1
00:00:14,570 --> 00:00:25,800
yeah we got that okay let's take the

2
00:00:18,000 --> 00:00:31,500
house lights down and we shall begin no

3
00:00:25,800 --> 00:00:33,299
need these laser pointer works okay good

4
00:00:31,500 --> 00:00:34,729
evening ladies and gentlemen and welcome

5
00:00:33,299 --> 00:00:37,949
to the space telescope science

6
00:00:34,729 --> 00:00:40,049
Institute's public lecture series it is

7
00:00:37,950 --> 00:00:41,790
by joy and pleasure to be your host i am

8
00:00:40,049 --> 00:00:44,488
dr. Frank summers of the office of

9
00:00:41,789 --> 00:00:46,350
public outreach for the gentleman who

10
00:00:44,488 --> 00:00:49,349
just came in late you didn't get a

11
00:00:46,350 --> 00:00:51,448
pretty picture yet pretty bitches are

12
00:00:49,350 --> 00:00:53,429
down there on the corner and today

13
00:00:51,448 --> 00:00:59,729
tights pretty picture is the butterfly

14
00:00:53,429 --> 00:01:02,759
nebulae also known as NGC 6302 this is a

15
00:00:59,729 --> 00:01:05,009
dying star which is of significance for

16
00:01:02,759 --> 00:01:07,798
our speakers talk tonight because he's

17
00:01:05,010 --> 00:01:10,228
talking about you talking about I'll

18
00:01:07,799 --> 00:01:12,868
just go straight to it planetary tales

19
00:01:10,228 --> 00:01:16,429
from the stellar crypt exoplanets

20
00:01:12,868 --> 00:01:19,890
surviving the death of their host star

21
00:01:16,430 --> 00:01:21,330
this is John devas who has spoken to us

22
00:01:19,890 --> 00:01:23,700
before with all sorts of interesting

23
00:01:21,329 --> 00:01:29,250
titles but I got to see John your title

24
00:01:23,700 --> 00:01:33,090
is so long that you get a small font on

25
00:01:29,250 --> 00:01:35,938
slide here next month we have Rachel

26
00:01:33,090 --> 00:01:38,070
Austin talking about why we need to

27
00:01:35,938 --> 00:01:41,489
understand stars to find the next earth

28
00:01:38,069 --> 00:01:44,008
and in May we have time Brown talking

29

00:01:41,489 --> 00:01:46,078
about on the table is analyses the

30
00:01:44,009 --> 00:01:48,060
oldest stars in the neighborhood and

31
00:01:46,078 --> 00:01:50,459
you'll see that both of them will also

32
00:01:48,060 --> 00:01:53,280
get similarly small fonts on their title

33
00:01:50,459 --> 00:01:55,199
slide but Nicole Lewis in June we

34
00:01:53,280 --> 00:01:57,329
talking about probing worlds beyond our

35
00:01:55,200 --> 00:01:58,740
solar system she'll get a little bit of

36
00:01:57,328 --> 00:02:01,949
a bigger font because she uses the

37
00:01:58,739 --> 00:02:04,199
shorter title there all right and if you

38
00:02:01,950 --> 00:02:05,439
are going to come to those talks as

39
00:02:04,200 --> 00:02:07,689
those of you

40
00:02:05,439 --> 00:02:09,728
you're found out tonight those are you

41
00:02:07,689 --> 00:02:13,060
on the web might find out if you come

42
00:02:09,729 --> 00:02:15,040
that the san martin drive south of the

43
00:02:13,060 --> 00:02:17,340

Space Telescope Science Institute will

44
00:02:15,039 --> 00:02:20,979
be closed until approximately September

45
00:02:17,340 --> 00:02:22,960
2016 if you come to visit us come to the

46
00:02:20,979 --> 00:02:25,899
auditorium you must approach from the

47
00:02:22,960 --> 00:02:28,210
north from the university parkway okay

48
00:02:25,900 --> 00:02:31,599
all the details are available at this

49
00:02:28,210 --> 00:02:33,250
web web address from Johns Hopkins but

50
00:02:31,599 --> 00:02:35,079
all you really no need to know is what's

51
00:02:33,250 --> 00:02:37,599
what's here just come come at us from

52
00:02:35,080 --> 00:02:39,610
the north all right you can find out

53
00:02:37,599 --> 00:02:44,139
information about our upcoming lectures

54
00:02:39,610 --> 00:02:45,520
on our webpage if you just put Hubble

55
00:02:44,139 --> 00:02:46,929
public talks into your favorite search

56
00:02:45,520 --> 00:02:49,570
engine you should come up with this web

57
00:02:46,930 --> 00:02:53,349
page this web page was redesigned last

58
00:02:49,569 --> 00:02:57,340
month excuse me it has links to the

59
00:02:53,349 --> 00:02:59,079
online a lot of it so that we can so

60
00:02:57,340 --> 00:03:01,330
that those of you who want to watch at

61
00:02:59,080 --> 00:03:03,730
home if you are sick and next month you

62
00:03:01,330 --> 00:03:06,820
can watch live online both on YouTube

63
00:03:03,729 --> 00:03:09,488
and on the stsci webcasting site we had

64
00:03:06,819 --> 00:03:12,430
the archives of stuff that's on youtube

65
00:03:09,489 --> 00:03:15,009
or in the stsci webcast archive we go

66
00:03:12,430 --> 00:03:17,560
all the way back to 2005 so that's like

67
00:03:15,009 --> 00:03:20,289
10 years of astronomical goodness for

68
00:03:17,560 --> 00:03:23,050
you to enjoy we also added to our

69
00:03:20,289 --> 00:03:25,509
website web page an easy way to

70
00:03:23,050 --> 00:03:28,180
subscribe to our announcements emailing

71
00:03:25,509 --> 00:03:30,399
list the one or two emails that I send

72
00:03:28,180 --> 00:03:32,770
every month reminding people of the neck

73
00:03:30,400 --> 00:03:35,650
upcoming lectures as well as telling you

74
00:03:32,770 --> 00:03:37,180
when the webcasts have been posted and

75
00:03:35,650 --> 00:03:39,760
where you can find those webcasts which

76
00:03:37,180 --> 00:03:42,090
is useful also on the right hand side

77
00:03:39,759 --> 00:03:46,149
you can see the links to the upcoming

78
00:03:42,090 --> 00:03:48,039
lectures about that email list if you

79
00:03:46,150 --> 00:03:50,650
don't want to use the easy way you want

80
00:03:48,039 --> 00:03:54,009
to do it the hard way you can buy going

81
00:03:50,650 --> 00:03:56,170
to mail list at stsci edu clicking on

82
00:03:54,009 --> 00:03:58,389
public lecture announced and providing

83
00:03:56,169 --> 00:04:00,518
your email address there or if you

84
00:03:58,389 --> 00:04:01,779
really want to be lazy just write it

85
00:04:00,519 --> 00:04:03,760
down on a piece of paper and hand it to

86

00:04:01,780 --> 00:04:05,560
me at the end of the talk okay and I'll

87
00:04:03,759 --> 00:04:08,379
make sure you get added to the email

88
00:04:05,560 --> 00:04:10,939
list if you would like to give us other

89
00:04:08,379 --> 00:04:14,150
contact us in other ways we have the

90
00:04:10,939 --> 00:04:16,100
public lecture at stsci edu comments

91
00:04:14,150 --> 00:04:18,290
questions and yet another way to sign up

92
00:04:16,100 --> 00:04:22,129
for announcements we got way too many

93
00:04:18,290 --> 00:04:23,360
ways in that right social media if you

94
00:04:22,129 --> 00:04:26,540
would like to follow us on social media

95
00:04:23,360 --> 00:04:28,400
Hubble has facebook to twitter accounts

96
00:04:26,540 --> 00:04:32,360
we're on google+ we're on pinterest and

97
00:04:28,399 --> 00:04:33,859
maybe a few more i myself have a blog

98
00:04:32,360 --> 00:04:35,540
Hubble's universe unfiltered on the

99
00:04:33,860 --> 00:04:38,240
Hubble site I'll have a new posting on

100
00:04:35,540 --> 00:04:39,620

Friday ok I don't post very often but I

101
00:04:38,240 --> 00:04:42,410
got there's a new one coming up on

102
00:04:39,620 --> 00:04:45,259
friday i'm on facebook google+ and on

103
00:04:42,410 --> 00:04:47,720
twitter but i'm only occasionally on

104
00:04:45,259 --> 00:04:50,500
those devices because social media can

105
00:04:47,720 --> 00:04:52,790
just eat up way too much of your time

106
00:04:50,500 --> 00:04:55,370
unfortunately this guy is not clear

107
00:04:52,790 --> 00:04:58,640
tonight so we will yet again not have

108
00:04:55,370 --> 00:05:00,230
observatory after the talk this is like

109
00:04:58,639 --> 00:05:02,360
three or four months in a row that we

110
00:05:00,230 --> 00:05:05,060
haven't had this I apologize I don't

111
00:05:02,360 --> 00:05:06,590
control the weather alright people may

112
00:05:05,060 --> 00:05:09,230
call me the master of the universe but I

113
00:05:06,589 --> 00:05:12,709
cannot control the weather for you so

114
00:05:09,230 --> 00:05:14,870
but if you go to maryland md dot space

115
00:05:12,709 --> 00:05:17,389
grant o RG the maryland space grant

116
00:05:14,870 --> 00:05:20,090
observatory you will find their webpage

117
00:05:17,389 --> 00:05:22,490
and their information about their open

118
00:05:20,089 --> 00:05:25,009
nights on friday nights I believe every

119
00:05:22,490 --> 00:05:26,810
Friday night that's clear again subject

120
00:05:25,009 --> 00:05:28,399
to the weather they will let you look

121
00:05:26,810 --> 00:05:30,889
through their wonderful telescope there

122
00:05:28,399 --> 00:05:33,769
ok so go to their website page and find

123
00:05:30,889 --> 00:05:36,909
out about that let's take it to our new

124
00:05:33,769 --> 00:05:41,810
summary news from the universe for march

125
00:05:36,910 --> 00:05:46,130
2016 our first story tonight when'd this

126
00:05:41,810 --> 00:05:48,649
galaxy cluster grow so big I mean every

127
00:05:46,129 --> 00:05:51,589
time my kids see their grandmothers like

128
00:05:48,649 --> 00:05:54,799
oh you've gotten so big when did this

129
00:05:51,589 --> 00:05:57,829
happen right well we astronomers do the

130
00:05:54,800 --> 00:06:01,310
same things but this time for galaxy

131
00:05:57,829 --> 00:06:02,930
clusters okay so here is a galaxy

132
00:06:01,310 --> 00:06:05,810
cluster in the nearby universe it's

133
00:06:02,930 --> 00:06:07,069
called the coma cluster okay and the

134
00:06:05,810 --> 00:06:09,050
coma cluster is one of the largest

135
00:06:07,069 --> 00:06:11,870
galaxies ocean it's got thousands of

136
00:06:09,050 --> 00:06:13,939
galaxies in it right and we have

137
00:06:11,870 --> 00:06:18,129
estimated the mass of the coma cluster

138
00:06:13,939 --> 00:06:20,300
and it's two quadrillion solar masses

139
00:06:18,129 --> 00:06:22,969
now I know some of you think I just made

140
00:06:20,300 --> 00:06:24,319
that up all right but I didn't okay it

141
00:06:22,970 --> 00:06:28,340
goes million

142
00:06:24,319 --> 00:06:30,439
billion trillion quadrillion okay and

143

00:06:28,339 --> 00:06:33,139
that math assessment here is actually

144
00:06:30,439 --> 00:06:35,480
two quadrillion all right it's two times

145
00:06:33,139 --> 00:06:37,370
ten to the fifteenth solar masses just a

146
00:06:35,480 --> 00:06:39,500
really big number but it's a number that

147
00:06:37,370 --> 00:06:41,990
I'm going to need later on and later on

148
00:06:39,500 --> 00:06:43,579
in this to it to F for comparison okay

149
00:06:41,990 --> 00:06:45,350
so two times ten to the fifteenth is

150
00:06:43,579 --> 00:06:47,899
your comparison number remember that

151
00:06:45,350 --> 00:06:49,760
we'll get back to it so as the galaxy

152
00:06:47,899 --> 00:06:56,079
cluster we're going to talk about is not

153
00:06:49,759 --> 00:06:59,659
coma it's this one called I dcs 1426 ok

154
00:06:56,079 --> 00:07:01,219
and this galaxy cluster looks kind of

155
00:06:59,660 --> 00:07:04,970
similar to coma lots and lots of

156
00:07:01,220 --> 00:07:07,400
galaxies but there's a clue when we look

157
00:07:04,970 --> 00:07:10,460

at the wavelengths in which Hubble

158
00:07:07,399 --> 00:07:13,489
observed this galaxy cluster because you

159
00:07:10,459 --> 00:07:17,180
can see the blue in this image is 606

160
00:07:13,490 --> 00:07:20,210
and 814 nanometers blue in visible light

161
00:07:17,180 --> 00:07:22,459
is actually around 400 to 450 nanometers

162
00:07:20,209 --> 00:07:26,509
right the blue in this image is actually

163
00:07:22,459 --> 00:07:30,229
read the green and the red in this image

164
00:07:26,509 --> 00:07:32,930
is actually the near-infrared so all of

165
00:07:30,230 --> 00:07:35,980
the filters use to observe this cluster

166
00:07:32,930 --> 00:07:39,439
I'll go from the red into the infrared

167
00:07:35,980 --> 00:07:43,009
why do we do that well because this is a

168
00:07:39,439 --> 00:07:44,870
high redshift cluster all right the

169
00:07:43,009 --> 00:07:47,149
galaxy is so far away that it's light

170
00:07:44,870 --> 00:07:50,149
has been red shifted from visible light

171
00:07:47,149 --> 00:07:52,159
toward the infrared light so it's better

172
00:07:50,149 --> 00:07:55,310
to see this galaxy cluster using

173
00:07:52,160 --> 00:07:58,430
infrared light okay this galaxy cluster

174
00:07:55,310 --> 00:08:02,030
is measured to be about 10 billion light

175
00:07:58,430 --> 00:08:04,310
years away okay it's 10 billion

176
00:08:02,029 --> 00:08:08,719
light-years away which means it's seen

177
00:08:04,310 --> 00:08:10,550
as it was 10 billion years ago so the

178
00:08:08,720 --> 00:08:12,830
question is all right this is about 4

179
00:08:10,550 --> 00:08:15,079
billion years after the Big Bang the

180
00:08:12,829 --> 00:08:18,639
question is how large of a galaxy

181
00:08:15,079 --> 00:08:21,740
cluster can you grow in 4 billion years

182
00:08:18,639 --> 00:08:23,180
let's find out so we're going to take

183
00:08:21,740 --> 00:08:25,040
that Hubble image and we're going to

184
00:08:23,180 --> 00:08:26,810
color it yellow all right we're going to

185
00:08:25,040 --> 00:08:28,160
do a composite image all right we're

186
00:08:26,810 --> 00:08:29,870
going to take all that that Hubble image

187
00:08:28,160 --> 00:08:31,460
and we're just going to call it visible

188
00:08:29,870 --> 00:08:33,139
even though between you and me it's

189
00:08:31,459 --> 00:08:35,840
really more infrared than visible light

190
00:08:33,139 --> 00:08:38,250
in this Hubble image okay we're going to

191
00:08:35,840 --> 00:08:40,379
use the Spitzer Space Telescope

192
00:08:38,250 --> 00:08:42,719
to observe it in deeper into the

193
00:08:40,379 --> 00:08:44,309
infrared okay Spitzer is an infrared

194
00:08:42,719 --> 00:08:45,960
telescope doesn't have the resolution of

195
00:08:44,309 --> 00:08:48,059
Hubble but it can see further into

196
00:08:45,960 --> 00:08:49,889
infrared which is better for seeing

197
00:08:48,059 --> 00:08:52,139
these higher redshift clusters in order

198
00:08:49,889 --> 00:08:54,179
to see the infrared emission from them

199
00:08:52,139 --> 00:08:56,549
and this is going to tell us a bit about

200

00:08:54,179 --> 00:08:59,069
these higher redshift galaxies but to

201
00:08:56,549 --> 00:09:01,289
really get great information about it to

202
00:08:59,070 --> 00:09:03,480
try and measure clusters of galaxies we

203
00:09:01,289 --> 00:09:06,389
want to go to the x-rays using the

204
00:09:03,480 --> 00:09:08,399
Chandra x-ray Observatory now these

205
00:09:06,389 --> 00:09:11,159
clusters of galaxies formed by the

206
00:09:08,399 --> 00:09:13,980
mergers of smaller clusters and the gas

207
00:09:11,159 --> 00:09:16,620
in between the galaxies as the clusters

208
00:09:13,980 --> 00:09:19,529
as the clusters merged together gets

209
00:09:16,620 --> 00:09:23,360
heated up heat it up until it's millions

210
00:09:19,529 --> 00:09:27,199
of degrees and glows in x-rays and

211
00:09:23,360 --> 00:09:29,279
because the energy put into that gas is

212
00:09:27,200 --> 00:09:30,720
indicative of the amount of energy of

213
00:09:29,279 --> 00:09:33,899
the kinetic energy of the galaxies

214
00:09:30,720 --> 00:09:36,120

colliding in the amount of x-ray

215
00:09:33,899 --> 00:09:39,929
emission is proportional to the amount

216
00:09:36,120 --> 00:09:42,000
of mass in the cluster okay from the

217
00:09:39,929 --> 00:09:44,159
amount of x-ray emission of the gas

218
00:09:42,000 --> 00:09:46,740
inside the cluster you could make a good

219
00:09:44,159 --> 00:09:49,199
estimate of the total amount of mass in

220
00:09:46,740 --> 00:09:51,629
the cluster all right so here's that

221
00:09:49,200 --> 00:09:55,640
composite image we were building here is

222
00:09:51,629 --> 00:09:58,200
the x-rays from Chandra and blue the

223
00:09:55,639 --> 00:10:00,360
visible flash near-infrared from Hubble

224
00:09:58,200 --> 00:10:03,330
and yellow and the infrared from Spitzer

225
00:10:00,360 --> 00:10:06,839
in red okay and this shows you the

226
00:10:03,330 --> 00:10:08,870
extent of the cluster of galaxies of the

227
00:10:06,839 --> 00:10:11,700
gas between the cluster and galaxies and

228
00:10:08,870 --> 00:10:13,529
using these we can make the estimate of

229
00:10:11,700 --> 00:10:16,890
the mass of this cluster of galaxies and

230
00:10:13,529 --> 00:10:21,600
the mass estimate is 500 trillion solar

231
00:10:16,889 --> 00:10:24,120
masses or 5 times 10 to the 14th okay

232
00:10:21,600 --> 00:10:25,560
now if you remember two times ten to the

233
00:10:24,120 --> 00:10:28,409
fifteenth was your reference number

234
00:10:25,559 --> 00:10:31,859
right this is about one-quarter the mass

235
00:10:28,409 --> 00:10:35,219
that's in the coma cluster however the

236
00:10:31,860 --> 00:10:39,600
coma cluster has had 10 billion more

237
00:10:35,220 --> 00:10:43,320
years to develop and grow that mass the

238
00:10:39,600 --> 00:10:46,649
question is can you really grow such a

239
00:10:43,320 --> 00:10:50,160
big galaxy cluster oh you know a half a

240
00:10:46,649 --> 00:10:51,480
half a quadrillion solar masses in four

241
00:10:50,159 --> 00:10:54,299
billion years

242
00:10:51,480 --> 00:10:56,850
for reference the Milky Way galaxy had

243
00:10:54,299 --> 00:10:59,219
just formed 10 billion years ago so in

244
00:10:56,850 --> 00:11:02,100
our part of the universe we just gotten

245
00:10:59,220 --> 00:11:04,199
one galaxy here we've got hundreds to

246
00:11:02,100 --> 00:11:07,019
thousands of galaxies together in the

247
00:11:04,198 --> 00:11:09,899
first four billion years obviously it

248
00:11:07,019 --> 00:11:13,528
can be done but it puts constraints on

249
00:11:09,899 --> 00:11:15,659
our hypothesis of how quickly things can

250
00:11:13,528 --> 00:11:18,659
grow in the universe and it appears that

251
00:11:15,659 --> 00:11:22,828
galaxy clusters you know they grow up so

252
00:11:18,659 --> 00:11:24,838
fast all right we can get a large galaxy

253
00:11:22,828 --> 00:11:27,120
cluster very early on in the universe

254
00:11:24,839 --> 00:11:30,930
and this is one of our Hubble press

255
00:11:27,120 --> 00:11:33,929
releases from last month all right okay

256
00:11:30,929 --> 00:11:36,479
our second story is not a Hubble story

257

00:11:33,929 --> 00:11:39,299
but it's too important to overlook a

258
00:11:36,480 --> 00:11:44,750
century later general relativity is

259
00:11:39,299 --> 00:11:47,819
still making waves all right so 1915

260
00:11:44,750 --> 00:11:51,000
Albert Einstein produces his general

261
00:11:47,820 --> 00:11:54,209
theory of relativity all right and we

262
00:11:51,000 --> 00:11:57,419
have celebrated its centennial last year

263
00:11:54,208 --> 00:12:00,419
ok now how many of you have been here to

264
00:11:57,419 --> 00:12:01,559
the public lecture series before ok how

265
00:12:00,419 --> 00:12:04,469
many of you have heard me talk about

266
00:12:01,559 --> 00:12:06,119
gravitational lensing how many of you

267
00:12:04,470 --> 00:12:09,629
have heard my three word summary of

268
00:12:06,120 --> 00:12:14,519
general relativity can anybody quote it

269
00:12:09,629 --> 00:12:17,759
back to me mass warps space or bends

270
00:12:14,519 --> 00:12:19,980
space as you said yes ok so what I've

271
00:12:17,759 --> 00:12:23,338

mostly told you about general relativity

272
00:12:19,980 --> 00:12:26,879
is described by this this image ok that

273
00:12:23,339 --> 00:12:31,019
the presence of mass puts a bend a warp

274
00:12:26,879 --> 00:12:33,299
in space ok and that light traveling

275
00:12:31,019 --> 00:12:36,659
through that warp space takes a curved

276
00:12:33,299 --> 00:12:40,429
path ok because it follows the contours

277
00:12:36,659 --> 00:12:43,110
of that curved space this is how we get

278
00:12:40,429 --> 00:12:46,169
gravitational lensing these giant

279
00:12:43,110 --> 00:12:48,990
clusters of galaxies warp space so much

280
00:12:46,169 --> 00:12:50,338
that the galaxies on the far side their

281
00:12:48,990 --> 00:12:52,709
light comes through and gums stretched

282
00:12:50,339 --> 00:12:55,800
and becomes the streaky our key things

283
00:12:52,708 --> 00:12:58,289
along here gravitational lensing ok and

284
00:12:55,799 --> 00:13:00,809
I have sometimes called this visual

285
00:12:58,289 --> 00:13:02,458
proof of general relativity because

286
00:13:00,809 --> 00:13:04,889
Newton's theory of gravity doesn't

287
00:13:02,458 --> 00:13:05,309
produce gravitational lensing Einstein's

288
00:13:04,889 --> 00:13:08,970
theory

289
00:13:05,309 --> 00:13:11,459
does however there are many other proofs

290
00:13:08,970 --> 00:13:14,240
of general relativity all right between

291
00:13:11,460 --> 00:13:17,610
the the time delays and and other things

292
00:13:14,240 --> 00:13:19,799
there is however one prediction of

293
00:13:17,610 --> 00:13:25,050
general relativity that had never been

294
00:13:19,799 --> 00:13:28,409
verified okay if you can warp space you

295
00:13:25,049 --> 00:13:30,959
can also send a ripple across space okay

296
00:13:28,409 --> 00:13:33,778
so making a warping space can actually

297
00:13:30,960 --> 00:13:38,430
send a ripple across space called

298
00:13:33,778 --> 00:13:41,610
gravitational waves okay so they set up

299
00:13:38,429 --> 00:13:43,829
detectors observatories to try and

300
00:13:41,610 --> 00:13:45,509
observe them and this is the laser

301
00:13:43,830 --> 00:13:47,850
interferometer gravitational-wave

302
00:13:45,509 --> 00:13:49,740
Observatory which everyone just calls

303
00:13:47,850 --> 00:13:52,680
LIGO because it's a lot less of a

304
00:13:49,740 --> 00:13:55,379
mouthful and in hanford washington and

305
00:13:52,679 --> 00:13:57,838
Livingston Louisiana they have two

306
00:13:55,379 --> 00:13:59,399
detectors set up I'm not going to get

307
00:13:57,839 --> 00:14:03,110
into the details of how it works but let

308
00:13:59,399 --> 00:14:06,019
me just give you the basics each arm of

309
00:14:03,110 --> 00:14:09,990
these detectors is four kilometers long

310
00:14:06,019 --> 00:14:13,500
they take a laser beam split it and send

311
00:14:09,990 --> 00:14:15,299
it down both arms and back when it comes

312
00:14:13,500 --> 00:14:18,480
back together they cause it to interfere

313
00:14:15,299 --> 00:14:23,279
with itself and in doing so they can

314

00:14:18,480 --> 00:14:24,720
measure extremely precise distances okay

315
00:14:23,279 --> 00:14:29,309
they can measure the distance along

316
00:14:24,720 --> 00:14:31,470
those arms extremely precisely now if a

317
00:14:29,309 --> 00:14:34,709
gravitational wave was coming through

318
00:14:31,470 --> 00:14:36,480
and stretching space well then one

319
00:14:34,710 --> 00:14:39,210
direction would get stretched just a

320
00:14:36,480 --> 00:14:41,850
tiny tiny bit and the other one would

321
00:14:39,210 --> 00:14:43,700
get shortened just a tiny tiny bit okay

322
00:14:41,850 --> 00:14:48,089
all right in the perpendicular direction

323
00:14:43,700 --> 00:14:50,759
so by measuring the distance deviation

324
00:14:48,089 --> 00:14:53,580
on between these two arms they could

325
00:14:50,759 --> 00:14:58,338
actually measure the idea of a

326
00:14:53,580 --> 00:15:01,709
gravitational wave going past okay so

327
00:14:58,339 --> 00:15:05,130
they measured something September 14

328
00:15:01,708 --> 00:15:09,689

2015 they got this signal which is

329
00:15:05,129 --> 00:15:12,000
dubbed GW 15 09 14 all right and it was

330
00:15:09,690 --> 00:15:13,860
measured in the hanford data shown in

331
00:15:12,000 --> 00:15:16,708
this orange color and the Livingston

332
00:15:13,860 --> 00:15:18,990
data shown in this blue color now it's

333
00:15:16,708 --> 00:15:21,359
important that you measure it in two

334
00:15:18,990 --> 00:15:23,639
replaces because a signal like this

335
00:15:21,360 --> 00:15:25,470
could be caused by you know some

336
00:15:23,639 --> 00:15:27,929
technician dropping a hammer next to the

337
00:15:25,470 --> 00:15:30,810
instrument okay all right but a hammer

338
00:15:27,929 --> 00:15:33,419
in Washington state is not going to be

339
00:15:30,809 --> 00:15:35,429
measured in Louisiana and vice versa so

340
00:15:33,419 --> 00:15:37,829
if you're measuring the same signal in

341
00:15:35,429 --> 00:15:38,939
both places that tells you hey it's

342
00:15:37,830 --> 00:15:41,250
pretty much coming from the universe

343
00:15:38,940 --> 00:15:44,790
maybe it's Thor's hammer you know or

344
00:15:41,250 --> 00:15:47,309
something like that excuse me all right

345
00:15:44,789 --> 00:15:48,809
and you can also see from this plot that

346
00:15:47,309 --> 00:15:52,109
they measured pretty much the same

347
00:15:48,809 --> 00:15:58,169
signal both in Washington State and in

348
00:15:52,110 --> 00:16:01,800
Louisiana what would it be ok well the

349
00:15:58,169 --> 00:16:05,879
hypothesis would be that it is two black

350
00:16:01,799 --> 00:16:07,769
holes merging together ok two black

351
00:16:05,879 --> 00:16:10,799
holes caught in orbit around each other

352
00:16:07,769 --> 00:16:13,049
giving off energy as they spiral in and

353
00:16:10,799 --> 00:16:16,949
then merge together to form one black

354
00:16:13,049 --> 00:16:19,939
hole right we're talking about to really

355
00:16:16,950 --> 00:16:22,740
really massive gravitational distortions

356
00:16:19,940 --> 00:16:25,470
merging together creating a

357
00:16:22,740 --> 00:16:28,709
gravitational wave big enough to be

358
00:16:25,470 --> 00:16:31,740
observed across the universe all right

359
00:16:28,708 --> 00:16:35,338
how big does it need to be well they did

360
00:16:31,740 --> 00:16:37,829
simulations and here is the hanford data

361
00:16:35,339 --> 00:16:39,690
and this yellow line going through it is

362
00:16:37,828 --> 00:16:42,179
the prediction of the simulation and

363
00:16:39,690 --> 00:16:43,680
there's the Livingston data and again

364
00:16:42,179 --> 00:16:44,789
the blue line light blue line going

365
00:16:43,679 --> 00:16:47,039
through it is prediction of that data

366
00:16:44,789 --> 00:16:49,860
and you can see how wonderfully this

367
00:16:47,039 --> 00:16:51,659
this matches so in doing the various

368
00:16:49,860 --> 00:16:53,940
Suites of simulations to try and figure

369
00:16:51,659 --> 00:16:58,559
out what this is they determined that

370
00:16:53,940 --> 00:17:01,290
it's a 36 solar mass black hole and a 29

371

00:16:58,559 --> 00:17:05,279
solar mass black hole merging together

372
00:17:01,289 --> 00:17:08,909
to form a 62 solar mass black hole and

373
00:17:05,279 --> 00:17:10,920
that would produce that signal which the

374
00:17:08,910 --> 00:17:14,429
signal that they observed in Washington

375
00:17:10,920 --> 00:17:16,769
and in Louisiana from the amplitude of

376
00:17:14,429 --> 00:17:20,120
that signal they can detect they can

377
00:17:16,769 --> 00:17:24,240
tell that the merger would have happened

378
00:17:20,119 --> 00:17:27,088
1.3 billion light-years away that's

379
00:17:24,240 --> 00:17:30,269
billion with ab e 1.3 billion so in a

380
00:17:27,088 --> 00:17:32,700
distant galaxy okay ten percent of the

381
00:17:30,269 --> 00:17:36,180
way across the observable

382
00:17:32,700 --> 00:17:40,200
and if you do the math you heard that I

383
00:17:36,180 --> 00:17:43,799
said 36 and 29 makes 62 no they don't

384
00:17:40,200 --> 00:17:47,250
there's three solar masses missing where

385
00:17:43,799 --> 00:17:50,960

did that three solar masses go into the

386
00:17:47,250 --> 00:17:54,059
fabric of space that three solar masses

387
00:17:50,960 --> 00:17:56,519
was put into the fabric of space to

388
00:17:54,059 --> 00:18:00,720
create a gravitational waves such an

389
00:17:56,519 --> 00:18:04,200
amazing event okay an amazing event that

390
00:18:00,720 --> 00:18:06,029
lasted you know less than a second

391
00:18:04,200 --> 00:18:08,009
actually about two-tenths of a second

392
00:18:06,029 --> 00:18:10,200
you can see from the graph okay well

393
00:18:08,009 --> 00:18:12,180
we'll be generous with ya we'll call it

394
00:18:10,200 --> 00:18:14,180
full two tenths of a second and they say

395
00:18:12,180 --> 00:18:16,680
I have to quote this the peak wattage

396
00:18:14,180 --> 00:18:18,420
for that tiny little fraction of a

397
00:18:16,680 --> 00:18:21,210
second was greater than the combined

398
00:18:18,420 --> 00:18:27,539
light of all the stars in the observable

399
00:18:21,210 --> 00:18:31,440
universe but still still all that energy

400
00:18:27,539 --> 00:18:35,789
going into it only stretch the fabric of

401
00:18:31,440 --> 00:18:41,070
space by one one thousandth the diameter

402
00:18:35,789 --> 00:18:44,339
of a proton that much energy what they

403
00:18:41,069 --> 00:18:46,439
measured was space being stretched by

404
00:18:44,339 --> 00:18:48,419
one one thousandth the diameter of

405
00:18:46,440 --> 00:18:50,100
proton first of all the fact that we

406
00:18:48,420 --> 00:18:53,009
could measure that is absolutely amazing

407
00:18:50,099 --> 00:18:55,759
right but so much energy to create such

408
00:18:53,009 --> 00:18:58,920
a tiny little deviation in space okay

409
00:18:55,759 --> 00:19:02,369
gravitational waves are really really

410
00:18:58,920 --> 00:19:03,840
really small okay and we talk about

411
00:19:02,369 --> 00:19:06,029
gravity being the weakest of the four

412
00:19:03,839 --> 00:19:08,039
fundamental forces here's your evidence

413
00:19:06,029 --> 00:19:10,170
that you have to destroy three solar

414
00:19:08,039 --> 00:19:13,799
masses three times the mass of the Sun

415
00:19:10,170 --> 00:19:19,289
just to stretch space by less than the

416
00:19:13,799 --> 00:19:21,960
width of a proton yes the amplitude of

417
00:19:19,289 --> 00:19:24,180
course of changes with it Goes Down Goes

418
00:19:21,960 --> 00:19:25,890
Down linearly with distance okay in this

419
00:19:24,180 --> 00:19:27,330
case I'm not exactly sure why it doesn't

420
00:19:25,890 --> 00:19:29,690
goes down linearly instead of by the

421
00:19:27,329 --> 00:19:33,779
square I couldn't figure that out today

422
00:19:29,690 --> 00:19:37,680
but i'm not i'm not a gr physicist on

423
00:19:33,779 --> 00:19:40,589
that okay so here is the paper that they

424
00:19:37,680 --> 00:19:43,140
released last month okay on the first

425
00:19:40,589 --> 00:19:45,569
observation of gravitational waves from

426
00:19:43,140 --> 00:19:46,110
a binary black hole merger first of all

427
00:19:45,569 --> 00:19:49,279
the result

428

00:19:46,109 --> 00:19:52,109
health is that black holes do merge okay

429
00:19:49,279 --> 00:19:54,178
we had thought that they would we had

430
00:19:52,109 --> 00:19:57,178
guessed that they would but there was no

431
00:19:54,179 --> 00:20:00,090
evidence for it until this paper was

432
00:19:57,179 --> 00:20:02,190
released second thing gravitational

433
00:20:00,089 --> 00:20:04,829
waves exist this is a fundamental

434
00:20:02,190 --> 00:20:06,840
prediction of general relativity that

435
00:20:04,829 --> 00:20:08,879
had never been tested before some call

436
00:20:06,839 --> 00:20:10,428
it the final prediction of general

437
00:20:08,880 --> 00:20:13,770
relativity that needed to be tested

438
00:20:10,429 --> 00:20:16,769
gravitational waves do exist the third

439
00:20:13,769 --> 00:20:18,960
thing due to the time delay between when

440
00:20:16,769 --> 00:20:20,450
it was observed in Washington and when

441
00:20:18,960 --> 00:20:22,650
it was deserved in Louisiana

442
00:20:20,450 --> 00:20:24,900

gravitational waves as predicted by

443
00:20:22,650 --> 00:20:28,380
general relativity travel at the speed

444
00:20:24,900 --> 00:20:31,080
of light there was no evidence to allow

445
00:20:28,380 --> 00:20:32,850
for any deviation from the speed of

446
00:20:31,079 --> 00:20:35,699
light for this gravitational wave

447
00:20:32,849 --> 00:20:37,529
disturbance they said it was oh I forget

448
00:20:35,700 --> 00:20:39,269
what the the number of milliseconds was

449
00:20:37,529 --> 00:20:42,410
like six milliseconds differential

450
00:20:39,269 --> 00:20:44,639
between the two sites and finally

451
00:20:42,410 --> 00:20:48,210
general relativity has been proved

452
00:20:44,640 --> 00:20:50,280
correct yet again all right so now we

453
00:20:48,210 --> 00:20:52,910
have a brand-new window on the universe

454
00:20:50,279 --> 00:20:56,399
we can observe the stretching of space

455
00:20:52,910 --> 00:20:58,650
to see these really high energy events

456
00:20:56,400 --> 00:21:00,450
and you're saying well like it was 1.3

457
00:20:58,650 --> 00:21:04,530
billion light-years away is just one

458
00:21:00,450 --> 00:21:07,048
event however LIGO wasn't even in

459
00:21:04,529 --> 00:21:09,210
production mode at the time when they

460
00:21:07,048 --> 00:21:13,548
saw this it was in its pre production

461
00:21:09,210 --> 00:21:17,130
mode okay LIGO we have the hanford and

462
00:21:13,548 --> 00:21:18,990
Livingston ones here in the US under

463
00:21:17,130 --> 00:21:21,929
construction we have Virgo in Europe on

464
00:21:18,990 --> 00:21:23,819
the Geo 600 is online LIGO India's

465
00:21:21,929 --> 00:21:27,059
planned we have CAG are coming along and

466
00:21:23,819 --> 00:21:30,659
in Japan when we get the full suite of

467
00:21:27,058 --> 00:21:31,649
them as well as the planned upgrades to

468
00:21:30,660 --> 00:21:33,330
them which will increase their

469
00:21:31,650 --> 00:21:36,840
sensitivity by another factor of ten or

470
00:21:33,329 --> 00:21:39,960
two all right we will be able to see the

471
00:21:36,839 --> 00:21:43,289
prediction is dozens to thousands of

472
00:21:39,960 --> 00:21:45,360
these events over the next decade so we

473
00:21:43,289 --> 00:21:47,668
have started I feel like this is like

474
00:21:45,359 --> 00:21:49,469
the exoplanets I think where we were in

475
00:21:47,669 --> 00:21:51,000
the 1990s with exoplanets we just saw

476
00:21:49,470 --> 00:21:52,890
the first exoplanets around start

477
00:21:51,000 --> 00:21:55,630
planets around other stars we're now

478
00:21:52,890 --> 00:21:58,720
being able to see the first of these

479
00:21:55,630 --> 00:22:00,190
really massive events black hole mergers

480
00:21:58,720 --> 00:22:02,710
we should be able to see neutron star

481
00:22:00,190 --> 00:22:05,200
neutron star mergers will be able to

482
00:22:02,710 --> 00:22:07,120
characterize them and understand what

483
00:22:05,200 --> 00:22:09,100
their prevalence is out there in the

484
00:22:07,119 --> 00:22:12,069
universe so we're at a really cool place

485

00:22:09,099 --> 00:22:13,659
and yes your answer to the question

486
00:22:12,069 --> 00:22:16,059
that's always asked this will probably

487
00:22:13,660 --> 00:22:19,180
produce a Nobel Prize maybe about 15

488
00:22:16,059 --> 00:22:21,069
years from now okay Nobel Prizes aren't

489
00:22:19,180 --> 00:22:22,600
given immediately they definitely gotta

490
00:22:21,069 --> 00:22:24,909
wait until make sure that everything

491
00:22:22,599 --> 00:22:26,889
everything everything holds together but

492
00:22:24,910 --> 00:22:29,290
yeah I can easily see this producing a

493
00:22:26,890 --> 00:22:35,220
Nobel Prize in about 15 years all right

494
00:22:29,289 --> 00:22:37,089
question well we have a small

495
00:22:35,220 --> 00:22:38,200
localization on the sky that's actually

496
00:22:37,089 --> 00:22:40,629
something I thank glad you mentioned

497
00:22:38,200 --> 00:22:43,330
that because by having more detectors

498
00:22:40,630 --> 00:22:45,190
around the world will be able to reduce

499
00:22:43,329 --> 00:22:47,379

the angular size of it there was a swath

500
00:22:45,190 --> 00:22:49,120
because I the only two we could say all

501
00:22:47,380 --> 00:22:51,700
right here's a swath of the sky because

502
00:22:49,119 --> 00:22:53,619
you're observing basically the sky above

503
00:22:51,700 --> 00:22:55,059
you when you do when you with the gender

504
00:22:53,619 --> 00:22:57,189
of a gravitational wave detector right

505
00:22:55,059 --> 00:22:59,349
and if you have them all around the

506
00:22:57,190 --> 00:23:00,940
world whoever sees it or doesn't see it

507
00:22:59,349 --> 00:23:03,099
and when they see it gives you

508
00:23:00,940 --> 00:23:05,759
triangulation all right in order to be

509
00:23:03,099 --> 00:23:09,849
able to pick a finer point on the sky

510
00:23:05,759 --> 00:23:11,950
folks have looked in the region where it

511
00:23:09,849 --> 00:23:15,009
was whereas determined it could have

512
00:23:11,950 --> 00:23:17,289
come from and nobody's found anything of

513
00:23:15,009 --> 00:23:20,109
any significance yet for that for that

514
00:23:17,289 --> 00:23:22,000
region but with more detectors online

515
00:23:20,109 --> 00:23:23,949
we'll be able to do it and now people

516
00:23:22,000 --> 00:23:25,450
will actually believe them okay if they

517
00:23:23,950 --> 00:23:26,860
set out a telegram boy we thought no

518
00:23:25,450 --> 00:23:28,360
gravitational wave go look at people

519
00:23:26,859 --> 00:23:30,579
like yeah my going to waste my telus

520
00:23:28,359 --> 00:23:31,929
telescope time on that right now they

521
00:23:30,579 --> 00:23:34,599
will believe them they will do the

522
00:23:31,930 --> 00:23:37,269
follow-up so that will be a that'll be a

523
00:23:34,599 --> 00:23:39,279
hot topic to better than that does it

524
00:23:37,269 --> 00:23:42,460
make sense to talk about frequency and

525
00:23:39,279 --> 00:23:47,319
amplitude of these gravitational waves

526
00:23:42,460 --> 00:23:49,000
or are you just a really miniscule that

527
00:23:47,319 --> 00:23:51,069
the miniscule is the amp and think that

528
00:23:49,000 --> 00:23:54,460
the amount of motion is very very small

529
00:23:51,069 --> 00:23:58,599
but the frequencies are in Hertz to two

530
00:23:54,460 --> 00:24:00,789
kilohertz okay and the detectors are

531
00:23:58,599 --> 00:24:03,549
only sensitive over a certain range of

532
00:24:00,789 --> 00:24:04,450
frequencies and that was it actually

533
00:24:03,549 --> 00:24:07,389
another

534
00:24:04,450 --> 00:24:09,220
important point was that the another

535
00:24:07,390 --> 00:24:12,250
reason why they built that they believe

536
00:24:09,220 --> 00:24:14,440
the graviton has no mass and then

537
00:24:12,250 --> 00:24:16,569
travels at the speed of light is that if

538
00:24:14,440 --> 00:24:18,130
it had massed there would be deviation

539
00:24:16,569 --> 00:24:19,629
along the frequencies the frequencies

540
00:24:18,130 --> 00:24:22,030
would arrive just slightly different

541
00:24:19,630 --> 00:24:24,400
flex slightly slightly different times

542

00:24:22,029 --> 00:24:28,960
and there was no deviation and frequency

543
00:24:24,400 --> 00:24:31,420
of scene okay all right let go and go

544
00:24:28,960 --> 00:24:35,200
down here so more gravitational waves

545
00:24:31,420 --> 00:24:37,330
the same thing is graviton no gravitons

546
00:24:35,200 --> 00:24:40,059
are the particle that would carry the

547
00:24:37,329 --> 00:24:41,740
gravitational force but the way there's

548
00:24:40,059 --> 00:24:43,929
a particle wave duality that we talk

549
00:24:41,740 --> 00:24:46,240
about like the photon is the particle

550
00:24:43,930 --> 00:24:47,799
that carries light whereas light is also

551
00:24:46,240 --> 00:24:49,870
considered an electromagnetic wave in

552
00:24:47,799 --> 00:24:52,779
the same way you have gravitational

553
00:24:49,869 --> 00:24:55,659
waves you also have a graviton to carry

554
00:24:52,779 --> 00:24:58,899
gravitational forces okay yeah it's it's

555
00:24:55,660 --> 00:25:00,519
it's this particle wave dualities it's

556
00:24:58,900 --> 00:25:03,850

fuzzy even for us professionals to do it

557
00:25:00,519 --> 00:25:06,220
okay question here Oh 600 didn't pick

558
00:25:03,849 --> 00:25:07,480
anything up as far as I know Gio 600 did

559
00:25:06,220 --> 00:25:10,779
not pick anything up it was not in the

560
00:25:07,480 --> 00:25:12,759
paper that I read one other question in

561
00:25:10,779 --> 00:25:15,220
the back oh yeah plans underway right

562
00:25:12,759 --> 00:25:17,349
now to put detectors in space so they'll

563
00:25:15,220 --> 00:25:20,920
be 3 billion miles apart and therefore

564
00:25:17,349 --> 00:25:23,049
much more accurate there is the ELISA

565
00:25:20,920 --> 00:25:26,230
project which is the laser

566
00:25:23,049 --> 00:25:27,579
interferometer or interferometry Space

567
00:25:26,230 --> 00:25:30,519
Observatory or something like that I

568
00:25:27,579 --> 00:25:31,960
don't know much about that but yes there

569
00:25:30,519 --> 00:25:33,579
are plans to try and put laser

570
00:25:31,960 --> 00:25:37,029
interferometers in space to measure

571
00:25:33,579 --> 00:25:39,429
gravitational waves from space I say I'm

572
00:25:37,029 --> 00:25:41,649
not an expert on all right don't want to

573
00:25:39,430 --> 00:25:42,880
pull up John's talk and any birth you

574
00:25:41,650 --> 00:25:45,610
get more question about gravitation

575
00:25:42,880 --> 00:25:47,550
waste come see me afterwards right now

576
00:25:45,609 --> 00:25:50,439
let me introduce our featured speaker

577
00:25:47,549 --> 00:25:52,359
john davis got his bachelor's degree

578
00:25:50,440 --> 00:25:56,190
from across the street at johns hopkins

579
00:25:52,359 --> 00:25:56,189
university give it out for John Hopkins

580
00:25:57,980 --> 00:26:04,808
or med state on a decade ago and did

581
00:26:02,119 --> 00:26:06,949
post arcs postdoc down at Carnegie

582
00:26:04,808 --> 00:26:11,089
Department of terrestrial magnetism down

583
00:26:06,950 --> 00:26:14,710
in DC they he was at Goddard Space

584
00:26:11,089 --> 00:26:16,819
Flight Center what does NPP stand for ah

585
00:26:14,710 --> 00:26:17,929
suppose doctoral programs trying to

586
00:26:16,819 --> 00:26:20,269
figure that out when you gave this to a

587
00:26:17,929 --> 00:26:22,669
dispatcher dude I've down a Goddard for

588
00:26:20,269 --> 00:26:26,089
three years and then he came up to us in

589
00:26:22,669 --> 00:26:27,590
2011 here at the Space Telescope Science

590
00:26:26,089 --> 00:26:30,409
Institute besides being a wonderful

591
00:26:27,589 --> 00:26:33,319
communicator of science he is the lead

592
00:26:30,410 --> 00:26:35,450
for the space telescope imaging

593
00:26:33,319 --> 00:26:38,710
spectrograph so ladies and gentlemen

594
00:26:35,450 --> 00:26:38,710
John Devin's

595
00:26:44,329 --> 00:26:50,849
right so we're going to have a little

596
00:26:47,670 --> 00:26:53,220
death and destruction tonight the last

597
00:26:50,849 --> 00:26:56,159
time I gave the talk I talked about a

598
00:26:53,220 --> 00:26:57,420
zombie planet around filmer hut and this

599

00:26:56,160 --> 00:26:59,490
time we're going to be talking about a

600
00:26:57,420 --> 00:27:03,180
whole bunch of dead stars and the sort

601
00:26:59,490 --> 00:27:06,470
of leftover debris that might be in

602
00:27:03,180 --> 00:27:09,840
orbit around them so when we talk about

603
00:27:06,470 --> 00:27:12,120
planets these days planets are

604
00:27:09,839 --> 00:27:14,579
everywhere it used to be whenever

605
00:27:12,119 --> 00:27:16,469
someone had an idea that some observable

606
00:27:14,579 --> 00:27:18,449
signature was due to planets people

607
00:27:16,470 --> 00:27:19,829
would kind of laugh at them because oh

608
00:27:18,450 --> 00:27:21,390
there haven't been that many planets

609
00:27:19,829 --> 00:27:24,210
found we don't know where planets exist

610
00:27:21,390 --> 00:27:25,860
that kind of thing but now we're in an

611
00:27:24,210 --> 00:27:27,720
era where we have thousands of

612
00:27:25,859 --> 00:27:31,740
exoplanets that have been discovered and

613
00:27:27,720 --> 00:27:34,860

this is a plot from EXO planet zorg just

614
00:27:31,740 --> 00:27:37,049
the other day where I took all the

615
00:27:34,859 --> 00:27:40,829
observed planets both from radial

616
00:27:37,049 --> 00:27:42,599
velocity surveys Kepler direct imaging

617
00:27:40,829 --> 00:27:44,939
and I plotted them up in a sort of a

618
00:27:42,599 --> 00:27:47,309
weird way I plotted them as a function

619
00:27:44,940 --> 00:27:50,009
of the effective temperature of the star

620
00:27:47,309 --> 00:27:53,069
that they were orbiting around their

621
00:27:50,009 --> 00:27:55,950
mass the simple size gives you the mass

622
00:27:53,069 --> 00:28:00,240
of the star and the color bar gives you

623
00:27:55,950 --> 00:28:03,779
how big the star is so most of the

624
00:28:00,240 --> 00:28:06,450
planets we have seen are around sun-like

625
00:28:03,779 --> 00:28:09,059
temperature stars they have a large

626
00:28:06,450 --> 00:28:11,220
range now in planet mass thanks to

627
00:28:09,059 --> 00:28:13,529
things like Kepler and very precise

628
00:28:11,220 --> 00:28:16,200
radial velocity surveys but we're also

629
00:28:13,529 --> 00:28:18,569
starting to probe stars of very

630
00:28:16,200 --> 00:28:20,279
different radii as well and what that's

631
00:28:18,569 --> 00:28:22,230
telling us is that we're seeing star

632
00:28:20,279 --> 00:28:24,539
we're seeing planets in orbit around

633
00:28:22,230 --> 00:28:27,390
stars of many different kinds of

634
00:28:24,539 --> 00:28:29,869
evolutionary states for Barry from

635
00:28:27,390 --> 00:28:32,310
somewhat young stars all the way up to

636
00:28:29,869 --> 00:28:33,959
giant stars which are sort of sun-like

637
00:28:32,309 --> 00:28:37,109
stars that are going through their end

638
00:28:33,960 --> 00:28:40,529
phases of life and so when I was a wee

639
00:28:37,109 --> 00:28:43,859
grad student back in the early 2000s my

640
00:28:40,529 --> 00:28:45,960
advisor talked to me and he said you

641
00:28:43,859 --> 00:28:48,209
know you should take a look and see what

642
00:28:45,960 --> 00:28:51,390
happens to a planetary system when its

643
00:28:48,210 --> 00:28:53,549
star dies and that was my fault in my

644
00:28:51,390 --> 00:28:56,430
second year of grad school and it became

645
00:28:53,549 --> 00:28:57,119
eventually my most cited paper on dead

646
00:28:56,430 --> 00:28:59,370
planet

647
00:28:57,119 --> 00:29:03,869
systems so we'll talk a little bit about

648
00:28:59,369 --> 00:29:06,929
that so the end point for most stars is

649
00:29:03,869 --> 00:29:08,629
the white dwarf white dwarfs are also

650
00:29:06,930 --> 00:29:11,730
known as gin degenerate stars

651
00:29:08,630 --> 00:29:15,780
degenerates right so not 2016

652
00:29:11,730 --> 00:29:19,019
presidential candidates but what's

653
00:29:15,779 --> 00:29:21,420
happening here is basically the star as

654
00:29:19,019 --> 00:29:24,990
it's burning it's hydrogen fusing it

655
00:29:21,420 --> 00:29:28,080
into helium it's creating this core of

656

00:29:24,990 --> 00:29:30,390
fusion ash at it's at the center of the

657
00:29:28,079 --> 00:29:33,750
star and over time it exhausts all

658
00:29:30,390 --> 00:29:36,300
that's heal hydrogen and it puffs up to

659
00:29:33,750 --> 00:29:38,910
a giant and eventually starts burning

660
00:29:36,299 --> 00:29:41,849
helium into carbon and other things and

661
00:29:38,910 --> 00:29:44,640
eventually that runs out and it puffs

662
00:29:41,849 --> 00:29:47,369
again into a bigger giant and eventually

663
00:29:44,640 --> 00:29:48,929
loses most of its mass about a half if

664
00:29:47,369 --> 00:29:51,389
we're talking about a solar type star

665
00:29:48,929 --> 00:29:53,100
and so you're left with this sort of

666
00:29:51,390 --> 00:29:55,620
corpse of the star called a white dwarf

667
00:29:53,099 --> 00:29:59,219
which is basically just the degenerate

668
00:29:55,619 --> 00:30:02,279
core of that star and it's so dense that

669
00:29:59,220 --> 00:30:04,170
the electrons are sort of bouncing

670
00:30:02,279 --> 00:30:06,450

together and they're providing the

671
00:30:04,170 --> 00:30:08,940
pressure support against the gravity of

672
00:30:06,450 --> 00:30:11,039
the mass so a typical white dwarf is

673
00:30:08,940 --> 00:30:13,110
about six-tenths of the solar mass and

674
00:30:11,039 --> 00:30:15,389
its radius is similar to that of the

675
00:30:13,109 --> 00:30:17,490
earth so these are very dense objects

676
00:30:15,390 --> 00:30:20,190
they're the endpoint to stellar

677
00:30:17,490 --> 00:30:23,099
evolution for any kind of star that's

678
00:30:20,190 --> 00:30:24,870
not going to explode and for the longest

679
00:30:23,099 --> 00:30:27,629
time people thought that this process

680
00:30:24,869 --> 00:30:30,149
losing more than half of its mass during

681
00:30:27,630 --> 00:30:32,000
this evolution from being a normal star

682
00:30:30,150 --> 00:30:34,920
to a giant eventually to a white dwarf

683
00:30:32,000 --> 00:30:35,970
meant that any planetary system that

684
00:30:34,920 --> 00:30:38,279
must be around it must be destroyed

685
00:30:35,970 --> 00:30:40,230
instantly from this process if you do

686
00:30:38,279 --> 00:30:42,960
sort of a simple gravitational

687
00:30:40,230 --> 00:30:45,179
calculation you think okay if I suddenly

688
00:30:42,960 --> 00:30:47,220
remove half the mass from a star all

689
00:30:45,179 --> 00:30:48,809
your planet's just go flying out right

690
00:30:47,220 --> 00:30:51,660
because they suddenly have way too much

691
00:30:48,808 --> 00:30:53,509
energy for the gravity of the star but

692
00:30:51,660 --> 00:30:56,490
it turns out that's not what's happening

693
00:30:53,509 --> 00:30:58,230
and then I'll just point out and i'll

694
00:30:56,490 --> 00:31:00,299
get to more of that story later but i'll

695
00:30:58,230 --> 00:31:03,539
just point out if you just take a census

696
00:31:00,299 --> 00:31:05,639
of the the nearest 10 parsecs or 32

697
00:31:03,539 --> 00:31:07,289
light-years we have you know sort of

698
00:31:05,640 --> 00:31:10,020
estimates for the numbers of different

699
00:31:07,289 --> 00:31:11,220
exoplanets and m dwarfs brown dwarfs all

700
00:31:10,019 --> 00:31:14,429
the way up to a star

701
00:31:11,220 --> 00:31:16,350
ours and it unfortunately they didn't

702
00:31:14,429 --> 00:31:20,250
include white dwarfs my favorite star

703
00:31:16,349 --> 00:31:23,579
but white dwarfs are about as numerous

704
00:31:20,250 --> 00:31:24,990
in local space as sun-like stars so you

705
00:31:23,579 --> 00:31:26,579
just want to keep that in the back your

706
00:31:24,990 --> 00:31:29,579
head and I'll get back to that by the

707
00:31:26,579 --> 00:31:31,649
end of our talk okay so we can do a

708
00:31:29,579 --> 00:31:33,329
thought experiment about what happens to

709
00:31:31,650 --> 00:31:35,280
planetary systems by thinking about our

710
00:31:33,329 --> 00:31:36,599
own solar system now we're definitely in

711
00:31:35,279 --> 00:31:38,069
an age where we shouldn't only be

712
00:31:36,599 --> 00:31:41,668
thinking of our solar system as a

713

00:31:38,069 --> 00:31:43,558
prototypical or archetypal planetary

714
00:31:41,669 --> 00:31:45,419
system but the solar system is always a

715
00:31:43,558 --> 00:31:47,129
good place to start right we shouldn't

716
00:31:45,419 --> 00:31:49,049
be limited by what our solar system

717
00:31:47,130 --> 00:31:50,460
tells us but it's always a good place to

718
00:31:49,048 --> 00:31:52,019
do thought experiments and stuff like

719
00:31:50,460 --> 00:31:55,409
that so if we have a little picture of

720
00:31:52,019 --> 00:31:57,960
the sort of inner solar system including

721
00:31:55,409 --> 00:31:59,880
Jupiter and Saturn our asteroid belt and

722
00:31:57,960 --> 00:32:01,409
then all the terrestrial planets we're

723
00:31:59,880 --> 00:32:05,370
sitting here four and a half billion

724
00:32:01,409 --> 00:32:07,350
years don't argue with me about that and

725
00:32:05,369 --> 00:32:10,319
and we're in it you know we're in a nice

726
00:32:07,349 --> 00:32:12,658
stable kind of happy place nothing's

727
00:32:10,319 --> 00:32:14,788

going to happen for a while I do have to

728
00:32:12,659 --> 00:32:18,090
say unfortunately in a billion years

729
00:32:14,788 --> 00:32:20,400
we're hosed that's when the Sun due to

730
00:32:18,089 --> 00:32:21,509
its fusion keeps getting a little bit

731
00:32:20,400 --> 00:32:24,150
hotter a little bit hotter and we'll

732
00:32:21,509 --> 00:32:26,129
have runaway greenhouse gas effect you

733
00:32:24,150 --> 00:32:30,179
know global warming on a much more

734
00:32:26,130 --> 00:32:33,390
severe scale okay so that's fine about

735
00:32:30,179 --> 00:32:35,580
maybe there and then eventually we're

736
00:32:33,390 --> 00:32:39,390
going to be in the red giant phase right

737
00:32:35,579 --> 00:32:42,449
our son is going to puff up i also have

738
00:32:39,390 --> 00:32:44,490
bad news if the heat doesn't get us the

739
00:32:42,450 --> 00:32:48,319
stellar surface will because it's going

740
00:32:44,490 --> 00:32:50,909
to puff up to the to greater than an au

741
00:32:48,319 --> 00:32:53,009
and a couple things are happening right

742
00:32:50,909 --> 00:32:54,780
it's so big it has thi it's really

743
00:32:53,009 --> 00:32:58,288
strong tide so anything close to the

744
00:32:54,779 --> 00:32:59,970
star gets eaten and once we once it goes

745
00:32:58,288 --> 00:33:03,509
in the stellar envelope we think that's

746
00:32:59,970 --> 00:33:06,750
pretty much the end but Mars seems to

747
00:33:03,509 --> 00:33:08,879
survive this process maybe and part of

748
00:33:06,750 --> 00:33:11,069
the asteroid belt might survive and I'll

749
00:33:08,880 --> 00:33:12,870
go more into that later and Jupiter's

750
00:33:11,069 --> 00:33:14,788
all the way out here now by this point

751
00:33:12,869 --> 00:33:17,428
the Sun actually hasn't lost a whole lot

752
00:33:14,788 --> 00:33:21,240
of mass maybe a tenth or two tenths of a

753
00:33:17,429 --> 00:33:23,000
solar mass so you'll notice if we go

754
00:33:21,240 --> 00:33:25,819
back if I can figure out yeah

755
00:33:23,000 --> 00:33:28,849
hey that worked where's Jupiter is it in

756
00:33:25,819 --> 00:33:30,679
the same place no it's getting a little

757
00:33:28,849 --> 00:33:33,589
bigger it's further out so what's

758
00:33:30,680 --> 00:33:37,009
happening here is the star is losing

759
00:33:33,589 --> 00:33:40,250
mass but its losing mass pretty slowly

760
00:33:37,009 --> 00:33:41,569
so that the orbit is not perturbed vary

761
00:33:40,250 --> 00:33:44,000
greatly we call this an adiabatic

762
00:33:41,569 --> 00:33:47,329
process this is like boiling the Frog

763
00:33:44,000 --> 00:33:50,509
you put the frog in the pot you slowly

764
00:33:47,329 --> 00:33:52,159
turn up the heat frogs fine slowly turn

765
00:33:50,509 --> 00:33:54,349
up the heat a little more frogs still

766
00:33:52,160 --> 00:33:57,230
fine then you keep going until suddenly

767
00:33:54,349 --> 00:33:59,869
the fog is dead right so we're basically

768
00:33:57,230 --> 00:34:01,640
boiling the frog with Jupiter here it

769
00:33:59,869 --> 00:34:04,459
doesn't really care that the Sun is

770

00:34:01,640 --> 00:34:07,070
losing mass its orbit to conserve

771
00:34:04,460 --> 00:34:09,320
angular momentum just slowly expands a

772
00:34:07,069 --> 00:34:11,690
little bit and it expands by a

773
00:34:09,320 --> 00:34:14,929
predictable amount so if the Sun has

774
00:34:11,690 --> 00:34:18,079
lost two you know it has eighty percent

775
00:34:14,929 --> 00:34:19,668
of its mass jupiter has moved to an

776
00:34:18,079 --> 00:34:22,579
orbital separation that's one over

777
00:34:19,668 --> 00:34:24,440
eighty percent right a little over one

778
00:34:22,579 --> 00:34:29,449
point whatever i can't do math in front

779
00:34:24,440 --> 00:34:32,809
of people anyway eventually the star

780
00:34:29,449 --> 00:34:35,599
loses mass a bit more quickly and we're

781
00:34:32,809 --> 00:34:37,878
left with the remnant white dwarf but it

782
00:34:35,599 --> 00:34:41,898
hasn't lost still has not lost mass too

783
00:34:37,878 --> 00:34:44,210
quickly for the orbits not to react to

784
00:34:41,898 --> 00:34:46,609

it and the other thing that i want you

785
00:34:44,210 --> 00:34:48,559
to remember is that now we have instead

786
00:34:46,610 --> 00:34:51,378
of a solar mass we have like a half four

787
00:34:48,559 --> 00:34:53,360
of six tenths of a solar mass object at

788
00:34:51,378 --> 00:34:55,250
the center of this planetary system that

789
00:34:53,360 --> 00:34:57,019
for all intents and purposes i'm going

790
00:34:55,250 --> 00:35:00,199
to claim to you survives and then i will

791
00:34:57,019 --> 00:35:03,320
prove it to you in some way later but

792
00:35:00,199 --> 00:35:07,579
basically everything now is much more

793
00:35:03,320 --> 00:35:09,500
powerful right so in dynamics we often

794
00:35:07,579 --> 00:35:13,759
care about the mass ratio between a

795
00:35:09,500 --> 00:35:17,059
planet and its central object ok so when

796
00:35:13,760 --> 00:35:20,180
jupiter tugs on anything we think about

797
00:35:17,059 --> 00:35:23,000
how much that happens by the ratio of

798
00:35:20,179 --> 00:35:25,669
Jupiter's mass to the central mass so

799
00:35:23,000 --> 00:35:28,909
now the central mass has gotten smaller

800
00:35:25,670 --> 00:35:31,490
Jupiter is already kind of a beefy fella

801
00:35:28,909 --> 00:35:32,989
he's now even more beefy with gravity

802
00:35:31,489 --> 00:35:36,089
because he's more of an influential

803
00:35:32,989 --> 00:35:37,769
player in this gravitational system

804
00:35:36,090 --> 00:35:41,880
that will become important later but

805
00:35:37,769 --> 00:35:44,099
again not right now okay so now a little

806
00:35:41,880 --> 00:35:47,309
detour so five years after Einstein

807
00:35:44,099 --> 00:35:49,799
predicted gravitational waves van Manon

808
00:35:47,309 --> 00:35:53,369
was at the Mount Wilson Observatory and

809
00:35:49,800 --> 00:35:56,370
he found a curious faint star and he

810
00:35:53,369 --> 00:35:58,739
noted when he took the spectrum this is

811
00:35:56,369 --> 00:36:01,769
by far the faintest f-type star known at

812
00:35:58,739 --> 00:36:05,699
the present time so what he had actually

813
00:36:01,769 --> 00:36:08,429
seen was not an F star this is a modern

814
00:36:05,699 --> 00:36:11,730
spectrum of van maanen star it still

815
00:36:08,429 --> 00:36:13,679
carries his name to this day but it was

816
00:36:11,730 --> 00:36:15,539
very unusual because he was able to

817
00:36:13,679 --> 00:36:18,419
measure the parallax the star and found

818
00:36:15,539 --> 00:36:21,000
that it was very close to Earth so given

819
00:36:18,420 --> 00:36:24,300
that it was faint in visual magnitudes

820
00:36:21,000 --> 00:36:27,230
and close by and moving very fast on the

821
00:36:24,300 --> 00:36:30,030
sky you could tell that it was a very

822
00:36:27,230 --> 00:36:33,300
intrinsically faint star not just

823
00:36:30,030 --> 00:36:36,810
visually faint so this was the first ish

824
00:36:33,300 --> 00:36:39,030
discovery of a white dwarf and in on top

825
00:36:36,809 --> 00:36:41,250
of it it wasn't even a typical white

826
00:36:39,030 --> 00:36:43,740
dwarf it looked like an f star because

827

00:36:41,250 --> 00:36:46,110
it had these metal lines present you

828
00:36:43,739 --> 00:36:47,579
know if you look at a solar type stars

829
00:36:46,110 --> 00:36:50,099
they have lots of metal lines from

830
00:36:47,579 --> 00:36:53,789
different atomic elements and here we

831
00:36:50,099 --> 00:36:57,569
have calcium these very strong lines or

832
00:36:53,789 --> 00:36:59,969
calcium in fact the H&K lines so it

833
00:36:57,570 --> 00:37:02,850
looked weird and it was faint and within

834
00:36:59,969 --> 00:37:04,980
a few years people realized that these

835
00:37:02,849 --> 00:37:08,009
were intrinsically faint stars about a

836
00:37:04,980 --> 00:37:11,159
10,000th the luminosity of the sun and

837
00:37:08,010 --> 00:37:14,130
that these must be unusual stars then

838
00:37:11,159 --> 00:37:16,019
they called them white dwarfs and and

839
00:37:14,130 --> 00:37:18,180
now we know what they are they are the

840
00:37:16,019 --> 00:37:19,860
dead corpses of stars but they didn't

841
00:37:18,179 --> 00:37:22,669

know that bend and they didn't know why

842
00:37:19,860 --> 00:37:25,530
there were metal lines and it turns out

843
00:37:22,670 --> 00:37:28,320
you wouldn't expect to see metal lines

844
00:37:25,530 --> 00:37:31,140
in most white dwarfs and that's because

845
00:37:28,320 --> 00:37:33,090
they're very dense so what happens with

846
00:37:31,139 --> 00:37:35,069
a white dwarf is you have this core of

847
00:37:33,090 --> 00:37:37,289
carbon and oxygen and then you have a

848
00:37:35,070 --> 00:37:41,130
very thin layer of either hydrogen or

849
00:37:37,289 --> 00:37:43,139
helium very low-density gas and if you

850
00:37:41,130 --> 00:37:45,809
have any kind of metals in this very

851
00:37:43,139 --> 00:37:49,799
thin atmosphere they get pulled to the

852
00:37:45,809 --> 00:37:51,420
center of the star out of sight so

853
00:37:49,800 --> 00:37:53,610
it fair in a very short time much

854
00:37:51,420 --> 00:37:57,389
shorter than the time we would be able

855
00:37:53,610 --> 00:37:59,700
to actually observe these things these

856
00:37:57,389 --> 00:38:00,809
metals in whatever remnant metals might

857
00:37:59,699 --> 00:38:02,279
be present in the atmosphere would

858
00:38:00,809 --> 00:38:06,059
disappear so you would only expect to

859
00:38:02,280 --> 00:38:09,000
see pure hydrogen or pure helium white

860
00:38:06,059 --> 00:38:10,889
dwarfs or if you had no thin layer of

861
00:38:09,000 --> 00:38:12,539
hydrogen or helium or there was some

862
00:38:10,889 --> 00:38:14,730
sort of convective process you might

863
00:38:12,539 --> 00:38:16,559
also get carbon but those were the only

864
00:38:14,730 --> 00:38:19,889
three elements you might expect to see

865
00:38:16,559 --> 00:38:23,009
so it's actually a puzzle why you might

866
00:38:19,889 --> 00:38:24,869
have metals in these atmospheres so for

867
00:38:23,010 --> 00:38:26,370
the longest time people thought the

868
00:38:24,869 --> 00:38:28,289
metals came from the interstellar medium

869
00:38:26,369 --> 00:38:31,259
you know where the interstellar medium

870
00:38:28,289 --> 00:38:34,380
the stuff between the stars is not empty

871
00:38:31,260 --> 00:38:36,690
there's dust and gas and other things so

872
00:38:34,380 --> 00:38:38,970
it's you have a white dwarf plowing

873
00:38:36,690 --> 00:38:41,400
through space it will pick up some of

874
00:38:38,969 --> 00:38:43,319
this materials is it ah that must be why

875
00:38:41,400 --> 00:38:47,599
you see metals they're just picking up

876
00:38:43,320 --> 00:38:51,059
dust from the interstellar medium 1919

877
00:38:47,599 --> 00:38:52,500
the 50s 60s and 70s was when people came

878
00:38:51,059 --> 00:38:56,579
up with the idea that the interstellar

879
00:38:52,500 --> 00:39:01,019
medium was accreting stuff and then 1987

880
00:38:56,579 --> 00:39:06,480
happened and something unusual was found

881
00:39:01,019 --> 00:39:09,150
so two men Erik beclan and Ben Zuckerman

882
00:39:06,480 --> 00:39:10,829
at UCLA we're doing an interesting study

883
00:39:09,150 --> 00:39:13,050
they were looking for brown dwarfs and

884

00:39:10,829 --> 00:39:16,019
in 1987 no one had seen a brown dwarf

885
00:39:13,050 --> 00:39:18,120
before and they thought quite rightly

886
00:39:16,019 --> 00:39:20,519
that it would be easy to find brown

887
00:39:18,119 --> 00:39:22,109
dwarfs or in orbit around white dwarfs

888
00:39:20,519 --> 00:39:25,440
because white dwarfs are intrinsically

889
00:39:22,110 --> 00:39:27,000
faint and so faint brown dwarfs are easy

890
00:39:25,440 --> 00:39:28,559
to find especially if you look in the

891
00:39:27,000 --> 00:39:30,570
near infrared at sort of the same

892
00:39:28,559 --> 00:39:32,610
wavelengths that Frank was putting up

893
00:39:30,570 --> 00:39:34,800
for that galaxy cluster so what they did

894
00:39:32,610 --> 00:39:36,240
is they were looking at a whole bunch of

895
00:39:34,800 --> 00:39:38,970
white dwarfs looking for brown dwarfs

896
00:39:36,239 --> 00:39:41,819
and they made a discovery they said we

897
00:39:38,969 --> 00:39:44,219
found a brown dwarf yay and so they you

898
00:39:41,820 --> 00:39:46,019

know if you took a you know measurement

899
00:39:44,219 --> 00:39:48,949
of the brightness of the white dwarf at

900
00:39:46,019 --> 00:39:51,119
different wavelengths so this is flux

901
00:39:48,949 --> 00:39:53,009
excuse me in wavelength as you get to

902
00:39:51,119 --> 00:39:57,359
longer wavelengths this is the white

903
00:39:53,010 --> 00:39:58,680
dwarf it's flux goes down and when you

904
00:39:57,360 --> 00:40:02,640
actually observe this particular

905
00:39:58,679 --> 00:40:03,629
pulsating white dwarf gee 2938 it does

906
00:40:02,639 --> 00:40:05,690
not go down

907
00:40:03,630 --> 00:40:08,849
as you would expect it gets brighter

908
00:40:05,690 --> 00:40:12,420
this is unusual so what's happening is

909
00:40:08,849 --> 00:40:14,219
that there's an extra cool source of

910
00:40:12,420 --> 00:40:16,170
light in the system that's unresolved

911
00:40:14,219 --> 00:40:19,409
this is called a spectral energy

912
00:40:16,170 --> 00:40:20,789
distribution so when era beclin and

913
00:40:19,409 --> 00:40:22,920
Zuckerman first did it they only had a

914
00:40:20,789 --> 00:40:24,960
couple of photometric points and they

915
00:40:22,920 --> 00:40:26,909
said we think we have a brown dwarf but

916
00:40:24,960 --> 00:40:29,159
it could be dust could be some other

917
00:40:26,909 --> 00:40:32,250
things well it turns out this is dust

918
00:40:29,159 --> 00:40:37,079
there's dust in orbit around white

919
00:40:32,250 --> 00:40:38,699
dwarfs so that's already weird and uh it

920
00:40:37,079 --> 00:40:40,710
kind of you know there was this great

921
00:40:38,699 --> 00:40:42,299
paper in 1990 just a few years after

922
00:40:40,710 --> 00:40:44,309
this was discovered some people thought

923
00:40:42,300 --> 00:40:45,720
this was a black hole some people

924
00:40:44,309 --> 00:40:48,389
thought this was a pulsating neutron

925
00:40:45,719 --> 00:40:51,149
star they had no idea it was weird but

926
00:40:48,389 --> 00:40:52,710
they decided in the end the best

927
00:40:51,150 --> 00:40:55,170
explanation was that it was probably

928
00:40:52,710 --> 00:40:57,659
dust right it was too bright to be a

929
00:40:55,170 --> 00:40:59,940
brown dwarf in the end and brown dwarfs

930
00:40:57,659 --> 00:41:02,099
were eventually discovered now you can

931
00:40:59,940 --> 00:41:05,099
sort of make a model of the dust disk

932
00:41:02,099 --> 00:41:08,489
that must be around it and you can just

933
00:41:05,099 --> 00:41:11,579
assume a very thin flat disk that's

934
00:41:08,489 --> 00:41:14,009
passive Leary radiating the light from

935
00:41:11,579 --> 00:41:15,900
the white dwarf and when you do that you

936
00:41:14,010 --> 00:41:18,900
infer that this dust is between ten

937
00:41:15,900 --> 00:41:21,570
white door for a TI and 30 white door

938
00:41:18,900 --> 00:41:24,000
for a DI now if you remember a white

939
00:41:21,570 --> 00:41:26,930
dwarf radius is about the same radius as

940
00:41:24,000 --> 00:41:30,750
the earth so that's not very big and

941

00:41:26,929 --> 00:41:33,599
this is a massive six-tenths of a solar

942
00:41:30,750 --> 00:41:35,519
mass star so the orbit the orbital

943
00:41:33,599 --> 00:41:37,589
velocity here is several hundred

944
00:41:35,519 --> 00:41:39,840
kilometers per second we're starting to

945
00:41:37,590 --> 00:41:42,539
get to an appreciable fraction of the

946
00:41:39,840 --> 00:41:45,570
speed of light at these velocities so

947
00:41:42,539 --> 00:41:49,619
you have dust nearly at the edge of a

948
00:41:45,570 --> 00:41:51,390
white dwarf surface whipping around okay

949
00:41:49,619 --> 00:41:53,880
how do you get dust well you get dust

950
00:41:51,389 --> 00:41:57,900
from planetesimals maybe that's what

951
00:41:53,880 --> 00:42:04,829
James Graham postulated okay and there

952
00:41:57,900 --> 00:42:07,200
it stood for 10 12 years and not much

953
00:42:04,829 --> 00:42:10,590
else was done it was an oddity it was

954
00:42:07,199 --> 00:42:12,239
just one so you can nature's weird it

955
00:42:10,590 --> 00:42:14,039

always makes weird things you can

956
00:42:12,239 --> 00:42:16,799
explain one thing very easily and then

957
00:42:14,039 --> 00:42:17,400
forget about it and mainly we've forgot

958
00:42:16,800 --> 00:42:19,110
about it

959
00:42:17,400 --> 00:42:21,329
because you know there wasn't a lot of

960
00:42:19,110 --> 00:42:23,880
mid-infrared observing going on you know

961
00:42:21,329 --> 00:42:26,429
five to ten microns is very hard to do

962
00:42:23,880 --> 00:42:29,700
from the ground and so there it stayed

963
00:42:26,429 --> 00:42:31,949
until Spitzer was launched and then

964
00:42:29,699 --> 00:42:34,559
suddenly we had the whole sky in the

965
00:42:31,949 --> 00:42:37,619
infrared to look at at with very fine

966
00:42:34,559 --> 00:42:39,509
detail and with very fine sensitivity

967
00:42:37,619 --> 00:42:41,429
and that's when a whole bunch more of

968
00:42:39,510 --> 00:42:43,410
these dusty white dwarfs were discovered

969
00:42:41,429 --> 00:42:45,419
furthermore they were discovered not

970
00:42:43,409 --> 00:42:46,829
only to have dust but when you took a

971
00:42:45,420 --> 00:42:48,780
spectrum of the white door if you would

972
00:42:46,829 --> 00:42:50,909
see metal lines and its atmosphere and

973
00:42:48,780 --> 00:42:53,160
if you thought van man and star was

974
00:42:50,909 --> 00:42:54,629
weird these wide or sir even weirder

975
00:42:53,159 --> 00:42:56,940
because a lot of them had only pure

976
00:42:54,630 --> 00:42:59,760
hydrogen atmospheres and they were warm

977
00:42:56,940 --> 00:43:02,190
pretty hot white dwarfs so the settling

978
00:42:59,760 --> 00:43:05,100
time if you dropped a bunch of metals

979
00:43:02,190 --> 00:43:06,840
into the atmosphere the metals would

980
00:43:05,099 --> 00:43:10,110
completely disappear within a couple of

981
00:43:06,840 --> 00:43:12,090
days so the fact that you even see metal

982
00:43:10,110 --> 00:43:13,620
lines in these white dwarfs meant that

983
00:43:12,090 --> 00:43:17,250
they were accreting an appreciable

984
00:43:13,619 --> 00:43:19,409
amount of material constantly not just

985
00:43:17,250 --> 00:43:25,199
over a billion years or something but

986
00:43:19,409 --> 00:43:27,509
that minute okay so keep that in your

987
00:43:25,199 --> 00:43:29,399
mind with the other things I think I've

988
00:43:27,510 --> 00:43:30,600
got more than six things in your mind so

989
00:43:29,400 --> 00:43:33,269
you've probably forgotten half of them

990
00:43:30,599 --> 00:43:35,929
but that's okay i will remind you in any

991
00:43:33,269 --> 00:43:38,519
case if we go back to the structure idea

992
00:43:35,929 --> 00:43:40,230
we can think about maybe a little bit

993
00:43:38,519 --> 00:43:42,269
more about what might be causing these

994
00:43:40,230 --> 00:43:45,139
strange dust rings and why this might

995
00:43:42,269 --> 00:43:47,639
have a connection to planetary systems

996
00:43:45,139 --> 00:43:49,859
so you have your white dwarf and you

997
00:43:47,639 --> 00:43:52,679
assume that you don't get dust closer

998

00:43:49,860 --> 00:43:54,990
than where dust turns into gas seems

999
00:43:52,679 --> 00:43:57,449
like a reasonable assumption and you say

1000
00:43:54,989 --> 00:43:59,279
okay how far out do they extend they

1001
00:43:57,449 --> 00:44:01,230
tend to extend not too far out and

1002
00:43:59,280 --> 00:44:03,210
certainly well within what is known as

1003
00:44:01,230 --> 00:44:07,110
the title disruption radius of the white

1004
00:44:03,210 --> 00:44:09,329
dwarf so if we put a planet were you

1005
00:44:07,110 --> 00:44:11,820
know anything very large here it gets

1006
00:44:09,329 --> 00:44:15,900
shredded apart and turned into little

1007
00:44:11,820 --> 00:44:17,940
bits and so basically the dust lives

1008
00:44:15,900 --> 00:44:19,800
within a zone where anything that might

1009
00:44:17,940 --> 00:44:23,159
stray in that zone would get toward up

1010
00:44:19,800 --> 00:44:25,050
to little bits you can have different

1011
00:44:23,159 --> 00:44:27,329
flavors of your model because this

1012
00:44:25,050 --> 00:44:29,940

explains more technical details like why

1013
00:44:27,329 --> 00:44:31,380
you see may be additional emission lines

1014
00:44:29,940 --> 00:44:33,179
like this this

1015
00:44:31,380 --> 00:44:35,150
is due to silicates this is how we know

1016
00:44:33,179 --> 00:44:38,219
it's really dust and not something else

1017
00:44:35,150 --> 00:44:40,740
because there's a very strong silicon

1018
00:44:38,219 --> 00:44:44,250
emission feature it's a smoking gun for

1019
00:44:40,739 --> 00:44:47,818
dust and it rocky dust not anything

1020
00:44:44,250 --> 00:44:51,298
weird and now in the era of Spitzer and

1021
00:44:47,818 --> 00:44:54,449
then the wise survey we have dozens now

1022
00:44:51,298 --> 00:44:57,509
of dust rings around white dwarfs and

1023
00:44:54,449 --> 00:45:00,899
all the dust rings are about within a

1024
00:44:57,509 --> 00:45:05,210
solar radius or you know a little bit

1025
00:45:00,900 --> 00:45:09,778
larger than Saturn's rings so there's

1026
00:45:05,210 --> 00:45:12,000
rocks shredding up somehow and draining

1027
00:45:09,778 --> 00:45:15,150
onto their white dwarf surfaces leaving

1028
00:45:12,000 --> 00:45:18,630
telltale fingerprints of the material

1029
00:45:15,150 --> 00:45:21,539
that they are made of so already that is

1030
00:45:18,630 --> 00:45:23,880
super cool this is why I stayed in

1031
00:45:21,539 --> 00:45:26,940
astronomy because my second year project

1032
00:45:23,880 --> 00:45:29,068
told me about crazy stars that should

1033
00:45:26,940 --> 00:45:30,960
have nothing around them having really

1034
00:45:29,068 --> 00:45:33,298
cool things around them shredding up and

1035
00:45:30,960 --> 00:45:38,298
doing weird things so that's it I was

1036
00:45:33,298 --> 00:45:40,349
hooked and so over the next 10 15 years

1037
00:45:38,298 --> 00:45:42,449
we tried to come up with explanations

1038
00:45:40,349 --> 00:45:44,759
for why this might be happening and and

1039
00:45:42,449 --> 00:45:47,338
learn more about what this dust actually

1040
00:45:44,759 --> 00:45:48,568
was so we took spectra of white dwarfs

1041
00:45:47,338 --> 00:45:50,670
we looked at the white doors in the

1042
00:45:48,568 --> 00:45:53,429
infrared we tried to gain populations to

1043
00:45:50,670 --> 00:45:56,009
understand what was going on etc etc and

1044
00:45:53,429 --> 00:45:57,989
you know we came up with complicated

1045
00:45:56,009 --> 00:46:01,380
theories for how the discs evolve with

1046
00:45:57,989 --> 00:46:04,078
time this is more for the scientist but

1047
00:46:01,380 --> 00:46:05,940
basically we think there's dust the dust

1048
00:46:04,079 --> 00:46:08,039
goes beyond the sublimation it turns

1049
00:46:05,940 --> 00:46:09,869
into gas it creats onto the white dwarf

1050
00:46:08,039 --> 00:46:11,579
that's why you get the metals some of

1051
00:46:09,869 --> 00:46:13,769
the gas goes out back so you have sort

1052
00:46:11,579 --> 00:46:17,630
of a mixture of gas and dust maybe you

1053
00:46:13,768 --> 00:46:20,219
can see this gas and in fact you can so

1054
00:46:17,630 --> 00:46:22,890
while people were taking spectra of

1055

00:46:20,219 --> 00:46:25,528
white dwarfs to look for the metal lines

1056
00:46:22,889 --> 00:46:28,139
they also discovered hey there's these

1057
00:46:25,528 --> 00:46:31,199
weird emission lines at 8,500 this is

1058
00:46:28,139 --> 00:46:32,848
again calcium but now in a mission so if

1059
00:46:31,199 --> 00:46:34,858
you have calcium and emission that means

1060
00:46:32,849 --> 00:46:36,838
you've got gas that's glowing hotter

1061
00:46:34,858 --> 00:46:39,598
than the star at these wavelengths and

1062
00:46:36,838 --> 00:46:42,630
in fact it wasn't just glowing it was

1063
00:46:39,599 --> 00:46:44,838
glowing with this very pronounced double

1064
00:46:42,630 --> 00:46:46,309
peaked structure this is like a

1065
00:46:44,838 --> 00:46:49,248
looking garden for an accretion disk

1066
00:46:46,309 --> 00:46:50,900
right because you have different parts

1067
00:46:49,248 --> 00:46:53,268
of that disk moving at different

1068
00:46:50,900 --> 00:46:55,969
velocities which creates your double

1069
00:46:53,268 --> 00:46:57,709

sort of peak shape there as you take all

1070
00:46:55,969 --> 00:46:59,900
these little bits of velocities and put

1071
00:46:57,710 --> 00:47:03,650
them spread them out in velocity space

1072
00:46:59,900 --> 00:47:06,380
or wavelength space same thing so we

1073
00:47:03,650 --> 00:47:08,568
have gas we have dust we have dust and

1074
00:47:06,380 --> 00:47:13,338
gas going on to the white dwarfs we have

1075
00:47:08,568 --> 00:47:16,009
things shredding up somehow we even have

1076
00:47:13,338 --> 00:47:17,900
like pictures of the gas this is so cool

1077
00:47:16,009 --> 00:47:20,539
this is just in the last couple of

1078
00:47:17,900 --> 00:47:22,670
months there's a technique where if you

1079
00:47:20,539 --> 00:47:25,099
take lots and lots of spectra and build

1080
00:47:22,670 --> 00:47:27,528
it all up and decompose everything into

1081
00:47:25,099 --> 00:47:28,999
velocity space / time with the

1082
00:47:27,528 --> 00:47:32,748
assumption that you've got some sort of

1083
00:47:28,998 --> 00:47:35,449
regular periodic event occurring you can

1084
00:47:32,748 --> 00:47:39,318
what do what's called Doppler tomography

1085
00:47:35,449 --> 00:47:41,899
you basically pull out an image from the

1086
00:47:39,318 --> 00:47:43,699
information the velocity information so

1087
00:47:41,900 --> 00:47:46,789
what we're seeing here is an inside-out

1088
00:47:43,699 --> 00:47:48,468
picture so it's a not intuitive so

1089
00:47:46,789 --> 00:47:51,799
you're not seeing exactly a ring like

1090
00:47:48,469 --> 00:47:54,079
this going from the center to the outer

1091
00:47:51,798 --> 00:47:55,969
area it's more the other way around this

1092
00:47:54,079 --> 00:47:57,469
is this this is getting toward the

1093
00:47:55,969 --> 00:47:59,568
center of the star and this is getting

1094
00:47:57,469 --> 00:48:02,509
further away but in any case you've got

1095
00:47:59,568 --> 00:48:05,478
this very interesting elliptical

1096
00:48:02,509 --> 00:48:08,659
processing ring of gas around a white

1097
00:48:05,478 --> 00:48:11,179
dwarf that with lots and lots of spectra

1098
00:48:08,659 --> 00:48:13,969
you can synthesize into sort of an image

1099
00:48:11,179 --> 00:48:16,788
of what's going on with the gas and sure

1100
00:48:13,969 --> 00:48:18,499
enough just like the double peak

1101
00:48:16,789 --> 00:48:20,989
structure told us there was some kind of

1102
00:48:18,498 --> 00:48:23,028
a disk the reconstruction of the

1103
00:48:20,989 --> 00:48:24,440
velocity show that there is a disk but

1104
00:48:23,028 --> 00:48:26,599
not only that there's a disk but its

1105
00:48:24,440 --> 00:48:29,119
processing around this elliptical shape

1106
00:48:26,599 --> 00:48:31,130
is processing around and changing the

1107
00:48:29,119 --> 00:48:34,039
shape of the spectral features that we

1108
00:48:31,130 --> 00:48:35,568
see so this is cool I I don't even

1109
00:48:34,039 --> 00:48:37,819
understand this yet I need to think

1110
00:48:35,568 --> 00:48:40,278
about this more but it's a really

1111
00:48:37,818 --> 00:48:42,108
interesting way to sort of get a picture

1112

00:48:40,278 --> 00:48:44,358
of the system that we will never be able

1113
00:48:42,108 --> 00:48:48,619
to actually resolve with a telescope in

1114
00:48:44,358 --> 00:48:51,170
any easy time now I've taken some

1115
00:48:48,619 --> 00:48:53,960
spectra as well an in tradition to gas

1116
00:48:51,170 --> 00:48:56,568
in emission we've even seen gas in

1117
00:48:53,960 --> 00:48:58,340
absorption around these white dwarfs so

1118
00:48:56,568 --> 00:49:01,340
if you look at sort of the spectrum

1119
00:48:58,340 --> 00:49:04,070
again around the calcium H&K lines you

1120
00:49:01,340 --> 00:49:06,530
have the main photospheric line but then

1121
00:49:04,070 --> 00:49:08,690
you have this little blip just blue

1122
00:49:06,530 --> 00:49:10,190
words right now the other thing about

1123
00:49:08,690 --> 00:49:13,099
white dwarfs because they're so dense

1124
00:49:10,190 --> 00:49:16,190
they have a strong pull of gravity much

1125
00:49:13,099 --> 00:49:18,949
like those galaxy clusters much like the

1126
00:49:16,190 --> 00:49:21,829

universe redshifts things white dwarfs

1127
00:49:18,949 --> 00:49:25,159
locally redshift light so what happens

1128
00:49:21,829 --> 00:49:27,139
is the the light coming from the white

1129
00:49:25,159 --> 00:49:29,569
dwarf surface is redder than it would

1130
00:49:27,139 --> 00:49:33,440
normally be so it's photospheric metal

1131
00:49:29,570 --> 00:49:35,570
lines are pulled away from the velocity

1132
00:49:33,440 --> 00:49:40,099
of the white dwarf so if you have a disc

1133
00:49:35,570 --> 00:49:42,260
you've got the duh the gas at not

1134
00:49:40,099 --> 00:49:45,289
reddened quite so much and it's like a

1135
00:49:42,260 --> 00:49:46,880
curtain being pulled away so though the

1136
00:49:45,289 --> 00:49:48,909
white dwarfs gravity pulls the curtain

1137
00:49:46,880 --> 00:49:51,800
away and allows us to find these weak

1138
00:49:48,909 --> 00:49:54,199
circumstellar gas features you can

1139
00:49:51,800 --> 00:49:57,260
actually do some calculations about okay

1140
00:49:54,199 --> 00:49:59,000
given how wide the gases in velocity

1141
00:49:57,260 --> 00:50:01,910
where might it be around the white dwarf

1142
00:49:59,000 --> 00:50:04,130
and sure enough it's you know within a

1143
00:50:01,909 --> 00:50:06,500
hundred white dwarf radii or one solar

1144
00:50:04,130 --> 00:50:08,360
radius and that's roughly about where

1145
00:50:06,500 --> 00:50:10,760
the sublimation radius of the dust is

1146
00:50:08,360 --> 00:50:13,400
for this particular white dwarfs for

1147
00:50:10,760 --> 00:50:15,560
this particular white dwarf and you know

1148
00:50:13,400 --> 00:50:18,110
so you can look at a lot of white doors

1149
00:50:15,559 --> 00:50:20,110
maybe and find similar things this also

1150
00:50:18,110 --> 00:50:23,440
says that this particular white dwarf

1151
00:50:20,110 --> 00:50:25,550
probably worth seeing the disk edge on

1152
00:50:23,440 --> 00:50:29,840
right through we're looking right

1153
00:50:25,550 --> 00:50:31,789
through it so that's kind of cool so

1154
00:50:29,840 --> 00:50:33,230
we've got these metal lines if you have

1155
00:50:31,789 --> 00:50:35,869
enough metal lines you can actually

1156
00:50:33,230 --> 00:50:37,760
build up the composition of the dust the

1157
00:50:35,869 --> 00:50:39,230
other thing that I should mention is

1158
00:50:37,760 --> 00:50:41,840
that white dwarfs are extremely

1159
00:50:39,230 --> 00:50:44,659
sensitive probes to accretion a me sighs

1160
00:50:41,840 --> 00:50:48,380
boulder falling onto a white dwarf every

1161
00:50:44,659 --> 00:50:50,539
second is observable that's not a lot of

1162
00:50:48,380 --> 00:50:52,369
material when astronomers talk about

1163
00:50:50,539 --> 00:50:54,099
mass they usually talk about solar

1164
00:50:52,369 --> 00:50:57,409
masses well these are like

1165
00:50:54,099 --> 00:50:59,719
kilometer-sized asteroids falling onto

1166
00:50:57,409 --> 00:51:01,909
the white dwarf every couple days or so

1167
00:50:59,719 --> 00:51:04,579
or every year so it's not a lot of

1168
00:51:01,909 --> 00:51:07,129
material it's a suspiciously asteroidal

1169

00:51:04,579 --> 00:51:10,130
amount of material and when we look at

1170
00:51:07,130 --> 00:51:12,230
the composition with these spectra we

1171
00:51:10,130 --> 00:51:14,660
find a suspiciously asteroidal

1172
00:51:12,230 --> 00:51:18,190
opposition a rocky composition that is

1173
00:51:14,659 --> 00:51:20,629
not unlike the bulk earth composition or

1174
00:51:18,190 --> 00:51:23,420
asteroid Alcoa's itions in our own solar

1175
00:51:20,630 --> 00:51:25,519
system so not only our white doors weird

1176
00:51:23,420 --> 00:51:27,559
because they have this dust that drains

1177
00:51:25,519 --> 00:51:29,630
onto their surfaces and we get to learn

1178
00:51:27,559 --> 00:51:32,029
about interesting disk and accretion

1179
00:51:29,630 --> 00:51:35,090
properties in sort of a extreme

1180
00:51:32,030 --> 00:51:37,700
environment we also for free get dust

1181
00:51:35,090 --> 00:51:40,640
composition and if we can link this dust

1182
00:51:37,699 --> 00:51:44,449
to planets we suddenly then have a way

1183
00:51:40,639 --> 00:51:47,179

of sampling the terrestrial chemistry of

1184
00:51:44,449 --> 00:51:50,000
dead planetary systems so I'm going to

1185
00:51:47,179 --> 00:51:51,799
argue now that these are asteroids these

1186
00:51:50,000 --> 00:51:53,989
are asteroids that have somehow strayed

1187
00:51:51,800 --> 00:51:56,660
too close to their white dwarf they've

1188
00:51:53,989 --> 00:51:59,539
gotten shredded up they've drained onto

1189
00:51:56,659 --> 00:52:03,170
the white dwarf and we can read their

1190
00:51:59,539 --> 00:52:05,539
properties from the spectra of these

1191
00:52:03,170 --> 00:52:08,599
white dwarf this is incredibly powerful

1192
00:52:05,539 --> 00:52:11,449
we cannot go to other planets very

1193
00:52:08,599 --> 00:52:14,329
easily especially the rocky ones and

1194
00:52:11,449 --> 00:52:17,779
measure what the rocks are we can do it

1195
00:52:14,329 --> 00:52:18,920
with Mars send a couple robots it's

1196
00:52:17,780 --> 00:52:22,730
going to be a little hard to do it

1197
00:52:18,920 --> 00:52:23,809
around Alpha Centauri or HD 209 458 it's

1198
00:52:22,730 --> 00:52:26,990
going to take a little while to get

1199
00:52:23,809 --> 00:52:28,730
there so this is one of our best ways of

1200
00:52:26,989 --> 00:52:31,309
understanding the chemistry of

1201
00:52:28,730 --> 00:52:33,289
terrestrial planet formation this has

1202
00:52:31,309 --> 00:52:35,900
implications for understanding how

1203
00:52:33,289 --> 00:52:38,659
different or how typical our own earth

1204
00:52:35,900 --> 00:52:41,420
is relative to other stellar systems and

1205
00:52:38,659 --> 00:52:43,819
on top of that there's only a couple of

1206
00:52:41,420 --> 00:52:46,970
other techniques that get at the sort of

1207
00:52:43,820 --> 00:52:49,430
chemistry of planet formation or the

1208
00:52:46,969 --> 00:52:51,169
chemistry of planet atmospheres so

1209
00:52:49,429 --> 00:52:52,940
Nicole Lewis in a few months will tell

1210
00:52:51,170 --> 00:52:55,039
you about how they do the chemistry of

1211
00:52:52,940 --> 00:52:58,039
atmospheres but this is sort of like the

1212
00:52:55,039 --> 00:53:00,559
chemistry of rocks so it's very exciting

1213
00:52:58,039 --> 00:53:05,179
I can't overstate that enough very cool

1214
00:53:00,559 --> 00:53:07,299
and this is being helped quite a bit by

1215
00:53:05,179 --> 00:53:09,739
the ultraviolet instruments on Hubble

1216
00:53:07,300 --> 00:53:11,690
because white dwarfs are typically more

1217
00:53:09,739 --> 00:53:13,849
bright in the ultraviolet and there are

1218
00:53:11,690 --> 00:53:15,858
a ton of metal ions in the ultraviolet

1219
00:53:13,849 --> 00:53:18,199
that are often not accessible in the

1220
00:53:15,858 --> 00:53:20,329
optical so instruments likes disks which

1221
00:53:18,199 --> 00:53:23,989
I'm in charge of and I'm legally

1222
00:53:20,329 --> 00:53:25,079
obligated to promote and also costs both

1223
00:53:23,989 --> 00:53:27,929
of them have been in

1224
00:53:25,079 --> 00:53:29,819
your mental in measuring compositions

1225
00:53:27,929 --> 00:53:33,449
especially costs because it's very

1226

00:53:29,820 --> 00:53:35,940
sensitive okay so these things are also

1227
00:53:33,449 --> 00:53:38,250
not static in time we've seen examples

1228
00:53:35,940 --> 00:53:41,490
of some of these dust disks changing on

1229
00:53:38,250 --> 00:53:45,449
yearly timescales we don't understand

1230
00:53:41,489 --> 00:53:47,759
why and we even see the emission lines

1231
00:53:45,449 --> 00:53:50,039
changing with time which maybe we

1232
00:53:47,760 --> 00:53:51,660
understand some of them are maybe just

1233
00:53:50,039 --> 00:53:53,699
processing rings and that's why they're

1234
00:53:51,659 --> 00:53:55,649
changing with time but these are kind of

1235
00:53:53,699 --> 00:53:57,539
disappearing so there's a quick

1236
00:53:55,650 --> 00:54:00,329
evolution on a yearly time scale for

1237
00:53:57,539 --> 00:54:04,409
some of these observable phenomena that

1238
00:54:00,329 --> 00:54:07,619
we see okay but now we've got this

1239
00:54:04,409 --> 00:54:10,019
question right I just showed you how our

1240
00:54:07,619 --> 00:54:11,969

solar system would survive post main

1241
00:54:10,019 --> 00:54:14,280
sequence evolution or the death of their

1242
00:54:11,969 --> 00:54:16,609
star and it doesn't look too good for

1243
00:54:14,280 --> 00:54:20,130
stuff that's a one solar radius away

1244
00:54:16,610 --> 00:54:22,590
right it gets obliterated so nothing

1245
00:54:20,130 --> 00:54:25,349
that started out that close is going to

1246
00:54:22,590 --> 00:54:27,600
survive that close the star is going to

1247
00:54:25,349 --> 00:54:32,610
scrub all the material out to one or 2a

1248
00:54:27,599 --> 00:54:35,369
you because of its evolution so we have

1249
00:54:32,610 --> 00:54:37,860
asteroids living somewhere in these dead

1250
00:54:35,369 --> 00:54:42,299
planetary systems and they have to start

1251
00:54:37,860 --> 00:54:45,599
out at a few to maybe ten au and they

1252
00:54:42,300 --> 00:54:48,060
have to go all the way down to four

1253
00:54:45,599 --> 00:54:50,159
point five times ten to the minus 38 you

1254
00:54:48,059 --> 00:54:52,769
so remember an au is the distance from

1255
00:54:50,159 --> 00:54:57,149
the earth to the Sun so they start out

1256
00:54:52,769 --> 00:54:59,940
far and they get really really close so

1257
00:54:57,150 --> 00:55:04,019
how do we do it this is something that

1258
00:54:59,940 --> 00:55:05,579
me as a dynamicists or a pretend

1259
00:55:04,019 --> 00:55:08,130
dynamicists because i'm not a real

1260
00:55:05,579 --> 00:55:11,429
dynamicists I just play one as an

1261
00:55:08,130 --> 00:55:13,530
astronomer but this is hard to do you

1262
00:55:11,429 --> 00:55:15,119
get a little panicky you get worried how

1263
00:55:13,530 --> 00:55:18,120
am I going to do this this is my thesis

1264
00:55:15,119 --> 00:55:22,559
how am I going to finish it don't worry

1265
00:55:18,119 --> 00:55:25,589
keep calm and focus on resonances what

1266
00:55:22,559 --> 00:55:28,079
are resonances okay so you have Jupiter

1267
00:55:25,590 --> 00:55:30,930
right it goes around a certain amount of

1268
00:55:28,079 --> 00:55:33,960
time and in certain orbits you have

1269
00:55:30,929 --> 00:55:36,869
objects that go two times for every one

1270
00:55:33,960 --> 00:55:38,650
time Jupiter goes around they be inside

1271
00:55:36,869 --> 00:55:41,980
if they did that or

1272
00:55:38,650 --> 00:55:45,130
half a time as Jupiter went once these

1273
00:55:41,980 --> 00:55:46,869
are special orbits because at a given

1274
00:55:45,130 --> 00:55:49,900
point in their orbit they line up with

1275
00:55:46,869 --> 00:55:52,059
Jupiter they get a little extra tug and

1276
00:55:49,900 --> 00:55:53,800
they get a little extra tug and they get

1277
00:55:52,059 --> 00:55:55,750
a little extra tug over over over and

1278
00:55:53,800 --> 00:55:58,240
again until they have different orbits

1279
00:55:55,750 --> 00:56:02,489
and you can really mess things up this

1280
00:55:58,239 --> 00:56:07,809
way gravity is weak but it's persistent

1281
00:56:02,489 --> 00:56:10,509
okay so first I said I claimed asteroids

1282
00:56:07,809 --> 00:56:13,509
survived post main-sequence evolution or

1283

00:56:10,510 --> 00:56:15,550
the evolution of their star from middle

1284
00:56:13,510 --> 00:56:18,190
age to the end of their life but I

1285
00:56:15,550 --> 00:56:19,990
didn't really prove it to you so this is

1286
00:56:18,190 --> 00:56:24,539
these are some simple calculations of

1287
00:56:19,989 --> 00:56:30,519
the survival of fairly large asteroids

1288
00:56:24,539 --> 00:56:33,550
from Pluto size give or take down to

1289
00:56:30,519 --> 00:56:36,340
very tiny asteroids and these are

1290
00:56:33,550 --> 00:56:39,220
survival curves for different situations

1291
00:56:36,340 --> 00:56:42,100
so the the Sun will get to a maximum

1292
00:56:39,219 --> 00:56:44,949
luminosity during its evolution of about

1293
00:56:42,099 --> 00:56:48,759
10,000 times the current velocity

1294
00:56:44,949 --> 00:56:52,179
because it gets really really big and so

1295
00:56:48,760 --> 00:56:57,940
anything that is smaller and closer than

1296
00:56:52,179 --> 00:56:59,549
this line here will evaporate now let's

1297
00:56:57,940 --> 00:57:02,679

say you bump it up twice as much than

1298
00:56:59,550 --> 00:57:07,630
anything below this curve will survive

1299
00:57:02,679 --> 00:57:10,119
now we know from your pictures there

1300
00:57:07,630 --> 00:57:14,680
might be a little bit of gas expelled

1301
00:57:10,119 --> 00:57:17,500
during the late stages of death and so

1302
00:57:14,679 --> 00:57:19,169
what that wind while it doesn't mess

1303
00:57:17,500 --> 00:57:24,250
anything up to terribly four big planets

1304
00:57:19,170 --> 00:57:27,130
can actually drag on small asteroids and

1305
00:57:24,250 --> 00:57:30,250
pull them into the inner system where

1306
00:57:27,130 --> 00:57:32,410
they evaporate so if you're in these

1307
00:57:30,250 --> 00:57:35,199
sort of regions below these regions here

1308
00:57:32,409 --> 00:57:37,750
for given initial stellar masses so if

1309
00:57:35,199 --> 00:57:40,299
we talk about the Sun you have these two

1310
00:57:37,750 --> 00:57:44,590
curves intersecting and anything below

1311
00:57:40,300 --> 00:57:48,060
and interior gets destroyed but you know

1312
00:57:44,590 --> 00:57:51,200
our our asteroid belt extends from about

1313
00:57:48,059 --> 00:57:53,630
you know here to here

1314
00:57:51,199 --> 00:57:56,929
and so there's plenty of big things that

1315
00:57:53,630 --> 00:57:59,809
can survive these processes and even if

1316
00:57:56,929 --> 00:58:03,679
the big things here don't survive these

1317
00:57:59,809 --> 00:58:05,690
small things here move in and eventually

1318
00:58:03,679 --> 00:58:08,328
survive if you get thing if you get the

1319
00:58:05,690 --> 00:58:11,389
timing right so you can get anything

1320
00:58:08,329 --> 00:58:13,490
that started out here to survive and

1321
00:58:11,389 --> 00:58:15,710
also you have to remember things are

1322
00:58:13,489 --> 00:58:18,169
moving out in response to the mass loss

1323
00:58:15,710 --> 00:58:19,639
of the star so you can get a whole bunch

1324
00:58:18,170 --> 00:58:21,320
of stuff that survives and a whole bunch

1325
00:58:19,639 --> 00:58:24,170
of stuff from the outer system that

1326
00:58:21,320 --> 00:58:26,300
moves in toward the resonances if you're

1327
00:58:24,170 --> 00:58:28,940
talking about interior resonances to

1328
00:58:26,300 --> 00:58:31,460
Jupiter which is what these are you can

1329
00:58:28,940 --> 00:58:33,820
also have exterior exterior residences

1330
00:58:31,460 --> 00:58:37,190
so if you have chains of planets like

1331
00:58:33,820 --> 00:58:39,170
the typical Kepler planetary system is

1332
00:58:37,190 --> 00:58:41,329
actually like five or six super Earths

1333
00:58:39,170 --> 00:58:43,250
all mushed together in very tight orbits

1334
00:58:41,329 --> 00:58:45,050
so if you have chains of those kinds of

1335
00:58:43,250 --> 00:58:47,570
planets you can have lots of resonances

1336
00:58:45,050 --> 00:58:49,579
interior and exterior our own solar

1337
00:58:47,570 --> 00:58:53,269
system has exterior resonances with the

1338
00:58:49,579 --> 00:58:56,530
Kuiper belt objects and there have been

1339
00:58:53,269 --> 00:59:00,440
people the list is here have who have

1340

00:58:56,530 --> 00:59:03,440
you know measure or model the dynamics

1341
00:59:00,440 --> 00:59:05,720
to see whether asteroids or comets in

1342
00:59:03,440 --> 00:59:08,000
exterior resonances get kicked into the

1343
00:59:05,719 --> 00:59:10,578
inner system and what happens is the

1344
00:59:08,000 --> 00:59:13,400
gravity of your chain of planets or a

1345
00:59:10,579 --> 00:59:14,839
couple of planets basically kicks from

1346
00:59:13,400 --> 00:59:18,710
one planet to the next until eventually

1347
00:59:14,838 --> 00:59:20,539
they get kicked to the inner system now

1348
00:59:18,710 --> 00:59:23,568
the problem is that most of the stuff

1349
00:59:20,539 --> 00:59:25,279
that's far out is icy and will get

1350
00:59:23,568 --> 00:59:27,619
evaporated much more quickly than the

1351
00:59:25,280 --> 00:59:29,450
rocky stuff so I actually favored that

1352
00:59:27,619 --> 00:59:32,480
the stuff on the interior even though it

1353
00:59:29,449 --> 00:59:34,549
has a harder time of it during the stars

1354
00:59:32,480 --> 00:59:36,619

evolution well it because it's rocky

1355
00:59:34,550 --> 00:59:39,710
will survive better than the icy stuff

1356
00:59:36,619 --> 00:59:41,809
far out so I actually worked on an idea

1357
00:59:39,710 --> 00:59:45,559
where i took the thought experiment of

1358
00:59:41,809 --> 00:59:47,568
our solar system and i just measured and

1359
00:59:45,559 --> 00:59:49,489
i put a whole bunch of asteroids our own

1360
00:59:47,568 --> 00:59:52,099
asteroids in our solar system with the

1361
00:59:49,489 --> 00:59:53,719
known orbital elements and i ran them

1362
00:59:52,099 --> 00:59:57,140
through an end body simulation where i

1363
00:59:53,719 --> 00:59:59,500
made the Sun evolve through its end of

1364
00:59:57,139 --> 01:00:02,199
at life and I just watched what happened

1365
00:59:59,500 --> 01:00:05,000
between the asteroids and Jupiter and

1366
01:00:02,199 --> 01:00:05,569
what I found was that asteroids that

1367
01:00:05,000 --> 01:00:08,269
were in the

1368
01:00:05,570 --> 01:00:10,789
21 mean motion resonance with Jupiter an

1369
01:00:08,269 --> 01:00:14,090
interior residence with Jupiter would

1370
01:00:10,789 --> 01:00:19,279
get kicked in and Title II disrupt a few

1371
01:00:14,090 --> 01:00:22,039
at a time at a rate of you know a few

1372
01:00:19,280 --> 01:00:24,290
per year or a few / tens of hundreds of

1373
01:00:22,039 --> 01:00:27,349
years depending on the how long it's

1374
01:00:24,289 --> 01:00:29,509
been running and you can compare these

1375
01:00:27,349 --> 01:00:31,579
models with the observed accretion rate

1376
01:00:29,510 --> 01:00:33,920
of a population of white dwarfs to see

1377
01:00:31,579 --> 01:00:37,309
if the model makes sense so what do I

1378
01:00:33,920 --> 01:00:42,010
have here okay so the blue points are my

1379
01:00:37,309 --> 01:00:44,630
simulations the red and black points are

1380
01:00:42,010 --> 01:00:47,690
white dwarfs that have metal lines only

1381
01:00:44,630 --> 01:00:52,130
the red ones are metal lines and dusty

1382
01:00:47,690 --> 01:00:54,409
disks and you have sort of my

1383
01:00:52,130 --> 01:00:57,619
simulations explaining sort of the the

1384
01:00:54,409 --> 01:00:59,269
weakest accretion rates over time so

1385
01:00:57,619 --> 01:01:02,210
this is temperature the white dwarf

1386
01:00:59,269 --> 01:01:03,889
which is sort of a proxy of evolutionary

1387
01:01:02,210 --> 01:01:07,010
timescale wide doors go from being

1388
01:01:03,889 --> 01:01:10,009
hotter to colder with time as they cool

1389
01:01:07,010 --> 01:01:12,230
down and this is the mass accretion rate

1390
01:01:10,010 --> 01:01:14,780
so if you just took sort of an average

1391
01:01:12,230 --> 01:01:18,230
of my models and you kicked it up by a

1392
01:01:14,780 --> 01:01:21,440
factor of 10 or 100 or more I can't

1393
01:01:18,230 --> 01:01:23,420
remember now let's say a few hundred you

1394
01:01:21,440 --> 01:01:24,889
would roughly match the highest

1395
01:01:23,420 --> 01:01:27,769
accretion rates that we actually observe

1396
01:01:24,889 --> 01:01:30,559
so maybe we have solar systems that have

1397

01:01:27,769 --> 01:01:32,900
a lot more rocks than we do maybe that's

1398
01:01:30,559 --> 01:01:35,329
one explanation now I worked with a

1399
01:01:32,900 --> 01:01:37,070
summer intern for a while and instead of

1400
01:01:35,329 --> 01:01:39,799
having a small number of asteroids we

1401
01:01:37,070 --> 01:01:42,320
put as many asteroids as are actually

1402
01:01:39,800 --> 01:01:45,440
observed in our solar system and try it

1403
01:01:42,320 --> 01:01:48,170
again and when you put a lot more you

1404
01:01:45,440 --> 01:01:50,300
get a lot higher accretion rates so now

1405
01:01:48,170 --> 01:01:53,599
it's more like we need only like 10 or

1406
01:01:50,300 --> 01:01:55,850
20 times what our own solar system seems

1407
01:01:53,599 --> 01:01:57,799
to have in terms of a reservoir of Title

1408
01:01:55,849 --> 01:02:00,230
II disrupting planets but this is sort

1409
01:01:57,800 --> 01:02:02,990
of like a proof of concept we can get

1410
01:02:00,230 --> 01:02:05,990
asteroids that start out very far with

1411
01:02:02,989 --> 01:02:08,479

the resonance to a big planet Jupiter or

1412
01:02:05,989 --> 01:02:11,000
Saturn and they get kicked in and what's

1413
01:02:08,480 --> 01:02:14,119
happening is it's because Jupiter is

1414
01:02:11,000 --> 01:02:16,190
getting more muscley okay so Jupiter

1415
01:02:14,119 --> 01:02:19,278
over its evolution there used to be a

1416
01:02:16,190 --> 01:02:20,688
ton of asteroids right here at the 22

1417
01:02:19,278 --> 01:02:22,458
resonance this is the two-to-one

1418
01:02:20,688 --> 01:02:24,739
resonance but what would happen is once

1419
01:02:22,458 --> 01:02:27,918
they got caught her and eventually so

1420
01:02:24,739 --> 01:02:30,679
this is semi major axis of orbit for the

1421
01:02:27,918 --> 01:02:33,918
asteroid versus eccentricity so they

1422
01:02:30,679 --> 01:02:35,719
were random walk in this region and then

1423
01:02:33,918 --> 01:02:38,449
eventually get so high in eccentricities

1424
01:02:35,719 --> 01:02:40,489
to get they escape they either interact

1425
01:02:38,449 --> 01:02:43,909
with earth they get kicked out whatever

1426
01:02:40,489 --> 01:02:46,880
it is they go into the Sun but when the

1427
01:02:43,909 --> 01:02:48,949
Sun loses its mass suddenly Jupiter is

1428
01:02:46,880 --> 01:02:51,439
much stronger and so everything that was

1429
01:02:48,949 --> 01:02:54,679
on the edge here is now trapped in the

1430
01:02:51,438 --> 01:02:57,438
resonance and starts moving around until

1431
01:02:54,679 --> 01:03:01,939
it gets to the white dwarf and causes a

1432
01:02:57,438 --> 01:03:03,618
dust disk and causes dust and we can

1433
01:03:01,938 --> 01:03:06,139
even probe you know with these

1434
01:03:03,619 --> 01:03:09,919
simulations you know the distribution of

1435
01:03:06,139 --> 01:03:13,808
how much material gets and how close it

1436
01:03:09,918 --> 01:03:16,400
gets so if you remember we were seeing

1437
01:03:13,809 --> 01:03:19,400
dust rings that were sort of in this

1438
01:03:16,400 --> 01:03:22,219
region here right and so what you would

1439
01:03:19,400 --> 01:03:24,619
expect is if something came in to 60

1440
01:03:22,219 --> 01:03:26,298
white dwarf radii it would shred up here

1441
01:03:24,619 --> 01:03:29,809
and then all the dust would sort of

1442
01:03:26,298 --> 01:03:32,869
drain in that way so the outer extent is

1443
01:03:29,809 --> 01:03:35,089
a rough measure of where the asteroid

1444
01:03:32,869 --> 01:03:37,880
maybe came in and what this is saying is

1445
01:03:35,088 --> 01:03:40,219
that you expect a lot of you expect more

1446
01:03:37,880 --> 01:03:42,769
things right at the edge of the title

1447
01:03:40,219 --> 01:03:45,708
disruption radius then really deep into

1448
01:03:42,768 --> 01:03:47,868
close to the white dwarf so that's

1449
01:03:45,708 --> 01:03:50,239
interesting it also means there's a

1450
01:03:47,869 --> 01:03:54,380
whole bunch more stuff just outside

1451
01:03:50,239 --> 01:03:56,119
thats hanging around waiting for i don't

1452
01:03:54,380 --> 01:03:57,559
know what but there's a whole bunch of

1453
01:03:56,119 --> 01:03:59,719
stuff that doesn't get tidally disrupted

1454

01:03:57,559 --> 01:04:01,579
that's just hanging around it might

1455
01:03:59,719 --> 01:04:04,789
collide if the white dwarf is

1456
01:04:01,579 --> 01:04:07,999
particularly hot the stuff out here will

1457
01:04:04,789 --> 01:04:11,390
will evaporate stuff off keep that in

1458
01:04:07,998 --> 01:04:14,509
mind you've got number eight or nine I

1459
01:04:11,389 --> 01:04:16,278
don't even know okay anyway so now we

1460
01:04:14,509 --> 01:04:18,769
can do the same calculation where we

1461
01:04:16,278 --> 01:04:20,958
compared to a larger sample of observed

1462
01:04:18,768 --> 01:04:24,139
white dwarfs with different accretion

1463
01:04:20,958 --> 01:04:26,268
rates and the simulations and now so the

1464
01:04:24,139 --> 01:04:28,338
solar system looks a little wimpy still

1465
01:04:26,268 --> 01:04:30,948
but this is sort of like a your most

1466
01:04:28,338 --> 01:04:32,659
conservative estimate of how much mass

1467
01:04:30,949 --> 01:04:34,909
you would get accreting onto a white

1468
01:04:32,659 --> 01:04:36,920

orff but we still measure sort of the

1469
01:04:34,909 --> 01:04:38,808
bottom fraction but we're only like a

1470
01:04:36,920 --> 01:04:41,480
factor of ten or so and at least that

1471
01:04:38,809 --> 01:04:43,160
early times for our solar system we can

1472
01:04:41,480 --> 01:04:45,920
even match the highest accretion rates

1473
01:04:43,159 --> 01:04:48,170
that are observed but our solar system

1474
01:04:45,920 --> 01:04:50,720
will eventually weaken pretty quickly

1475
01:04:48,170 --> 01:04:53,088
you know you run out of stuff and it

1476
01:04:50,719 --> 01:04:55,639
slowly falls to very low accretion rates

1477
01:04:53,088 --> 01:04:59,989
over time and so then these are the

1478
01:04:55,639 --> 01:05:02,358
times after the star dies you know as a

1479
01:04:59,989 --> 01:05:04,759
mapped to the temperature of the white

1480
01:05:02,358 --> 01:05:08,449
dwarf so we still see quite a bit of

1481
01:05:04,760 --> 01:05:10,119
accretion in nature that we don't expect

1482
01:05:08,449 --> 01:05:12,858
to see from our own solar system

1483
01:05:10,119 --> 01:05:14,420
planetary architecture so we need to

1484
01:05:12,858 --> 01:05:17,449
investigate different planetary

1485
01:05:14,420 --> 01:05:19,818
architectures to sort of get a hint at

1486
01:05:17,449 --> 01:05:21,818
what maybe is causing the higher

1487
01:05:19,818 --> 01:05:23,869
accretion rates that we actually observe

1488
01:05:21,818 --> 01:05:25,579
okay I'm going to skip that not very

1489
01:05:23,869 --> 01:05:27,500
interesting but I will tell you about a

1490
01:05:25,579 --> 01:05:30,019
mystery so I mentioned that Kepler had

1491
01:05:27,500 --> 01:05:31,880
discovered many many planets well it

1492
01:05:30,019 --> 01:05:35,750
also found something extremely weird

1493
01:05:31,880 --> 01:05:37,309
around a white dwarf a piddling faint

1494
01:05:35,750 --> 01:05:40,778
little white dwarf that everyone had

1495
01:05:37,309 --> 01:05:44,089
ignored for many years and someone

1496
01:05:40,778 --> 01:05:46,608
during k2 so remember Kepler had a main

1497
01:05:44,088 --> 01:05:49,278
mission its reaction wheels failed and

1498
01:05:46,608 --> 01:05:51,078
now has this new mission called k2 which

1499
01:05:49,278 --> 01:05:53,449
is doing great stuff because now it's

1500
01:05:51,079 --> 01:05:56,440
looking at wider swathes of the sky and

1501
01:05:53,449 --> 01:05:59,419
they looked at this one white dwarf and

1502
01:05:56,440 --> 01:06:01,700
someone noticed that the durn thing kept

1503
01:05:59,420 --> 01:06:04,519
dipping at a period of about four and a

1504
01:06:01,699 --> 01:06:06,919
half hours and then when you add

1505
01:06:04,519 --> 01:06:09,650
everything up you see these strange dips

1506
01:06:06,920 --> 01:06:11,409
that are pretty small now remember white

1507
01:06:09,650 --> 01:06:15,019
dwarfs are about the size of the earth

1508
01:06:11,409 --> 01:06:19,179
so any dips are from small things

1509
01:06:15,019 --> 01:06:22,369
smaller than the earth so these dips

1510
01:06:19,179 --> 01:06:24,048
I'll look strange there's no way to put

1511

01:06:22,369 --> 01:06:26,980
it it doesn't look like a planetary

1512
01:06:24,048 --> 01:06:29,420
transit because the the dips are not

1513
01:06:26,980 --> 01:06:33,199
regular like a transit they're all over

1514
01:06:29,420 --> 01:06:35,829
the place they're kind of strange we

1515
01:06:33,199 --> 01:06:38,838
think this is we're actually seeing

1516
01:06:35,829 --> 01:06:40,670
disintegrating asteroids in real time

1517
01:06:38,838 --> 01:06:43,880
because what's happening is we're seeing

1518
01:06:40,670 --> 01:06:45,530
oh good yes we're seeing these dips that

1519
01:06:43,880 --> 01:06:47,720
are either very sharp

1520
01:06:45,530 --> 01:06:50,450
or sort of asymmetric and so we're

1521
01:06:47,719 --> 01:06:52,489
seeing bits that are sort of like a

1522
01:06:50,449 --> 01:06:54,980
comet tail right so we get these

1523
01:06:52,489 --> 01:06:57,019
asymmetric profiles from the tail

1524
01:06:54,980 --> 01:07:00,139
crossing in front of the white dwarf and

1525
01:06:57,019 --> 01:07:02,269

it's happening over and over again so

1526
01:07:00,139 --> 01:07:03,639
there's like a collection of bits going

1527
01:07:02,269 --> 01:07:06,739
around and around we don't really

1528
01:07:03,639 --> 01:07:08,509
understand this yet literally tomorrow I

1529
01:07:06,739 --> 01:07:10,309
am jumping on a train I'm going to New

1530
01:07:08,510 --> 01:07:13,250
Haven I'm going to be observing on the

1531
01:07:10,309 --> 01:07:15,079
Keck telescope on this object all night

1532
01:07:13,250 --> 01:07:17,420
long I'm just going to sit on it and see

1533
01:07:15,079 --> 01:07:19,489
if it does something weird because it

1534
01:07:17,420 --> 01:07:22,190
keeps changing these dips don't say

1535
01:07:19,489 --> 01:07:25,189
regular they change in depth they shift

1536
01:07:22,190 --> 01:07:26,840
around in time someone and this is like

1537
01:07:25,190 --> 01:07:28,280
a paper that came out a couple weeks ago

1538
01:07:26,840 --> 01:07:31,250
I didn't even put the reference sorry

1539
01:07:28,280 --> 01:07:32,840
apologize for that but they noticed okay

1540
01:07:31,250 --> 01:07:35,449
this is a weird plot they call it a

1541
01:07:32,840 --> 01:07:37,220
waterfall plot what's happening is these

1542
01:07:35,449 --> 01:07:40,539
are all the observations they took of

1543
01:07:37,219 --> 01:07:43,519
the star and anytime you see a blue

1544
01:07:40,539 --> 01:07:45,559
feature these were a series of dips and

1545
01:07:43,519 --> 01:07:48,019
they were able to match up those dips

1546
01:07:45,559 --> 01:07:49,579
from night tonight right they just sat

1547
01:07:48,019 --> 01:07:52,070
on this thing over and over and over

1548
01:07:49,579 --> 01:07:55,730
again they noticed that some of the dips

1549
01:07:52,070 --> 01:07:58,220
were sort of drifting in time so what

1550
01:07:55,730 --> 01:08:01,429
they interpret is happening is you have

1551
01:07:58,219 --> 01:08:04,419
a main asteroid or something serious

1552
01:08:01,429 --> 01:08:08,809
let's say and there are chunks of it

1553
01:08:04,420 --> 01:08:10,760
popping off and then swirling closer and

1554
01:08:08,809 --> 01:08:13,400
closer to the white dwarf that's what

1555
01:08:10,760 --> 01:08:16,819
they're interpreting these dips and the

1556
01:08:13,400 --> 01:08:19,130
drifts in the dip times as and when you

1557
01:08:16,819 --> 01:08:23,060
do that you can actually constrain the

1558
01:08:19,130 --> 01:08:26,659
mass of the planet or planetesimal from

1559
01:08:23,060 --> 01:08:28,910
how fast things are drifting I was not

1560
01:08:26,659 --> 01:08:31,489
aware of this but they claim this is

1561
01:08:28,909 --> 01:08:33,670
true so if they got that right they

1562
01:08:31,489 --> 01:08:36,139
think that this planetesimals that is

1563
01:08:33,670 --> 01:08:40,819
breaking off these chunks is about a

1564
01:08:36,140 --> 01:08:43,010
tenth of the massive series so series is

1565
01:08:40,819 --> 01:08:45,620
one of the largest asteroids in our

1566
01:08:43,010 --> 01:08:48,109
asteroid belt so something about the

1567
01:08:45,619 --> 01:08:50,119
tenth the size of Ceres is not crazy for

1568

01:08:48,109 --> 01:08:52,370
our solar system it would not be crazy

1569
01:08:50,119 --> 01:08:55,760
for another solar system as well so this

1570
01:08:52,369 --> 01:08:58,309
is starting to fill in a picture this is

1571
01:08:55,760 --> 01:08:59,239
sort of like the best example of a dusty

1572
01:08:58,310 --> 01:09:01,579
white dwarf because

1573
01:08:59,238 --> 01:09:03,379
not only do we have these dips so we're

1574
01:09:01,578 --> 01:09:05,899
seeing the disintegration in real time

1575
01:09:03,380 --> 01:09:07,639
there's an infrared excess so we can go

1576
01:09:05,899 --> 01:09:09,318
with james webb space telescope when it

1577
01:09:07,639 --> 01:09:11,210
launches and we look and look at the

1578
01:09:09,319 --> 01:09:13,130
spectrum of the dust and understand

1579
01:09:11,210 --> 01:09:16,069
something about what the dust is made of

1580
01:09:13,130 --> 01:09:18,349
we can see the bits sloughing off we can

1581
01:09:16,069 --> 01:09:20,659
maybe take spectra of the bits sloughing

1582
01:09:18,349 --> 01:09:23,420

off and get the dust composition that

1583
01:09:20,658 --> 01:09:25,548
way and then when we take spectra of the

1584
01:09:23,420 --> 01:09:27,498
white dwarf itself it has tons of metal

1585
01:09:25,548 --> 01:09:29,748
lines so we can get the composition of

1586
01:09:27,498 --> 01:09:32,929
the dust in the white dwarf we get every

1587
01:09:29,748 --> 01:09:35,568
step of this process with these

1588
01:09:32,929 --> 01:09:41,269
observations it's a really unique system

1589
01:09:35,569 --> 01:09:43,969
and it's very exciting so yay now if we

1590
01:09:41,269 --> 01:09:45,609
can see asteroids we can see a big

1591
01:09:43,969 --> 01:09:49,038
earth-like planet no trouble an

1592
01:09:45,609 --> 01:09:50,509
earth-like planet will make significant

1593
01:09:49,038 --> 01:09:52,158
changes to the brightness of a white

1594
01:09:50,509 --> 01:09:55,729
dwarf it goes if it goes in front of it

1595
01:09:52,158 --> 01:09:57,618
so this was thought of a couple years

1596
01:09:55,729 --> 01:09:59,649
ago some people have some really crazy

1597
01:09:57,618 --> 01:10:02,179
ideas of how you could maybe even see

1598
01:09:59,649 --> 01:10:05,828
atmospheres around these planets you

1599
01:10:02,179 --> 01:10:09,230
know even like industrial waste from

1600
01:10:05,828 --> 01:10:11,479
civilizations stuff like that but I am

1601
01:10:09,229 --> 01:10:13,279
interested in saying can we find

1602
01:10:11,479 --> 01:10:14,899
habitable planets around white doors

1603
01:10:13,279 --> 01:10:16,880
because white dwarfs evolve very slowly

1604
01:10:14,899 --> 01:10:18,888
they don't flare they don't do much of

1605
01:10:16,880 --> 01:10:21,590
anything they're about as common as G

1606
01:10:18,889 --> 01:10:24,469
stars in our local galaxy so if they

1607
01:10:21,590 --> 01:10:27,019
host planets which these dusty white

1608
01:10:24,469 --> 01:10:29,779
door seems suggest they host planets in

1609
01:10:27,019 --> 01:10:32,570
some way maybe these are also places to

1610
01:10:29,779 --> 01:10:34,368
look for habitable planets you have to

1611
01:10:32,569 --> 01:10:37,578
get very close to a white dwarf to be

1612
01:10:34,368 --> 01:10:39,889
habitable so you have to somehow okay if

1613
01:10:37,578 --> 01:10:41,420
you look at this so that's good from an

1614
01:10:39,889 --> 01:10:42,769
observational standpoint because you

1615
01:10:41,420 --> 01:10:44,569
don't have to look at any particular

1616
01:10:42,769 --> 01:10:46,639
object for very long to see if it has

1617
01:10:44,569 --> 01:10:49,639
the planet because it has a nice big

1618
01:10:46,639 --> 01:10:52,849
signal and a short period great problem

1619
01:10:49,639 --> 01:10:54,469
is it has a short period which means

1620
01:10:52,849 --> 01:10:57,380
that you somehow have to get a planet

1621
01:10:54,469 --> 01:11:00,559
that would have been destroyed during

1622
01:10:57,380 --> 01:11:03,828
the stars death somehow getting very

1623
01:11:00,559 --> 01:11:05,989
close so we see that asteroids do it

1624
01:11:03,828 --> 01:11:08,359
it's a little bit harder for planets so

1625

01:11:05,988 --> 01:11:09,618
there's no reason to expect that there

1626
01:11:08,359 --> 01:11:11,899
are a lot of planets close to white

1627
01:11:09,618 --> 01:11:12,250
dwarfs but it's so easy to look we might

1628
01:11:11,899 --> 01:11:13,899
as well

1629
01:11:12,250 --> 01:11:16,930
and we only have to look at a few

1630
01:11:13,899 --> 01:11:18,609
thousand white doors to find any kind to

1631
01:11:16,930 --> 01:11:20,710
put any kind of interesting constraints

1632
01:11:18,609 --> 01:11:23,979
on the frequency of habitable planets

1633
01:11:20,710 --> 01:11:27,130
around white doors so and one of the

1634
01:11:23,979 --> 01:11:28,929
nice things is if you have a planet with

1635
01:11:27,130 --> 01:11:31,090
an atmosphere that signal is very very

1636
01:11:28,930 --> 01:11:33,579
small for main sequence stars because

1637
01:11:31,090 --> 01:11:35,560
the signal the transit signal itself is

1638
01:11:33,579 --> 01:11:37,539
very small with a white dwarf you don't

1639
01:11:35,560 --> 01:11:39,010

have that problem so if there's a planet

1640
01:11:37,539 --> 01:11:41,560
around a white dwarf and if it has an

1641
01:11:39,010 --> 01:11:43,989
atmosphere it will be easily accessible

1642
01:11:41,560 --> 01:11:45,850
in our lifetimes compared to the earth

1643
01:11:43,989 --> 01:11:48,159
like planets around main sequence stars

1644
01:11:45,850 --> 01:11:50,100
or like earth-like or sun-like stars

1645
01:11:48,159 --> 01:11:53,289
that would be very hard to do and

1646
01:11:50,100 --> 01:11:56,050
especially if we look in the ultraviolet

1647
01:11:53,289 --> 01:11:58,689
there are these large comparatively to

1648
01:11:56,050 --> 01:12:03,070
the visible signatures of say oxygen or

1649
01:11:58,689 --> 01:12:05,409
ozone so I work on a ultraviolet

1650
01:12:03,069 --> 01:12:08,859
instrument I used to work on the costs

1651
01:12:05,409 --> 01:12:11,139
stiff steam and now it's Vikas team but

1652
01:12:08,859 --> 01:12:13,269
anyway costs has this really nice

1653
01:12:11,140 --> 01:12:15,490
ability that any spectrum it takes in

1654
01:12:13,270 --> 01:12:17,320
the ultraviolet can also be turned into

1655
01:12:15,489 --> 01:12:19,869
a light curve because the detector

1656
01:12:17,319 --> 01:12:23,319
records the time and location of every

1657
01:12:19,869 --> 01:12:25,300
photon that hits the detector and so any

1658
01:12:23,319 --> 01:12:27,309
spectrum that's ever been taken by the

1659
01:12:25,300 --> 01:12:30,400
cost instrument over the last five or

1660
01:12:27,310 --> 01:12:32,140
six years is also a UV light curve for

1661
01:12:30,399 --> 01:12:34,269
free so I have a friend here at the

1662
01:12:32,140 --> 01:12:36,520
Institute that developed software to

1663
01:12:34,270 --> 01:12:38,650
turn every cost spectrum whether people

1664
01:12:36,520 --> 01:12:40,840
wanted it to or not into a light curve

1665
01:12:38,649 --> 01:12:42,369
and so I asked him can you give me all

1666
01:12:40,840 --> 01:12:45,550
the white dwarfs please and there were

1667
01:12:42,369 --> 01:12:48,430
about a hundred and then I asked my high

1668
01:12:45,550 --> 01:12:53,289
school high school in turn Phoebe Santos

1669
01:12:48,430 --> 01:12:54,520
she's now a freshman at UMBC so keep an

1670
01:12:53,289 --> 01:12:57,189
eye out for her I think she has a bright

1671
01:12:54,520 --> 01:12:59,500
future because she taught herself how to

1672
01:12:57,189 --> 01:13:02,469
program a computer how to do research

1673
01:12:59,500 --> 01:13:04,600
and she found out that within our white

1674
01:13:02,470 --> 01:13:06,610
dwarfs some of them had been observed so

1675
01:13:04,600 --> 01:13:10,900
many times that you actually could have

1676
01:13:06,609 --> 01:13:13,779
seen for a range of periods things as

1677
01:13:10,899 --> 01:13:16,929
small as Pluto or maybe things even as

1678
01:13:13,779 --> 01:13:19,090
smallest series that's how sensitive

1679
01:13:16,930 --> 01:13:20,860
cost is when you have a lot of light and

1680
01:13:19,090 --> 01:13:23,319
you're talking about a white dwarf where

1681
01:13:20,859 --> 01:13:25,479
the signals are large so Phoebe did this

1682

01:13:23,319 --> 01:13:27,399
we have a paper that is accepted

1683
01:13:25,479 --> 01:13:29,289
by the astrophysical journal it will be

1684
01:13:27,399 --> 01:13:31,659
out soon but basically she discovered

1685
01:13:29,289 --> 01:13:33,279
that if you wanted to if you found a

1686
01:13:31,659 --> 01:13:35,260
transiting planet around a white dwarf

1687
01:13:33,279 --> 01:13:38,229
you could follow it up with Hubble and

1688
01:13:35,260 --> 01:13:39,940
get exquisite precision especially if it

1689
01:13:38,229 --> 01:13:41,439
was an earth-like planet down to the

1690
01:13:39,939 --> 01:13:44,500
levels that you would probably need to

1691
01:13:41,439 --> 01:13:46,988
look for an atmosphere so let's hope

1692
01:13:44,500 --> 01:13:50,319
cost doesn't die before we find an

1693
01:13:46,988 --> 01:13:52,869
interesting transiting planet so James

1694
01:13:50,319 --> 01:13:55,840
Webb will be very useful to you can look

1695
01:13:52,869 --> 01:13:57,789
at planets around white dwarfs in the

1696
01:13:55,840 --> 01:13:59,980

infrared just as easily as you can in

1697
01:13:57,789 --> 01:14:02,079
the visible or the OP or in the

1698
01:13:59,979 --> 01:14:04,719
ultraviolet there's a mission called

1699
01:14:02,079 --> 01:14:08,050
tests the transiting exoplanet survey

1700
01:14:04,720 --> 01:14:11,020
satellite it's going to look all across

1701
01:14:08,050 --> 01:14:12,699
the sky for transiting objects so it

1702
01:14:11,020 --> 01:14:15,520
will look at a few thousand white dwarfs

1703
01:14:12,699 --> 01:14:17,590
for free and so we will be able to maybe

1704
01:14:15,520 --> 01:14:19,420
hopefully answer the question of whether

1705
01:14:17,590 --> 01:14:21,850
there are habitable planets around white

1706
01:14:19,420 --> 01:14:23,500
dwarfs and if there are if you find a

1707
01:14:21,850 --> 01:14:26,110
lot of them then they may be the most

1708
01:14:23,500 --> 01:14:29,260
common type of habitable planet in the

1709
01:14:26,109 --> 01:14:31,238
universe so we have you know M Dwarfs as

1710
01:14:29,260 --> 01:14:32,560
a good candidate for habitable planets

1711
01:14:31,238 --> 01:14:34,719
because we've actually found some

1712
01:14:32,560 --> 01:14:36,640
interesting planets in close orbit we

1713
01:14:34,720 --> 01:14:38,949
have earth-like planets around sun-like

1714
01:14:36,640 --> 01:14:42,010
stars those are also very interesting

1715
01:14:38,949 --> 01:14:44,920
because we have one habitable planet

1716
01:14:42,010 --> 01:14:46,420
that we know for sure us and then a

1717
01:14:44,920 --> 01:14:48,430
whole bunch of other candidates that

1718
01:14:46,420 --> 01:14:50,920
might be interesting and then after them

1719
01:14:48,430 --> 01:14:53,230
white dwarfs are actually the next most

1720
01:14:50,920 --> 01:14:56,980
common type of star so if we can prove

1721
01:14:53,229 --> 01:14:59,259
that these stars have planets just like

1722
01:14:56,979 --> 01:15:00,849
all the other stars we seem to find that

1723
01:14:59,260 --> 01:15:02,650
have planets well then we'll be in

1724
01:15:00,850 --> 01:15:05,110
business will have three different types

1725
01:15:02,649 --> 01:15:07,238
of stars to understand plan information

1726
01:15:05,109 --> 01:15:09,609
about and even if we don't find any

1727
01:15:07,238 --> 01:15:11,049
planets around white dwarfs that's okay

1728
01:15:09,609 --> 01:15:13,539
because we certainly see the

1729
01:15:11,050 --> 01:15:15,670
fingerprints of rocky planets around

1730
01:15:13,539 --> 01:15:19,659
white doors and we can get a really good

1731
01:15:15,670 --> 01:15:24,069
idea of how rocky planets form in the

1732
01:15:19,659 --> 01:15:26,289
universe so dusty white dwarfs they have

1733
01:15:24,069 --> 01:15:29,619
tiny little disks they are caused by

1734
01:15:26,289 --> 01:15:32,380
asteroids that shred up the dust turns

1735
01:15:29,619 --> 01:15:33,340
into a disk it eventually accretes onto

1736
01:15:32,380 --> 01:15:36,670
the white dwarf and you get a

1737
01:15:33,340 --> 01:15:39,369
fingerprint of the dusts composition

1738
01:15:36,670 --> 01:15:43,119
right elements

1739

01:15:39,369 --> 01:15:45,729
and relative abundances and then we are

1740
01:15:43,119 --> 01:15:48,970
actually seeing this disintegration in

1741
01:15:45,729 --> 01:15:50,769
real time around dead stars and we think

1742
01:15:48,970 --> 01:15:52,210
there might be a lot of planets around

1743
01:15:50,770 --> 01:15:53,980
these white doors that are really

1744
01:15:52,210 --> 01:15:55,359
interesting to follow up on I should

1745
01:15:53,979 --> 01:15:57,309
also mention that James Webb will

1746
01:15:55,359 --> 01:15:59,859
actually be sensitive to find

1747
01:15:57,310 --> 01:16:01,539
jupiter-like planets at large

1748
01:15:59,859 --> 01:16:04,299
separations from their white doors

1749
01:16:01,539 --> 01:16:08,019
presumably the perturb airs that caused

1750
01:16:04,300 --> 01:16:10,270
all these dusty conundrums so with that

1751
01:16:08,020 --> 01:16:12,340
I'm just going to advertise a citizen

1752
01:16:10,270 --> 01:16:14,950
science project that I'm part of called

1753
01:16:12,340 --> 01:16:16,539

dis detective so if you like dust or if

1754
01:16:14,949 --> 01:16:17,800
I have suddenly convinced you that dust

1755
01:16:16,539 --> 01:16:20,350
is the most amazing thing in the

1756
01:16:17,800 --> 01:16:22,600
universe you can look for more dusty

1757
01:16:20,350 --> 01:16:25,570
stars with dis detective it's through

1758
01:16:22,600 --> 01:16:27,130
the Zooniverse website and that's a fun

1759
01:16:25,569 --> 01:16:30,369
thing to check out you'll you'll help us

1760
01:16:27,130 --> 01:16:32,050
find dusty stars yourself and with that

1761
01:16:30,369 --> 01:16:34,170
I will be happy to take questions thank

1762
01:16:32,050 --> 01:16:34,170
you

1763
01:16:39,270 --> 01:16:47,170
yes simulation analysis to see what did

1764
01:16:44,590 --> 01:16:49,360
it in our solar system the Goldilocks

1765
01:16:47,170 --> 01:16:51,309
zone move out is our son kind of

1766
01:16:49,359 --> 01:16:52,988
increased right so I haven't done that

1767
01:16:51,309 --> 01:16:55,570
but there are people who have looked

1768
01:16:52,988 --> 01:16:57,399
into that and yes what happens is the

1769
01:16:55,569 --> 01:17:01,389
you know the region where you can

1770
01:16:57,399 --> 01:17:04,899
sustain liquid water expands as the star

1771
01:17:01,389 --> 01:17:06,609
becomes a giant but the problem with

1772
01:17:04,899 --> 01:17:08,529
that or you know maybe it's a problem

1773
01:17:06,609 --> 01:17:10,839
maybe it's not is that the Stars

1774
01:17:08,529 --> 01:17:13,719
evolving pretty quickly so it gets big

1775
01:17:10,840 --> 01:17:17,559
pretty quickly and then eventually it

1776
01:17:13,719 --> 01:17:20,038
goes out so we think that that's

1777
01:17:17,559 --> 01:17:22,538
probably too quick for life to

1778
01:17:20,038 --> 01:17:26,319
spontaneously generate and evolve into

1779
01:17:22,538 --> 01:17:28,750
people that drink coffee but you know

1780
01:17:26,319 --> 01:17:31,238
you there are periods of evolution where

1781
01:17:28,750 --> 01:17:33,219
it you know the the Sun the star would

1782
01:17:31,238 --> 01:17:36,519
be a bit brighter so when it first

1783
01:17:33,219 --> 01:17:38,109
starts fusing helium it's sort of steady

1784
01:17:36,520 --> 01:17:40,059
for a while until it runs out of the

1785
01:17:38,109 --> 01:17:42,519
helium that's probably the next longest

1786
01:17:40,059 --> 01:17:44,590
time and now we push things a little bit

1787
01:17:42,520 --> 01:17:47,110
further out but yeah when when when

1788
01:17:44,590 --> 01:17:54,819
we're a giant star Titan will be pretty

1789
01:17:47,109 --> 01:17:57,479
nice yeah beachfront property how

1790
01:17:54,819 --> 01:17:59,439
quickly do some of these objects

1791
01:17:57,479 --> 01:18:02,828
disintegrate that produces something

1792
01:17:59,439 --> 01:18:04,569
okay the planetesimals yeah well yeah

1793
01:18:02,828 --> 01:18:06,908
that's a great question I don't think we

1794
01:18:04,569 --> 01:18:08,380
have a good answer for that yet I did I

1795
01:18:06,908 --> 01:18:11,469
personally did a few dynamical

1796

01:18:08,380 --> 01:18:14,409
simulations and when I found is at least

1797
01:18:11,469 --> 01:18:17,020
in the first pass what happens is the

1798
01:18:14,408 --> 01:18:18,908
asteroid gets shredded but then it all

1799
01:18:17,020 --> 01:18:20,860
just goes back out again because there's

1800
01:18:18,908 --> 01:18:22,899
really nothing slowing the material down

1801
01:18:20,859 --> 01:18:24,429
you would think maybe that all the

1802
01:18:22,899 --> 01:18:26,469
energy would dissipate in that at the

1803
01:18:24,429 --> 01:18:31,000
disruption but that's not what we found

1804
01:18:26,469 --> 01:18:32,649
another very talented researcher Dmitri

1805
01:18:31,000 --> 01:18:36,010
varus who's done a lot of work on this

1806
01:18:32,649 --> 01:18:38,649
kind of thing found that through mutual

1807
01:18:36,010 --> 01:18:40,210
collisions of the chunks that get torn

1808
01:18:38,649 --> 01:18:41,920
apart you eventually get something that

1809
01:18:40,210 --> 01:18:44,198
settles down maybe after a few hundred

1810
01:18:41,920 --> 01:18:46,059

orbital time scales but the question

1811
01:18:44,198 --> 01:18:48,009
it's not clear to me whether that's

1812
01:18:46,059 --> 01:18:50,679
orbital timescales very close to the

1813
01:18:48,010 --> 01:18:51,130
white door for that full eccentric orbit

1814
01:18:50,679 --> 01:18:53,260
where you

1815
01:18:51,130 --> 01:18:56,170
basically it started a few a you out and

1816
01:18:53,260 --> 01:18:58,329
came an so you're talking a few hundred

1817
01:18:56,170 --> 01:19:00,489
years maybe you would finally get things

1818
01:18:58,329 --> 01:19:02,198
settling down into a nice disc so the

1819
01:19:00,488 --> 01:19:03,908
question is do we see a whole bunch of

1820
01:19:02,198 --> 01:19:06,129
nice regular discs that have already

1821
01:19:03,908 --> 01:19:08,829
settled down or are we seeing different

1822
01:19:06,130 --> 01:19:10,359
phases of that settling and that's still

1823
01:19:08,829 --> 01:19:12,579
in a very much open question because

1824
01:19:10,359 --> 01:19:14,710
each system looks a little bit different

1825
01:19:12,579 --> 01:19:17,019
you know we don't really fully

1826
01:19:14,710 --> 01:19:18,250
understand the structure of these things

1827
01:19:17,020 --> 01:19:20,679
because all we have are a few

1828
01:19:18,250 --> 01:19:22,600
photometric points and that doesn't

1829
01:19:20,679 --> 01:19:24,399
really constrain the the structural

1830
01:19:22,600 --> 01:19:26,409
property or that you know the spatial

1831
01:19:24,399 --> 01:19:29,019
distribution of dust very well at this

1832
01:19:26,408 --> 01:19:30,879
point so there's still a lot of

1833
01:19:29,020 --> 01:19:32,260
questions about how this all works but

1834
01:19:30,880 --> 01:19:34,150
we we think we sort of have the general

1835
01:19:32,260 --> 01:19:35,980
picture and this is one of the few times

1836
01:19:34,149 --> 01:19:38,469
that I can think of in science where we

1837
01:19:35,979 --> 01:19:40,119
had a really crazy explanation for an

1838
01:19:38,469 --> 01:19:42,609
observation that required a lot of

1839
01:19:40,119 --> 01:19:44,198
looming complicated parts and it

1840
01:19:42,609 --> 01:19:46,359
actually you know as time goes on it's

1841
01:19:44,198 --> 01:19:47,799
become the best and best explanation

1842
01:19:46,359 --> 01:19:49,630
because as we get more and more

1843
01:19:47,800 --> 01:19:51,610
observations this crazy idea of some

1844
01:19:49,630 --> 01:19:53,800
random planetesimal far out getting

1845
01:19:51,609 --> 01:19:56,710
kicked all the way in and disintegrating

1846
01:19:53,800 --> 01:19:58,630
is what we keep seeing you know so our

1847
01:19:56,710 --> 01:20:01,029
next step really is to tie what we're

1848
01:19:58,630 --> 01:20:02,980
seeing directly to some planets that are

1849
01:20:01,029 --> 01:20:04,599
further out and that's we're not quite

1850
01:20:02,979 --> 01:20:06,638
there yet because we just don't have the

1851
01:20:04,600 --> 01:20:10,480
sensitivity to those far out planets

1852
01:20:06,639 --> 01:20:13,020
their old cold far away and small and so

1853

01:20:10,479 --> 01:20:15,698
we can't directly image them very well

1854
01:20:13,020 --> 01:20:18,510
you know maybe we can do something with

1855
01:20:15,698 --> 01:20:20,619
Gaia where they have like astrometric a

1856
01:20:18,510 --> 01:20:23,170
sort of precision where they could maybe

1857
01:20:20,619 --> 01:20:25,719
find some planets radial velocity

1858
01:20:23,170 --> 01:20:27,579
surveys wouldn't work because white

1859
01:20:25,719 --> 01:20:30,340
dwarfs just don't have enough lines to

1860
01:20:27,579 --> 01:20:33,309
get precise velocities so there's very

1861
01:20:30,340 --> 01:20:35,739
few ways to actually find planets far

1862
01:20:33,310 --> 01:20:38,110
away and that's what's limiting us right

1863
01:20:35,738 --> 01:20:42,789
now I'm really pitting down how all the

1864
01:20:38,109 --> 01:20:44,139
steps work other questions if you

1865
01:20:42,789 --> 01:20:48,039
mentioned something about the Kuiper

1866
01:20:44,139 --> 01:20:50,590
belt objects being culprit yes they

1867
01:20:48,039 --> 01:20:52,960

could also that they also could be we

1868
01:20:50,590 --> 01:20:55,139
actually find some white dwarfs that

1869
01:20:52,960 --> 01:20:57,730
have accreted water rich material or

1870
01:20:55,139 --> 01:20:59,590
carbonaceous water rich material they

1871
01:20:57,729 --> 01:21:02,138
seem to be rare compared to the ones

1872
01:20:59,590 --> 01:21:03,579
that just seem to be pure rocky but

1873
01:21:02,139 --> 01:21:06,010
there's still a question of whether

1874
01:21:03,579 --> 01:21:07,869
you know if you have a lot of Kuiper

1875
01:21:06,010 --> 01:21:10,090
belt objects that are sort of like hunks

1876
01:21:07,869 --> 01:21:12,279
of rock with a layer of ice the ice

1877
01:21:10,090 --> 01:21:14,170
would go away but the hunk of rock would

1878
01:21:12,279 --> 01:21:16,329
stay but if you have a bunch of dirty

1879
01:21:14,170 --> 01:21:18,819
snowballs that are just dust and ice

1880
01:21:16,329 --> 01:21:20,649
mixed together more finely that would

1881
01:21:18,819 --> 01:21:22,299
just turn into little dust clouds that

1882
01:21:20,649 --> 01:21:24,489
would dissipate before they would

1883
01:21:22,300 --> 01:21:26,860
accrete onto the white dwarf so

1884
01:21:24,489 --> 01:21:29,409
depending on what fraction of the dirty

1885
01:21:26,859 --> 01:21:31,179
snowballs versus icy rocks we have in

1886
01:21:29,409 --> 01:21:37,769
the Kuiper belt which I don't think is a

1887
01:21:31,180 --> 01:21:40,030
soft question yet it may be those are a

1888
01:21:37,770 --> 01:21:42,880
contributor but it's not clear to me how

1889
01:21:40,029 --> 01:21:45,069
much you also can do you it's much

1890
01:21:42,880 --> 01:21:48,819
easier to do it with one planet with the

1891
01:21:45,069 --> 01:21:50,500
sort of rocky interior asteroid belts

1892
01:21:48,819 --> 01:21:51,939
than it is with the Kuiper belt because

1893
01:21:50,500 --> 01:21:54,220
with the Kuiper belt you need more than

1894
01:21:51,939 --> 01:21:55,989
one planet which you know we're also

1895
01:21:54,220 --> 01:21:57,909
finding is fairly common that there are

1896
01:21:55,989 --> 01:21:59,710
multiple planet systems more often than

1897
01:21:57,909 --> 01:22:02,859
not so maybe that's not a real limiter

1898
01:21:59,710 --> 01:22:05,050
so we might be able to find through the

1899
01:22:02,859 --> 01:22:06,699
composition whether the relative rates

1900
01:22:05,050 --> 01:22:09,100
are but we're not at the point yet where

1901
01:22:06,699 --> 01:22:11,529
we say this was a comment this wasn't

1902
01:22:09,100 --> 01:22:15,039
astral and we can broadly say this was

1903
01:22:11,529 --> 01:22:17,949
rocky okay so John I have a question

1904
01:22:15,039 --> 01:22:21,189
sure um mario livio would say that the

1905
01:22:17,949 --> 01:22:24,279
sun isn't going to go red giant hmm that

1906
01:22:21,189 --> 01:22:26,469
it requires a two solar mass star to go

1907
01:22:24,279 --> 01:22:29,289
red giant and a lot of what you did uses

1908
01:22:26,470 --> 01:22:32,110
our solar system as a proxy for what

1909
01:22:29,289 --> 01:22:34,000
you're seeing in these if indeed mario

1910

01:22:32,109 --> 01:22:37,329
is correct and only two solar mass stars

1911
01:22:34,000 --> 01:22:39,609
and above can go red giant to to go

1912
01:22:37,329 --> 01:22:41,739
planetary nebula and such with that

1913
01:22:39,609 --> 01:22:43,809
change significantly or actually help

1914
01:22:41,739 --> 01:22:46,059
your ideas provided push you to a higher

1915
01:22:43,810 --> 01:22:47,530
accretion rate possibly yeah it would

1916
01:22:46,060 --> 01:22:50,320
certainly help because you would destroy

1917
01:22:47,529 --> 01:22:52,899
less material and presumably you'd have

1918
01:22:50,319 --> 01:22:54,489
more planets surviving as well so maybe

1919
01:22:52,899 --> 01:22:56,799
you'd have earth and some other things

1920
01:22:54,489 --> 01:22:59,800
surviving but at least for the more

1921
01:22:56,800 --> 01:23:02,529
canonical stellar evolution models that

1922
01:22:59,800 --> 01:23:05,710
people have done you know even though it

1923
01:23:02,529 --> 01:23:07,899
may not have quite the same evolution as

1924
01:23:05,710 --> 01:23:09,189

a two solar mass star the sudden at

1925
01:23:07,899 --> 01:23:11,829
least from what I've seen still is

1926
01:23:09,189 --> 01:23:16,750
predicted to get pretty large if not

1927
01:23:11,829 --> 01:23:19,059
like super huge I Mario

1928
01:23:16,750 --> 01:23:21,430
one raised these adamant Oh with this

1929
01:23:19,060 --> 01:23:24,880
conclusion mario's never wishy-washy no

1930
01:23:21,430 --> 01:23:29,430
no that's the they speak of astronomers

1931
01:23:24,880 --> 01:23:29,430
we are never in doubt although often in

1932
01:23:30,210 --> 01:23:37,840
arias all right I have one more question

1933
01:23:34,359 --> 01:23:39,880
um guys you talk about how the planets

1934
01:23:37,840 --> 01:23:43,750
around white dwarves but your plot

1935
01:23:39,880 --> 01:23:45,850
showed maximum of like 40 our orbits

1936
01:23:43,750 --> 01:23:47,770
okay so we're talking about orbiting an

1937
01:23:45,850 --> 01:23:50,740
entire star in what is essentially one

1938
01:23:47,770 --> 01:23:54,970
earth day yep does the term habitable

1939
01:23:50,739 --> 01:23:57,010
really apply right so depending on who

1940
01:23:54,970 --> 01:23:58,600
you talk to some people say you can't

1941
01:23:57,010 --> 01:24:00,699
get any sort of habitability there

1942
01:23:58,600 --> 01:24:02,410
because you'd be tidally locked so what

1943
01:24:00,699 --> 01:24:05,349
that means is you'd have one side of

1944
01:24:02,409 --> 01:24:08,319
your planet facing the star at all times

1945
01:24:05,350 --> 01:24:10,120
which eventually some people say due to

1946
01:24:08,319 --> 01:24:12,009
tidal interactions would actually kill

1947
01:24:10,119 --> 01:24:14,260
the planet it would just sort of mush it

1948
01:24:12,010 --> 01:24:17,560
up and make it too hot or it would crash

1949
01:24:14,260 --> 01:24:22,780
into the so that potential is certainly

1950
01:24:17,560 --> 01:24:25,060
there these are orbits that are just

1951
01:24:22,779 --> 01:24:28,989
outside the title disruption radius so

1952
01:24:25,060 --> 01:24:31,030
the planet should be physically okay the

1953
01:24:28,989 --> 01:24:32,859
but the details of how the title

1954
01:24:31,029 --> 01:24:34,840
evolution of a planet around a white

1955
01:24:32,859 --> 01:24:36,309
dwarf that's still probably an open

1956
01:24:34,840 --> 01:24:39,039
question because I don't know how well

1957
01:24:36,310 --> 01:24:42,780
we understand tides in that sort of

1958
01:24:39,039 --> 01:24:45,819
situation so I I prefer to be optimistic

1959
01:24:42,779 --> 01:24:47,829
it's so easy to find these things that I

1960
01:24:45,819 --> 01:24:50,439
think we will either find them or we

1961
01:24:47,829 --> 01:24:52,539
won't and then if we really I mean it's

1962
01:24:50,439 --> 01:24:54,939
really you know you don't have to find

1963
01:24:52,539 --> 01:24:56,560
you don't have to do this to like the

1964
01:24:54,939 --> 01:24:59,919
third significant figure you basically

1965
01:24:56,560 --> 01:25:01,750
have to say our white dwarfs orbited by

1966
01:24:59,920 --> 01:25:03,159
more or less than about you know if

1967

01:25:01,750 --> 01:25:05,949
fifty percent of white doors have some

1968
01:25:03,159 --> 01:25:07,659
kind of habitable star or less which we

1969
01:25:05,949 --> 01:25:09,309
can constrain with it by looking at a

1970
01:25:07,659 --> 01:25:11,920
few thousand white dwarves we basically

1971
01:25:09,310 --> 01:25:13,630
rule white dwarfs in or out as

1972
01:25:11,920 --> 01:25:15,010
interesting targets to look for

1973
01:25:13,630 --> 01:25:16,989
habitable world so I think we can do

1974
01:25:15,010 --> 01:25:18,720
this experiment once or twice with

1975
01:25:16,989 --> 01:25:21,039
existing technology or

1976
01:25:18,720 --> 01:25:22,510
soon-to-be-launched technology and then

1977
01:25:21,039 --> 01:25:24,100
sort of be done with that question on

1978
01:25:22,510 --> 01:25:25,869
the way we'll find really interesting

1979
01:25:24,100 --> 01:25:29,320
things like these disintegrating

1980
01:25:25,869 --> 01:25:31,809
planetesimals all right last quit

1981
01:25:29,319 --> 01:25:35,769

less chance of questions I don't see

1982
01:25:31,810 --> 01:25:38,320
anything but there is a question online

1983
01:25:35,770 --> 01:25:40,570
I wonder what influence changers T might

1984
01:25:38,319 --> 01:25:41,828
have regarding this field and you

1985
01:25:40,569 --> 01:25:44,500
actually did mention you answer that

1986
01:25:41,828 --> 01:25:49,149
yeah well I can answer it again it's

1987
01:25:44,500 --> 01:25:50,590
going to be huge yeah also since that's

1988
01:25:49,149 --> 01:25:52,569
where our bread and butter will become

1989
01:25:50,590 --> 01:25:54,730
for the next ten years I'm legally

1990
01:25:52,569 --> 01:25:57,158
obligated to promote James Webb but in

1991
01:25:54,729 --> 01:25:58,899
this case it's pretty easy to do I don't

1992
01:25:57,158 --> 01:26:00,698
have to really be forced to do it but

1993
01:25:58,899 --> 01:26:02,618
James Webb because it'll have

1994
01:26:00,698 --> 01:26:04,539
spectroscopic capability in the

1995
01:26:02,618 --> 01:26:05,948
mid-infrared not only will it be able to

1996
01:26:04,539 --> 01:26:08,019
find maybe the planets that are

1997
01:26:05,948 --> 01:26:11,289
perturbing the planetesimals it will

1998
01:26:08,020 --> 01:26:13,210
also directly characterize the dust that

1999
01:26:11,289 --> 01:26:15,069
we see so some of the brightest disks

2000
01:26:13,210 --> 01:26:18,179
that we've already found with Spitzer

2001
01:26:15,069 --> 01:26:20,799
and wise and Hubble those will be

2002
01:26:18,179 --> 01:26:23,889
characterized in very fine detail with

2003
01:26:20,800 --> 01:26:26,409
James webs spectroscopic capabilities

2004
01:26:23,889 --> 01:26:28,569
either through near cam or mirrored both

2005
01:26:26,408 --> 01:26:30,519
of them have the ability to basically do

2006
01:26:28,569 --> 01:26:33,189
the same kind of fingerprinting of the

2007
01:26:30,520 --> 01:26:35,530
dust but now we're looking at the stuff

2008
01:26:33,189 --> 01:26:37,809
in orbit so if we can find a lot of

2009
01:26:35,529 --> 01:26:39,939
white dwarfs that are accreting and so

2010
01:26:37,810 --> 01:26:41,980
we have very exquisite compositions and

2011
01:26:39,939 --> 01:26:44,289
the atmospheres we can compare them to

2012
01:26:41,979 --> 01:26:45,848
the fingerprints of the dust already in

2013
01:26:44,289 --> 01:26:47,920
orbit and that tells us something about

2014
01:26:45,849 --> 01:26:49,389
how well well we understand the

2015
01:26:47,920 --> 01:26:51,399
atmospheres of the white Doris which

2016
01:26:49,389 --> 01:26:54,368
gives us that predictive power for the

2017
01:26:51,399 --> 01:26:56,649
chemistry of this dust now you're really

2018
01:26:54,368 --> 01:26:58,960
test of how well we understand those

2019
01:26:56,649 --> 01:27:02,109
physics and hopefully we'll get a

2020
01:26:58,960 --> 01:27:03,819
consistent answer but we probably won't

2021
01:27:02,109 --> 01:27:06,729
because that's the way science works we

2022
01:27:03,819 --> 01:27:08,618
never have things all figured out all

2023
01:27:06,729 --> 01:27:12,189
right we're approaching 9 30 so I got to

2024

01:27:08,618 --> 01:27:15,158
cut things off next month we have Rachel

2025
01:27:12,189 --> 01:27:18,928
Austin speaking please come and join us

2026
01:27:15,158 --> 01:27:18,929
and let's give it one more hand for John

2027
01:27:32,479 --> 01:27:39,199
so I mean this is unit we had more time

2028
01:27:37,050 --> 01:27:39,199
I