:01,770
the present time so what he had actually

810
00:36:08,420 --> 00:36:05,700
seen was not an F star this is a modern

811
00:36:11,720 --> 00:36:08,430
spectrum of van maanen star it still

812
00:36:13,670 --> 00:36:11,730
carries his name to this day but it was

813
00:36:15,530 --> 00:36:13,680

very unusual because he was able to

814
00:36:18,410 --> 00:36:15,540
measure the parallax the star and found

815
00:36:20,990 --> 00:36:18,420
that it was very close to Earth so given

816
00:36:24,290 --> 00:36:21,000
that it was faint in visual magnitudes

817
00:36:27,220 --> 00:36:24,300
and close by and moving very fast on the

818
00:36:30,020 --> 00:36:27,230
sky you could tell that it was a very

819
00:36:33,290 --> 00:36:30,030
intrinsically faint star not just

820
00:36:36,800 --> 00:36:33,300
visually faint so this was the first ish

821
00:36:39,020 --> 00:36:36,810
discovery of a white dwarf and in on top

822
00:36:41,240 --> 00:36:39,030
of it it wasn't even a typical white

823
00:36:43,730 --> 00:36:41,250
dwarf it looked like an f star because

824
00:36:46,100 --> 00:36:43,740
it had these metal lines present you

825
00:36:47,570 --> 00:36:46,110
know if you look at a solar type stars

826
00:36:50,090 --> 00:36:47,580
they have lots of metal lines from

827
00:36:53,780 --> 00:36:50,100
different atomic elements and here we

828
00:36:57,560 --> 00:36:53,790
have calcium these very strong lines or

829
00:36:59,960 --> 00:36:57,570
calcium in fact the H&K lines so it

830
00:37:02,840 --> 00:36:59,970
looked weird and it was faint and within

831
00:37:04,970 --> 00:37:02,850
a few years people realized that these

832
00:37:08,000 --> 00:37:04,980
were intrinsically faint stars about a

833
00:37:11,150 --> 00:37:08,010
10,000th the luminosity of the sun and

834
00:37:14,120 --> 00:37:11,160
that these must be unusual stars then

835
00:37:16,010 --> 00:37:14,130
they called them white dwarfs and and

836
00:37:18,170 --> 00:37:16,020
now we know what they are they are the

837
00:37:19,850 --> 00:37:18,180
dead corpses of stars but they didn't

838
00:37:22,660 --> 00:37:19,860

know that bend and they didn't know why

839
00:37:25,520 --> 00:37:22,670
there were metal lines and it turns out

840
00:37:28,310 --> 00:37:25,530
you wouldn't expect to see metal lines

841
00:37:31,130 --> 00:37:28,320
in most white dwarfs and that's because

842
00:37:33,080 --> 00:37:31,140
they're very dense so what happens with

843
00:37:35,060 --> 00:37:33,090
a white dwarf is you have this core of

844
00:37:37,280 --> 00:37:35,070
carbon and oxygen and then you have a

845
00:37:41,120 --> 00:37:37,290
very thin layer of either hydrogen or

846
00:37:43,130 --> 00:37:41,130
helium very low-density gas and if you

847
00:37:45,800 --> 00:37:43,140
have any kind of metals in this very

848
00:37:49,790 --> 00:37:45,810
thin atmosphere they get pulled to the

849
00:37:51,410 --> 00:37:49,800
center of the star out of sight so

850
00:37:53,600 --> 00:37:51,420
it fair in a very short time much

851
00:37:57,380 --> 00:37:53,610
shorter than the time we would be able

852
00:37:59,690 --> 00:37:57,390
to actually observe these things these

853
00:38:00,800 --> 00:37:59,700
metals in whatever remnant metals might

854
00:38:02,270 --> 00:38:00,810
be present in the atmosphere would

855
00:38:06,050 --> 00:38:02,280
disappear so you would only expect to

856
00:38:08,990 --> 00:38:06,060
see pure hydrogen or pure helium white

857
00:38:10,880 --> 00:38:09,000
dwarfs or if you had no thin layer of

858
00:38:12,530 --> 00:38:10,890
hydrogen or helium or there was some

859
00:38:14,720 --> 00:38:12,540
sort of convective process you might

860
00:38:16,550 --> 00:38:14,730
also get carbon but those were the only

861
00:38:19,880 --> 00:38:16,560
three elements you might expect to see

862
00:38:23,000 --> 00:38:19,890
so it's actually a puzzle why you might

863
00:38:24,860 --> 00:38:23,010

have metals in these atmospheres so for

864
00:38:26,360 --> 00:38:24,870
the longest time people thought the

865
00:38:28,280 --> 00:38:26,370
metals came from the interstellar medium

866
00:38:31,250 --> 00:38:28,290
you know where the interstellar medium

867
00:38:34,370 --> 00:38:31,260
the stuff between the stars is not empty

868
00:38:36,680 --> 00:38:34,380
there's dust and gas and other things so

869
00:38:38,960 --> 00:38:36,690
it's you have a white dwarf plowing

870
00:38:41,390 --> 00:38:38,970
through space it will pick up some of

871
00:38:43,310 --> 00:38:41,400
this materials is it ah that must be why

872
00:38:47,590 --> 00:38:43,320
you see metals they're just picking up

873
00:38:51,050 --> 00:38:47,600
dust from the interstellar medium 1919

874
00:38:52,490 --> 00:38:51,060
the 50s 60s and 70s was when people came

875
00:38:56,570 --> 00:38:52,500
up with the idea that the interstellar

876
00:39:01,010 --> 00:38:56,580
medium was accreting stuff and then 1987

877
00:39:06,470 --> 00:39:01,020
happened and something unusual was found

878
00:39:09,140 --> 00:39:06,480
so two men Erik beclan and Ben Zuckerman

879
00:39:10,820 --> 00:39:09,150
at UCLA we're doing an interesting study

880
00:39:13,040 --> 00:39:10,830
they were looking for brown dwarfs and

881
00:39:16,010 --> 00:39:13,050
in 1987 no one had seen a brown dwarf

882
00:39:18,110 --> 00:39:16,020
before and they thought quite rightly

883
00:39:20,510 --> 00:39:18,120
that it would be easy to find brown

884
00:39:22,100 --> 00:39:20,520
dwarfs or in orbit around white dwarfs

885
00:39:25,430 --> 00:39:22,110
because white dwarfs are intrinsically

886
00:39:26,990 --> 00:39:25,440
faint and so faint brown dwarfs are easy

887
00:39:28,550 --> 00:39:27,000
to find especially if you look in the

888
00:39:30,560 --> 00:39:28,560

near infrared at sort of the same

889
00:39:32,600 --> 00:39:30,570
wavelengths that Frank was putting up

890
00:39:34,790 --> 00:39:32,610
for that galaxy cluster so what they did

891
00:39:36,230 --> 00:39:34,800
is they were looking at a whole bunch of

892
00:39:38,960 --> 00:39:36,240
white dwarfs looking for brown dwarfs

893
00:39:41,810 --> 00:39:38,970
and they made a discovery they said we

894
00:39:44,210 --> 00:39:41,820
found a brown dwarf yay and so they you

895
00:39:46,010 --> 00:39:44,220
know if you took a you know measurement

896
00:39:48,940 --> 00:39:46,020
of the brightness of the white dwarf at

897
00:39:51,110 --> 00:39:48,950
different wavelengths so this is flux

898
00:39:53,000 --> 00:39:51,120
excuse me in wavelength as you get to

899
00:39:57,350 --> 00:39:53,010
longer wavelengths this is the white

900
00:39:58,670 --> 00:39:57,360
dwarf it's flux goes down and when you

901
00:40:02,630 --> 00:39:58,680
actually observe this particular

902
00:40:03,620 --> 00:40:02,640
pulsating white dwarf gee 2938 it does

903
00:40:05,680 --> 00:40:03,630
not go down

904
00:40:08,840 --> 00:40:05,690
as you would expect it gets brighter

905
00:40:12,410 --> 00:40:08,850
this is unusual so what's happening is

906
00:40:14,210 --> 00:40:12,420
that there's an extra cool source of

907
00:40:16,160 --> 00:40:14,220
light in the system that's unresolved

908
00:40:19,400 --> 00:40:16,170
this is called a spectral energy

909
00:40:20,780 --> 00:40:19,410
distribution so when era beclin and

910
00:40:22,910 --> 00:40:20,790
Zuckerman first did it they only had a

911
00:40:24,950 --> 00:40:22,920
couple of photometric points and they

912
00:40:26,900 --> 00:40:24,960
said we think we have a brown dwarf but

913
00:40:29,150 --> 00:40:26,910

it could be dust could be some other

914
00:40:32,240 --> 00:40:29,160
things well it turns out this is dust

915
00:40:37,070 --> 00:40:32,250
there's dust in orbit around white

916
00:40:38,690 --> 00:40:37,080
dwarfs so that's already weird and uh it

917
00:40:40,700 --> 00:40:38,700
kind of you know there was this great

918
00:40:42,290 --> 00:40:40,710
paper in 1990 just a few years after

919
00:40:44,300 --> 00:40:42,300
this was discovered some people thought

920
00:40:45,710 --> 00:40:44,310
this was a black hole some people

921
00:40:48,380 --> 00:40:45,720
thought this was a pulsating neutron

922
00:40:51,140 --> 00:40:48,390
star they had no idea it was weird but

923
00:40:52,700 --> 00:40:51,150
they decided in the end the best

924
00:40:55,160 --> 00:40:52,710
explanation was that it was probably

925
00:40:57,650 --> 00:40:55,170
dust right it was too bright to be a

926
00:40:59,930 --> 00:40:57,660
brown dwarf in the end and brown dwarfs

927
00:41:02,090 --> 00:40:59,940
were eventually discovered now you can

928
00:41:05,090 --> 00:41:02,100
sort of make a model of the dust disk

929
00:41:08,480 --> 00:41:05,100
that must be around it and you can just

930
00:41:11,570 --> 00:41:08,490
assume a very thin flat disk that's

931
00:41:14,000 --> 00:41:11,580
passive Leary radiating the light from

932
00:41:15,890 --> 00:41:14,010
the white dwarf and when you do that you

933
00:41:18,890 --> 00:41:15,900
infer that this dust is between ten

934
00:41:21,560 --> 00:41:18,900
white door for a TI and 30 white door

935
00:41:23,990 --> 00:41:21,570
for a DI now if you remember a white

936
00:41:26,920 --> 00:41:24,000
dwarf radius is about the same radius as

937
00:41:30,740 --> 00:41:26,930
the earth so that's not very big and

938
00:41:33,590 --> 00:41:30,750

this is a massive six-tenths of a solar

939
00:41:35,510 --> 00:41:33,600
mass star so the orbit the orbital

940
00:41:37,580 --> 00:41:35,520
velocity here is several hundred

941
00:41:39,830 --> 00:41:37,590
kilometers per second we're starting to

942
00:41:42,530 --> 00:41:39,840
get to an appreciable fraction of the

943
00:41:45,560 --> 00:41:42,540
speed of light at these velocities so

944
00:41:49,610 --> 00:41:45,570
you have dust nearly at the edge of a

945
00:41:51,380 --> 00:41:49,620
white dwarf surface whipping around okay

946
00:41:53,870 --> 00:41:51,390
how do you get dust well you get dust

947
00:41:57,890 --> 00:41:53,880
from planetesimals maybe that's what

948
00:42:04,820 --> 00:41:57,900
James Graham postulated okay and there

949
00:42:07,190 --> 00:42:04,830
it stood for 10 12 years and not much

950
00:42:10,580 --> 00:42:07,200
else was done it was an oddity it was

951
00:42:12,230 --> 00:42:10,590
just one so you can nature's weird it

952
00:42:14,030 --> 00:42:12,240
always makes weird things you can

953
00:42:16,790 --> 00:42:14,040
explain one thing very easily and then

954
00:42:17,390 --> 00:42:16,800
forget about it and mainly we've forgot

955
00:42:19,100 --> 00:42:17,400
about it

956
00:42:21,320 --> 00:42:19,110
because you know there wasn't a lot of

957
00:42:23,870 --> 00:42:21,330
mid-infrared observing going on you know

958
00:42:26,420 --> 00:42:23,880
five to ten microns is very hard to do

959
00:42:29,690 --> 00:42:26,430
from the ground and so there it stayed

960
00:42:31,940 --> 00:42:29,700
until Spitzer was launched and then

961
00:42:34,550 --> 00:42:31,950
suddenly we had the whole sky in the

962
00:42:37,610 --> 00:42:34,560
infrared to look at at with very fine

963
00:42:39,500 --> 00:42:37,620

detail and with very fine sensitivity

964
00:42:41,420 --> 00:42:39,510
and that's when a whole bunch more of

965
00:42:43,400 --> 00:42:41,430
these dusty white dwarfs were discovered

966
00:42:45,410 --> 00:42:43,410
furthermore they were discovered not

967
00:42:46,820 --> 00:42:45,420
only to have dust but when you took a

968
00:42:48,770 --> 00:42:46,830
spectrum of the white door if you would

969
00:42:50,900 --> 00:42:48,780
see metal lines and its atmosphere and

970
00:42:53,150 --> 00:42:50,910
if you thought van man and star was

971
00:42:54,620 --> 00:42:53,160
weird these wide or sir even weirder

972
00:42:56,930 --> 00:42:54,630
because a lot of them had only pure

973
00:42:59,750 --> 00:42:56,940
hydrogen atmospheres and they were warm

974
00:43:02,180 --> 00:42:59,760
pretty hot white dwarfs so the settling

975
00:43:05,090 --> 00:43:02,190
time if you dropped a bunch of metals

976
00:43:06,830 --> 00:43:05,100
into the atmosphere the metals would

977
00:43:10,100 --> 00:43:06,840
completely disappear within a couple of

978
00:43:12,080 --> 00:43:10,110
days so the fact that you even see metal

979
00:43:13,610 --> 00:43:12,090
lines in these white dwarfs meant that

980
00:43:17,240 --> 00:43:13,620
they were accreting an appreciable

981
00:43:19,400 --> 00:43:17,250
amount of material constantly not just

982
00:43:25,190 --> 00:43:19,410
over a billion years or something but

983
00:43:27,500 --> 00:43:25,200
that minute okay so keep that in your

984
00:43:29,390 --> 00:43:27,510
mind with the other things I think I've

985
00:43:30,590 --> 00:43:29,400
got more than six things in your mind so

986
00:43:33,260 --> 00:43:30,600
you've probably forgotten half of them

987
00:43:35,920 --> 00:43:33,270
but that's okay i will remind you in any

988
00:43:38,510 --> 00:43:35,930

case if we go back to the structure idea

989
00:43:40,220 --> 00:43:38,520
we can think about maybe a little bit

990
00:43:42,260 --> 00:43:40,230
more about what might be causing these

991
00:43:45,130 --> 00:43:42,270
strange dust rings and why this might

992
00:43:47,630 --> 00:43:45,140
have a connection to planetary systems

993
00:43:49,850 --> 00:43:47,640
so you have your white dwarf and you

994
00:43:52,670 --> 00:43:49,860
assume that you don't get dust closer

995
00:43:54,980 --> 00:43:52,680
than where dust turns into gas seems

996
00:43:57,440 --> 00:43:54,990
like a reasonable assumption and you say

997
00:43:59,270 --> 00:43:57,450
okay how far out do they extend they

998
00:44:01,220 --> 00:43:59,280
tend to extend not too far out and

999
00:44:03,200 --> 00:44:01,230
certainly well within what is known as

1000
00:44:07,100 --> 00:44:03,210
the title disruption radius of the white

1001
00:44:09,320 --> 00:44:07,110
dwarf so if we put a planet were you

1002
00:44:11,810 --> 00:44:09,330
know anything very large here it gets

1003
00:44:15,890 --> 00:44:11,820
shredded apart and turned into little

1004
00:44:17,930 --> 00:44:15,900
bits and so basically the dust lives

1005
00:44:19,790 --> 00:44:17,940
within a zone where anything that might

1006
00:44:23,150 --> 00:44:19,800
stray in that zone would get toward up

1007
00:44:25,040 --> 00:44:23,160
to little bits you can have different

1008
00:44:27,320 --> 00:44:25,050
flavors of your model because this

1009
00:44:29,930 --> 00:44:27,330
explains more technical details like why

1010
00:44:31,370 --> 00:44:29,940
you see may be additional emission lines

1011
00:44:33,170 --> 00:44:31,380
like this this

1012
00:44:35,140 --> 00:44:33,180
is due to silicates this is how we know

1013
00:44:38,210 --> 00:44:35,150

it's really dust and not something else

1014
00:44:40,730 --> 00:44:38,220
because there's a very strong silicon

1015
00:44:44,240 --> 00:44:40,740
emission feature it's a smoking gun for

1016
00:44:47,809 --> 00:44:44,250
dust and it rocky dust not anything

1017
00:44:51,289 --> 00:44:47,819
weird and now in the era of Spitzer and

1018
00:44:54,440 --> 00:44:51,299
then the wise survey we have dozens now

1019
00:44:57,499 --> 00:44:54,450
of dust rings around white dwarfs and

1020
00:45:00,890 --> 00:44:57,509
all the dust rings are about within a

1021
00:45:05,200 --> 00:45:00,900
solar radius or you know a little bit

1022
00:45:09,769 --> 00:45:05,210
larger than Saturn's rings so there's

1023
00:45:11,990 --> 00:45:09,779
rocks shredding up somehow and draining

1024
00:45:15,140 --> 00:45:12,000
onto their white dwarf surfaces leaving

1025
00:45:18,620 --> 00:45:15,150
telltale fingerprints of the material

1026
00:45:21,529 --> 00:45:18,630
that they are made of so already that is

1027
00:45:23,870 --> 00:45:21,539
super cool this is why I stayed in

1028
00:45:26,930 --> 00:45:23,880
astronomy because my second year project

1029
00:45:29,059 --> 00:45:26,940
told me about crazy stars that should

1030
00:45:30,950 --> 00:45:29,069
have nothing around them having really

1031
00:45:33,289 --> 00:45:30,960
cool things around them shredding up and

1032
00:45:38,289 --> 00:45:33,299
doing weird things so that's it I was

1033
00:45:40,339 --> 00:45:38,299
hooked and so over the next 10 15 years

1034
00:45:42,440 --> 00:45:40,349
we tried to come up with explanations

1035
00:45:44,749 --> 00:45:42,450
for why this might be happening and and

1036
00:45:47,329 --> 00:45:44,759
learn more about what this dust actually

1037
00:45:48,559 --> 00:45:47,339
was so we took spectra of white dwarfs

1038
00:45:50,660 --> 00:45:48,569

we looked at the white doors in the

1039
00:45:53,420 --> 00:45:50,670
infrared we tried to gain populations to

1040
00:45:55,999 --> 00:45:53,430
understand what was going on etc etc and

1041
00:45:57,980 --> 00:45:56,009
you know we came up with complicated

1042
00:46:01,370 --> 00:45:57,990
theories for how the discs evolve with

1043
00:46:04,069 --> 00:46:01,380
time this is more for the scientist but

1044
00:46:05,930 --> 00:46:04,079
basically we think there's dust the dust

1045
00:46:08,029 --> 00:46:05,940
goes beyond the sublimation it turns

1046
00:46:09,859 --> 00:46:08,039
into gas it creats onto the white dwarf

1047
00:46:11,569 --> 00:46:09,869
that's why you get the metals some of

1048
00:46:13,759 --> 00:46:11,579
the gas goes out back so you have sort

1049
00:46:17,620 --> 00:46:13,769
of a mixture of gas and dust maybe you

1050
00:46:20,210 --> 00:46:17,630
can see this gas and in fact you can so

1051
00:46:22,880 --> 00:46:20,220
while people were taking spectra of

1052
00:46:25,519 --> 00:46:22,890
white dwarfs to look for the metal lines

1053
00:46:28,130 --> 00:46:25,529
they also discovered hey there's these

1054
00:46:31,190 --> 00:46:28,140
weird emission lines at 8,500 this is

1055
00:46:32,839 --> 00:46:31,200
again calcium but now in a mission so if

1056
00:46:34,849 --> 00:46:32,849
you have calcium and emission that means

1057
00:46:36,829 --> 00:46:34,859
you've got gas that's glowing hotter

1058
00:46:39,589 --> 00:46:36,839
than the star at these wavelengths and

1059
00:46:42,620 --> 00:46:39,599
in fact it wasn't just glowing it was

1060
00:46:44,829 --> 00:46:42,630
glowing with this very pronounced double

1061
00:46:46,299 --> 00:46:44,839
peaked structure this is like a

1062
00:46:49,239 --> 00:46:46,309
looking garden for an accretion disk

1063
00:46:50,890 --> 00:46:49,249

right because you have different parts

1064
00:46:53,259 --> 00:46:50,900
of that disk moving at different

1065
00:46:55,959 --> 00:46:53,269
velocities which creates your double

1066
00:46:57,700 --> 00:46:55,969
sort of peak shape there as you take all

1067
00:46:59,890 --> 00:46:57,710
these little bits of velocities and put

1068
00:47:03,640 --> 00:46:59,900
them spread them out in velocity space

1069
00:47:06,370 --> 00:47:03,650
or wavelength space same thing so we

1070
00:47:08,559 --> 00:47:06,380
have gas we have dust we have dust and

1071
00:47:13,329 --> 00:47:08,569
gas going on to the white dwarfs we have

1072
00:47:15,999 --> 00:47:13,339
things shredding up somehow we even have

1073
00:47:17,890 --> 00:47:16,009
like pictures of the gas this is so cool

1074
00:47:20,529 --> 00:47:17,900
this is just in the last couple of

1075
00:47:22,660 --> 00:47:20,539
months there's a technique where if you

1076
00:47:25,089 --> 00:47:22,670
take lots and lots of spectra and build

1077
00:47:27,519 --> 00:47:25,099
it all up and decompose everything into

1078
00:47:28,989 --> 00:47:27,529
velocity space / time with the

1079
00:47:32,739 --> 00:47:28,999
assumption that you've got some sort of

1080
00:47:35,440 --> 00:47:32,749
regular periodic event occurring you can

1081
00:47:39,309 --> 00:47:35,450
what do what's called Doppler tomography

1082
00:47:41,890 --> 00:47:39,319
you basically pull out an image from the

1083
00:47:43,690 --> 00:47:41,900
information the velocity information so

1084
00:47:46,779 --> 00:47:43,700
what we're seeing here is an inside-out

1085
00:47:48,459 --> 00:47:46,789
picture so it's a not intuitive so

1086
00:47:51,789 --> 00:47:48,469
you're not seeing exactly a ring like

1087
00:47:54,069 --> 00:47:51,799
this going from the center to the outer

1088
00:47:55,959 --> 00:47:54,079

area it's more the other way around this

1089
00:47:57,459 --> 00:47:55,969
is this this is getting toward the

1090
00:47:59,559 --> 00:47:57,469
center of the star and this is getting

1091
00:48:02,499 --> 00:47:59,569
further away but in any case you've got

1092
00:48:05,469 --> 00:48:02,509
this very interesting elliptical

1093
00:48:08,650 --> 00:48:05,479
processing ring of gas around a white

1094
00:48:11,170 --> 00:48:08,660
dwarf that with lots and lots of spectra

1095
00:48:13,959 --> 00:48:11,180
you can synthesize into sort of an image

1096
00:48:16,779 --> 00:48:13,969
of what's going on with the gas and sure

1097
00:48:18,489 --> 00:48:16,789
enough just like the double peak

1098
00:48:20,979 --> 00:48:18,499
structure told us there was some kind of

1099
00:48:23,019 --> 00:48:20,989
a disk the reconstruction of the

1100
00:48:24,430 --> 00:48:23,029
velocity show that there is a disk but

1101
00:48:26,589 --> 00:48:24,440
not only that there's a disk but its

1102
00:48:29,109 --> 00:48:26,599
processing around this elliptical shape

1103
00:48:31,120 --> 00:48:29,119
is processing around and changing the

1104
00:48:34,029 --> 00:48:31,130
shape of the spectral features that we

1105
00:48:35,559 --> 00:48:34,039
see so this is cool I I don't even

1106
00:48:37,809 --> 00:48:35,569
understand this yet I need to think

1107
00:48:40,269 --> 00:48:37,819
about this more but it's a really

1108
00:48:42,099 --> 00:48:40,279
interesting way to sort of get a picture

1109
00:48:44,349 --> 00:48:42,109
of the system that we will never be able

1110
00:48:48,609 --> 00:48:44,359
to actually resolve with a telescope in

1111
00:48:51,160 --> 00:48:48,619
any easy time now I've taken some

1112
00:48:53,950 --> 00:48:51,170
spectra as well an in tradition to gas

1113
00:48:56,559 --> 00:48:53,960

in emission we've even seen gas in

1114
00:48:58,330 --> 00:48:56,569
absorption around these white dwarfs so

1115
00:49:01,330 --> 00:48:58,340
if you look at sort of the spectrum

1116
00:49:04,060 --> 00:49:01,340
again around the calcium H&K lines you

1117
00:49:06,520 --> 00:49:04,070
have the main photospheric line but then

1118
00:49:08,680 --> 00:49:06,530
you have this little blip just blue

1119
00:49:10,180 --> 00:49:08,690
words right now the other thing about

1120
00:49:13,090 --> 00:49:10,190
white dwarfs because they're so dense

1121
00:49:16,180 --> 00:49:13,100
they have a strong pull of gravity much

1122
00:49:18,940 --> 00:49:16,190
like those galaxy clusters much like the

1123
00:49:21,820 --> 00:49:18,950
universe redshifts things white dwarfs

1124
00:49:25,150 --> 00:49:21,830
locally redshift light so what happens

1125
00:49:27,130 --> 00:49:25,160
is the the light coming from the white

1126
00:49:29,560 --> 00:49:27,140
dwarf surface is redder than it would

1127
00:49:33,430 --> 00:49:29,570
normally be so it's photospheric metal

1128
00:49:35,560 --> 00:49:33,440
lines are pulled away from the velocity

1129
00:49:40,090 --> 00:49:35,570
of the white dwarf so if you have a disc

1130
00:49:42,250 --> 00:49:40,100
you've got the duh the gas at not

1131
00:49:45,280 --> 00:49:42,260
reddened quite so much and it's like a

1132
00:49:46,870 --> 00:49:45,290
curtain being pulled away so though the

1133
00:49:48,900 --> 00:49:46,880
white dwarfs gravity pulls the curtain

1134
00:49:51,790 --> 00:49:48,910
away and allows us to find these weak

1135
00:49:54,190 --> 00:49:51,800
circumstellar gas features you can

1136
00:49:57,250 --> 00:49:54,200
actually do some calculations about okay

1137
00:49:58,990 --> 00:49:57,260
given how wide the gases in velocity

1138
00:50:01,900 --> 00:49:59,000

where might it be around the white dwarf

1139
00:50:04,120 --> 00:50:01,910
and sure enough it's you know within a

1140
00:50:06,490 --> 00:50:04,130
hundred white dwarf radii or one solar

1141
00:50:08,350 --> 00:50:06,500
radius and that's roughly about where

1142
00:50:10,750 --> 00:50:08,360
the sublimation radius of the dust is

1143
00:50:13,390 --> 00:50:10,760
for this particular white dwarfs for

1144
00:50:15,550 --> 00:50:13,400
this particular white dwarf and you know

1145
00:50:18,100 --> 00:50:15,560
so you can look at a lot of white doors

1146
00:50:20,100 --> 00:50:18,110
maybe and find similar things this also

1147
00:50:23,430 --> 00:50:20,110
says that this particular white dwarf

1148
00:50:25,540 --> 00:50:23,440
probably worth seeing the disk edge on

1149
00:50:29,830 --> 00:50:25,550
right through we're looking right

1150
00:50:31,780 --> 00:50:29,840
through it so that's kind of cool so

1151
00:50:33,220 --> 00:50:31,790
we've got these metal lines if you have

1152
00:50:35,860 --> 00:50:33,230
enough metal lines you can actually

1153
00:50:37,750 --> 00:50:35,870
build up the composition of the dust the

1154
00:50:39,220 --> 00:50:37,760
other thing that I should mention is

1155
00:50:41,830 --> 00:50:39,230
that white dwarfs are extremely

1156
00:50:44,650 --> 00:50:41,840
sensitive probes to accretion a me sighs

1157
00:50:48,370 --> 00:50:44,660
boulder falling onto a white dwarf every

1158
00:50:50,530 --> 00:50:48,380
second is observable that's not a lot of

1159
00:50:52,360 --> 00:50:50,540
material when astronomers talk about

1160
00:50:54,090 --> 00:50:52,370
mass they usually talk about solar

1161
00:50:57,400 --> 00:50:54,100
masses well these are like

1162
00:50:59,710 --> 00:50:57,410
kilometer-sized asteroids falling onto

1163
00:51:01,900 --> 00:50:59,720

the white dwarf every couple days or so

1164
00:51:04,570 --> 00:51:01,910
or every year so it's not a lot of

1165
00:51:07,120 --> 00:51:04,580
material it's a suspiciously asteroidal

1166
00:51:10,120 --> 00:51:07,130
amount of material and when we look at

1167
00:51:12,220 --> 00:51:10,130
the composition with these spectra we

1168
00:51:14,650 --> 00:51:12,230
find a suspiciously asteroidal

1169
00:51:18,180 --> 00:51:14,660
opposition a rocky composition that is

1170
00:51:20,620 --> 00:51:18,190
not unlike the bulk earth composition or

1171
00:51:23,410 --> 00:51:20,630
asteroid Alcoa's itions in our own solar

1172
00:51:25,510 --> 00:51:23,420
system so not only our white doors weird

1173
00:51:27,550 --> 00:51:25,520
because they have this dust that drains

1174
00:51:29,620 --> 00:51:27,560
onto their surfaces and we get to learn

1175
00:51:32,020 --> 00:51:29,630
about interesting disk and accretion

1176
00:51:35,080 --> 00:51:32,030
properties in sort of a extreme

1177
00:51:37,690 --> 00:51:35,090
environment we also for free get dust

1178
00:51:40,630 --> 00:51:37,700
composition and if we can link this dust

1179
00:51:44,440 --> 00:51:40,640
to planets we suddenly then have a way

1180
00:51:47,170 --> 00:51:44,450
of sampling the terrestrial chemistry of

1181
00:51:49,990 --> 00:51:47,180
dead planetary systems so I'm going to

1182
00:51:51,790 --> 00:51:50,000
argue now that these are asteroids these

1183
00:51:53,980 --> 00:51:51,800
are asteroids that have somehow strayed

1184
00:51:56,650 --> 00:51:53,990
too close to their white dwarf they've

1185
00:51:59,530 --> 00:51:56,660
gotten shredded up they've drained onto

1186
00:52:03,160 --> 00:51:59,540
the white dwarf and we can read their

1187
00:52:05,530 --> 00:52:03,170
properties from the spectra of these

1188
00:52:08,590 --> 00:52:05,540

white dwarf this is incredibly powerful

1189
00:52:11,440 --> 00:52:08,600
we cannot go to other planets very

1190
00:52:14,320 --> 00:52:11,450
easily especially the rocky ones and

1191
00:52:17,770 --> 00:52:14,330
measure what the rocks are we can do it

1192
00:52:18,910 --> 00:52:17,780
with Mars send a couple robots it's

1193
00:52:22,720 --> 00:52:18,920
going to be a little hard to do it

1194
00:52:23,800 --> 00:52:22,730
around Alpha Centauri or HD 209 458 it's

1195
00:52:26,980 --> 00:52:23,810
going to take a little while to get

1196
00:52:28,720 --> 00:52:26,990
there so this is one of our best ways of

1197
00:52:31,300 --> 00:52:28,730
understanding the chemistry of

1198
00:52:33,280 --> 00:52:31,310
terrestrial planet formation this has

1199
00:52:35,890 --> 00:52:33,290
implications for understanding how

1200
00:52:38,650 --> 00:52:35,900
different or how typical our own earth

1201
00:52:41,410 --> 00:52:38,660
is relative to other stellar systems and

1202
00:52:43,810 --> 00:52:41,420
on top of that there's only a couple of

1203
00:52:46,960 --> 00:52:43,820
other techniques that get at the sort of

1204
00:52:49,420 --> 00:52:46,970
chemistry of planet formation or the

1205
00:52:51,160 --> 00:52:49,430
chemistry of planet atmospheres so

1206
00:52:52,930 --> 00:52:51,170
Nicole Lewis in a few months will tell

1207
00:52:55,030 --> 00:52:52,940
you about how they do the chemistry of

1208
00:52:58,030 --> 00:52:55,040
atmospheres but this is sort of like the

1209
00:53:00,550 --> 00:52:58,040
chemistry of rocks so it's very exciting

1210
00:53:05,170 --> 00:53:00,560
I can't overstate that enough very cool

1211
00:53:07,290 --> 00:53:05,180
and this is being helped quite a bit by

1212
00:53:09,730 --> 00:53:07,300
the ultraviolet instruments on Hubble

1213
00:53:11,680 --> 00:53:09,740

because white dwarfs are typically more

1214
00:53:13,840 --> 00:53:11,690
bright in the ultraviolet and there are

1215
00:53:15,849 --> 00:53:13,850
a ton of metal ions in the ultraviolet

1216
00:53:18,190 --> 00:53:15,859
that are often not accessible in the

1217
00:53:20,320 --> 00:53:18,200
optical so instruments likes disks which

1218
00:53:23,980 --> 00:53:20,330
I'm in charge of and I'm legally

1219
00:53:25,070 --> 00:53:23,990
obligated to promote and also costs both

1220
00:53:27,920 --> 00:53:25,080
of them have been in

1221
00:53:29,810 --> 00:53:27,930
your mental in measuring compositions

1222
00:53:33,440 --> 00:53:29,820
especially costs because it's very

1223
00:53:35,930 --> 00:53:33,450
sensitive okay so these things are also

1224
00:53:38,240 --> 00:53:35,940
not static in time we've seen examples

1225
00:53:41,480 --> 00:53:38,250
of some of these dust disks changing on

1226
00:53:45,440 --> 00:53:41,490
yearly timescales we don't understand

1227
00:53:47,750 --> 00:53:45,450
why and we even see the emission lines

1228
00:53:50,030 --> 00:53:47,760
changing with time which maybe we

1229
00:53:51,650 --> 00:53:50,040
understand some of them are maybe just

1230
00:53:53,690 --> 00:53:51,660
processing rings and that's why they're

1231
00:53:55,640 --> 00:53:53,700
changing with time but these are kind of

1232
00:53:57,530 --> 00:53:55,650
disappearing so there's a quick

1233
00:54:00,320 --> 00:53:57,540
evolution on a yearly time scale for

1234
00:54:04,400 --> 00:54:00,330
some of these observable phenomena that

1235
00:54:07,610 --> 00:54:04,410
we see okay but now we've got this

1236
00:54:10,010 --> 00:54:07,620
question right I just showed you how our

1237
00:54:11,960 --> 00:54:10,020
solar system would survive post main

1238
00:54:14,270 --> 00:54:11,970

sequence evolution or the death of their

1239
00:54:16,600 --> 00:54:14,280
star and it doesn't look too good for

1240
00:54:20,120 --> 00:54:16,610
stuff that's a one solar radius away

1241
00:54:22,580 --> 00:54:20,130
right it gets obliterated so nothing

1242
00:54:25,340 --> 00:54:22,590
that started out that close is going to

1243
00:54:27,590 --> 00:54:25,350
survive that close the star is going to

1244
00:54:32,600 --> 00:54:27,600
scrub all the material out to one or 2a

1245
00:54:35,360 --> 00:54:32,610
you because of its evolution so we have

1246
00:54:37,850 --> 00:54:35,370
asteroids living somewhere in these dead

1247
00:54:42,290 --> 00:54:37,860
planetary systems and they have to start

1248
00:54:45,590 --> 00:54:42,300
out at a few to maybe ten au and they

1249
00:54:48,050 --> 00:54:45,600
have to go all the way down to four

1250
00:54:50,150 --> 00:54:48,060
point five times ten to the minus 38 you

1251
00:54:52,760 --> 00:54:50,160
so remember an au is the distance from

1252
00:54:57,140 --> 00:54:52,770
the earth to the Sun so they start out

1253
00:54:59,930 --> 00:54:57,150
far and they get really really close so

1254
00:55:04,010 --> 00:54:59,940
how do we do it this is something that

1255
00:55:05,570 --> 00:55:04,020
me as a dynamicists or a pretend

1256
00:55:08,120 --> 00:55:05,580
dynamicists because i'm not a real

1257
00:55:11,420 --> 00:55:08,130
dynamicists I just play one as an

1258
00:55:13,520 --> 00:55:11,430
astronomer but this is hard to do you

1259
00:55:15,110 --> 00:55:13,530
get a little panicky you get worried how

1260
00:55:18,110 --> 00:55:15,120
am I going to do this this is my thesis

1261
00:55:22,550 --> 00:55:18,120
how am I going to finish it don't worry

1262
00:55:25,580 --> 00:55:22,560
keep calm and focus on resonances what

1263
00:55:28,070 --> 00:55:25,590

are resonances okay so you have Jupiter

1264
00:55:30,920 --> 00:55:28,080
right it goes around a certain amount of

1265
00:55:33,950 --> 00:55:30,930
time and in certain orbits you have

1266
00:55:36,860 --> 00:55:33,960
objects that go two times for every one

1267
00:55:38,640 --> 00:55:36,870
time Jupiter goes around they be inside

1268
00:55:41,970 --> 00:55:38,650
if they did that or

1269
00:55:45,120 --> 00:55:41,980
half a time as Jupiter went once these

1270
00:55:46,860 --> 00:55:45,130
are special orbits because at a given

1271
00:55:49,890 --> 00:55:46,870
point in their orbit they line up with

1272
00:55:52,050 --> 00:55:49,900
Jupiter they get a little extra tug and

1273
00:55:53,790 --> 00:55:52,060
they get a little extra tug and they get

1274
00:55:55,740 --> 00:55:53,800
a little extra tug over over over and

1275
00:55:58,230 --> 00:55:55,750
again until they have different orbits

1276
00:56:02,480 --> 00:55:58,240
and you can really mess things up this

1277
00:56:07,800 --> 00:56:02,490
way gravity is weak but it's persistent

1278
00:56:10,500 --> 00:56:07,810
okay so first I said I claimed asteroids

1279
00:56:13,500 --> 00:56:10,510
survived post main-sequence evolution or

1280
00:56:15,540 --> 00:56:13,510
the evolution of their star from middle

1281
00:56:18,180 --> 00:56:15,550
age to the end of their life but I

1282
00:56:19,980 --> 00:56:18,190
didn't really prove it to you so this is

1283
00:56:24,530 --> 00:56:19,990
these are some simple calculations of

1284
00:56:30,510 --> 00:56:24,540
the survival of fairly large asteroids

1285
00:56:33,540 --> 00:56:30,520
from Pluto size give or take down to

1286
00:56:36,330 --> 00:56:33,550
very tiny asteroids and these are

1287
00:56:39,210 --> 00:56:36,340
survival curves for different situations

1288
00:56:42,090 --> 00:56:39,220

so the the Sun will get to a maximum

1289
00:56:44,940 --> 00:56:42,100
luminosity during its evolution of about

1290
00:56:48,750 --> 00:56:44,950
10,000 times the current velocity

1291
00:56:52,170 --> 00:56:48,760
because it gets really really big and so

1292
00:56:57,930 --> 00:56:52,180
anything that is smaller and closer than

1293
00:56:59,540 --> 00:56:57,940
this line here will evaporate now let's

1294
00:57:02,670 --> 00:56:59,550
say you bump it up twice as much than

1295
00:57:07,620 --> 00:57:02,680
anything below this curve will survive

1296
00:57:10,110 --> 00:57:07,630
now we know from your pictures there

1297
00:57:14,670 --> 00:57:10,120
might be a little bit of gas expelled

1298
00:57:17,490 --> 00:57:14,680
during the late stages of death and so

1299
00:57:19,160 --> 00:57:17,500
what that wind while it doesn't mess

1300
00:57:24,240 --> 00:57:19,170
anything up to terribly four big planets

1301
00:57:27,120 --> 00:57:24,250
can actually drag on small asteroids and

1302
00:57:30,240 --> 00:57:27,130
pull them into the inner system where

1303
00:57:32,400 --> 00:57:30,250
they evaporate so if you're in these

1304
00:57:35,190 --> 00:57:32,410
sort of regions below these regions here

1305
00:57:37,740 --> 00:57:35,200
for given initial stellar masses so if

1306
00:57:40,290 --> 00:57:37,750
we talk about the Sun you have these two

1307
00:57:44,580 --> 00:57:40,300
curves intersecting and anything below

1308
00:57:48,050 --> 00:57:44,590
and interior gets destroyed but you know

1309
00:57:51,190 --> 00:57:48,060
our our asteroid belt extends from about

1310
00:57:53,620 --> 00:57:51,200
you know here to here

1311
00:57:56,920 --> 00:57:53,630
and so there's plenty of big things that

1312
00:57:59,800 --> 00:57:56,930
can survive these processes and even if

1313
00:58:03,670 --> 00:57:59,810

the big things here don't survive these

1314
00:58:05,680 --> 00:58:03,680
small things here move in and eventually

1315
00:58:08,319 --> 00:58:05,690
survive if you get thing if you get the

1316
00:58:11,380 --> 00:58:08,329
timing right so you can get anything

1317
00:58:13,480 --> 00:58:11,390
that started out here to survive and

1318
00:58:15,700 --> 00:58:13,490
also you have to remember things are

1319
00:58:18,160 --> 00:58:15,710
moving out in response to the mass loss

1320
00:58:19,630 --> 00:58:18,170
of the star so you can get a whole bunch

1321
00:58:21,310 --> 00:58:19,640
of stuff that survives and a whole bunch

1322
00:58:24,160 --> 00:58:21,320
of stuff from the outer system that

1323
00:58:26,290 --> 00:58:24,170
moves in toward the resonances if you're

1324
00:58:28,930 --> 00:58:26,300
talking about interior resonances to

1325
00:58:31,450 --> 00:58:28,940
Jupiter which is what these are you can

1326
00:58:33,810 --> 00:58:31,460
also have exterior exterior residences

1327
00:58:37,180 --> 00:58:33,820
so if you have chains of planets like

1328
00:58:39,160 --> 00:58:37,190
the typical Kepler planetary system is

1329
00:58:41,319 --> 00:58:39,170
actually like five or six super Earths

1330
00:58:43,240 --> 00:58:41,329
all mushed together in very tight orbits

1331
00:58:45,040 --> 00:58:43,250
so if you have chains of those kinds of

1332
00:58:47,560 --> 00:58:45,050
planets you can have lots of resonances

1333
00:58:49,569 --> 00:58:47,570
interior and exterior our own solar

1334
00:58:53,260 --> 00:58:49,579
system has exterior resonances with the

1335
00:58:56,520 --> 00:58:53,270
Kuiper belt objects and there have been

1336
00:59:00,430 --> 00:58:56,530
people the list is here have who have

1337
00:59:03,430 --> 00:59:00,440
you know measure or model the dynamics

1338
00:59:05,710 --> 00:59:03,440

to see whether asteroids or comets in

1339
00:59:07,990 --> 00:59:05,720
exterior resonances get kicked into the

1340
00:59:10,569 --> 00:59:08,000
inner system and what happens is the

1341
00:59:13,390 --> 00:59:10,579
gravity of your chain of planets or a

1342
00:59:14,829 --> 00:59:13,400
couple of planets basically kicks from

1343
00:59:18,700 --> 00:59:14,839
one planet to the next until eventually

1344
00:59:20,530 --> 00:59:18,710
they get kicked to the inner system now

1345
00:59:23,559 --> 00:59:20,540
the problem is that most of the stuff

1346
00:59:25,270 --> 00:59:23,569
that's far out is icy and will get

1347
00:59:27,609 --> 00:59:25,280
evaporated much more quickly than the

1348
00:59:29,440 --> 00:59:27,619
rocky stuff so I actually favored that

1349
00:59:32,470 --> 00:59:29,450
the stuff on the interior even though it

1350
00:59:34,540 --> 00:59:32,480
has a harder time of it during the stars

1351
00:59:36,609 --> 00:59:34,550
evolution well it because it's rocky

1352
00:59:39,700 --> 00:59:36,619
will survive better than the icy stuff

1353
00:59:41,800 --> 00:59:39,710
far out so I actually worked on an idea

1354
00:59:45,550 --> 00:59:41,810
where i took the thought experiment of

1355
00:59:47,559 --> 00:59:45,560
our solar system and i just measured and

1356
00:59:49,480 --> 00:59:47,569
i put a whole bunch of asteroids our own

1357
00:59:52,089 --> 00:59:49,490
asteroids in our solar system with the

1358
00:59:53,710 --> 00:59:52,099
known orbital elements and i ran them

1359
00:59:57,130 --> 00:59:53,720
through an end body simulation where i

1360
00:59:59,490 --> 00:59:57,140
made the Sun evolve through its end of

1361
01:00:02,190 --> 00:59:59,500
at life and I just watched what happened

1362
01:00:04,990 --> 01:00:02,200
between the asteroids and Jupiter and

1363
01:00:05,560 --> 01:00:05,000

what I found was that asteroids that

1364
01:00:08,260 --> 01:00:05,570
were in the

1365
01:00:10,780 --> 01:00:08,270
21 mean motion resonance with Jupiter an

1366
01:00:14,080 --> 01:00:10,790
interior residence with Jupiter would

1367
01:00:19,270 --> 01:00:14,090
get kicked in and Title II disrupt a few

1368
01:00:22,030 --> 01:00:19,280
at a time at a rate of you know a few

1369
01:00:24,280 --> 01:00:22,040
per year or a few / tens of hundreds of

1370
01:00:27,340 --> 01:00:24,290
years depending on the how long it's

1371
01:00:29,500 --> 01:00:27,350
been running and you can compare these

1372
01:00:31,570 --> 01:00:29,510
models with the observed accretion rate

1373
01:00:33,910 --> 01:00:31,580
of a population of white dwarfs to see

1374
01:00:37,300 --> 01:00:33,920
if the model makes sense so what do I

1375
01:00:42,000 --> 01:00:37,310
have here okay so the blue points are my

1376
01:00:44,620 --> 01:00:42,010
simulations the red and black points are

1377
01:00:47,680 --> 01:00:44,630
white dwarfs that have metal lines only

1378
01:00:52,120 --> 01:00:47,690
the red ones are metal lines and dusty

1379
01:00:54,400 --> 01:00:52,130
disks and you have sort of my

1380
01:00:57,610 --> 01:00:54,410
simulations explaining sort of the the

1381
01:00:59,260 --> 01:00:57,620
weakest accretion rates over time so

1382
01:01:02,200 --> 01:00:59,270
this is temperature the white dwarf

1383
01:01:03,880 --> 01:01:02,210
which is sort of a proxy of evolutionary

1384
01:01:07,000 --> 01:01:03,890
timescale wide doors go from being

1385
01:01:10,000 --> 01:01:07,010
hotter to colder with time as they cool

1386
01:01:12,220 --> 01:01:10,010
down and this is the mass accretion rate

1387
01:01:14,770 --> 01:01:12,230
so if you just took sort of an average

1388
01:01:18,220 --> 01:01:14,780

of my models and you kicked it up by a

1389
01:01:21,430 --> 01:01:18,230
factor of 10 or 100 or more I can't

1390
01:01:23,410 --> 01:01:21,440
remember now let's say a few hundred you

1391
01:01:24,880 --> 01:01:23,420
would roughly match the highest

1392
01:01:27,760 --> 01:01:24,890
accretion rates that we actually observe

1393
01:01:30,550 --> 01:01:27,770
so maybe we have solar systems that have

1394
01:01:32,890 --> 01:01:30,560
a lot more rocks than we do maybe that's

1395
01:01:35,320 --> 01:01:32,900
one explanation now I worked with a

1396
01:01:37,060 --> 01:01:35,330
summer intern for a while and instead of

1397
01:01:39,790 --> 01:01:37,070
having a small number of asteroids we

1398
01:01:42,310 --> 01:01:39,800
put as many asteroids as are actually

1399
01:01:45,430 --> 01:01:42,320
observed in our solar system and try it

1400
01:01:48,160 --> 01:01:45,440
again and when you put a lot more you

1401
01:01:50,290 --> 01:01:48,170
get a lot higher accretion rates so now

1402
01:01:53,590 --> 01:01:50,300
it's more like we need only like 10 or

1403
01:01:55,840 --> 01:01:53,600
20 times what our own solar system seems

1404
01:01:57,790 --> 01:01:55,850
to have in terms of a reservoir of Title

1405
01:02:00,220 --> 01:01:57,800
II disrupting planets but this is sort

1406
01:02:02,980 --> 01:02:00,230
of like a proof of concept we can get

1407
01:02:05,980 --> 01:02:02,990
asteroids that start out very far with

1408
01:02:08,470 --> 01:02:05,990
the resonance to a big planet Jupiter or

1409
01:02:10,990 --> 01:02:08,480
Saturn and they get kicked in and what's

1410
01:02:14,110 --> 01:02:11,000
happening is it's because Jupiter is

1411
01:02:16,180 --> 01:02:14,120
getting more muscley okay so Jupiter

1412
01:02:19,269 --> 01:02:16,190
over its evolution there used to be a

1413
01:02:20,679 --> 01:02:19,279

ton of asteroids right here at the 22

1414
01:02:22,449 --> 01:02:20,689
resonance this is the two-to-one

1415
01:02:24,729 --> 01:02:22,459
resonance but what would happen is once

1416
01:02:27,909 --> 01:02:24,739
they got caught her and eventually so

1417
01:02:30,669 --> 01:02:27,919
this is semi major axis of orbit for the

1418
01:02:33,909 --> 01:02:30,679
asteroid versus eccentricity so they

1419
01:02:35,709 --> 01:02:33,919
were random walk in this region and then

1420
01:02:38,439 --> 01:02:35,719
eventually get so high in eccentricities

1421
01:02:40,479 --> 01:02:38,449
to get they escape they either interact

1422
01:02:43,899 --> 01:02:40,489
with earth they get kicked out whatever

1423
01:02:46,870 --> 01:02:43,909
it is they go into the Sun but when the

1424
01:02:48,939 --> 01:02:46,880
Sun loses its mass suddenly Jupiter is

1425
01:02:51,429 --> 01:02:48,949
much stronger and so everything that was

1426
01:02:54,669 --> 01:02:51,439
on the edge here is now trapped in the

1427
01:02:57,429 --> 01:02:54,679
resonance and starts moving around until

1428
01:03:01,929 --> 01:02:57,439
it gets to the white dwarf and causes a

1429
01:03:03,609 --> 01:03:01,939
dust disk and causes dust and we can

1430
01:03:06,130 --> 01:03:03,619
even probe you know with these

1431
01:03:09,909 --> 01:03:06,140
simulations you know the distribution of

1432
01:03:13,799 --> 01:03:09,919
how much material gets and how close it

1433
01:03:16,390 --> 01:03:13,809
gets so if you remember we were seeing

1434
01:03:19,390 --> 01:03:16,400
dust rings that were sort of in this

1435
01:03:22,209 --> 01:03:19,400
region here right and so what you would

1436
01:03:24,609 --> 01:03:22,219
expect is if something came in to 60

1437
01:03:26,289 --> 01:03:24,619
white dwarf radii it would shred up here

1438
01:03:29,799 --> 01:03:26,299

and then all the dust would sort of

1439
01:03:32,859 --> 01:03:29,809
drain in that way so the outer extent is

1440
01:03:35,079 --> 01:03:32,869
a rough measure of where the asteroid

1441
01:03:37,870 --> 01:03:35,089
maybe came in and what this is saying is

1442
01:03:40,209 --> 01:03:37,880
that you expect a lot of you expect more

1443
01:03:42,759 --> 01:03:40,219
things right at the edge of the title

1444
01:03:45,699 --> 01:03:42,769
disruption radius then really deep into

1445
01:03:47,859 --> 01:03:45,709
close to the white dwarf so that's

1446
01:03:50,229 --> 01:03:47,869
interesting it also means there's a

1447
01:03:54,370 --> 01:03:50,239
whole bunch more stuff just outside

1448
01:03:56,109 --> 01:03:54,380
thats hanging around waiting for i don't

1449
01:03:57,549 --> 01:03:56,119
know what but there's a whole bunch of

1450
01:03:59,709 --> 01:03:57,559
stuff that doesn't get tidally disrupted

1451
01:04:01,569 --> 01:03:59,719
that's just hanging around it might

1452
01:04:04,779 --> 01:04:01,579
collide if the white dwarf is

1453
01:04:07,989 --> 01:04:04,789
particularly hot the stuff out here will

1454
01:04:11,380 --> 01:04:07,999
will evaporate stuff off keep that in

1455
01:04:14,499 --> 01:04:11,390
mind you've got number eight or nine I

1456
01:04:16,269 --> 01:04:14,509
don't even know okay anyway so now we

1457
01:04:18,759 --> 01:04:16,279
can do the same calculation where we

1458
01:04:20,949 --> 01:04:18,769
compared to a larger sample of observed

1459
01:04:24,130 --> 01:04:20,959
white dwarfs with different accretion

1460
01:04:26,259 --> 01:04:24,140
rates and the simulations and now so the

1461
01:04:28,329 --> 01:04:26,269
solar system looks a little wimpy still

1462
01:04:30,939 --> 01:04:28,339
but this is sort of like a your most

1463
01:04:32,650 --> 01:04:30,949

conservative estimate of how much mass

1464
01:04:34,900 --> 01:04:32,660
you would get accreting onto a white

1465
01:04:36,910 --> 01:04:34,910
orff but we still measure sort of the

1466
01:04:38,799 --> 01:04:36,920
bottom fraction but we're only like a

1467
01:04:41,470 --> 01:04:38,809
factor of ten or so and at least that

1468
01:04:43,150 --> 01:04:41,480
early times for our solar system we can

1469
01:04:45,910 --> 01:04:43,160
even match the highest accretion rates

1470
01:04:48,160 --> 01:04:45,920
that are observed but our solar system

1471
01:04:50,710 --> 01:04:48,170
will eventually weaken pretty quickly

1472
01:04:53,079 --> 01:04:50,720
you know you run out of stuff and it

1473
01:04:55,630 --> 01:04:53,089
slowly falls to very low accretion rates

1474
01:04:59,980 --> 01:04:55,640
over time and so then these are the

1475
01:05:02,349 --> 01:04:59,990
times after the star dies you know as a

1476
01:05:04,750 --> 01:05:02,359
mapped to the temperature of the white

1477
01:05:08,440 --> 01:05:04,760
dwarf so we still see quite a bit of

1478
01:05:10,109 --> 01:05:08,450
accretion in nature that we don't expect

1479
01:05:12,849 --> 01:05:10,119
to see from our own solar system

1480
01:05:14,410 --> 01:05:12,859
planetary architecture so we need to

1481
01:05:17,440 --> 01:05:14,420
investigate different planetary

1482
01:05:19,809 --> 01:05:17,450
architectures to sort of get a hint at

1483
01:05:21,809 --> 01:05:19,819
what maybe is causing the higher

1484
01:05:23,859 --> 01:05:21,819
accretion rates that we actually observe

1485
01:05:25,569 --> 01:05:23,869
okay I'm going to skip that not very

1486
01:05:27,490 --> 01:05:25,579
interesting but I will tell you about a

1487
01:05:30,010 --> 01:05:27,500
mystery so I mentioned that Kepler had

1488
01:05:31,870 --> 01:05:30,020

discovered many many planets well it

1489
01:05:35,740 --> 01:05:31,880
also found something extremely weird

1490
01:05:37,299 --> 01:05:35,750
around a white dwarf a piddling faint

1491
01:05:40,769 --> 01:05:37,309
little white dwarf that everyone had

1492
01:05:44,079 --> 01:05:40,779
ignored for many years and someone

1493
01:05:46,599 --> 01:05:44,089
during k2 so remember Kepler had a main

1494
01:05:49,269 --> 01:05:46,609
mission its reaction wheels failed and

1495
01:05:51,069 --> 01:05:49,279
now has this new mission called k2 which

1496
01:05:53,440 --> 01:05:51,079
is doing great stuff because now it's

1497
01:05:56,430 --> 01:05:53,450
looking at wider swathes of the sky and

1498
01:05:59,410 --> 01:05:56,440
they looked at this one white dwarf and

1499
01:06:01,690 --> 01:05:59,420
someone noticed that the durn thing kept

1500
01:06:04,510 --> 01:06:01,700
dipping at a period of about four and a

1501
01:06:06,910 --> 01:06:04,520
half hours and then when you add

1502
01:06:09,640 --> 01:06:06,920
everything up you see these strange dips

1503
01:06:11,400 --> 01:06:09,650
that are pretty small now remember white

1504
01:06:15,010 --> 01:06:11,410
dwarfs are about the size of the earth

1505
01:06:19,170 --> 01:06:15,020
so any dips are from small things

1506
01:06:22,359 --> 01:06:19,180
smaller than the earth so these dips

1507
01:06:24,039 --> 01:06:22,369
I'll look strange there's no way to put

1508
01:06:26,970 --> 01:06:24,049
it it doesn't look like a planetary

1509
01:06:29,410 --> 01:06:26,980
transit because the the dips are not

1510
01:06:33,190 --> 01:06:29,420
regular like a transit they're all over

1511
01:06:35,819 --> 01:06:33,200
the place they're kind of strange we

1512
01:06:38,829 --> 01:06:35,829
think this is we're actually seeing

1513
01:06:40,660 --> 01:06:38,839

disintegrating asteroids in real time

1514
01:06:43,870 --> 01:06:40,670
because what's happening is we're seeing

1515
01:06:45,520 --> 01:06:43,880
oh good yes we're seeing these dips that

1516
01:06:47,710 --> 01:06:45,530
are either very sharp

1517
01:06:50,440 --> 01:06:47,720
or sort of asymmetric and so we're

1518
01:06:52,480 --> 01:06:50,450
seeing bits that are sort of like a

1519
01:06:54,970 --> 01:06:52,490
comet tail right so we get these

1520
01:06:57,010 --> 01:06:54,980
asymmetric profiles from the tail

1521
01:07:00,130 --> 01:06:57,020
crossing in front of the white dwarf and

1522
01:07:02,260 --> 01:07:00,140
it's happening over and over again so

1523
01:07:03,630 --> 01:07:02,270
there's like a collection of bits going

1524
01:07:06,730 --> 01:07:03,640
around and around we don't really

1525
01:07:08,500 --> 01:07:06,740
understand this yet literally tomorrow I

1526
01:07:10,300 --> 01:07:08,510
am jumping on a train I'm going to New

1527
01:07:13,240 --> 01:07:10,310
Haven I'm going to be observing on the

1528
01:07:15,070 --> 01:07:13,250
Keck telescope on this object all night

1529
01:07:17,410 --> 01:07:15,080
long I'm just going to sit on it and see

1530
01:07:19,480 --> 01:07:17,420
if it does something weird because it

1531
01:07:22,180 --> 01:07:19,490
keeps changing these dips don't say

1532
01:07:25,180 --> 01:07:22,190
regular they change in depth they shift

1533
01:07:26,830 --> 01:07:25,190
around in time someone and this is like

1534
01:07:28,270 --> 01:07:26,840
a paper that came out a couple weeks ago

1535
01:07:31,240 --> 01:07:28,280
I didn't even put the reference sorry

1536
01:07:32,830 --> 01:07:31,250
apologize for that but they noticed okay

1537
01:07:35,440 --> 01:07:32,840
this is a weird plot they call it a

1538
01:07:37,210 --> 01:07:35,450

waterfall plot what's happening is these

1539
01:07:40,530 --> 01:07:37,220
are all the observations they took of

1540
01:07:43,510 --> 01:07:40,540
the star and anytime you see a blue

1541
01:07:45,550 --> 01:07:43,520
feature these were a series of dips and

1542
01:07:48,010 --> 01:07:45,560
they were able to match up those dips

1543
01:07:49,570 --> 01:07:48,020
from night tonight right they just sat

1544
01:07:52,060 --> 01:07:49,580
on this thing over and over and over

1545
01:07:55,720 --> 01:07:52,070
again they noticed that some of the dips

1546
01:07:58,210 --> 01:07:55,730
were sort of drifting in time so what

1547
01:08:01,420 --> 01:07:58,220
they interpret is happening is you have

1548
01:08:04,410 --> 01:08:01,430
a main asteroid or something serious

1549
01:08:08,800 --> 01:08:04,420
let's say and there are chunks of it

1550
01:08:10,750 --> 01:08:08,810
popping off and then swirling closer and

1551
01:08:13,390 --> 01:08:10,760
closer to the white dwarf that's what

1552
01:08:16,809 --> 01:08:13,400
they're interpreting these dips and the

1553
01:08:19,120 --> 01:08:16,819
drifts in the dip times as and when you

1554
01:08:23,050 --> 01:08:19,130
do that you can actually constrain the

1555
01:08:26,650 --> 01:08:23,060
mass of the planet or planetesimal from

1556
01:08:28,900 --> 01:08:26,660
how fast things are drifting I was not

1557
01:08:31,480 --> 01:08:28,910
aware of this but they claim this is

1558
01:08:33,660 --> 01:08:31,490
true so if they got that right they

1559
01:08:36,130 --> 01:08:33,670
think that this planetesimals that is

1560
01:08:40,809 --> 01:08:36,140
breaking off these chunks is about a

1561
01:08:43,000 --> 01:08:40,819
tenth of the massive series so series is

1562
01:08:45,610 --> 01:08:43,010
one of the largest asteroids in our

1563
01:08:48,099 --> 01:08:45,620

asteroid belt so something about the

1564
01:08:50,110 --> 01:08:48,109
tenth the size of Ceres is not crazy for

1565
01:08:52,360 --> 01:08:50,120
our solar system it would not be crazy

1566
01:08:55,750 --> 01:08:52,370
for another solar system as well so this

1567
01:08:58,300 --> 01:08:55,760
is starting to fill in a picture this is

1568
01:08:59,229 --> 01:08:58,310
sort of like the best example of a dusty

1569
01:09:01,569 --> 01:08:59,239
white dwarf because

1570
01:09:03,370 --> 01:09:01,579
not only do we have these dips so we're

1571
01:09:05,890 --> 01:09:03,380
seeing the disintegration in real time

1572
01:09:07,629 --> 01:09:05,900
there's an infrared excess so we can go

1573
01:09:09,309 --> 01:09:07,639
with james webb space telescope when it

1574
01:09:11,200 --> 01:09:09,319
launches and we look and look at the

1575
01:09:13,120 --> 01:09:11,210
spectrum of the dust and understand

1576
01:09:16,059 --> 01:09:13,130
something about what the dust is made of

1577
01:09:18,339 --> 01:09:16,069
we can see the bits sloughing off we can

1578
01:09:20,649 --> 01:09:18,349
maybe take spectra of the bits sloughing

1579
01:09:23,410 --> 01:09:20,659
off and get the dust composition that

1580
01:09:25,539 --> 01:09:23,420
way and then when we take spectra of the

1581
01:09:27,489 --> 01:09:25,549
white dwarf itself it has tons of metal

1582
01:09:29,739 --> 01:09:27,499
lines so we can get the composition of

1583
01:09:32,919 --> 01:09:29,749
the dust in the white dwarf we get every

1584
01:09:35,559 --> 01:09:32,929
step of this process with these

1585
01:09:41,259 --> 01:09:35,569
observations it's a really unique system

1586
01:09:43,959 --> 01:09:41,269
and it's very exciting so yay now if we

1587
01:09:45,599 --> 01:09:43,969
can see asteroids we can see a big

1588
01:09:49,029 --> 01:09:45,609

earth-like planet no trouble an

1589
01:09:50,499 --> 01:09:49,039
earth-like planet will make significant

1590
01:09:52,149 --> 01:09:50,509
changes to the brightness of a white

1591
01:09:55,720 --> 01:09:52,159
dwarf it goes if it goes in front of it

1592
01:09:57,609 --> 01:09:55,730
so this was thought of a couple years

1593
01:09:59,640 --> 01:09:57,619
ago some people have some really crazy

1594
01:10:02,169 --> 01:09:59,650
ideas of how you could maybe even see

1595
01:10:05,819 --> 01:10:02,179
atmospheres around these planets you

1596
01:10:09,220 --> 01:10:05,829
know even like industrial waste from

1597
01:10:11,470 --> 01:10:09,230
civilizations stuff like that but I am

1598
01:10:13,270 --> 01:10:11,480
interested in saying can we find

1599
01:10:14,890 --> 01:10:13,280
habitable planets around white doors

1600
01:10:16,870 --> 01:10:14,900
because white dwarfs evolve very slowly

1601
01:10:18,879 --> 01:10:16,880
they don't flare they don't do much of

1602
01:10:21,580 --> 01:10:18,889
anything they're about as common as G

1603
01:10:24,459 --> 01:10:21,590
stars in our local galaxy so if they

1604
01:10:27,009 --> 01:10:24,469
host planets which these dusty white

1605
01:10:29,770 --> 01:10:27,019
door seems suggest they host planets in

1606
01:10:32,560 --> 01:10:29,780
some way maybe these are also places to

1607
01:10:34,359 --> 01:10:32,570
look for habitable planets you have to

1608
01:10:37,569 --> 01:10:34,369
get very close to a white dwarf to be

1609
01:10:39,879 --> 01:10:37,579
habitable so you have to somehow okay if

1610
01:10:41,410 --> 01:10:39,889
you look at this so that's good from an

1611
01:10:42,759 --> 01:10:41,420
observational standpoint because you

1612
01:10:44,560 --> 01:10:42,769
don't have to look at any particular

1613
01:10:46,629 --> 01:10:44,570

object for very long to see if it has

1614
01:10:49,629 --> 01:10:46,639
the planet because it has a nice big

1615
01:10:52,839 --> 01:10:49,639
signal and a short period great problem

1616
01:10:54,459 --> 01:10:52,849
is it has a short period which means

1617
01:10:57,370 --> 01:10:54,469
that you somehow have to get a planet

1618
01:11:00,549 --> 01:10:57,380
that would have been destroyed during

1619
01:11:03,819 --> 01:11:00,559
the stars death somehow getting very

1620
01:11:05,979 --> 01:11:03,829
close so we see that asteroids do it

1621
01:11:08,350 --> 01:11:05,989
it's a little bit harder for planets so

1622
01:11:09,609 --> 01:11:08,360
there's no reason to expect that there

1623
01:11:11,890 --> 01:11:09,619
are a lot of planets close to white

1624
01:11:12,240 --> 01:11:11,900
dwarfs but it's so easy to look we might

1625
01:11:13,890 --> 01:11:12,250
as well

1626
01:11:16,920 --> 01:11:13,900
and we only have to look at a few

1627
01:11:18,600 --> 01:11:16,930
thousand white doors to find any kind to

1628
01:11:20,700 --> 01:11:18,610
put any kind of interesting constraints

1629
01:11:23,970 --> 01:11:20,710
on the frequency of habitable planets

1630
01:11:27,120 --> 01:11:23,980
around white doors so and one of the

1631
01:11:28,920 --> 01:11:27,130
nice things is if you have a planet with

1632
01:11:31,080 --> 01:11:28,930
an atmosphere that signal is very very

1633
01:11:33,570 --> 01:11:31,090
small for main sequence stars because

1634
01:11:35,550 --> 01:11:33,580
the signal the transit signal itself is

1635
01:11:37,530 --> 01:11:35,560
very small with a white dwarf you don't

1636
01:11:39,000 --> 01:11:37,540
have that problem so if there's a planet

1637
01:11:41,550 --> 01:11:39,010
around a white dwarf and if it has an

1638
01:11:43,980 --> 01:11:41,560

atmosphere it will be easily accessible

1639
01:11:45,840 --> 01:11:43,990
in our lifetimes compared to the earth

1640
01:11:48,150 --> 01:11:45,850
like planets around main sequence stars

1641
01:11:50,090 --> 01:11:48,160
or like earth-like or sun-like stars

1642
01:11:53,280 --> 01:11:50,100
that would be very hard to do and

1643
01:11:56,040 --> 01:11:53,290
especially if we look in the ultraviolet

1644
01:11:58,680 --> 01:11:56,050
there are these large comparatively to

1645
01:12:03,060 --> 01:11:58,690
the visible signatures of say oxygen or

1646
01:12:05,400 --> 01:12:03,070
ozone so I work on a ultraviolet

1647
01:12:08,850 --> 01:12:05,410
instrument I used to work on the costs

1648
01:12:11,130 --> 01:12:08,860
stiff steam and now it's Vikas team but

1649
01:12:13,260 --> 01:12:11,140
anyway costs has this really nice

1650
01:12:15,480 --> 01:12:13,270
ability that any spectrum it takes in

1651
01:12:17,310 --> 01:12:15,490
the ultraviolet can also be turned into

1652
01:12:19,860 --> 01:12:17,320
a light curve because the detector

1653
01:12:23,310 --> 01:12:19,870
records the time and location of every

1654
01:12:25,290 --> 01:12:23,320
photon that hits the detector and so any

1655
01:12:27,300 --> 01:12:25,300
spectrum that's ever been taken by the

1656
01:12:30,390 --> 01:12:27,310
cost instrument over the last five or

1657
01:12:32,130 --> 01:12:30,400
six years is also a UV light curve for

1658
01:12:34,260 --> 01:12:32,140
free so I have a friend here at the

1659
01:12:36,510 --> 01:12:34,270
Institute that developed software to

1660
01:12:38,640 --> 01:12:36,520
turn every cost spectrum whether people

1661
01:12:40,830 --> 01:12:38,650
wanted it to or not into a light curve

1662
01:12:42,360 --> 01:12:40,840
and so I asked him can you give me all

1663
01:12:45,540 --> 01:12:42,370

the white dwarfs please and there were

1664
01:12:48,420 --> 01:12:45,550
about a hundred and then I asked my high

1665
01:12:53,280 --> 01:12:48,430
school high school in turn Phoebe Santos

1666
01:12:54,510 --> 01:12:53,290
she's now a freshman at UMBC so keep an

1667
01:12:57,180 --> 01:12:54,520
eye out for her I think she has a bright

1668
01:12:59,490 --> 01:12:57,190
future because she taught herself how to

1669
01:13:02,460 --> 01:12:59,500
program a computer how to do research

1670
01:13:04,590 --> 01:13:02,470
and she found out that within our white

1671
01:13:06,600 --> 01:13:04,600
dwarfs some of them had been observed so

1672
01:13:10,890 --> 01:13:06,610
many times that you actually could have

1673
01:13:13,770 --> 01:13:10,900
seen for a range of periods things as

1674
01:13:16,920 --> 01:13:13,780
small as Pluto or maybe things even as

1675
01:13:19,080 --> 01:13:16,930
smallest series that's how sensitive

1676
01:13:20,850 --> 01:13:19,090
cost is when you have a lot of light and

1677
01:13:23,310 --> 01:13:20,860
you're talking about a white dwarf where

1678
01:13:25,470 --> 01:13:23,320
the signals are large so Phoebe did this

1679
01:13:27,390 --> 01:13:25,480
we have a paper that is accepted

1680
01:13:29,280 --> 01:13:27,400
by the astrophysical journal it will be

1681
01:13:31,650 --> 01:13:29,290
out soon but basically she discovered

1682
01:13:33,270 --> 01:13:31,660
that if you wanted to if you found a

1683
01:13:35,250 --> 01:13:33,280
transiting planet around a white dwarf

1684
01:13:38,220 --> 01:13:35,260
you could follow it up with Hubble and

1685
01:13:39,930 --> 01:13:38,230
get exquisite precision especially if it

1686
01:13:41,430 --> 01:13:39,940
was an earth-like planet down to the

1687
01:13:44,490 --> 01:13:41,440
levels that you would probably need to

1688
01:13:46,979 --> 01:13:44,500

look for an atmosphere so let's hope

1689
01:13:50,310 --> 01:13:46,989
cost doesn't die before we find an

1690
01:13:52,860 --> 01:13:50,320
interesting transiting planet so James

1691
01:13:55,830 --> 01:13:52,870
Webb will be very useful to you can look

1692
01:13:57,780 --> 01:13:55,840
at planets around white dwarfs in the

1693
01:13:59,970 --> 01:13:57,790
infrared just as easily as you can in

1694
01:14:02,070 --> 01:13:59,980
the visible or the OP or in the

1695
01:14:04,710 --> 01:14:02,080
ultraviolet there's a mission called

1696
01:14:08,040 --> 01:14:04,720
tests the transiting exoplanet survey

1697
01:14:11,010 --> 01:14:08,050
satellite it's going to look all across

1698
01:14:12,690 --> 01:14:11,020
the sky for transiting objects so it

1699
01:14:15,510 --> 01:14:12,700
will look at a few thousand white dwarfs

1700
01:14:17,580 --> 01:14:15,520
for free and so we will be able to maybe

1701
01:14:19,410 --> 01:14:17,590
hopefully answer the question of whether

1702
01:14:21,840 --> 01:14:19,420
there are habitable planets around white

1703
01:14:23,490 --> 01:14:21,850
dwarfs and if there are if you find a

1704
01:14:26,100 --> 01:14:23,500
lot of them then they may be the most

1705
01:14:29,250 --> 01:14:26,110
common type of habitable planet in the

1706
01:14:31,229 --> 01:14:29,260
universe so we have you know M Dwarfs as

1707
01:14:32,550 --> 01:14:31,239
a good candidate for habitable planets

1708
01:14:34,710 --> 01:14:32,560
because we've actually found some

1709
01:14:36,630 --> 01:14:34,720
interesting planets in close orbit we

1710
01:14:38,940 --> 01:14:36,640
have earth-like planets around sun-like

1711
01:14:42,000 --> 01:14:38,950
stars those are also very interesting

1712
01:14:44,910 --> 01:14:42,010
because we have one habitable planet

1713
01:14:46,410 --> 01:14:44,920

that we know for sure us and then a

1714
01:14:48,420 --> 01:14:46,420
whole bunch of other candidates that

1715
01:14:50,910 --> 01:14:48,430
might be interesting and then after them

1716
01:14:53,220 --> 01:14:50,920
white dwarfs are actually the next most

1717
01:14:56,970 --> 01:14:53,230
common type of star so if we can prove

1718
01:14:59,250 --> 01:14:56,980
that these stars have planets just like

1719
01:15:00,840 --> 01:14:59,260
all the other stars we seem to find that

1720
01:15:02,640 --> 01:15:00,850
have planets well then we'll be in

1721
01:15:05,100 --> 01:15:02,650
business will have three different types

1722
01:15:07,229 --> 01:15:05,110
of stars to understand plan information

1723
01:15:09,600 --> 01:15:07,239
about and even if we don't find any

1724
01:15:11,040 --> 01:15:09,610
planets around white dwarfs that's okay

1725
01:15:13,530 --> 01:15:11,050
because we certainly see the

1726
01:15:15,660 --> 01:15:13,540
fingerprints of rocky planets around

1727
01:15:19,650 --> 01:15:15,670
white doors and we can get a really good

1728
01:15:24,060 --> 01:15:19,660
idea of how rocky planets form in the

1729
01:15:26,280 --> 01:15:24,070
universe so dusty white dwarfs they have

1730
01:15:29,610 --> 01:15:26,290
tiny little disks they are caused by

1731
01:15:32,370 --> 01:15:29,620
asteroids that shred up the dust turns

1732
01:15:33,330 --> 01:15:32,380
into a disk it eventually accretes onto

1733
01:15:36,660 --> 01:15:33,340
the white dwarf and you get a

1734
01:15:39,360 --> 01:15:36,670
fingerprint of the dusts composition

1735
01:15:43,110 --> 01:15:39,370
right elements

1736
01:15:45,720 --> 01:15:43,120
and relative abundances and then we are

1737
01:15:48,960 --> 01:15:45,730
actually seeing this disintegration in

1738
01:15:50,760 --> 01:15:48,970

real time around dead stars and we think

1739
01:15:52,200 --> 01:15:50,770
there might be a lot of planets around

1740
01:15:53,970 --> 01:15:52,210
these white doors that are really

1741
01:15:55,350 --> 01:15:53,980
interesting to follow up on I should

1742
01:15:57,300 --> 01:15:55,360
also mention that James Webb will

1743
01:15:59,850 --> 01:15:57,310
actually be sensitive to find

1744
01:16:01,530 --> 01:15:59,860
jupiter-like planets at large

1745
01:16:04,290 --> 01:16:01,540
separations from their white doors

1746
01:16:08,010 --> 01:16:04,300
presumably the perturb airs that caused

1747
01:16:10,260 --> 01:16:08,020
all these dusty conundrums so with that

1748
01:16:12,330 --> 01:16:10,270
I'm just going to advertise a citizen

1749
01:16:14,940 --> 01:16:12,340
science project that I'm part of called

1750
01:16:16,530 --> 01:16:14,950
dis detective so if you like dust or if

1751
01:16:17,790 --> 01:16:16,540
I have suddenly convinced you that dust

1752
01:16:20,340 --> 01:16:17,800
is the most amazing thing in the

1753
01:16:22,590 --> 01:16:20,350
universe you can look for more dusty

1754
01:16:25,560 --> 01:16:22,600
stars with dis detective it's through

1755
01:16:27,120 --> 01:16:25,570
the Zooniverse website and that's a fun

1756
01:16:30,360 --> 01:16:27,130
thing to check out you'll you'll help us

1757
01:16:32,040 --> 01:16:30,370
find dusty stars yourself and with that

1758
01:16:39,260 --> 01:16:32,050
I will be happy to take questions thank

1759
01:16:47,160 --> 01:16:44,580
yes simulation analysis to see what did

1760
01:16:49,350 --> 01:16:47,170
it in our solar system the Goldilocks

1761
01:16:51,299 --> 01:16:49,360
zone move out is our son kind of

1762
01:16:52,979 --> 01:16:51,309
increased right so I haven't done that

1763
01:16:55,560 --> 01:16:52,989

but there are people who have looked

1764
01:16:57,390 --> 01:16:55,570
into that and yes what happens is the

1765
01:17:01,379 --> 01:16:57,400
you know the region where you can

1766
01:17:04,890 --> 01:17:01,389
sustain liquid water expands as the star

1767
01:17:06,600 --> 01:17:04,900
becomes a giant but the problem with

1768
01:17:08,520 --> 01:17:06,610
that or you know maybe it's a problem

1769
01:17:10,830 --> 01:17:08,530
maybe it's not is that the Stars

1770
01:17:13,709 --> 01:17:10,840
evolving pretty quickly so it gets big

1771
01:17:17,549 --> 01:17:13,719
pretty quickly and then eventually it

1772
01:17:20,029 --> 01:17:17,559
goes out so we think that that's

1773
01:17:22,529 --> 01:17:20,039
probably too quick for life to

1774
01:17:26,310 --> 01:17:22,539
spontaneously generate and evolve into

1775
01:17:28,740 --> 01:17:26,320
people that drink coffee but you know

1776
01:17:31,229 --> 01:17:28,750
you there are periods of evolution where

1777
01:17:33,209 --> 01:17:31,239
it you know the the Sun the star would

1778
01:17:36,510 --> 01:17:33,219
be a bit brighter so when it first

1779
01:17:38,100 --> 01:17:36,520
starts fusing helium it's sort of steady

1780
01:17:40,049 --> 01:17:38,110
for a while until it runs out of the

1781
01:17:42,510 --> 01:17:40,059
helium that's probably the next longest

1782
01:17:44,580 --> 01:17:42,520
time and now we push things a little bit

1783
01:17:47,100 --> 01:17:44,590
further out but yeah when when when

1784
01:17:54,810 --> 01:17:47,110
we're a giant star Titan will be pretty

1785
01:17:57,470 --> 01:17:54,820
nice yeah beachfront property how

1786
01:17:59,430 --> 01:17:57,480
quickly do some of these objects

1787
01:18:02,819 --> 01:17:59,440
disintegrate that produces something

1788
01:18:04,560 --> 01:18:02,829

okay the planetesimals yeah well yeah

1789
01:18:06,899 --> 01:18:04,570
that's a great question I don't think we

1790
01:18:08,370 --> 01:18:06,909
have a good answer for that yet I did I

1791
01:18:11,459 --> 01:18:08,380
personally did a few dynamical

1792
01:18:14,399 --> 01:18:11,469
simulations and when I found is at least

1793
01:18:17,010 --> 01:18:14,409
in the first pass what happens is the

1794
01:18:18,899 --> 01:18:17,020
asteroid gets shredded but then it all

1795
01:18:20,850 --> 01:18:18,909
just goes back out again because there's

1796
01:18:22,890 --> 01:18:20,860
really nothing slowing the material down

1797
01:18:24,419 --> 01:18:22,900
you would think maybe that all the

1798
01:18:26,459 --> 01:18:24,429
energy would dissipate in that at the

1799
01:18:30,990 --> 01:18:26,469
disruption but that's not what we found

1800
01:18:32,640 --> 01:18:31,000
another very talented researcher Dmitri

1801
01:18:36,000 --> 01:18:32,650
varus who's done a lot of work on this

1802
01:18:38,640 --> 01:18:36,010
kind of thing found that through mutual

1803
01:18:40,200 --> 01:18:38,650
collisions of the chunks that get torn

1804
01:18:41,910 --> 01:18:40,210
apart you eventually get something that

1805
01:18:44,189 --> 01:18:41,920
settles down maybe after a few hundred

1806
01:18:46,049 --> 01:18:44,199
orbital time scales but the question

1807
01:18:48,000 --> 01:18:46,059
it's not clear to me whether that's

1808
01:18:50,669 --> 01:18:48,010
orbital timescales very close to the

1809
01:18:51,120 --> 01:18:50,679
white door for that full eccentric orbit

1810
01:18:53,250 --> 01:18:51,130
where you

1811
01:18:56,160 --> 01:18:53,260
basically it started a few a you out and

1812
01:18:58,320 --> 01:18:56,170
came an so you're talking a few hundred

1813
01:19:00,479 --> 01:18:58,330

years maybe you would finally get things

1814
01:19:02,189 --> 01:19:00,489
settling down into a nice disc so the

1815
01:19:03,899 --> 01:19:02,199
question is do we see a whole bunch of

1816
01:19:06,120 --> 01:19:03,909
nice regular discs that have already

1817
01:19:08,820 --> 01:19:06,130
settled down or are we seeing different

1818
01:19:10,350 --> 01:19:08,830
phases of that settling and that's still

1819
01:19:12,570 --> 01:19:10,360
in a very much open question because

1820
01:19:14,700 --> 01:19:12,580
each system looks a little bit different

1821
01:19:17,010 --> 01:19:14,710
you know we don't really fully

1822
01:19:18,240 --> 01:19:17,020
understand the structure of these things

1823
01:19:20,669 --> 01:19:18,250
because all we have are a few

1824
01:19:22,590 --> 01:19:20,679
photometric points and that doesn't

1825
01:19:24,390 --> 01:19:22,600
really constrain the the structural

1826
01:19:26,399 --> 01:19:24,400
property or that you know the spatial

1827
01:19:29,010 --> 01:19:26,409
distribution of dust very well at this

1828
01:19:30,870 --> 01:19:29,020
point so there's still a lot of

1829
01:19:32,250 --> 01:19:30,880
questions about how this all works but

1830
01:19:34,140 --> 01:19:32,260
we we think we sort of have the general

1831
01:19:35,970 --> 01:19:34,150
picture and this is one of the few times

1832
01:19:38,459 --> 01:19:35,980
that I can think of in science where we

1833
01:19:40,110 --> 01:19:38,469
had a really crazy explanation for an

1834
01:19:42,600 --> 01:19:40,120
observation that required a lot of

1835
01:19:44,189 --> 01:19:42,610
looming complicated parts and it

1836
01:19:46,350 --> 01:19:44,199
actually you know as time goes on it's

1837
01:19:47,790 --> 01:19:46,360
become the best and best explanation

1838
01:19:49,620 --> 01:19:47,800

because as we get more and more

1839
01:19:51,600 --> 01:19:49,630
observations this crazy idea of some

1840
01:19:53,790 --> 01:19:51,610
random planetesimal far out getting

1841
01:19:56,700 --> 01:19:53,800
kicked all the way in and disintegrating

1842
01:19:58,620 --> 01:19:56,710
is what we keep seeing you know so our

1843
01:20:01,020 --> 01:19:58,630
next step really is to tie what we're

1844
01:20:02,970 --> 01:20:01,030
seeing directly to some planets that are

1845
01:20:04,590 --> 01:20:02,980
further out and that's we're not quite

1846
01:20:06,629 --> 01:20:04,600
there yet because we just don't have the

1847
01:20:10,470 --> 01:20:06,639
sensitivity to those far out planets

1848
01:20:13,010 --> 01:20:10,480
their old cold far away and small and so

1849
01:20:15,689 --> 01:20:13,020
we can't directly image them very well

1850
01:20:18,500 --> 01:20:15,699
you know maybe we can do something with

1851
01:20:20,610 --> 01:20:18,510
Gaia where they have like astrometric a

1852
01:20:23,160 --> 01:20:20,620
sort of precision where they could maybe

1853
01:20:25,709 --> 01:20:23,170
find some planets radial velocity

1854
01:20:27,570 --> 01:20:25,719
surveys wouldn't work because white

1855
01:20:30,330 --> 01:20:27,580
dwarfs just don't have enough lines to

1856
01:20:33,300 --> 01:20:30,340
get precise velocities so there's very

1857
01:20:35,729 --> 01:20:33,310
few ways to actually find planets far

1858
01:20:38,100 --> 01:20:35,739
away and that's what's limiting us right

1859
01:20:42,780 --> 01:20:38,110
now I'm really pitting down how all the

1860
01:20:44,129 --> 01:20:42,790
steps work other questions if you

1861
01:20:48,030 --> 01:20:44,139
mentioned something about the Kuiper

1862
01:20:50,580 --> 01:20:48,040
belt objects being culprit yes they

1863
01:20:52,950 --> 01:20:50,590

could also that they also could be we

1864
01:20:55,129 --> 01:20:52,960
actually find some white dwarfs that

1865
01:20:57,720 --> 01:20:55,139
have accreted water rich material or

1866
01:20:59,580 --> 01:20:57,730
carbonaceous water rich material they

1867
01:21:02,129 --> 01:20:59,590
seem to be rare compared to the ones

1868
01:21:03,570 --> 01:21:02,139
that just seem to be pure rocky but

1869
01:21:06,000 --> 01:21:03,580
there's still a question of whether

1870
01:21:07,860 --> 01:21:06,010
you know if you have a lot of Kuiper

1871
01:21:10,080 --> 01:21:07,870
belt objects that are sort of like hunks

1872
01:21:12,270 --> 01:21:10,090
of rock with a layer of ice the ice

1873
01:21:14,160 --> 01:21:12,280
would go away but the hunk of rock would

1874
01:21:16,320 --> 01:21:14,170
stay but if you have a bunch of dirty

1875
01:21:18,810 --> 01:21:16,330
snowballs that are just dust and ice

1876
01:21:20,640 --> 01:21:18,820
mixed together more finely that would

1877
01:21:22,290 --> 01:21:20,650
just turn into little dust clouds that

1878
01:21:24,480 --> 01:21:22,300
would dissipate before they would

1879
01:21:26,850 --> 01:21:24,490
accrete onto the white dwarf so

1880
01:21:29,400 --> 01:21:26,860
depending on what fraction of the dirty

1881
01:21:31,170 --> 01:21:29,410
snowballs versus icy rocks we have in

1882
01:21:37,760 --> 01:21:31,180
the Kuiper belt which I don't think is a

1883
01:21:40,020 --> 01:21:37,770
soft question yet it may be those are a

1884
01:21:42,870 --> 01:21:40,030
contributor but it's not clear to me how

1885
01:21:45,060 --> 01:21:42,880
much you also can do you it's much

1886
01:21:48,810 --> 01:21:45,070
easier to do it with one planet with the

1887
01:21:50,490 --> 01:21:48,820
sort of rocky interior asteroid belts

1888
01:21:51,930 --> 01:21:50,500

than it is with the Kuiper belt because

1889
01:21:54,210 --> 01:21:51,940
with the Kuiper belt you need more than

1890
01:21:55,980 --> 01:21:54,220
one planet which you know we're also

1891
01:21:57,900 --> 01:21:55,990
finding is fairly common that there are

1892
01:21:59,700 --> 01:21:57,910
multiple planet systems more often than

1893
01:22:02,850 --> 01:21:59,710
not so maybe that's not a real limiter

1894
01:22:05,040 --> 01:22:02,860
so we might be able to find through the

1895
01:22:06,690 --> 01:22:05,050
composition whether the relative rates

1896
01:22:09,090 --> 01:22:06,700
are but we're not at the point yet where

1897
01:22:11,520 --> 01:22:09,100
we say this was a comment this wasn't

1898
01:22:15,030 --> 01:22:11,530
astral and we can broadly say this was

1899
01:22:17,940 --> 01:22:15,040
rocky okay so John I have a question

1900
01:22:21,180 --> 01:22:17,950
sure um mario livio would say that the

1901
01:22:24,270 --> 01:22:21,190
sun isn't going to go red giant hmm that

1902
01:22:26,460 --> 01:22:24,280
it requires a two solar mass star to go

1903
01:22:29,280 --> 01:22:26,470
red giant and a lot of what you did uses

1904
01:22:32,100 --> 01:22:29,290
our solar system as a proxy for what

1905
01:22:33,990 --> 01:22:32,110
you're seeing in these if indeed mario

1906
01:22:37,320 --> 01:22:34,000
is correct and only two solar mass stars

1907
01:22:39,600 --> 01:22:37,330
and above can go red giant to to go

1908
01:22:41,730 --> 01:22:39,610
planetary nebula and such with that

1909
01:22:43,800 --> 01:22:41,740
change significantly or actually help

1910
01:22:46,050 --> 01:22:43,810
your ideas provided push you to a higher

1911
01:22:47,520 --> 01:22:46,060
accretion rate possibly yeah it would

1912
01:22:50,310 --> 01:22:47,530
certainly help because you would destroy

1913
01:22:52,890 --> 01:22:50,320

less material and presumably you'd have

1914
01:22:54,480 --> 01:22:52,900
more planets surviving as well so maybe

1915
01:22:56,790 --> 01:22:54,490
you'd have earth and some other things

1916
01:22:59,790 --> 01:22:56,800
surviving but at least for the more

1917
01:23:02,520 --> 01:22:59,800
canonical stellar evolution models that

1918
01:23:05,700 --> 01:23:02,530
people have done you know even though it

1919
01:23:07,890 --> 01:23:05,710
may not have quite the same evolution as

1920
01:23:09,180 --> 01:23:07,900
a two solar mass star the sudden at

1921
01:23:11,820 --> 01:23:09,190
least from what I've seen still is

1922
01:23:16,740 --> 01:23:11,830
predicted to get pretty large if not

1923
01:23:19,050 --> 01:23:16,750
like super huge I Mario

1924
01:23:21,420 --> 01:23:19,060
one raised these adamant Oh with this

1925
01:23:24,870 --> 01:23:21,430
conclusion mario's never wishy-washy no

1926
01:23:30,200 --> 01:23:24,880
no that's the they speak of astronomers

1927
01:23:37,830 --> 01:23:34,350
arias all right I have one more question

1928
01:23:39,870 --> 01:23:37,840
um guys you talk about how the planets

1929
01:23:43,740 --> 01:23:39,880
around white dwarves but your plot

1930
01:23:45,840 --> 01:23:43,750
showed maximum of like 40 our orbits

1931
01:23:47,760 --> 01:23:45,850
okay so we're talking about orbiting an

1932
01:23:50,730 --> 01:23:47,770
entire star in what is essentially one

1933
01:23:54,960 --> 01:23:50,740
earth day yep does the term habitable

1934
01:23:57,000 --> 01:23:54,970
really apply right so depending on who

1935
01:23:58,590 --> 01:23:57,010
you talk to some people say you can't

1936
01:24:00,690 --> 01:23:58,600
get any sort of habitability there

1937
01:24:02,400 --> 01:24:00,700
because you'd be tidally locked so what

1938
01:24:05,340 --> 01:24:02,410

that means is you'd have one side of

1939
01:24:08,310 --> 01:24:05,350
your planet facing the star at all times

1940
01:24:10,110 --> 01:24:08,320
which eventually some people say due to

1941
01:24:12,000 --> 01:24:10,120
tidal interactions would actually kill

1942
01:24:14,250 --> 01:24:12,010
the planet it would just sort of mush it

1943
01:24:17,550 --> 01:24:14,260
up and make it too hot or it would crash

1944
01:24:22,770 --> 01:24:17,560
into the so that potential is certainly

1945
01:24:25,050 --> 01:24:22,780
there these are orbits that are just

1946
01:24:28,980 --> 01:24:25,060
outside the title disruption radius so

1947
01:24:31,020 --> 01:24:28,990
the planet should be physically okay the

1948
01:24:32,850 --> 01:24:31,030
but the details of how the title

1949
01:24:34,830 --> 01:24:32,860
evolution of a planet around a white

1950
01:24:36,300 --> 01:24:34,840
dwarf that's still probably an open

1951
01:24:39,030 --> 01:24:36,310
question because I don't know how well

1952
01:24:42,770 --> 01:24:39,040
we understand tides in that sort of

1953
01:24:45,810 --> 01:24:42,780
situation so I I prefer to be optimistic

1954
01:24:47,820 --> 01:24:45,820
it's so easy to find these things that I

1955
01:24:50,430 --> 01:24:47,830
think we will either find them or we

1956
01:24:52,530 --> 01:24:50,440
won't and then if we really I mean it's

1957
01:24:54,930 --> 01:24:52,540
really you know you don't have to find

1958
01:24:56,550 --> 01:24:54,940
you don't have to do this to like the

1959
01:24:59,910 --> 01:24:56,560
third significant figure you basically

1960
01:25:01,740 --> 01:24:59,920
have to say our white dwarfs orbited by

1961
01:25:03,150 --> 01:25:01,750
more or less than about you know if

1962
01:25:05,940 --> 01:25:03,160
fifty percent of white doors have some

1963
01:25:07,650 --> 01:25:05,950

kind of habitable star or less which we

1964
01:25:09,300 --> 01:25:07,660
can constrain with it by looking at a

1965
01:25:11,910 --> 01:25:09,310
few thousand white dwarves we basically

1966
01:25:13,620 --> 01:25:11,920
rule white dwarfs in or out as

1967
01:25:15,000 --> 01:25:13,630
interesting targets to look for

1968
01:25:16,980 --> 01:25:15,010
habitable world so I think we can do

1969
01:25:18,710 --> 01:25:16,990
this experiment once or twice with

1970
01:25:21,030 --> 01:25:18,720
existing technology or

1971
01:25:22,500 --> 01:25:21,040
soon-to-be-launched technology and then

1972
01:25:24,090 --> 01:25:22,510
sort of be done with that question on

1973
01:25:25,860 --> 01:25:24,100
the way we'll find really interesting

1974
01:25:29,310 --> 01:25:25,870
things like these disintegrating

1975
01:25:31,800 --> 01:25:29,320
planetesimals all right last quit

1976
01:25:35,760 --> 01:25:31,810
less chance of questions I don't see

1977
01:25:38,310 --> 01:25:35,770
anything but there is a question online

1978
01:25:40,560 --> 01:25:38,320
I wonder what influence changers T might

1979
01:25:41,819 --> 01:25:40,570
have regarding this field and you

1980
01:25:44,490 --> 01:25:41,829
actually did mention you answer that

1981
01:25:49,140 --> 01:25:44,500
yeah well I can answer it again it's

1982
01:25:50,580 --> 01:25:49,150
going to be huge yeah also since that's

1983
01:25:52,560 --> 01:25:50,590
where our bread and butter will become

1984
01:25:54,720 --> 01:25:52,570
for the next ten years I'm legally

1985
01:25:57,149 --> 01:25:54,730
obligated to promote James Webb but in

1986
01:25:58,890 --> 01:25:57,159
this case it's pretty easy to do I don't

1987
01:26:00,689 --> 01:25:58,900
have to really be forced to do it but

1988
01:26:02,609 --> 01:26:00,699

James Webb because it'll have

1989
01:26:04,530 --> 01:26:02,619
spectroscopic capability in the

1990
01:26:05,939 --> 01:26:04,540
mid-infrared not only will it be able to

1991
01:26:08,010 --> 01:26:05,949
find maybe the planets that are

1992
01:26:11,280 --> 01:26:08,020
perturbing the planetesimals it will

1993
01:26:13,200 --> 01:26:11,290
also directly characterize the dust that

1994
01:26:15,060 --> 01:26:13,210
we see so some of the brightest disks

1995
01:26:18,169 --> 01:26:15,070
that we've already found with Spitzer

1996
01:26:20,790 --> 01:26:18,179
and wise and Hubble those will be

1997
01:26:23,879 --> 01:26:20,800
characterized in very fine detail with

1998
01:26:26,399 --> 01:26:23,889
James webs spectroscopic capabilities

1999
01:26:28,560 --> 01:26:26,409
either through near cam or mirrored both

2000
01:26:30,510 --> 01:26:28,570
of them have the ability to basically do

2001
01:26:33,180 --> 01:26:30,520
the same kind of fingerprinting of the

2002
01:26:35,520 --> 01:26:33,190
dust but now we're looking at the stuff

2003
01:26:37,800 --> 01:26:35,530
in orbit so if we can find a lot of

2004
01:26:39,930 --> 01:26:37,810
white dwarfs that are accreting and so

2005
01:26:41,970 --> 01:26:39,940
we have very exquisite compositions and

2006
01:26:44,280 --> 01:26:41,980
the atmospheres we can compare them to

2007
01:26:45,839 --> 01:26:44,290
the fingerprints of the dust already in

2008
01:26:47,910 --> 01:26:45,849
orbit and that tells us something about

2009
01:26:49,379 --> 01:26:47,920
how well well we understand the

2010
01:26:51,390 --> 01:26:49,389
atmospheres of the white Doris which

2011
01:26:54,359 --> 01:26:51,400
gives us that predictive power for the

2012
01:26:56,640 --> 01:26:54,369
chemistry of this dust now you're really

2013
01:26:58,950 --> 01:26:56,650

test of how well we understand those

2014
01:27:02,100 --> 01:26:58,960
physics and hopefully we'll get a

2015
01:27:03,810 --> 01:27:02,110
consistent answer but we probably won't

2016
01:27:06,720 --> 01:27:03,820
because that's the way science works we

2017
01:27:08,609 --> 01:27:06,730
never have things all figured out all

2018
01:27:12,180 --> 01:27:08,619
right we're approaching 9 30 so I got to

2019
01:27:15,149 --> 01:27:12,190
cut things off next month we have Rachel

2020
01:27:32,470 --> 01:27:15,159
Austin speaking please come and join us