PUBLIC LECTURE SERIES

To Catch A Dancing Star: The Story of "Extreme Precision" Spectroscopy

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Featuring Guest Speaker:
Arpita Roy

1
00:00:06,710 --> 00:00:04,630
hello and welcome to the space telescope

2
00:00:09,910 --> 00:00:06,720
public lecture series

3
00:00:13,350 --> 00:00:09,920
today's talk to catch a dancing star the

4
00:00:15,190 --> 00:00:13,360
story of extreme precision spectroscopy

5
00:00:18,230 --> 00:00:15,200
with arpeggio roy from the space

6
00:00:20,470 --> 00:00:18,240
telescope science institute

7
00:00:22,550 --> 00:00:20,480
i'm your host dr frank summers of the

8
00:00:23,750 --> 00:00:22,560
office of public outreach here at space

9
00:00:26,470 --> 00:00:23,760
telescope

10
00:00:28,150 --> 00:00:26,480
and i always always want to thank the

11
00:00:30,950 --> 00:00:28,160
amazing tech team that gets it set up

12
00:00:32,709 --> 00:00:30,960
for to stream this out thomas marufu and

13
00:00:34,310 --> 00:00:32,719

grant justice

14
00:00:35,670 --> 00:00:34,320
i will also note that the space

15
00:00:38,310 --> 00:00:35,680
telescope public

16
00:00:39,750 --> 00:00:38,320
lecture series will be online only until

17
00:00:41,590 --> 00:00:39,760
further notice

18
00:00:44,630 --> 00:00:41,600
we did have somebody send in a question

19
00:00:45,510 --> 00:00:44,640
about why is this and when will we be be

20
00:00:47,430 --> 00:00:45,520
back

21
00:00:49,750 --> 00:00:47,440
unfortunately i can't give you a direct

22
00:00:52,869 --> 00:00:49,760
answer when will we be when we will be

23
00:00:56,150 --> 00:00:52,879
back the answer is basically whenever

24
00:00:59,349 --> 00:00:56,160
it's safe for 150 people to congregate

25
00:01:01,430 --> 00:00:59,359
in an auditorium at close distance for

26
00:01:02,470 --> 00:01:01,440
about two hours okay

27
00:01:04,229 --> 00:01:02,480
um

28
00:01:06,630 --> 00:01:04,239
i honestly haven't been back in the

29
00:01:08,550 --> 00:01:06,640
office but four or five times since the

30
00:01:10,149 --> 00:01:08,560
start of the pandemic and we're being

31
00:01:12,230 --> 00:01:10,159
kind of careful because we're now the

32
00:01:14,950 --> 00:01:12,240
missions operations center of the james

33
00:01:16,870 --> 00:01:14,960
webb space telescope so i really can't

34
00:01:18,789 --> 00:01:16,880
tell you when will we be when we will be

35
00:01:21,350 --> 00:01:18,799
back but

36
00:01:23,190 --> 00:01:21,360
i will continue to reevaluate as things

37
00:01:24,789 --> 00:01:23,200
progress

38
00:01:25,830 --> 00:01:24,799

you want to know about our upcoming

39
00:01:29,030 --> 00:01:25,840
lectures

40
00:01:30,670 --> 00:01:29,040
next month on march 1st we have hubble

41
00:01:33,749 --> 00:01:30,680
from space and integral field

42
00:01:36,469 --> 00:01:33,759
spectroscopy from the ground seeing both

43
00:01:38,550 --> 00:01:36,479
the forests and the trees and this is

44
00:01:41,510 --> 00:01:38,560
going to be our first lecture from

45
00:01:45,030 --> 00:01:41,520
across the pond mark sazi

46
00:01:46,710 --> 00:01:45,040
of arma observatory and planetarium

47
00:01:48,870 --> 00:01:46,720
on april 5th

48
00:01:49,670 --> 00:01:48,880
we will have neutrino astronomy with ice

49
00:01:51,590 --> 00:01:49,680
cube

50
00:01:55,670 --> 00:01:51,600
from marco santander of the university

51
00:01:57,910 --> 00:01:55,680
of alabama and on may 3rd a wonderful

52
00:01:59,749 --> 00:01:57,920
speaker will prevent present a

53
00:02:01,510 --> 00:01:59,759
fascinating topic

54
00:02:03,190 --> 00:02:01,520
i actually have to choose between a

55
00:02:05,830 --> 00:02:03,200
couple speakers for that and we have not

56
00:02:07,749 --> 00:02:05,840
gotten that set just yet but that will

57
00:02:09,990 --> 00:02:07,759
be set very very soon

58
00:02:11,710 --> 00:02:10,000
you can find out about it when it is set

59
00:02:13,589 --> 00:02:11,720
on our website

60
00:02:16,390 --> 00:02:13,599
sdsci.edu

61
00:02:20,390 --> 00:02:16,400
public hyphen lectures where you will

62
00:02:22,390 --> 00:02:20,400
find a list links to our webcasts and

63
00:02:24,630 --> 00:02:22,400

also a helpful button

64
00:02:26,150 --> 00:02:24,640
where you can subscribe to our email

65
00:02:30,150 --> 00:02:26,160
list

66
00:02:32,150 --> 00:02:30,160
all the upcoming lectures

67
00:02:34,710 --> 00:02:32,160
and if you click on any one of those

68
00:02:37,190 --> 00:02:34,720
lectures you find all the details about

69
00:02:40,390 --> 00:02:37,200
it including after it's been recorded

70
00:02:43,190 --> 00:02:40,400
the link to the stsci webcast as well as

71
00:02:45,830 --> 00:02:43,200
the webcast on youtube

72
00:02:48,070 --> 00:02:45,840
uh the email that i talked about well

73
00:02:50,710 --> 00:02:48,080
the announcements are just much easiest

74
00:02:53,270 --> 00:02:50,720
to sign up at the at the website

75
00:02:55,670 --> 00:02:53,280
you can also subscribe to our youtube

76
00:02:58,790 --> 00:02:55,680
channel which is youtube.com slash

77
00:03:01,750 --> 00:02:58,800
hubble space telescope all one word

78
00:03:04,470 --> 00:03:01,760
and you will get new video notices and

79
00:03:05,830 --> 00:03:04,480
reminders of these live events

80
00:03:08,470 --> 00:03:05,840
finally if you have comments or

81
00:03:10,630 --> 00:03:08,480
questions you can send them to us via

82
00:03:13,830 --> 00:03:10,640
the email address public lecture

83
00:03:18,710 --> 00:03:17,030
you can also contact us via social media

84
00:03:20,949 --> 00:03:18,720
we have social media accounts for the

85
00:03:22,470 --> 00:03:20,959
hubble space telescope for the web

86
00:03:24,550 --> 00:03:22,480
space telescope and for the space

87
00:03:27,110 --> 00:03:24,560
telescope science institute as you can

88
00:03:30,229 --> 00:03:27,120

see on facebook twitter youtube and

89
00:03:32,550 --> 00:03:30,239
instagram i myself do a tiny tiny amount

90
00:03:35,990 --> 00:03:32,560
of social media on facebook and twitter

91
00:03:38,070 --> 00:03:36,000
as dr frank summers

92
00:03:41,110 --> 00:03:38,080
and now the news from the universe for

93
00:03:43,270 --> 00:03:41,120
february 2022

94
00:03:47,110 --> 00:03:43,280
our top story tonight

95
00:03:49,270 --> 00:03:47,120
home home on lagrange or if you actually

96
00:03:52,470 --> 00:03:49,280
speak french it would be lagrange

97
00:03:55,270 --> 00:03:52,480
because we are talking about the james

98
00:03:59,190 --> 00:03:55,280
webb space telescope which has finally

99
00:04:01,190 --> 00:03:59,200
made it home at lagrange point 2.

100
00:04:03,990 --> 00:04:01,200
now last month if you were paying

101
00:04:05,990 --> 00:04:04,000
attention uh you know that astronomers

102
00:04:08,070 --> 00:04:06,000
got their holiday present with the

103
00:04:09,910 --> 00:04:08,080
launch of the james webb space telescope

104
00:04:12,869 --> 00:04:09,920
on christmas day

105
00:04:17,110 --> 00:04:12,879
and since then it has been doing its

106
00:04:19,909 --> 00:04:17,120
unfolding on its way out to the l2 point

107
00:04:22,550 --> 00:04:19,919
let's see so last time it was january

108
00:04:24,550 --> 00:04:22,560
3rd or 4th and the sunshield had just

109
00:04:27,510 --> 00:04:24,560
finished deploying okay

110
00:04:29,189 --> 00:04:27,520
after that the secondary mirror unfolds

111
00:04:32,070 --> 00:04:29,199
so you can see here that the secondary

112
00:04:34,950 --> 00:04:32,080
mirror which is this uh strut out here

113
00:04:36,870 --> 00:04:34,960

that unfold and on january 7th and 8th

114
00:04:40,150 --> 00:04:36,880
the wings of the mirror these three

115
00:04:43,510 --> 00:04:40,160
mirrors on either side they unfolded and

116
00:04:45,189 --> 00:04:43,520
by january 8th we had a full telescope

117
00:04:47,830 --> 00:04:45,199
it looked like you know all the pictures

118
00:04:50,870 --> 00:04:47,840
we've shown of you until now it finished

119
00:04:52,870 --> 00:04:50,880
its unfolding and this was immense a

120
00:04:54,550 --> 00:04:52,880
source of relief for us

121
00:04:57,030 --> 00:04:54,560
on the project

122
00:04:59,670 --> 00:04:57,040
i also showed you this diagram

123
00:05:01,749 --> 00:04:59,680
showing webb's path to the lagrangian

124
00:05:03,909 --> 00:05:01,759
two point and this notice that it

125
00:05:05,909 --> 00:05:03,919
doesn't actually sit at the lagrangian

126
00:05:07,990 --> 00:05:05,919
two point it orbits around the

127
00:05:11,590 --> 00:05:08,000
lagrangian dew point matter of fact the

128
00:05:14,790 --> 00:05:11,600
diameter of this orbit is almost the

129
00:05:17,510 --> 00:05:14,800
same distance as it is away from earth

130
00:05:19,990 --> 00:05:17,520
so it's a really really big orbit okay

131
00:05:22,390 --> 00:05:20,000
they call these orbits halo orbits

132
00:05:25,110 --> 00:05:22,400
and it actually takes about six months

133
00:05:26,870 --> 00:05:25,120
to go around this orbit

134
00:05:28,950 --> 00:05:26,880
and in order to stay in this orbit it

135
00:05:31,029 --> 00:05:28,960
has to do a little station keeping uh

136
00:05:33,670 --> 00:05:31,039
just a little uh thrustered thruster

137
00:05:35,830 --> 00:05:33,680
bursts every two weeks they plan those

138
00:05:37,909 --> 00:05:35,840

to be so you know it's it's a big giant

139
00:05:40,070 --> 00:05:37,919
orbit you know it has just a tiny little

140
00:05:41,510 --> 00:05:40,080
bit of station keeping uh to keep it on

141
00:05:43,510 --> 00:05:41,520
this on this orbit

142
00:05:45,830 --> 00:05:43,520
and basically you can think of this very

143
00:05:48,870 --> 00:05:45,840
first orbit around the lagrangian two

144
00:05:51,510 --> 00:05:48,880
point as the commissioning time scale

145
00:05:53,749 --> 00:05:51,520
now you want proof that web is out there

146
00:05:55,670 --> 00:05:53,759
um i can't give you absolute proof but i

147
00:05:58,790 --> 00:05:55,680
can give you a picture

148
00:06:01,029 --> 00:05:58,800
that uh taken by a group of folks who

149
00:06:03,189 --> 00:06:01,039
run the virtual telescope

150
00:06:05,029 --> 00:06:03,199
and they tell us that tiny little dot

151
00:06:07,670 --> 00:06:05,039
right in there that tiny little dot in

152
00:06:09,670 --> 00:06:07,680
there is the james webb space telescope

153
00:06:12,790 --> 00:06:09,680
now this was taken after the sun shield

154
00:06:15,110 --> 00:06:12,800
had had unfolded so web is actually

155
00:06:17,270 --> 00:06:15,120
highly reflective on its backside that

156
00:06:19,189 --> 00:06:17,280
faces earth right because of course it's

157
00:06:20,790 --> 00:06:19,199
blocking all the sun so it's highly

158
00:06:22,950 --> 00:06:20,800
reflective there and they can get this

159
00:06:24,550 --> 00:06:22,960
picture of webb

160
00:06:26,390 --> 00:06:24,560
kind of cool

161
00:06:29,029 --> 00:06:26,400
if you want to know what's next for webb

162
00:06:30,550 --> 00:06:29,039
well during this first orbit

163
00:06:31,590 --> 00:06:30,560

we're going to be doing commissioning

164
00:06:33,270 --> 00:06:31,600
okay

165
00:06:34,950 --> 00:06:33,280
so the first thing mirror alignment

166
00:06:36,790 --> 00:06:34,960
they've already unlocked the mirrors and

167
00:06:38,390 --> 00:06:36,800
moved them out of their launch positions

168
00:06:39,830 --> 00:06:38,400
they're sort of uh they're they're

169
00:06:41,510 --> 00:06:39,840
locked down for launch so that they

170
00:06:42,950 --> 00:06:41,520
don't vibrate too much and they've been

171
00:06:45,510 --> 00:06:42,960
released and now they're gonna start

172
00:06:47,830 --> 00:06:45,520
doing focusing all right and focusing

173
00:06:49,510 --> 00:06:47,840
begins with what we call first light the

174
00:06:51,270 --> 00:06:49,520
first

175
00:06:55,150 --> 00:06:51,280
photons that get processed by the

176
00:06:56,790 --> 00:06:55,160
telescope and they chose this star hd

177
00:06:58,150 --> 00:06:56,800
84406

178
00:07:00,469 --> 00:06:58,160
which is a bright star in the

179
00:07:03,110 --> 00:07:00,479
constellation ursa major

180
00:07:04,710 --> 00:07:03,120
and it's actually much too bright for uh

181
00:07:06,710 --> 00:07:04,720
webb to observe when up when web is

182
00:07:08,150 --> 00:07:06,720
fully focused okay this is a six and a

183
00:07:10,629 --> 00:07:08,160
half magnitude star and that's too

184
00:07:12,230 --> 00:07:10,639
bright for a web to look at but it

185
00:07:14,309 --> 00:07:12,240
actually works very well for just the

186
00:07:15,589 --> 00:07:14,319
initial work of getting focused because

187
00:07:17,029 --> 00:07:15,599
you know the first images that we're

188
00:07:18,870 --> 00:07:17,039

going to get aren't going to be bright

189
00:07:21,430 --> 00:07:18,880
crisp images they're going to be blurry

190
00:07:23,270 --> 00:07:21,440
um and then they'll spend three months

191
00:07:25,830 --> 00:07:23,280
that's it's going to take three months

192
00:07:27,670 --> 00:07:25,840
because you've got 18 mirrors and you've

193
00:07:29,909 --> 00:07:27,680
got multiple instruments spread across

194
00:07:31,909 --> 00:07:29,919
the focus plane and you've got to check

195
00:07:33,830 --> 00:07:31,919
that the focus is perfect on every

196
00:07:36,469 --> 00:07:33,840
single one of those instruments through

197
00:07:40,070 --> 00:07:36,479
and adjust all 18 mirrors so these tiny

198
00:07:41,909 --> 00:07:40,080
tiny tiny little adjustments okay so

199
00:07:43,350 --> 00:07:41,919
yeah that's going to take three months

200
00:07:46,230 --> 00:07:43,360
uh the other thing that's going on also

201
00:07:47,909 --> 00:07:46,240
of course is the cooling and outgassing

202
00:07:50,469 --> 00:07:47,919
now the instruments have been kept

203
00:07:53,270 --> 00:07:50,479
heated okay they're just been heated so

204
00:07:55,749 --> 00:07:53,280
that as they out gas some of the the

205
00:07:57,830 --> 00:07:55,759
outgas things don't deposit onto the

206
00:08:00,309 --> 00:07:57,840
instruments themselves for example if

207
00:08:01,830 --> 00:08:00,319
water vapor outgasses and it deposits on

208
00:08:03,670 --> 00:08:01,840
the in the industry it could freeze and

209
00:08:04,550 --> 00:08:03,680
you can get ice and that would be a bad

210
00:08:06,550 --> 00:08:04,560
thing

211
00:08:07,830 --> 00:08:06,560
so they will start turning off those

212
00:08:09,830 --> 00:08:07,840
heaters i think they've already turned

213
00:08:11,670 --> 00:08:09,840

off one i'm not exactly sure

214
00:08:13,350 --> 00:08:11,680
and then let the instruments passively

215
00:08:15,510 --> 00:08:13,360
cool once they figure all the outgassing

216
00:08:17,350 --> 00:08:15,520
that needs to occur has occurred they'll

217
00:08:20,629 --> 00:08:17,360
turn them off and let them cool and they

218
00:08:22,469 --> 00:08:20,639
really have to cool way way way way way

219
00:08:24,150 --> 00:08:22,479
way down

220
00:08:26,070 --> 00:08:24,160
you're going to get to

221
00:08:27,830 --> 00:08:26,080
40 kelvin for the near infrared

222
00:08:30,790 --> 00:08:27,840
instruments um

223
00:08:34,230 --> 00:08:30,800
40 kelvin scale is the absolute scale

224
00:08:37,630 --> 00:08:34,240
it's 273 degree degrees below zero

225
00:08:40,709 --> 00:08:37,640
centigrade which is like twice that like

226
00:08:43,190 --> 00:08:40,719
470 degrees below zero fahrenheit

227
00:08:45,269 --> 00:08:43,200
um and the miri actually has a cryo

228
00:08:46,550 --> 00:08:45,279
cooler to get it even colder mary is the

229
00:08:48,870 --> 00:08:46,560
mid-infamous

230
00:08:50,710 --> 00:08:48,880
mid infrared instrument and that

231
00:08:53,829 --> 00:08:50,720
cryo-cooler will get that down to six

232
00:08:55,350 --> 00:08:53,839
kelvin six degrees above absolute zero

233
00:08:58,550 --> 00:08:55,360
and that's the kind of temperatures you

234
00:09:01,030 --> 00:08:58,560
want to get to do research level science

235
00:09:03,350 --> 00:09:01,040
in the infrared

236
00:09:05,269 --> 00:09:03,360
also during this first orbit they will

237
00:09:07,269 --> 00:09:05,279
be doing instrument checkout

238
00:09:08,710 --> 00:09:07,279

they have lots of instruments and these

239
00:09:11,350 --> 00:09:08,720
instruments have lots of different

240
00:09:13,509 --> 00:09:11,360
observing modes and every single one of

241
00:09:16,389 --> 00:09:13,519
them must be put through its paces with

242
00:09:18,550 --> 00:09:16,399
you know guide star with the sample

243
00:09:20,230 --> 00:09:18,560
observations out there and so there's

244
00:09:21,829 --> 00:09:20,240
just i mean this telescope is really

245
00:09:23,670 --> 00:09:21,839
really powerful and could do many many

246
00:09:25,110 --> 00:09:23,680
things but every single one of those

247
00:09:26,470 --> 00:09:25,120
things needs to be checked out during

248
00:09:28,310 --> 00:09:26,480
commissioning

249
00:09:29,350 --> 00:09:28,320
that is why it's going to take six

250
00:09:31,269 --> 00:09:29,360
months

251
00:09:32,710 --> 00:09:31,279
so the associated universities for

252
00:09:34,550 --> 00:09:32,720
research and astronomy put out this

253
00:09:37,430 --> 00:09:34,560
really cool graphic all right so it's

254
00:09:39,269 --> 00:09:37,440
cool to us geeks okay um

255
00:09:41,750 --> 00:09:39,279
you know how you can download it i think

256
00:09:43,990 --> 00:09:41,760
they posted it on twitter about the web

257
00:09:45,509 --> 00:09:44,000
commissioning and you can follow all of

258
00:09:48,150 --> 00:09:45,519
the various things that should be

259
00:09:51,030 --> 00:09:48,160
happening over the course of this first

260
00:09:53,509 --> 00:09:51,040
orbit this first six months and we can

261
00:09:55,430 --> 00:09:53,519
you can expect that we will get

262
00:09:56,389 --> 00:09:55,440
actual observations released to the

263
00:09:59,030 --> 00:09:56,399

public

264
00:10:00,310 --> 00:09:59,040
starting in earliest july fourth time

265
00:10:02,710 --> 00:10:00,320
frame okay

266
00:10:05,910 --> 00:10:02,720
so that's uh that's the next six months

267
00:10:07,269 --> 00:10:05,920
of web and it's it's a really exciting

268
00:10:08,230 --> 00:10:07,279
time okay

269
00:10:10,389 --> 00:10:08,240
all right

270
00:10:12,310 --> 00:10:10,399
as i gave you last week if you want

271
00:10:13,750 --> 00:10:12,320
ongoing web info you can go to this

272
00:10:14,710 --> 00:10:13,760
where is web

273
00:10:17,190 --> 00:10:14,720
website

274
00:10:19,269 --> 00:10:17,200
um you can go to the nasa web blog which

275
00:10:21,269 --> 00:10:19,279
is actually the place i go to most these

276
00:10:23,430 --> 00:10:21,279
days uh now that you know the unfolding

277
00:10:26,230 --> 00:10:23,440
is all happening the nasa web blog has

278
00:10:28,069 --> 00:10:26,240
the uh the cool information um and then

279
00:10:29,430 --> 00:10:28,079
when special things happen maybe they'll

280
00:10:33,110 --> 00:10:29,440
do some doing something special for

281
00:10:34,389 --> 00:10:33,120
first light um nasa live

282
00:10:36,790 --> 00:10:34,399
okay

283
00:10:38,870 --> 00:10:36,800
so a second story today and just a

284
00:10:41,670 --> 00:10:38,880
little short one because i knew webb was

285
00:10:44,949 --> 00:10:41,680
going to be a long one um but ada carney

286
00:10:48,310 --> 00:10:44,959
erupts into 3d

287
00:10:51,750 --> 00:10:48,320
so these are some nasa observations of

288
00:10:53,670 --> 00:10:51,760

uh the massive massive star eta rna now

289
00:10:56,230 --> 00:10:53,680
you'll also you'll often hear people say

290
00:10:58,230 --> 00:10:56,240
call it eta carinae okay that's actually

291
00:11:00,630 --> 00:10:58,240
wrong because the fault the correct name

292
00:11:02,790 --> 00:11:00,640
is eta carnae but of course that's kind

293
00:11:04,470 --> 00:11:02,800
of funky to say so everyone just calls

294
00:11:06,310 --> 00:11:04,480
it ada car okay

295
00:11:09,430 --> 00:11:06,320
and ada car is one of the most massive

296
00:11:11,990 --> 00:11:09,440
stars known and in 18 in the 1840s it

297
00:11:13,829 --> 00:11:12,000
had this eruption okay

298
00:11:15,910 --> 00:11:13,839
and what it did and you can see here

299
00:11:17,350 --> 00:11:15,920
invisible is it actually blew out a

300
00:11:19,190 --> 00:11:17,360
small nebula this is called the

301
00:11:20,790 --> 00:11:19,200
homunculus nebula

302
00:11:21,910 --> 00:11:20,800
and hubble has looked at it several

303
00:11:23,350 --> 00:11:21,920
times

304
00:11:25,509 --> 00:11:23,360
and this is actually hubble's

305
00:11:27,350 --> 00:11:25,519
observations in the ultraviolet and

306
00:11:28,630 --> 00:11:27,360
hubble's observations in the hydrogen

307
00:11:30,630 --> 00:11:28,640
alpha filter

308
00:11:33,350 --> 00:11:30,640
also the chandra space telescope has

309
00:11:34,630 --> 00:11:33,360
observed it and here are these x-rays

310
00:11:36,870 --> 00:11:34,640
all right

311
00:11:38,870 --> 00:11:36,880
and so what our team did here at space

312
00:11:43,269 --> 00:11:38,880
telescope science institute

313
00:11:45,350 --> 00:11:43,279

is take these images and turn them into

314
00:11:47,430 --> 00:11:45,360
three-dimensional models

315
00:11:49,190 --> 00:11:47,440
so here is a small little movie of it

316
00:11:51,190 --> 00:11:49,200
starting with a visible light homunculus

317
00:11:53,910 --> 00:11:51,200
nebula and you can see the dumbbell

318
00:11:55,590 --> 00:11:53,920
shape of it sort of the hourglass shape

319
00:11:58,790 --> 00:11:55,600
and then some of that ultraviolet light

320
00:12:00,870 --> 00:11:58,800
spreads through the uh homunculus nebula

321
00:12:03,030 --> 00:12:00,880
and outside of that is gas that was

322
00:12:05,030 --> 00:12:03,040
ejected from ada car that's heated up to

323
00:12:07,190 --> 00:12:05,040
hydrogen alpha temperatures and then

324
00:12:09,350 --> 00:12:07,200
there's this x-ray gas out of the edge

325
00:12:11,509 --> 00:12:09,360
which actually makes no sense because

326
00:12:14,069 --> 00:12:11,519
why should the highest energy stuff be

327
00:12:16,949 --> 00:12:14,079
the farthest away from the star

328
00:12:18,389 --> 00:12:16,959
well i know you want to know more so go

329
00:12:20,069 --> 00:12:18,399
to hubble site or universe of

330
00:12:22,949 --> 00:12:20,079
learning.org

331
00:12:25,350 --> 00:12:22,959
there you will find the full videos

332
00:12:27,030 --> 00:12:25,360
the full one is ada rna the

333
00:12:29,190 --> 00:12:27,040
the great eruption of a massive star

334
00:12:31,110 --> 00:12:29,200
it's a four and a half minute video that

335
00:12:33,670 --> 00:12:31,120
goes through it and explains a good

336
00:12:35,269 --> 00:12:33,680
amount of it and then we have this uh

337
00:12:36,230 --> 00:12:35,279
shorter one which is about a minute and

338
00:12:37,590 --> 00:12:36,240

a half

339
00:12:39,670 --> 00:12:37,600
which is just the three-dimensional

340
00:12:42,069 --> 00:12:39,680
models um but it goes through it much

341
00:12:43,910 --> 00:12:42,079
more slowly so you can watch it what i

342
00:12:45,990 --> 00:12:43,920
just showed you is what we put on social

343
00:12:48,230 --> 00:12:46,000
media and social media says i can't do

344
00:12:50,470 --> 00:12:48,240
anything more than 30 seconds so you got

345
00:12:55,110 --> 00:12:50,480
the 30-second version but the longer

346
00:12:59,030 --> 00:12:57,110
so let's go to our featured speaker

347
00:13:02,310 --> 00:12:59,040
tonight um

348
00:13:05,190 --> 00:13:02,320
arbiter roy is an astronomer here at the

349
00:13:07,670 --> 00:13:05,200
space telescope science institute she's

350
00:13:09,430 --> 00:13:07,680
been here just over a year so

351
00:13:12,550 --> 00:13:09,440
um like another of our speakers that

352
00:13:13,350 --> 00:13:12,560
introduced she works at sdsci but she's

353
00:13:14,949 --> 00:13:13,360
never

354
00:13:17,509 --> 00:13:14,959
been in an office i'm not sure she even

355
00:13:18,790 --> 00:13:17,519
has an office um we've hired some people

356
00:13:20,870 --> 00:13:18,800
that

357
00:13:23,670 --> 00:13:20,880
never been in in the office

358
00:13:26,629 --> 00:13:23,680
she came to us from a postdoc at cal

359
00:13:28,470 --> 00:13:26,639
tech where she was a milliken fellow

360
00:13:31,430 --> 00:13:28,480
and before that she did her graduate

361
00:13:33,670 --> 00:13:31,440
work at penn state

362
00:13:35,030 --> 00:13:33,680
here at space telescope she is working

363
00:13:35,750 --> 00:13:35,040

on um

364
00:13:41,350 --> 00:13:35,760
the

365
00:13:42,710 --> 00:13:41,360
infrared um uh spectra spectrograph

366
00:13:46,470 --> 00:13:42,720
called nearest

367
00:13:48,870 --> 00:13:46,480
and um she has a good experience in a

368
00:13:50,629 --> 00:13:48,880
range of astronomy doing building

369
00:13:52,710 --> 00:13:50,639
instruments observing with those

370
00:13:55,509 --> 00:13:52,720
instruments and doing the analysis of

371
00:13:57,750 --> 00:13:55,519
the data she's not a specialist

372
00:14:00,310 --> 00:13:57,760
and i always ask my speakers for one

373
00:14:02,389 --> 00:14:00,320
interesting thing about them and what

374
00:14:04,069 --> 00:14:02,399
arpata told me was that

375
00:14:05,509 --> 00:14:04,079
when she did her undergraduate work she

376
00:14:07,750 --> 00:14:05,519
was a double major

377
00:14:10,629 --> 00:14:07,760
yeah she did the usual geek science one

378
00:14:13,030 --> 00:14:10,639
but she also has a degree in creative

379
00:14:14,949 --> 00:14:13,040
writing so we have a wonderfully

380
00:14:19,110 --> 00:14:14,959
creative astronomer to present tonight

381
00:14:23,670 --> 00:14:21,269
thanks frank um it's a pleasure to be

382
00:14:27,110 --> 00:14:23,680
here today to talk to you

383
00:14:29,430 --> 00:14:27,120
about stars and measuring their emotions

384
00:14:32,310 --> 00:14:29,440
and to tell you the story of extreme

385
00:14:34,629 --> 00:14:32,320
precision spectroscopy

386
00:14:36,550 --> 00:14:34,639
now this is a story of technology

387
00:14:38,870 --> 00:14:36,560
development so extreme precision

388
00:14:40,710 --> 00:14:38,880

spectroscopy is a is a measurement

389
00:14:43,030 --> 00:14:40,720
method that we use

390
00:14:44,470 --> 00:14:43,040
and its trajectory was driven by a

391
00:14:47,110 --> 00:14:44,480
science question

392
00:14:48,949 --> 00:14:47,120
that of catching dancing stars

393
00:14:50,949 --> 00:14:48,959
now to catch a dancing star you might

394
00:14:53,189 --> 00:14:50,959
say it's kind of big sounds a little bit

395
00:14:55,750 --> 00:14:53,199
poetic so let me ground that in a little

396
00:14:58,069 --> 00:14:55,760
bit more physics language for you so

397
00:15:03,030 --> 00:14:58,079
really what we're talking about is to

398
00:15:08,629 --> 00:15:06,069
now our story begins in the 1500s

399
00:15:10,790 --> 00:15:08,639
astronomy of course is an ancient art

400
00:15:12,470 --> 00:15:10,800
people have been looking to the heavens

401
00:15:13,829 --> 00:15:12,480
almost as long as there has been

402
00:15:17,030 --> 00:15:13,839
humanity

403
00:15:19,670 --> 00:15:17,040
but this is still about 500 years ago

404
00:15:21,430 --> 00:15:19,680
we're still in early astronomy

405
00:15:23,750 --> 00:15:21,440
now these early observations of

406
00:15:26,230 --> 00:15:23,760
astronomy mostly related

407
00:15:28,069 --> 00:15:26,240
to measuring the motions of planets so

408
00:15:30,550 --> 00:15:28,079
when our ancestors looked up to the

409
00:15:33,990 --> 00:15:30,560
skies they observed what looked like a

410
00:15:35,749 --> 00:15:34,000
fixed grid of stars and moving planets

411
00:15:39,509 --> 00:15:35,759
against them which is why planets were

412
00:15:41,749 --> 00:15:39,519
called planets or wandering stars

413
00:15:44,230 --> 00:15:41,759

now to them the stars were merely fixed

414
00:15:46,389 --> 00:15:44,240
points of reference and it aided them to

415
00:15:48,389 --> 00:15:46,399
measure uh things like the planets the

416
00:15:52,069 --> 00:15:48,399
moon and the sun that were moving on

417
00:15:57,910 --> 00:15:54,710
this outlook continued into the early

418
00:16:00,150 --> 00:15:57,920
1700s and so if you had asked an

419
00:16:02,150 --> 00:16:00,160
astronomer of this time if the stars

420
00:16:04,870 --> 00:16:02,160
were truly fixed

421
00:16:06,870 --> 00:16:04,880
they might have hypothesized that these

422
00:16:09,509 --> 00:16:06,880
might be moving bodies

423
00:16:11,749 --> 00:16:09,519
but this was all theoretical because in

424
00:16:13,110 --> 00:16:11,759
reality these motions were too small to

425
00:16:14,870 --> 00:16:13,120
detect

426
00:16:17,509 --> 00:16:14,880
and so people

427
00:16:20,550 --> 00:16:17,519
looked at the skies and did not expect

428
00:16:23,030 --> 00:16:20,560
them to change very much

429
00:16:25,269 --> 00:16:23,040
however edmund haley famous for the

430
00:16:27,590 --> 00:16:25,279
comet that's named after him was perhaps

431
00:16:29,670 --> 00:16:27,600
the first to discover that some of the

432
00:16:31,749 --> 00:16:29,680
stars in the sky actually seemed to be

433
00:16:34,949 --> 00:16:31,759
moving with respect to other stars they

434
00:16:38,310 --> 00:16:34,959
were shifting their positions in the sky

435
00:16:41,110 --> 00:16:38,320
in 1718 he announced that several uh

436
00:16:43,749 --> 00:16:41,120
well-known bright stars that were uh

437
00:16:46,550 --> 00:16:43,759
observed with the naked eye uh from much

438
00:16:49,269 --> 00:16:46,560

before then sirius aldebaran beetlejuice

439
00:16:51,189 --> 00:16:49,279
arcturus these seem to be in different

440
00:16:53,350 --> 00:16:51,199
positions than they had been in

441
00:16:55,829 --> 00:16:53,360
ptolemy's catalog pstolami's catalogue

442
00:16:57,430 --> 00:16:55,839
was an ancient one recorded before the

443
00:16:59,269 --> 00:16:57,440
birth of christ

444
00:17:01,509 --> 00:16:59,279
and this was the first time that

445
00:17:04,470 --> 00:17:01,519
astronomers realized that the stars were

446
00:17:07,990 --> 00:17:04,480
moving perhaps very slowly against other

447
00:17:13,110 --> 00:17:10,069
now the observations of these motions of

448
00:17:15,590 --> 00:17:13,120
stars progressed very slowly at first

449
00:17:17,669 --> 00:17:15,600
just because there were no good records

450
00:17:19,990 --> 00:17:17,679
uh from the ancient times to compare

451
00:17:22,069 --> 00:17:20,000
against and so it was hard to tell if

452
00:17:23,029 --> 00:17:22,079
the stars had really moved or if there

453
00:17:25,189 --> 00:17:23,039
was

454
00:17:27,750 --> 00:17:25,199
errors in the in the records there were

455
00:17:31,110 --> 00:17:27,760
measurement errors um that made it seem

456
00:17:35,190 --> 00:17:33,110
however over the next decades this

457
00:17:36,789 --> 00:17:35,200
science of measuring the positions of

458
00:17:39,190 --> 00:17:36,799
stars in the sky

459
00:17:41,909 --> 00:17:39,200
also called astrometry or celestial

460
00:17:45,430 --> 00:17:41,919
cartography mapping the stars grew to

461
00:17:48,470 --> 00:17:45,440
encompass all of the nearby bright stars

462
00:17:50,549 --> 00:17:48,480
and so you see in these um

463
00:17:53,270 --> 00:17:50,559

call outs below

464
00:17:55,590 --> 00:17:53,280
in about the 1760s there was a

465
00:17:57,029 --> 00:17:55,600
remarkable catalog created by an

466
00:17:59,430 --> 00:17:57,039
astronomer called bradley at the

467
00:18:01,190 --> 00:17:59,440
greenwich observatory in the uk that had

468
00:18:03,270 --> 00:18:01,200
over a thousand stars measurements of

469
00:18:05,510 --> 00:18:03,280
over a thousand stars and and for a lot

470
00:18:07,270 --> 00:18:05,520
of work this is sort of the oldest

471
00:18:08,710 --> 00:18:07,280
anchoring point for the positions of

472
00:18:11,909 --> 00:18:08,720
stars

473
00:18:13,510 --> 00:18:11,919
in the 1880s uh pickering at harvard was

474
00:18:15,350 --> 00:18:13,520
a famous astronomer who started

475
00:18:17,590 --> 00:18:15,360
measuring the positions and colors of

476
00:18:21,029 --> 00:18:17,600
stars and published a catalogue called

477
00:18:23,669 --> 00:18:21,039
harvard photometry that had 4000 stars

478
00:18:25,510 --> 00:18:23,679
this work continued into the 1918s and

479
00:18:27,190 --> 00:18:25,520
the 1920s

480
00:18:29,510 --> 00:18:27,200
when the henry draper

481
00:18:31,909 --> 00:18:29,520
was was produced and this is a catalog

482
00:18:33,830 --> 00:18:31,919
and classification that we still use

483
00:18:36,150 --> 00:18:33,840
compiled by the very famous annie jump

484
00:18:39,110 --> 00:18:36,160
cannon who also came up with a

485
00:18:41,350 --> 00:18:39,120
stellar classification system

486
00:18:43,430 --> 00:18:41,360
and then on to the 1930s when there was

487
00:18:47,110 --> 00:18:43,440
a yale bright star catalogue that

488
00:18:49,350 --> 00:18:47,120

catalogued about 33 000 stars

489
00:18:51,110 --> 00:18:49,360
and so several catalogs were starting to

490
00:18:54,230 --> 00:18:51,120
record the shifting positions of the

491
00:18:56,630 --> 00:18:54,240
stars on the celestial sphere and this

492
00:18:59,350 --> 00:18:56,640
shift across over time

493
00:19:00,950 --> 00:18:59,360
which which really marked speed see this

494
00:19:06,070 --> 00:19:00,960
distance over time

495
00:19:09,270 --> 00:19:07,669
the proper motion is useful to

496
00:19:12,310 --> 00:19:09,280
understand what is happening in the

497
00:19:14,390 --> 00:19:12,320
universe but by itself it provides an

498
00:19:16,870 --> 00:19:14,400
incomplete picture

499
00:19:17,909 --> 00:19:16,880
and this is because proper motion only

500
00:19:20,950 --> 00:19:17,919
marks

501
00:19:23,830 --> 00:19:20,960
movement across the plane of the sky but

502
00:19:25,990 --> 00:19:23,840
in reality stars are moving in arbitrary

503
00:19:28,390 --> 00:19:26,000
directions and so they have some

504
00:19:30,630 --> 00:19:28,400
component of motion that is going away

505
00:19:33,029 --> 00:19:30,640
from us or towards us so along our line

506
00:19:35,110 --> 00:19:33,039
of sight and so to truly understand the

507
00:19:36,950 --> 00:19:35,120
star's motion in space we also need to

508
00:19:39,430 --> 00:19:36,960
know whether it is moving towards or

509
00:19:41,669 --> 00:19:39,440
away from us and so you'll see here in

510
00:19:43,990 --> 00:19:41,679
this illustration that the proper motion

511
00:19:46,390 --> 00:19:44,000
is against the plane of the sky

512
00:19:50,710 --> 00:19:46,400
but it does not tell you anything about

513
00:19:55,190 --> 00:19:52,870

so this motion along the line of sight

514
00:19:57,110 --> 00:19:55,200
is called the radial velocity

515
00:19:58,789 --> 00:19:57,120
and clearly this is an important piece

516
00:20:00,950 --> 00:19:58,799
of the stellar puzzle to really

517
00:20:03,110 --> 00:20:00,960
understand how the stars are moving in

518
00:20:05,270 --> 00:20:03,120
three dimensions in space

519
00:20:06,710 --> 00:20:05,280
but how can it be measured this was a

520
00:20:08,710 --> 00:20:06,720
question

521
00:20:10,070 --> 00:20:08,720
that was still unanswered in these early

522
00:20:11,510 --> 00:20:10,080
times

523
00:20:13,669 --> 00:20:11,520
it could not be measured the

524
00:20:16,070 --> 00:20:13,679
old-fashioned way by taking images of

525
00:20:17,669 --> 00:20:16,080
stars or drawing maps of the positions

526
00:20:19,669 --> 00:20:17,679
of stars on the sky

527
00:20:21,510 --> 00:20:19,679
because the line of sight motion does

528
00:20:24,149 --> 00:20:21,520
not change the positions of stars on the

529
00:20:26,310 --> 00:20:24,159
celestial sphere

530
00:20:28,470 --> 00:20:26,320
i might also ask you at this point how

531
00:20:30,950 --> 00:20:28,480
on earth you would measure if something

532
00:20:32,950 --> 00:20:30,960
was moving towards you or away from you

533
00:20:34,950 --> 00:20:32,960
and you might say that you you'd look at

534
00:20:36,870 --> 00:20:34,960
the size of the object right this object

535
00:20:39,270 --> 00:20:36,880
would get bigger as it got closer and

536
00:20:42,549 --> 00:20:39,280
smaller as it got further away

537
00:20:44,549 --> 00:20:42,559
but stars are so very very far away

538
00:20:46,390 --> 00:20:44,559

that they are not resolved objects where

539
00:20:49,190 --> 00:20:46,400
we can see their size so they're always

540
00:20:50,870 --> 00:20:49,200
pinpoints of light and so we definitely

541
00:20:53,270 --> 00:20:50,880
cannot measure the changes in their

542
00:20:55,990 --> 00:20:53,280
sizes if we cannot measure their sizes

543
00:20:57,750 --> 00:20:56,000
at all with imaging

544
00:20:59,510 --> 00:20:57,760
and so we turn now to a different

545
00:21:02,230 --> 00:20:59,520
phenomena we're going to move away from

546
00:21:03,990 --> 00:21:02,240
stellar mapping

547
00:21:06,630 --> 00:21:04,000
and and learn about a phenomenon called

548
00:21:11,110 --> 00:21:06,640
the doppler effect now at this point in

549
00:21:12,870 --> 00:21:11,120
the in the 1700s uh and the early 1800s

550
00:21:14,630 --> 00:21:12,880
the doppler effect was just being

551
00:21:18,230 --> 00:21:14,640
discovered so it was discovered by

552
00:21:20,070 --> 00:21:18,240
christian doppler in 1842

553
00:21:22,149 --> 00:21:20,080
and essentially what he discovered is

554
00:21:23,830 --> 00:21:22,159
that when a source of light has relative

555
00:21:26,070 --> 00:21:23,840
motion towards you

556
00:21:28,310 --> 00:21:26,080
it appears a little bit bluer than it

557
00:21:30,710 --> 00:21:28,320
originally was and when it's moving away

558
00:21:33,029 --> 00:21:30,720
from you it appears a little bit redder

559
00:21:35,270 --> 00:21:33,039
and the way to understand this is shown

560
00:21:37,430 --> 00:21:35,280
in the diagram below here

561
00:21:39,430 --> 00:21:37,440
um where if this if the source is moving

562
00:21:40,789 --> 00:21:39,440
towards you then every

563
00:21:43,350 --> 00:21:40,799

consecutive

564
00:21:45,350 --> 00:21:43,360
wave of light seems to come a little bit

565
00:21:47,270 --> 00:21:45,360
quicker and so the frequency of the

566
00:21:49,110 --> 00:21:47,280
light seems to go up

567
00:21:51,190 --> 00:21:49,120
whereas if the the source is moving away

568
00:21:53,510 --> 00:21:51,200
from you you can imagine each

569
00:21:56,070 --> 00:21:53,520
light the crest of every light wave

570
00:21:57,990 --> 00:21:56,080
takes a little bit longer to arrive

571
00:22:00,230 --> 00:21:58,000
and so it looks like the light wave is

572
00:22:02,230 --> 00:22:00,240
being stretched out which which changes

573
00:22:03,990 --> 00:22:02,240
the frequency of the light and it can

574
00:22:07,110 --> 00:22:04,000
appear redder

575
00:22:09,270 --> 00:22:07,120
um none of this of course is visible by

576
00:22:12,070 --> 00:22:09,280
our eyes these are very very small

577
00:22:14,390 --> 00:22:12,080
changes in the frequency of light

578
00:22:16,870 --> 00:22:14,400
and so even though there are slight blue

579
00:22:19,190 --> 00:22:16,880
and red shifts this is not something one

580
00:22:20,870 --> 00:22:19,200
can look at the stars and observe

581
00:22:25,350 --> 00:22:20,880
and so one needs

582
00:22:29,270 --> 00:22:27,190
and this is where we begin to talk about

583
00:22:31,350 --> 00:22:29,280
spectroscopy so

584
00:22:33,430 --> 00:22:31,360
to study the spectra of the stars is to

585
00:22:34,710 --> 00:22:33,440
look at the detail in the light from the

586
00:22:36,549 --> 00:22:34,720
stars

587
00:22:39,110 --> 00:22:36,559
when when the light from a star is

588
00:22:42,630 --> 00:22:39,120

passed through a dispersing element say

589
00:22:44,870 --> 00:22:42,640
a prism or a grating it gets dispersed

590
00:22:47,270 --> 00:22:44,880
into its constituent colors much like

591
00:22:49,830 --> 00:22:47,280
like a rainbow is formed

592
00:22:54,070 --> 00:22:49,840
and this these colors of light tell us

593
00:22:56,310 --> 00:22:54,080
what the star is made of um and and can

594
00:22:58,630 --> 00:22:56,320
tell us actually a lot about the history

595
00:23:01,350 --> 00:22:58,640
and formation of the star and how old it

596
00:23:03,990 --> 00:23:01,360
is um and where it might be going in its

597
00:23:07,590 --> 00:23:06,230
so the the first analysis of stellar

598
00:23:10,950 --> 00:23:07,600
spectra

599
00:23:13,350 --> 00:23:10,960
was conducted in in about 1817 by an

600
00:23:15,270 --> 00:23:13,360
astronomer called fraunhofer who looked

601
00:23:18,230 --> 00:23:15,280
at the the spectra of the sun and some

602
00:23:20,549 --> 00:23:18,240
of the brighter stars and noticed that

603
00:23:22,950 --> 00:23:20,559
these were not continuous rainbows of

604
00:23:25,350 --> 00:23:22,960
light but that they were punctuated by

605
00:23:26,549 --> 00:23:25,360
what he called absorption lines so there

606
00:23:28,710 --> 00:23:26,559
were dark

607
00:23:31,750 --> 00:23:28,720
regions in the spectrum where the light

608
00:23:34,310 --> 00:23:31,760
had been absorbed by something else

609
00:23:36,310 --> 00:23:34,320
and so fraunhofer empirically by looking

610
00:23:37,750 --> 00:23:36,320
at it classified hundreds of solar

611
00:23:39,750 --> 00:23:37,760
absorption lines

612
00:23:41,430 --> 00:23:39,760
and this was very much in line with with

613
00:23:43,269 --> 00:23:41,440

understanding that was emerging at the

614
00:23:44,549 --> 00:23:43,279
time in physics

615
00:23:47,269 --> 00:23:44,559
that

616
00:23:50,070 --> 00:23:47,279
hot gases gave off emitted certain

617
00:23:52,230 --> 00:23:50,080
wavelengths of light and conversely

618
00:23:54,630 --> 00:23:52,240
those gases when they were cool could

619
00:23:56,710 --> 00:23:54,640
absorb those same wavelengths of light

620
00:23:58,870 --> 00:23:56,720
and so fraunhofer along with several of

621
00:24:01,669 --> 00:23:58,880
his contemporary contemporaries like

622
00:24:03,990 --> 00:24:01,679
bunsen of the bunsen lamp thing were

623
00:24:06,470 --> 00:24:04,000
able to show that that the missing lines

624
00:24:09,350 --> 00:24:06,480
in the stellar spectrum corresponded to

625
00:24:10,789 --> 00:24:09,360
the stellar atmosphere uh composition so

626
00:24:12,710 --> 00:24:10,799
the cooler gases in the stellar

627
00:24:14,950 --> 00:24:12,720
atmosphere were absorbing certain

628
00:24:16,870 --> 00:24:14,960
components and leaving a fingerprint on

629
00:24:17,590 --> 00:24:16,880
the spectrum of what the star was made

630
00:24:22,789 --> 00:24:17,600
of

631
00:24:27,990 --> 00:24:22,799
what the what distant objects like stars

632
00:24:33,830 --> 00:24:30,950
and so to study these spectra people

633
00:24:35,510 --> 00:24:33,840
used very early spectrographs which were

634
00:24:36,710 --> 00:24:35,520
quite simple they were essentially made

635
00:24:38,789 --> 00:24:36,720
of a prism

636
00:24:40,549 --> 00:24:38,799
and a few lenses to guide the light in

637
00:24:43,269 --> 00:24:40,559
and out of the prism

638
00:24:46,870 --> 00:24:43,279

but what even very early spectrographs

639
00:24:48,470 --> 00:24:46,880
did was take colors of light

640
00:24:51,430 --> 00:24:48,480
and translate them to different

641
00:24:54,310 --> 00:24:51,440
positions on a photographic plate and so

642
00:24:56,950 --> 00:24:54,320
now color corresponded to position on a

643
00:24:59,350 --> 00:24:56,960
photographic plate and you could track

644
00:25:01,430 --> 00:24:59,360
the motion of different lines on those

645
00:25:03,590 --> 00:25:01,440
photographic plates so this was a

646
00:25:05,990 --> 00:25:03,600
brilliant way of of converting something

647
00:25:08,549 --> 00:25:06,000
that we could not see um the the very

648
00:25:10,549 --> 00:25:08,559
subtle change in the colors of stars to

649
00:25:12,390 --> 00:25:10,559
something we could see the movement of

650
00:25:14,710 --> 00:25:12,400
these dark absorption bands on the

651
00:25:16,149 --> 00:25:14,720
photographic plates

652
00:25:19,029 --> 00:25:16,159
so let me show you what some of these

653
00:25:21,110 --> 00:25:19,039
early photographic plates looked like um

654
00:25:23,029 --> 00:25:21,120
imagine yourself as an astronomer in the

655
00:25:25,590 --> 00:25:23,039
1800s

656
00:25:27,990 --> 00:25:25,600
pointing your your telescope and your

657
00:25:30,789 --> 00:25:28,000
your early spectrograph at an unknown

658
00:25:32,470 --> 00:25:30,799
object and and seeing what what light

659
00:25:33,990 --> 00:25:32,480
and what photons were coming from these

660
00:25:35,669 --> 00:25:34,000
distant stars

661
00:25:37,269 --> 00:25:35,679
it's really quite amazing

662
00:25:39,430 --> 00:25:37,279
the the first radial velocity

663
00:25:41,190 --> 00:25:39,440

observations of stars using uh

664
00:25:44,390 --> 00:25:41,200
photography photographic plates were

665
00:25:46,789 --> 00:25:44,400
taken almost 150 years ago from now in

666
00:25:49,269 --> 00:25:46,799
1872

667
00:25:52,310 --> 00:25:49,279
um and and the astronomer who discovered

668
00:25:53,669 --> 00:25:52,320
or conducted these first observations

669
00:25:55,990 --> 00:25:53,679
vogel

670
00:25:58,470 --> 00:25:56,000
along with pickering who i mentioned as

671
00:26:01,190 --> 00:25:58,480
one of uh one of the catalog creators

672
00:26:03,350 --> 00:26:01,200
also discovered the first binary stars

673
00:26:04,310 --> 00:26:03,360
and they did that because they tracked

674
00:26:11,430 --> 00:26:04,320
the

675
00:26:12,630 --> 00:26:11,440
and forth

676
00:26:15,269 --> 00:26:12,640
around

677
00:26:17,350 --> 00:26:15,279
a rest wavelength which indicated that

678
00:26:19,269 --> 00:26:17,360
the star itself was moving back and

679
00:26:20,630 --> 00:26:19,279
forth red shifting and blue shifting

680
00:26:23,269 --> 00:26:20,640
over time

681
00:26:24,549 --> 00:26:23,279
and that this wobble was being caused by

682
00:26:26,789 --> 00:26:24,559
a companion

683
00:26:29,590 --> 00:26:26,799
whose gravitational

684
00:26:30,630 --> 00:26:29,600
energy was wobbling the star

685
00:26:32,950 --> 00:26:30,640
and

686
00:26:35,029 --> 00:26:32,960
using the the already discovered

687
00:26:36,870 --> 00:26:35,039
astronomical and physics laws of those

688
00:26:39,110 --> 00:26:36,880

time they were able to measure the

689
00:26:41,269 --> 00:26:39,120
masses of the companions and guess at

690
00:26:43,750 --> 00:26:41,279
the masses of the companions

691
00:26:46,390 --> 00:26:43,760
and tell that those were also stars

692
00:26:51,190 --> 00:26:49,029
measuring the radial velocities of stars

693
00:26:55,110 --> 00:26:51,200
led to the discovery of binary stars the

694
00:26:58,870 --> 00:26:56,710
now i will say that these early

695
00:27:02,549 --> 00:26:58,880
measuring machines were very cumbersome

696
00:27:05,750 --> 00:27:02,559
to use astronomy currently is not

697
00:27:07,990 --> 00:27:05,760
a hugely physically taxing career

698
00:27:09,110 --> 00:27:08,000
but it could be at that time

699
00:27:11,110 --> 00:27:09,120
and so

700
00:27:12,950 --> 00:27:11,120
here is here's a picture of one of these

701
00:27:14,549 --> 00:27:12,960
early machines where one had to look

702
00:27:17,029 --> 00:27:14,559
through a microscope

703
00:27:19,029 --> 00:27:17,039
and manually move a micrometer screw in

704
00:27:20,549 --> 00:27:19,039
precision steps to try and measure the

705
00:27:22,470 --> 00:27:20,559
movements in these lines because they

706
00:27:23,909 --> 00:27:22,480
were still moving by very very small

707
00:27:25,590 --> 00:27:23,919
amounts

708
00:27:27,350 --> 00:27:25,600
and so you had to look at it very very

709
00:27:28,549 --> 00:27:27,360
carefully to measure it

710
00:27:30,710 --> 00:27:28,559
and

711
00:27:32,950 --> 00:27:30,720
the papers of the 1940s mentioned how

712
00:27:34,389 --> 00:27:32,960
the fancy updates of the time added a

713
00:27:36,470 --> 00:27:34,399

projector

714
00:27:38,230 --> 00:27:36,480
to this setup so that you could project

715
00:27:39,590 --> 00:27:38,240
the spectrum onto a wall so that it was

716
00:27:41,909 --> 00:27:39,600
much larger

717
00:27:44,470 --> 00:27:41,919
and now you could move a screw against

718
00:27:46,950 --> 00:27:44,480
it with your naked eye and this relieved

719
00:27:48,470 --> 00:27:46,960
the extreme eye strain that graduate

720
00:27:50,950 --> 00:27:48,480
students were undergoing and trying to

721
00:27:53,830 --> 00:27:50,960
measure these spectra

722
00:27:56,149 --> 00:27:53,840
it's also interesting to read about how

723
00:27:58,230 --> 00:27:56,159
how knowingly biased these observations

724
00:28:00,870 --> 00:27:58,240
used to be because every astronomer kind

725
00:28:01,909 --> 00:28:00,880
of had a technique for measuring the

726
00:28:04,389 --> 00:28:01,919
shifts

727
00:28:05,990 --> 00:28:04,399
and they always tend to either veer a

728
00:28:08,470 --> 00:28:06,000
little bit to the left or the right

729
00:28:10,230 --> 00:28:08,480
depending on on the astronomer and so a

730
00:28:12,310 --> 00:28:10,240
lot of the advice of this time says that

731
00:28:14,070 --> 00:28:12,320
you should pass through the spectrum one

732
00:28:15,590 --> 00:28:14,080
way going left to right and then the

733
00:28:18,870 --> 00:28:15,600
other time going right to left so you

734
00:28:20,310 --> 00:28:18,880
kind of cancel out your own bias

735
00:28:21,590 --> 00:28:20,320
very interesting how they were already

736
00:28:23,510 --> 00:28:21,600
thinking about these things but of

737
00:28:27,669 --> 00:28:23,520
course a far cry from how we would

738
00:28:32,630 --> 00:28:29,669

here's some early spectra measured from

739
00:28:34,389 --> 00:28:32,640
that machine that i just showed you

740
00:28:36,710 --> 00:28:34,399
and so always when they were measuring

741
00:28:38,389 --> 00:28:36,720
the shifts in these absorption lines you

742
00:28:40,310 --> 00:28:38,399
had to measure it with respect to

743
00:28:42,549 --> 00:28:40,320
something else so you needed a reference

744
00:28:44,549 --> 00:28:42,559
spectrum for comparison

745
00:28:47,430 --> 00:28:44,559
and here you'll see there are

746
00:28:49,750 --> 00:28:47,440
you know these these uh more continuous

747
00:28:52,789 --> 00:28:49,760
looking spectra are from the stars so

748
00:28:55,909 --> 00:28:52,799
there are one two three four five six

749
00:28:58,389 --> 00:28:55,919
stars here uh but along with the stars

750
00:29:01,029 --> 00:28:58,399
they observe a reference spectrum from

751
00:29:03,990 --> 00:29:01,039
an iron arc lamp so these are

752
00:29:06,310 --> 00:29:04,000
emission lines from from superheated

753
00:29:08,870 --> 00:29:06,320
iron and

754
00:29:11,190 --> 00:29:08,880
these lines are at known wavelengths and

755
00:29:13,350 --> 00:29:11,200
so using that you can basically create a

756
00:29:15,990 --> 00:29:13,360
ruler against which to measure the

757
00:29:18,230 --> 00:29:16,000
changes in the spectrum lines um

758
00:29:20,630 --> 00:29:18,240
this is this is quite old technology

759
00:29:22,470 --> 00:29:20,640
from the 1940s but this principle is

760
00:29:24,549 --> 00:29:22,480
still what we use now where we have a

761
00:29:27,029 --> 00:29:24,559
reference spectrum and we measure shifts

762
00:29:29,029 --> 00:29:27,039
against it so in reading some of these

763
00:29:30,149 --> 00:29:29,039

historic papers it's it's very

764
00:29:33,029 --> 00:29:30,159
interesting

765
00:29:34,710 --> 00:29:33,039
how some of the technology was was in a

766
00:29:36,710 --> 00:29:34,720
very early state

767
00:29:39,029 --> 00:29:36,720
but how a lot of the thinking was

768
00:29:42,789 --> 00:29:39,039
already in a very mature state and still

769
00:29:45,029 --> 00:29:42,799
some of the principles that we use today

770
00:29:48,310 --> 00:29:45,039
so these early measurements of the of

771
00:29:50,549 --> 00:29:48,320
the radial velocity of stars

772
00:29:53,029 --> 00:29:50,559
led to some really amazing insights into

773
00:29:54,789 --> 00:29:53,039
the nearby universe so the motion of the

774
00:29:57,510 --> 00:29:54,799
sun for example was measured for the

775
00:29:59,830 --> 00:29:57,520
first time uh before that again the sun

776
00:30:01,750 --> 00:29:59,840
seemed like it was a stationary object

777
00:30:04,389 --> 00:30:01,760
as far as we could tell from just

778
00:30:06,389 --> 00:30:04,399
looking at the sky um so without the

779
00:30:08,870 --> 00:30:06,399
spectra and without these measurements

780
00:30:11,029 --> 00:30:08,880
um these these small motions are not

781
00:30:13,190 --> 00:30:11,039
apparent at all

782
00:30:15,669 --> 00:30:13,200
um also very interestingly the sun and

783
00:30:17,990 --> 00:30:15,679
the nearby stars seem to be in slow

784
00:30:19,430 --> 00:30:18,000
revolution around a distant point in the

785
00:30:22,149 --> 00:30:19,440
galaxy

786
00:30:24,070 --> 00:30:22,159
so this is sort of foreshadowing a lot

787
00:30:26,710 --> 00:30:24,080
of the the astronomy that will come in

788
00:30:28,470 --> 00:30:26,720

the centuries after this um where we

789
00:30:31,350 --> 00:30:28,480
where we discovered the center of the

790
00:30:33,909 --> 00:30:31,360
the galaxy has a black hole um and and

791
00:30:37,269 --> 00:30:33,919
all of the stars are sort of rotating uh

792
00:30:39,830 --> 00:30:37,279
around that center also extremely

793
00:30:43,510 --> 00:30:39,840
distant spiral nebulae so these are what

794
00:30:46,389 --> 00:30:43,520
we would now call uh other galaxies um

795
00:30:48,789 --> 00:30:46,399
seem to be redshifted more and more

796
00:30:50,950 --> 00:30:48,799
depending on how far away they were so

797
00:30:52,789 --> 00:30:50,960
again this is a very early indication of

798
00:30:53,990 --> 00:30:52,799
later discoveries of the expansion of

799
00:30:55,590 --> 00:30:54,000
the universe

800
00:30:58,070 --> 00:30:55,600
but you can imagine this is the first

801
00:30:59,990 --> 00:30:58,080
time astronomers were really

802
00:31:04,549 --> 00:31:00,000
being able to look out with this level

803
00:31:09,590 --> 00:31:04,559
of insight into what was going on

804
00:31:11,669 --> 00:31:09,600
so we are now in the early 1950s um

805
00:31:13,110 --> 00:31:11,679
historically we are we are at an

806
00:31:15,669 --> 00:31:13,120
interesting moment in time where the

807
00:31:16,630 --> 00:31:15,679
second world war is over the cold war is

808
00:31:18,310 --> 00:31:16,640
dawning

809
00:31:20,710 --> 00:31:18,320
civil rights movements in the united

810
00:31:22,549 --> 00:31:20,720
states is picking up pace um just to

811
00:31:25,990 --> 00:31:22,559
remind ourselves that alongside the

812
00:31:29,750 --> 00:31:26,000
story uh of of other human history there

813
00:31:31,830 --> 00:31:29,760

is also the story of science developing

814
00:31:33,990 --> 00:31:31,840
so this is still a time before

815
00:31:35,990 --> 00:31:34,000
exoplanets the only known planets are

816
00:31:38,389 --> 00:31:36,000
those in the solar system

817
00:31:41,750 --> 00:31:38,399
and and the idea of alien worlds only

818
00:31:44,149 --> 00:31:41,760
exists in science fiction

819
00:31:46,310 --> 00:31:44,159
however in the world of astronomy

820
00:31:48,789 --> 00:31:46,320
a scientist called order struve writes

821
00:31:49,830 --> 00:31:48,799
one of the most prescient papers in the

822
00:31:51,110 --> 00:31:49,840
field

823
00:31:53,430 --> 00:31:51,120
he says

824
00:31:55,509 --> 00:31:53,440
we can already detect radio velocity

825
00:31:58,070 --> 00:31:55,519
shifts due to stellar companions right

826
00:32:00,549 --> 00:31:58,080
we know about binary stars

827
00:32:03,110 --> 00:32:00,559
if we increase our precision we should

828
00:32:05,269 --> 00:32:03,120
be able to detect smaller objects

829
00:32:07,110 --> 00:32:05,279
smaller companions and so

830
00:32:09,590 --> 00:32:07,120
if there are close in planetary

831
00:32:12,549 --> 00:32:09,600
companions these should be within our

832
00:32:14,310 --> 00:32:12,559
reach um of course with the caveat if

833
00:32:16,470 --> 00:32:14,320
they exist because there was still no

834
00:32:18,310 --> 00:32:16,480
proof that that planets existed outside

835
00:32:21,669 --> 00:32:18,320
the solar system

836
00:32:23,990 --> 00:32:21,679
this was quite a revolutionary idea um

837
00:32:26,230 --> 00:32:24,000
but it would still take decades

838
00:32:28,549 --> 00:32:26,240

for for technology to catch up to this

839
00:32:31,750 --> 00:32:28,559
visionary idea that that's true we had

840
00:32:34,470 --> 00:32:32,549
so

841
00:32:36,149 --> 00:32:34,480
this idea of developing precision

842
00:32:38,630 --> 00:32:36,159
spectroscopy

843
00:32:41,909 --> 00:32:38,640
comes from the the principle that the

844
00:32:43,909 --> 00:32:41,919
the planet is causing the star to wobble

845
00:32:45,830 --> 00:32:43,919
and both of these bodies are orbiting a

846
00:32:48,549 --> 00:32:45,840
common center of mass

847
00:32:50,630 --> 00:32:48,559
so just to center our discussion i

848
00:32:53,750 --> 00:32:50,640
wanted to show you what what this looks

849
00:32:56,710 --> 00:32:53,760
like where the planet uh being small is

850
00:32:59,269 --> 00:32:56,720
making a large orbit around the star

851
00:33:02,389 --> 00:32:59,279
the star being very large makes a very

852
00:33:04,710 --> 00:33:02,399
small orbit around the center of mass

853
00:33:06,789 --> 00:33:04,720
and and the motion of the star

854
00:33:09,110 --> 00:33:06,799
back and forth back and forth causes the

855
00:33:11,990 --> 00:33:09,120
spectrum to redshift and blue shift and

856
00:33:13,029 --> 00:33:12,000
those are the motions we're looking for

857
00:33:16,549 --> 00:33:13,039
however

858
00:33:18,950 --> 00:33:16,559
um the the problem between auto struve's

859
00:33:20,630 --> 00:33:18,960
idea and the actual realization of it

860
00:33:22,230 --> 00:33:20,640
was just how challenging this

861
00:33:24,070 --> 00:33:22,240
measurement can be

862
00:33:27,669 --> 00:33:24,080
so here we are at the beginning of the

863
00:33:29,990 --> 00:33:27,679

journey uh in the 1950s where rv

864
00:33:31,909 --> 00:33:30,000
precision is at about a thousand meters

865
00:33:34,070 --> 00:33:31,919
per second so about a kilometer per

866
00:33:35,990 --> 00:33:34,080
second um

867
00:33:39,110 --> 00:33:36,000
this is the this is the position at

868
00:33:40,870 --> 00:33:39,120
which you can discover stars uh

869
00:33:43,669 --> 00:33:40,880
companion stars

870
00:33:45,990 --> 00:33:43,679
but to get to planets you need to get

871
00:33:49,190 --> 00:33:46,000
orders of magnitude better so jupiter

872
00:33:51,509 --> 00:33:49,200
for example wobbles our sun by about 13

873
00:33:54,310 --> 00:33:51,519
meters per second

874
00:33:56,630 --> 00:33:54,320
and the earth wobbles our sun by only

875
00:33:58,630 --> 00:33:56,640
about 10 centimeters per second so you

876
00:34:02,070 --> 00:33:58,640
see on the y-axis here

877
00:34:05,430 --> 00:34:02,080
these are jumps in magnitudes of 10.

878
00:34:07,830 --> 00:34:05,440
and so we need to make one two three

879
00:34:10,550 --> 00:34:07,840
four jumps so we need to get four orders

880
00:34:13,430 --> 00:34:10,560
of magnitude better to start finding

881
00:34:15,349 --> 00:34:13,440
earth-like planets

882
00:34:18,470 --> 00:34:15,359
uh no big deal right four or ten

883
00:34:19,430 --> 00:34:18,480
thousand times better um

884
00:34:21,270 --> 00:34:19,440
and so

885
00:34:23,430 --> 00:34:21,280
this is what

886
00:34:26,230 --> 00:34:23,440
the monumental challenge that lay ahead

887
00:34:28,629 --> 00:34:26,240
of astronomers of the time um

888
00:34:30,069 --> 00:34:28,639

where we needed to get technology to a

889
00:34:32,149 --> 00:34:30,079
place that really couldn't even be

890
00:34:33,909 --> 00:34:32,159
imagined at the time

891
00:34:36,069 --> 00:34:33,919
so there was a lot of skepticism going

892
00:34:37,909 --> 00:34:36,079
around uh people were saying this this

893
00:34:40,310 --> 00:34:37,919
is an impossible task

894
00:34:42,950 --> 00:34:40,320
10 centimeters per second that is very

895
00:34:45,270 --> 00:34:42,960
very slow um that's slower than a person

896
00:34:47,109 --> 00:34:45,280
works it's about the speed of a tortoise

897
00:34:50,230 --> 00:34:47,119
and so you're trying to measure the

898
00:34:53,270 --> 00:34:50,240
motion of a tortoise light years away

899
00:34:55,109 --> 00:34:53,280
that's impossibly difficult

900
00:34:57,670 --> 00:34:55,119
and so a lot of people believe that

901
00:34:59,349 --> 00:34:57,680
finding planets would always stay in the

902
00:35:01,270 --> 00:34:59,359
realm of science fiction that it would

903
00:35:04,230 --> 00:35:01,280
never be something we could actually

904
00:35:05,510 --> 00:35:04,240
discover with with technology

905
00:35:09,990 --> 00:35:05,520
however

906
00:35:14,950 --> 00:35:12,950
and so we jump ahead to the 19

907
00:35:17,430 --> 00:35:14,960
late 1970s

908
00:35:18,390 --> 00:35:17,440
where a pair of astronomers campbell and

909
00:35:20,870 --> 00:35:18,400
walker

910
00:35:21,990 --> 00:35:20,880
did a very daring experiment using

911
00:35:24,630 --> 00:35:22,000
perhaps

912
00:35:26,150 --> 00:35:24,640
some of the most dangerous substances

913
00:35:27,990 --> 00:35:26,160

that have been used in this field of

914
00:35:31,750 --> 00:35:28,000
astronomy ever

915
00:35:34,870 --> 00:35:31,760
and so they had this idea of using

916
00:35:36,790 --> 00:35:34,880
a calibrator uh say a ruler

917
00:35:39,109 --> 00:35:36,800
that is imposed onto the stellar

918
00:35:41,829 --> 00:35:39,119
spectrum and so what they did was that

919
00:35:45,109 --> 00:35:41,839
they passed starlight through a hydrogen

920
00:35:47,030 --> 00:35:45,119
fluoride absorption cell to imprint the

921
00:35:49,270 --> 00:35:47,040
absorption lines of hydrogen fluoride

922
00:35:50,870 --> 00:35:49,280
onto the stellar spectrum

923
00:35:53,109 --> 00:35:50,880
there had also been

924
00:35:56,630 --> 00:35:53,119
a lot of advances in detector technology

925
00:35:58,310 --> 00:35:56,640
by this time making this experiment

926
00:36:00,310 --> 00:35:58,320
much more successful than any of the

927
00:36:02,390 --> 00:36:00,320
ones that had gone before it and so

928
00:36:04,470 --> 00:36:02,400
campbell and walker were able to get to

929
00:36:07,430 --> 00:36:04,480
something like 15 meters per second

930
00:36:09,510 --> 00:36:07,440
precision uh quite a bit better than the

931
00:36:12,310 --> 00:36:09,520
several hundred or thousand meter per

932
00:36:14,710 --> 00:36:12,320
second position that came before them of

933
00:36:16,710 --> 00:36:14,720
course the problem uh which is sort of

934
00:36:19,270 --> 00:36:16,720
understated in their published paper is

935
00:36:21,270 --> 00:36:19,280
that a drawback to hydrogen fluoride is

936
00:36:23,270 --> 00:36:21,280
its obnoxious nature

937
00:36:24,230 --> 00:36:23,280
what they don't mention is it's horribly

938
00:36:26,790 --> 00:36:24,240

toxic

939
00:36:29,190 --> 00:36:26,800
and even a little bit of hf on your skin

940
00:36:30,790 --> 00:36:29,200
or in your lungs can prove fatal

941
00:36:33,589 --> 00:36:30,800
uh and so while this experiment was

942
00:36:36,230 --> 00:36:33,599
successful this was probably not the the

943
00:36:38,310 --> 00:36:36,240
most feasible of solutions but what they

944
00:36:40,630 --> 00:36:38,320
had they had demonstrated was that an

945
00:36:42,710 --> 00:36:40,640
absorption cell

946
00:36:44,710 --> 00:36:42,720
with the right number of lines and in

947
00:36:46,790 --> 00:36:44,720
the right wavelength range

948
00:36:49,030 --> 00:36:46,800
might prove to be up to be a great

949
00:36:51,589 --> 00:36:49,040
solution

950
00:36:53,270 --> 00:36:51,599
so let's jump ahead to the early 19th so

951
00:36:56,069 --> 00:36:53,280
about a decade after the campbell and

952
00:36:58,550 --> 00:36:56,079
walker experiments

953
00:37:01,109 --> 00:36:58,560
and by this time there have been some

954
00:37:03,430 --> 00:37:01,119
hints of sub-stellar companions but

955
00:37:05,349 --> 00:37:03,440
still no definitive planets

956
00:37:07,589 --> 00:37:05,359
and two groups

957
00:37:11,589 --> 00:37:07,599
in two different continents are racing

958
00:37:13,829 --> 00:37:11,599
to be the first to find an exoplanet

959
00:37:15,109 --> 00:37:13,839
so uh stateside there is a group in

960
00:37:17,030 --> 00:37:15,119
california

961
00:37:18,630 --> 00:37:17,040
they've been building on this absorption

962
00:37:20,550 --> 00:37:18,640
cell idea and

963
00:37:22,470 --> 00:37:20,560

over many iterations have been looking

964
00:37:24,710 --> 00:37:22,480
for the best

965
00:37:26,790 --> 00:37:24,720
filler gas for for the absorption cell

966
00:37:29,030 --> 00:37:26,800
and they have settled on iodine which

967
00:37:31,190 --> 00:37:29,040
has some very nice lines uh in the

968
00:37:32,630 --> 00:37:31,200
optical part of the spectrum

969
00:37:35,349 --> 00:37:32,640
and they're using that at leak

970
00:37:37,430 --> 00:37:35,359
observatory to study many many stars and

971
00:37:39,670 --> 00:37:37,440
track them over time to see if there are

972
00:37:42,069 --> 00:37:39,680
planetary companions

973
00:37:44,150 --> 00:37:42,079
across the pond in switzerland actually

974
00:37:46,310 --> 00:37:44,160
the observatory is in front but the

975
00:37:48,390 --> 00:37:46,320
group is swiss there is a group that is

976
00:37:50,710 --> 00:37:48,400
going a different route so instead of

977
00:37:53,109 --> 00:37:50,720
imprinting the ruler onto their

978
00:37:54,870 --> 00:37:53,119
starlight they are still doing a

979
00:37:57,190 --> 00:37:54,880
simultaneous measurement sort of like

980
00:37:59,109 --> 00:37:57,200
the ones i showed you before

981
00:38:01,109 --> 00:37:59,119
where they are measured at the same time

982
00:38:02,150 --> 00:38:01,119
but next to each other so not on top of

983
00:38:04,710 --> 00:38:02,160
each other

984
00:38:08,069 --> 00:38:04,720
and this group is using a thorium argon

985
00:38:09,589 --> 00:38:08,079
lamp for its calibration uh but the the

986
00:38:11,270 --> 00:38:09,599
reason they are

987
00:38:13,670 --> 00:38:11,280
sort of decades ahead of the last

988
00:38:15,270 --> 00:38:13,680

experiments is that they are using a

989
00:38:17,349 --> 00:38:15,280
stabilized spectrograph so the

990
00:38:19,270 --> 00:38:17,359
spectrograph itself

991
00:38:21,510 --> 00:38:19,280
is built to be somewhat immune to

992
00:38:24,710 --> 00:38:21,520
temperature and pressure changes so that

993
00:38:28,470 --> 00:38:24,720
those spectra next to each other

994
00:38:29,829 --> 00:38:28,480
don't suffer very different systematics

995
00:38:32,310 --> 00:38:29,839
and so a lot of

996
00:38:34,069 --> 00:38:32,320
exciting works happens behind the scenes

997
00:38:35,990 --> 00:38:34,079
with these two groups

998
00:38:39,109 --> 00:38:36,000
but what the world sees is an

999
00:38:41,510 --> 00:38:39,119
announcement in 1995 of the first

1000
00:38:43,750 --> 00:38:41,520
exoplanet around the sun-like star so in

1001
00:38:45,270 --> 00:38:43,760
1995 the swiss group

1002
00:38:47,589 --> 00:38:45,280
mayor and quillow announced the

1003
00:38:49,829 --> 00:38:47,599
discovery of 51 peg b and actually the

1004
00:38:51,589 --> 00:38:49,839
california group perhaps already had

1005
00:38:53,270 --> 00:38:51,599
that discovery in their data but they

1006
00:38:55,750 --> 00:38:53,280
were able to verify it

1007
00:38:57,910 --> 00:38:55,760
almost immediately

1008
00:39:00,310 --> 00:38:57,920
but the the first exoplanet that we

1009
00:39:02,150 --> 00:39:00,320
found was unlike anything that was

1010
00:39:04,630 --> 00:39:02,160
expected based on the solar system

1011
00:39:07,589 --> 00:39:04,640
planets this planet was what we now call

1012
00:39:09,670 --> 00:39:07,599
a hot jupiter um so a very large planet

1013
00:39:12,150 --> 00:39:09,680

actually larger than jupiter that was

1014
00:39:14,390 --> 00:39:12,160
very close to its star much closer than

1015
00:39:17,030 --> 00:39:14,400
than mercury in the solar system

1016
00:39:19,990 --> 00:39:17,040
and this giant hot planet was whipping

1017
00:39:22,630 --> 00:39:20,000
around its star every four days

1018
00:39:25,750 --> 00:39:22,640
this was unlike anything we had expected

1019
00:39:27,990 --> 00:39:25,760
or seen before and with this staggering

1020
00:39:30,230 --> 00:39:28,000
discovery the field of exoplanet

1021
00:39:31,190 --> 00:39:30,240
detection was born

1022
00:39:32,950 --> 00:39:31,200
and i'll show you what the

1023
00:39:34,870 --> 00:39:32,960
state-of-the-art data looked at the time

1024
00:39:36,390 --> 00:39:34,880
if you look at the the plot here on the

1025
00:39:38,470 --> 00:39:36,400
top right

1026
00:39:40,950 --> 00:39:38,480
these are the measurements that were

1027
00:39:43,910 --> 00:39:40,960
taken over time of 51 peg b you can

1028
00:39:46,790 --> 00:39:43,920
imagine time on the x axis and this is

1029
00:39:49,349 --> 00:39:46,800
radial velocity in meters per second

1030
00:39:52,310 --> 00:39:49,359
on the y axis and you can see very

1031
00:39:54,069 --> 00:39:52,320
clearly that the star is shifting to the

1032
00:39:59,349 --> 00:39:54,079
red and the blue

1033
00:40:02,310 --> 00:39:59,359
beautiful periodic sinusoidal curve

1034
00:40:04,870 --> 00:40:02,320
that shows us that there is a companion

1035
00:40:07,510 --> 00:40:04,880
and the the size of the curve gives us

1036
00:40:09,270 --> 00:40:07,520
the mass of the companion essentially

1037
00:40:11,990 --> 00:40:09,280
and so it tells us that the companion is

1038
00:40:15,910 --> 00:40:12,000

smaller than a star much smaller

1039
00:40:21,589 --> 00:40:18,230
and so we've made great strides in

1040
00:40:24,069 --> 00:40:21,599
precision now from the the early 1940s

1041
00:40:26,150 --> 00:40:24,079
to the 1990s we are now at the in the

1042
00:40:28,950 --> 00:40:26,160
middle of our journey

1043
00:40:30,710 --> 00:40:28,960
of this 10 um four orders of magnitude

1044
00:40:33,430 --> 00:40:30,720
10 000 times that we're trying to get

1045
00:40:35,910 --> 00:40:33,440
better so we started off

1046
00:40:38,390 --> 00:40:35,920
at the speed of detecting the fastest

1047
00:40:39,270 --> 00:40:38,400
military aircraft at about kilometer per

1048
00:40:41,750 --> 00:40:39,280
second

1049
00:40:44,550 --> 00:40:41,760
we traverse through high-speed trains

1050
00:40:47,030 --> 00:40:44,560
and very fast runners and we are now

1051
00:40:48,950 --> 00:40:47,040
getting to about the average jogger so

1052
00:40:51,270 --> 00:40:48,960
still a little bit faster than you would

1053
00:40:54,950 --> 00:40:51,280
walk

1054
00:40:59,990 --> 00:40:56,550
the next challenge after this was

1055
00:41:02,710 --> 00:41:00,000
getting to one meter per second um and

1056
00:41:04,069 --> 00:41:02,720
the the swiss team that i mentioned grew

1057
00:41:05,510 --> 00:41:04,079
uh

1058
00:41:07,910 --> 00:41:05,520
in both

1059
00:41:11,109 --> 00:41:07,920
expertise and number of instruments that

1060
00:41:13,190 --> 00:41:11,119
they were producing um and they produced

1061
00:41:14,390 --> 00:41:13,200
in the 2000s the state of the art and

1062
00:41:15,589 --> 00:41:14,400
held that

1063
00:41:20,230 --> 00:41:15,599

distinction

1064
00:41:21,750 --> 00:41:20,240
as the as the team that has gotten to

1065
00:41:23,910 --> 00:41:21,760
the highest precisions on any

1066
00:41:26,069 --> 00:41:23,920
instruments and so harps defined the

1067
00:41:28,309 --> 00:41:26,079
state of the art in the 2000s and the

1068
00:41:30,069 --> 00:41:28,319
2010s um

1069
00:41:32,309 --> 00:41:30,079
this is the instrument on the left here

1070
00:41:35,510 --> 00:41:32,319
you can see this is a lot fancier than

1071
00:41:36,870 --> 00:41:35,520
those uh cranking micrometer instruments

1072
00:41:39,109 --> 00:41:36,880
we saw before

1073
00:41:41,430 --> 00:41:39,119
these are highly stabilized instruments

1074
00:41:44,630 --> 00:41:41,440
in a vacuum chamber

1075
00:41:47,750 --> 00:41:44,640
that that have large optics

1076
00:41:50,309 --> 00:41:47,760
and very high dispersion so they

1077
00:41:52,309 --> 00:41:50,319
they cover a large wavelength range of

1078
00:41:53,829 --> 00:41:52,319
light and they spread it out very finely

1079
00:41:55,349 --> 00:41:53,839
so that you can see the detail in the

1080
00:41:56,870 --> 00:41:55,359
spectral lines

1081
00:41:59,349 --> 00:41:56,880
and so the simultaneous measurement

1082
00:42:01,349 --> 00:41:59,359
technique slowly bypasses the absorption

1083
00:42:02,630 --> 00:42:01,359
cell technique and becomes the mainstay

1084
00:42:04,790 --> 00:42:02,640
of the field

1085
00:42:06,950 --> 00:42:04,800
it can cover a very broad wavelength

1086
00:42:09,270 --> 00:42:06,960
range

1087
00:42:11,109 --> 00:42:09,280
and it is it is proving very successful

1088
00:42:12,550 --> 00:42:11,119

we are finding hundreds to thousands of

1089
00:42:13,589 --> 00:42:12,560
planets with the radio velocity

1090
00:42:14,470 --> 00:42:13,599
technique

1091
00:42:17,430 --> 00:42:14,480
but

1092
00:42:19,829 --> 00:42:17,440
we are still at this point stuck at

1093
00:42:22,309 --> 00:42:19,839
about a meter per second so earth's

1094
00:42:24,550 --> 00:42:22,319
which are at 10 centimeters per second

1095
00:42:26,390 --> 00:42:24,560
um are still beyond the reach of this

1096
00:42:28,950 --> 00:42:26,400
technology

1097
00:42:31,430 --> 00:42:28,960
and so we've taken one more step here uh

1098
00:42:33,430 --> 00:42:31,440
in our in our journey to precision we

1099
00:42:36,069 --> 00:42:33,440
are now at a casual walk at about a

1100
00:42:37,349 --> 00:42:36,079
meter per second uh but still about 10

1101
00:42:39,190 --> 00:42:37,359
times

1102
00:42:41,910 --> 00:42:39,200
less precise than we need to be for

1103
00:42:46,550 --> 00:42:43,829
so how do we get better from here in the

1104
00:42:49,190 --> 00:42:46,560
early 2010s technology was already maxed

1105
00:42:49,990 --> 00:42:49,200
out we were using the state of the art

1106
00:42:52,630 --> 00:42:50,000
um

1107
00:42:55,030 --> 00:42:52,640
and so the the community

1108
00:42:57,750 --> 00:42:55,040
sort of rose to the challenge we decided

1109
00:43:00,390 --> 00:42:57,760
we would forge our own technology

1110
00:43:01,990 --> 00:43:00,400
and and drive forward the the areas that

1111
00:43:04,309 --> 00:43:02,000
needed to be improved

1112
00:43:06,309 --> 00:43:04,319
and to do this we looked at every

1113
00:43:08,550 --> 00:43:06,319

possible source of error that could be

1114
00:43:10,630 --> 00:43:08,560
detracting from rv precision so

1115
00:43:13,589 --> 00:43:10,640
starlight traveling from the start

1116
00:43:15,990 --> 00:43:13,599
through earth's atmosphere

1117
00:43:18,390 --> 00:43:16,000
through the telescope to the instrument

1118
00:43:20,230 --> 00:43:18,400
anything along that light path

1119
00:43:21,670 --> 00:43:20,240
can add errors and so we have to think

1120
00:43:23,510 --> 00:43:21,680
about everything

1121
00:43:25,829 --> 00:43:23,520
that the light encounters and how to

1122
00:43:28,870 --> 00:43:25,839
control it so that it doesn't

1123
00:43:31,030 --> 00:43:28,880
create fake shifts in the data

1124
00:43:31,990 --> 00:43:31,040
this is about also where i started my

1125
00:43:34,470 --> 00:43:32,000
career

1126
00:43:38,790 --> 00:43:34,480
in exoplanets thinking about what the

1127
00:43:42,950 --> 00:43:40,309
so here i'll show you what we call an

1128
00:43:46,069 --> 00:43:42,960
error budget so it is a

1129
00:43:48,230 --> 00:43:46,079
a systems engineering tool for for

1130
00:43:50,150 --> 00:43:48,240
describing all of the errors that we

1131
00:43:51,990 --> 00:43:50,160
think are possible and trying to put

1132
00:43:53,750 --> 00:43:52,000
some bounds on them lots of these are

1133
00:43:54,870 --> 00:43:53,760
actually very difficult to understand or

1134
00:43:56,550 --> 00:43:54,880
measure

1135
00:43:59,270 --> 00:43:56,560
and so you see they're color coded by

1136
00:44:00,390 --> 00:43:59,280
our confidence in them

1137
00:44:03,589 --> 00:44:00,400
but

1138
00:44:07,270 --> 00:44:03,599

i do want to show you sort of some of

1139
00:44:09,670 --> 00:44:07,280
the spheres of concerns that we have so

1140
00:44:12,230 --> 00:44:09,680
here is the main instrument and it has a

1141
00:44:13,990 --> 00:44:12,240
lot of thermal stability concerns so

1142
00:44:16,870 --> 00:44:14,000
we're trying to make it as mechanically

1143
00:44:18,550 --> 00:44:16,880
stable as possible and and not reactive

1144
00:44:20,870 --> 00:44:18,560
to temperature changes

1145
00:44:24,390 --> 00:44:20,880
um there is the detector itself which

1146
00:44:26,230 --> 00:44:24,400
records the incidence of photons on it

1147
00:44:27,670 --> 00:44:26,240
of course you can imagine lots of errors

1148
00:44:29,750 --> 00:44:27,680
creeping in there and so we have to

1149
00:44:31,910 --> 00:44:29,760
worry about things like the shapes and

1150
00:44:35,190 --> 00:44:31,920
the sizes of pixels

1151
00:44:37,190 --> 00:44:35,200
the thermal response of the detector etc

1152
00:44:38,630 --> 00:44:37,200
uh we also worry about

1153
00:44:39,910 --> 00:44:38,640
um

1154
00:44:41,750 --> 00:44:39,920
transporting the light from the

1155
00:44:43,750 --> 00:44:41,760
telescope to the instrument so we use

1156
00:44:46,710 --> 00:44:43,760
optical fibers to do that and so there

1157
00:44:48,829 --> 00:44:46,720
are several error terms that can crop up

1158
00:44:51,910 --> 00:44:48,839
while the light is traveling

1159
00:44:53,910 --> 00:44:51,920
um and then there are some external

1160
00:44:57,109 --> 00:44:53,920
errors like the telescope the telescope

1161
00:44:59,030 --> 00:44:57,119
might shake from the wind um or this we

1162
00:45:01,270 --> 00:44:59,040
might not be focusing on the star just

1163
00:45:03,190 --> 00:45:01,280

right um those are all things we worry

1164
00:45:04,470 --> 00:45:03,200
about and try to control as well as

1165
00:45:07,109 --> 00:45:04,480
possible

1166
00:45:09,750 --> 00:45:07,119
and lastly there are atmospheric effects

1167
00:45:12,230 --> 00:45:09,760
like clouds passing by

1168
00:45:14,790 --> 00:45:12,240
or or a particularly humid night all of

1169
00:45:16,790 --> 00:45:14,800
these affect the light as it as it

1170
00:45:18,390 --> 00:45:16,800
travels through

1171
00:45:20,630 --> 00:45:18,400
um there is another

1172
00:45:23,190 --> 00:45:20,640
major error term here which is the star

1173
00:45:24,950 --> 00:45:23,200
itself but it's not in this chart

1174
00:45:27,349 --> 00:45:24,960
because we have no control over it and

1175
00:45:29,750 --> 00:45:27,359
so all we can do there is to try to

1176
00:45:30,829 --> 00:45:29,760
understand the star and correct those uh

1177
00:45:35,829 --> 00:45:30,839
in

1178
00:45:37,910 --> 00:45:35,839
here for software because

1179
00:45:39,829 --> 00:45:37,920
at this point software

1180
00:45:41,670 --> 00:45:39,839
or your analysis technique is just as

1181
00:45:44,150 --> 00:45:41,680
important as your hardware and if you're

1182
00:45:45,510 --> 00:45:44,160
not careful you can introduce errors in

1183
00:45:48,309 --> 00:45:45,520
your analysis

1184
00:45:49,349 --> 00:45:48,319
um and so with all of those

1185
00:45:52,390 --> 00:45:49,359
um

1186
00:45:54,069 --> 00:45:52,400
worries in place uh we embark on

1187
00:45:56,150 --> 00:45:54,079
building these next generation of

1188
00:46:00,230 --> 00:45:56,160

instruments that that will hopefully

1189
00:46:02,150 --> 00:46:00,240
take us closer to earth-like planets

1190
00:46:04,230 --> 00:46:02,160
and so the overarching philosophy for

1191
00:46:06,470 --> 00:46:04,240
these instruments is that we are going

1192
00:46:08,470 --> 00:46:06,480
to stabilize everything everything

1193
00:46:09,910 --> 00:46:08,480
possible in hardware so these are built

1194
00:46:11,829 --> 00:46:09,920
to be

1195
00:46:13,190 --> 00:46:11,839
some of the most stable

1196
00:46:15,589 --> 00:46:13,200
pieces of

1197
00:46:17,990 --> 00:46:15,599
equipment in the world

1198
00:46:21,349 --> 00:46:18,000
they are they are stable to a thousandth

1199
00:46:22,470 --> 00:46:21,359
of a degree in temperature

1200
00:46:25,430 --> 00:46:22,480
and

1201
00:46:27,430 --> 00:46:25,440
once we stabilize everything in hardware

1202
00:46:28,950 --> 00:46:27,440
we don't expect it still to be perfect

1203
00:46:31,190 --> 00:46:28,960
we are then prepared to correct

1204
00:46:33,349 --> 00:46:31,200
everything that's left in software so we

1205
00:46:36,230 --> 00:46:33,359
put in as much effort into the software

1206
00:46:40,550 --> 00:46:38,390
so let me show you a few examples of the

1207
00:46:42,550 --> 00:46:40,560
the advances that we've made

1208
00:46:44,150 --> 00:46:42,560
we don't have time to go over all of it

1209
00:46:47,430 --> 00:46:44,160
uh but i'll show you some of the

1210
00:46:49,670 --> 00:46:47,440
highlights and and pretty pictures of

1211
00:46:51,190 --> 00:46:49,680
how we advance the field

1212
00:46:54,150 --> 00:46:51,200
so one of the things we worry about is

1213
00:46:56,230 --> 00:46:54,160

something called fiber modal noise um

1214
00:46:59,030 --> 00:46:56,240
it's basically an interference pattern

1215
00:47:00,550 --> 00:46:59,040
that arises uh as the light travels

1216
00:47:02,150 --> 00:47:00,560
through the fiber and so this is an

1217
00:47:03,190 --> 00:47:02,160
extreme case that i'm showing you if

1218
00:47:05,109 --> 00:47:03,200
there is a

1219
00:47:07,510 --> 00:47:05,119
a single wavelength of light going

1220
00:47:09,349 --> 00:47:07,520
through a fiber uh you see the worst

1221
00:47:11,750 --> 00:47:09,359
case of interference and so you see this

1222
00:47:13,190 --> 00:47:11,760
terrible speckly pattern

1223
00:47:14,230 --> 00:47:13,200
and you can imagine if you're trying to

1224
00:47:16,550 --> 00:47:14,240
measure

1225
00:47:18,870 --> 00:47:16,560
motions from us from a planet that would

1226
00:47:21,349 --> 00:47:18,880
wobble a star um

1227
00:47:23,270 --> 00:47:21,359
that would show up as very small changes

1228
00:47:25,270 --> 00:47:23,280
in the centroid of the light so the

1229
00:47:28,309 --> 00:47:25,280
center point of the light

1230
00:47:30,470 --> 00:47:28,319
and this kind of speckling just

1231
00:47:32,630 --> 00:47:30,480
overwhelms that you can't see the planet

1232
00:47:35,190 --> 00:47:32,640
at all all you see is noise from the

1233
00:47:36,710 --> 00:47:35,200
from the fiber

1234
00:47:38,790 --> 00:47:36,720
and so

1235
00:47:41,990 --> 00:47:38,800
as a grad student i i designed something

1236
00:47:43,829 --> 00:47:42,000
called a modal noise agitator um

1237
00:47:45,750 --> 00:47:43,839
the funny story that goes with this is

1238
00:47:48,470 --> 00:47:45,760

that this was actually a mechanical

1239
00:47:50,309 --> 00:47:48,480
design based on on how us graduate

1240
00:47:52,630 --> 00:47:50,319
students were wiggling the fiber which

1241
00:47:54,950 --> 00:47:52,640
seemed to work the best and so we had an

1242
00:47:56,069 --> 00:47:54,960
engineer try and mimic that exact same

1243
00:47:58,230 --> 00:47:56,079
motion so

1244
00:48:00,069 --> 00:47:58,240
this is a mechanical grad student trying

1245
00:48:02,069 --> 00:48:00,079
to trying to agitate the fiber in

1246
00:48:03,349 --> 00:48:02,079
exactly the same way and you'll see on

1247
00:48:05,430 --> 00:48:03,359
the right here

1248
00:48:07,589 --> 00:48:05,440
the effect of doing that so with now

1249
00:48:09,030 --> 00:48:07,599
with the same setup just with the modal

1250
00:48:10,630 --> 00:48:09,040
noise agitator

1251
00:48:13,270 --> 00:48:10,640
you'll see that the illumination that we

1252
00:48:15,589 --> 00:48:13,280
get out of the fiber is very very smooth

1253
00:48:17,589 --> 00:48:15,599
uh compared to before and it's

1254
00:48:20,150 --> 00:48:17,599
essentially smooth enough that now you

1255
00:48:22,150 --> 00:48:20,160
could measure the effect of a planet uh

1256
00:48:24,790 --> 00:48:22,160
instead of being overwhelmed by noise so

1257
00:48:26,950 --> 00:48:24,800
this is one one noise source in our list

1258
00:48:29,349 --> 00:48:26,960
of tens of noise sources

1259
00:48:31,670 --> 00:48:29,359
that is now retired so it's not a not a

1260
00:48:33,670 --> 00:48:31,680
problem anymore

1261
00:48:35,430 --> 00:48:33,680
uh here's another one so this has to do

1262
00:48:37,829 --> 00:48:35,440
with the interface of the telescope and

1263
00:48:42,950 --> 00:48:37,839

the fibers so the telescope tries to

1264
00:48:47,430 --> 00:48:45,190
because it cannot do it perfectly

1265
00:48:48,950 --> 00:48:47,440
sometimes the star can wander on the

1266
00:48:50,870 --> 00:48:48,960
face of the fiber

1267
00:48:53,430 --> 00:48:50,880
and if you are

1268
00:48:55,030 --> 00:48:53,440
not careful that can change the output

1269
00:48:57,190 --> 00:48:55,040
that goes into the instrument and

1270
00:48:59,109 --> 00:48:57,200
therefore the wobble that you measure so

1271
00:49:01,190 --> 00:48:59,119
it creates a fake wobble where there

1272
00:49:02,549 --> 00:49:01,200
isn't one

1273
00:49:05,109 --> 00:49:02,559
and so here again

1274
00:49:06,870 --> 00:49:05,119
uh i spent some of the

1275
00:49:09,510 --> 00:49:06,880
several years actually of graduate

1276
00:49:12,790 --> 00:49:09,520
school time developing this technology

1277
00:49:14,630 --> 00:49:12,800
um to scramble the light and so this is

1278
00:49:16,870 --> 00:49:14,640
this is called a ball lens scrambler is

1279
00:49:19,510 --> 00:49:16,880
it's essentially a tiny two millimeter

1280
00:49:22,630 --> 00:49:19,520
ball uh in this case

1281
00:49:24,790 --> 00:49:22,640
that is in the part of the fibers

1282
00:49:27,030 --> 00:49:24,800
and given the composition of the ball

1283
00:49:29,829 --> 00:49:27,040
and the alignment of this part it

1284
00:49:32,390 --> 00:49:29,839
basically scrambles the light removes

1285
00:49:34,549 --> 00:49:32,400
any memory of the input illumination and

1286
00:49:36,950 --> 00:49:34,559
now no matter where the star is on your

1287
00:49:39,349 --> 00:49:36,960
fiber in this very extreme scenario i'm

1288
00:49:41,589 --> 00:49:39,359

moving the star all the way from one end

1289
00:49:43,670 --> 00:49:41,599
to the other end of the fiber usually

1290
00:49:45,990 --> 00:49:43,680
the telescope does a better job but

1291
00:49:48,230 --> 00:49:46,000
but no matter where it is the output

1292
00:49:50,230 --> 00:49:48,240
illumination is perfectly stable and so

1293
00:49:52,790 --> 00:49:50,240
this bottom picture is actually also a

1294
00:49:55,270 --> 00:49:52,800
movie but you can see that by eye

1295
00:49:57,109 --> 00:49:55,280
it doesn't seem to be moving at all

1296
00:50:00,950 --> 00:49:57,119
and so this is another error term that

1297
00:50:05,670 --> 00:50:03,270
other ways we increased stability so we

1298
00:50:07,910 --> 00:50:05,680
design a new level of thermo-mechanical

1299
00:50:09,190 --> 00:50:07,920
stability so that means

1300
00:50:11,589 --> 00:50:09,200
mechanical

1301
00:50:13,670 --> 00:50:11,599
responses to changes in temperature and

1302
00:50:15,190 --> 00:50:13,680
pressure

1303
00:50:16,309 --> 00:50:15,200
this is a

1304
00:50:20,069 --> 00:50:16,319
the

1305
00:50:22,630 --> 00:50:20,079
spectrograph um

1306
00:50:24,790 --> 00:50:22,640
showing what's inside the the huge

1307
00:50:27,510 --> 00:50:24,800
vacuum tank

1308
00:50:30,390 --> 00:50:27,520
and this whole system is kept very very

1309
00:50:32,069 --> 00:50:30,400
stable so you'll see here uh how how an

1310
00:50:35,030 --> 00:50:32,079
instrument called new it another one of

1311
00:50:37,750 --> 00:50:35,040
these compares to harps um which was the

1312
00:50:39,910 --> 00:50:37,760
previous state of the art so it's about

1313
00:50:43,670 --> 00:50:39,920

two orders of magnitude more stable in

1314
00:50:46,150 --> 00:50:43,680
temperature and one two three four five

1315
00:50:48,470 --> 00:50:46,160
orders of magnitude more stable pressure

1316
00:50:49,430 --> 00:50:48,480
so we're we're doing our best to provide

1317
00:50:53,510 --> 00:50:49,440
a very

1318
00:50:55,990 --> 00:50:53,520
uh calm environment for this instrument

1319
00:50:57,829 --> 00:50:56,000
we also design a new level of optical

1320
00:50:59,910 --> 00:50:57,839
stability so this is an instrument

1321
00:51:01,990 --> 00:50:59,920
called the keck planet finder

1322
00:51:04,549 --> 00:51:02,000
and here is a beam of light traveling

1323
00:51:07,829 --> 00:51:04,559
through the optics of that system

1324
00:51:10,950 --> 00:51:07,839
this design itself is not very new it's

1325
00:51:13,349 --> 00:51:10,960
actually been in use for several decades

1326
00:51:15,430 --> 00:51:13,359
but the implementation of it is much

1327
00:51:16,870 --> 00:51:15,440
more careful than ever before and so we

1328
00:51:19,910 --> 00:51:16,880
do our best

1329
00:51:21,109 --> 00:51:19,920
to avoid errors that can arise while the

1330
00:51:24,870 --> 00:51:21,119
light is traveling through the

1331
00:51:28,630 --> 00:51:26,710
and lastly once your

1332
00:51:30,630 --> 00:51:28,640
detector records the photons and you

1333
00:51:32,630 --> 00:51:30,640
have your data then you move to analysis

1334
00:51:34,309 --> 00:51:32,640
so we also have to design

1335
00:51:37,190 --> 00:51:34,319
like i said before a new level of

1336
00:51:39,030 --> 00:51:37,200
algorithmic stability so again software

1337
00:51:40,630 --> 00:51:39,040
and data analysis is just as important

1338
00:51:42,549 --> 00:51:40,640

as the hardware here

1339
00:51:44,390 --> 00:51:42,559
and so we have to design precision

1340
00:51:45,990 --> 00:51:44,400
analysis software

1341
00:51:48,069 --> 00:51:46,000
i'll also show you what the data looks

1342
00:51:50,549 --> 00:51:48,079
like now compared to those

1343
00:51:52,549 --> 00:51:50,559
photographic plates so we've come we've

1344
00:51:53,589 --> 00:51:52,559
come a long way um

1345
00:51:55,829 --> 00:51:53,599
these are

1346
00:51:58,710 --> 00:51:55,839
really beautiful uh records of the

1347
00:52:01,510 --> 00:51:58,720
stellar spectrum you see here in the in

1348
00:52:04,150 --> 00:52:01,520
the zoomed in regions the the starlight

1349
00:52:06,309 --> 00:52:04,160
is this sort of continuum looking light

1350
00:52:08,390 --> 00:52:06,319
again with the absorption lines

1351
00:52:12,069 --> 00:52:08,400
and you'll see this beautiful

1352
00:52:13,829 --> 00:52:12,079
trace of dots next to it um which is

1353
00:52:16,069 --> 00:52:13,839
from something called a laser frequency

1354
00:52:16,950 --> 00:52:16,079
comb so this is the newest

1355
00:52:19,510 --> 00:52:16,960
and

1356
00:52:21,349 --> 00:52:19,520
best version of a ruler um that is

1357
00:52:23,990 --> 00:52:21,359
available now so moving away from the

1358
00:52:26,150 --> 00:52:24,000
absorption lamps the emission lamps uh

1359
00:52:28,630 --> 00:52:26,160
we now have this laser frequency comb

1360
00:52:30,870 --> 00:52:28,640
which in itself is actually nobel prize

1361
00:52:33,190 --> 00:52:30,880
winning technology um and much more

1362
00:52:34,390 --> 00:52:33,200
complex than our spectrograph uh but it

1363
00:52:36,790 --> 00:52:34,400

provides

1364
00:52:39,270 --> 00:52:36,800
uh a ruler that is tied to the atomic

1365
00:52:41,109 --> 00:52:39,280
standard uh and and just way more

1366
00:52:43,589 --> 00:52:41,119
precision than we actually need so it's

1367
00:52:47,270 --> 00:52:43,599
it's a it's a beautiful um reference to

1368
00:52:51,510 --> 00:52:49,190
so we are just finishing building this

1369
00:52:53,430 --> 00:52:51,520
new generation of extreme precision

1370
00:52:55,030 --> 00:52:53,440
spectrographs and these are called

1371
00:52:57,670 --> 00:52:55,040
extreme precision because they are the

1372
00:52:59,109 --> 00:52:57,680
last step

1373
00:53:00,710 --> 00:52:59,119
in that

1374
00:53:02,630 --> 00:53:00,720
progression of precision that i was

1375
00:53:05,510 --> 00:53:02,640
showing you and for the first time in

1376
00:53:08,230 --> 00:53:05,520
history we are now close to detecting

1377
00:53:10,790 --> 00:53:08,240
true earth-like planets uh and so here

1378
00:53:13,510 --> 00:53:10,800
is our last step that we have just taken

1379
00:53:15,190 --> 00:53:13,520
uh from a from the casual walk level to

1380
00:53:16,710 --> 00:53:15,200
that of the tortoise which we have been

1381
00:53:19,109 --> 00:53:16,720
aiming for

1382
00:53:22,150 --> 00:53:19,119
and while we are not at 10 centimeters

1383
00:53:23,990 --> 00:53:22,160
per second yet we are we are at about 30

1384
00:53:25,829 --> 00:53:24,000
centimeters per second and getting

1385
00:53:28,069 --> 00:53:25,839
getting closer to 10 centimeters per

1386
00:53:30,870 --> 00:53:28,079
second um some of that gap can actually

1387
00:53:33,430 --> 00:53:30,880
be closed with with algorithmic work

1388
00:53:35,430 --> 00:53:33,440

and not necessarily new instruments

1389
00:53:37,589 --> 00:53:35,440
and so there is a lot of work to be done

1390
00:53:39,750 --> 00:53:37,599
in this field as these new instruments

1391
00:53:41,829 --> 00:53:39,760
come online

1392
00:53:43,510 --> 00:53:41,839
and give us again a new view of the

1393
00:53:46,470 --> 00:53:43,520
universe just as those first

1394
00:53:47,990 --> 00:53:46,480
spectrographs did

1395
00:53:49,750 --> 00:53:48,000
and so just to show you that some of

1396
00:53:51,670 --> 00:53:49,760
these instruments are actually on skype

1397
00:53:54,150 --> 00:53:51,680
this is an instrument called new id one

1398
00:53:56,710 --> 00:53:54,160
of several instruments that i built

1399
00:53:59,270 --> 00:53:56,720
and it is observing right now uh at kitt

1400
00:54:01,589 --> 00:53:59,280
peak uh observatory in arizona and every

1401
00:54:03,430 --> 00:54:01,599
night it's looking for planets uh and

1402
00:54:04,470 --> 00:54:03,440
during the day it actually observes the

1403
00:54:08,790 --> 00:54:04,480
sun

1404
00:54:10,950 --> 00:54:08,800
but also understand our instrument

1405
00:54:12,390 --> 00:54:10,960
better because the sun is a relatively

1406
00:54:13,430 --> 00:54:12,400
well-known star

1407
00:54:15,430 --> 00:54:13,440
um

1408
00:54:17,750 --> 00:54:15,440
and we're we're polishing a lot of our

1409
00:54:19,990 --> 00:54:17,760
analysis techniques on the on data of

1410
00:54:24,230 --> 00:54:20,000
the sun before we apply to apply it to

1411
00:54:26,470 --> 00:54:24,240
the stars uh and so this is this is uh

1412
00:54:28,870 --> 00:54:26,480
science advancements that are happening

1413
00:54:32,150 --> 00:54:28,880

right now

1414
00:54:34,390 --> 00:54:32,160
uh and so that is mostly where the story

1415
00:54:36,789 --> 00:54:34,400
ends but i will leave you with a teaser

1416
00:54:37,910 --> 00:54:36,799
trailer uh for the next part of this

1417
00:54:40,309 --> 00:54:37,920
story

1418
00:54:41,829 --> 00:54:40,319
which is that at this level of precision

1419
00:54:44,549 --> 00:54:41,839
we have overcome

1420
00:54:47,030 --> 00:54:44,559
all of the instrumental barriers and so

1421
00:54:50,789 --> 00:54:47,040
it turns out that at this point our new

1422
00:54:53,109 --> 00:54:50,799
nemesis is the host stars themselves

1423
00:54:54,710 --> 00:54:53,119
and so in the sequel to this story uh

1424
00:54:58,150 --> 00:54:54,720
that you have to wait for

1425
00:55:01,349 --> 00:54:58,160
is how stars hide real planets um and

1426
00:55:03,670 --> 00:55:01,359
can pretend to have fake planets

1427
00:55:05,750 --> 00:55:03,680
uh that's all from me uh thank you so

1428
00:55:08,390 --> 00:55:05,760
much for listening and i'll turn it back

1429
00:55:11,589 --> 00:55:08,400
over to frank

1430
00:55:12,710 --> 00:55:11,599
oh thank you arpata that is uh quite the

1431
00:55:15,349 --> 00:55:12,720
journey

1432
00:55:16,309 --> 00:55:15,359
um from noticing uh different stellar

1433
00:55:17,270 --> 00:55:16,319
movements

1434
00:55:19,109 --> 00:55:17,280
between

1435
00:55:20,950 --> 00:55:19,119
old catalogs of stars that you couldn't

1436
00:55:21,990 --> 00:55:20,960
verify over the course of a thousand

1437
00:55:24,390 --> 00:55:22,000
years

1438
00:55:26,789 --> 00:55:24,400

down to finding you know that that tiny

1439
00:55:28,710 --> 00:55:26,799
little motion um and getting down to 30

1440
00:55:31,030 --> 00:55:28,720
kilometer 30 meter

1441
00:55:34,390 --> 00:55:31,040
30 centimeters per second

1442
00:55:36,309 --> 00:55:34,400
has been quite the journey um it's it's

1443
00:55:38,150 --> 00:55:36,319
kind of fun because you know i've

1444
00:55:40,390 --> 00:55:38,160
followed this from a distance being you

1445
00:55:42,230 --> 00:55:40,400
know somebody who's not in the game but

1446
00:55:44,309 --> 00:55:42,240
really followed the uh just the

1447
00:55:46,630 --> 00:55:44,319
enjoyment of seeing how things were

1448
00:55:48,710 --> 00:55:46,640
pushed down i was at berkeley uh

1449
00:55:50,870 --> 00:55:48,720
actually worked with the team uh with

1450
00:55:52,230 --> 00:55:50,880
some of their iodine uh things i was i

1451
00:55:54,950 --> 00:55:52,240
didn't do anything on the team for the

1452
00:55:56,950 --> 00:55:54,960
exoplanets but i was a computer geek so

1453
00:56:00,150 --> 00:55:56,960
i was able to help them improve their

1454
00:56:01,510 --> 00:56:00,160
software processing uh back in the year

1455
00:56:03,510 --> 00:56:01,520
that's really cool frank because i think

1456
00:56:06,390 --> 00:56:03,520
a lot of the challenges even then had to

1457
00:56:08,630 --> 00:56:06,400
do with processing the data

1458
00:56:10,230 --> 00:56:08,640
and and and getting a new machine you

1459
00:56:12,630 --> 00:56:10,240
know and running it on a new machine

1460
00:56:14,069 --> 00:56:12,640
just just totally speeded up things

1461
00:56:17,990 --> 00:56:14,079
or just you know using a different

1462
00:56:22,710 --> 00:56:20,789
all right um so we got um about 150

1463
00:56:25,190 --> 00:56:22,720

people watching online here and they had

1464
00:56:27,510 --> 00:56:25,200
a bunch of questions um you got a lot of

1465
00:56:29,109 --> 00:56:27,520
compliments by the way on the you know

1466
00:56:30,390 --> 00:56:29,119
clarity of your presentation i just want

1467
00:56:32,710 --> 00:56:30,400
to let you know that they've really

1468
00:56:34,470 --> 00:56:32,720
enjoyed uh the fact that how carefully

1469
00:56:36,630 --> 00:56:34,480
you you work through this

1470
00:56:38,390 --> 00:56:36,640
um but we had an interesting question on

1471
00:56:40,950 --> 00:56:38,400
because you mentioned that they were

1472
00:56:42,870 --> 00:56:40,960
able to start measuring the sun's motion

1473
00:56:44,150 --> 00:56:42,880
and one person sat there and said all

1474
00:56:45,910 --> 00:56:44,160
right so the sun

1475
00:56:48,150 --> 00:56:45,920
orbits the galaxy

1476
00:56:50,069 --> 00:56:48,160
does that mean it moves from spiral arm

1477
00:56:51,430 --> 00:56:50,079
to spiral arm what's that motion that

1478
00:56:52,870 --> 00:56:51,440
that we've measured here what's that all

1479
00:56:55,109 --> 00:56:52,880
about

1480
00:56:57,190 --> 00:56:55,119
yeah that's a great question um

1481
00:57:00,549 --> 00:56:57,200
so the the

1482
00:57:02,470 --> 00:57:00,559
sun they found was moving um but also

1483
00:57:04,789 --> 00:57:02,480
the nearby stars were moving with the

1484
00:57:07,190 --> 00:57:04,799
sun they were all moving together uh and

1485
00:57:09,190 --> 00:57:07,200
so the sun is not moving

1486
00:57:11,349 --> 00:57:09,200
away from its neighbors it's moving with

1487
00:57:13,030 --> 00:57:11,359
its neighbors and those are those are

1488
00:57:15,270 --> 00:57:13,040

the other stars that make up this fire

1489
00:57:17,990 --> 00:57:15,280
alarm so it turns out the whole spiral

1490
00:57:20,870 --> 00:57:18,000
arm is moving and um the galaxy sort of

1491
00:57:22,549 --> 00:57:20,880
retains its shape but the whole of it is

1492
00:57:25,190 --> 00:57:22,559
rotating

1493
00:57:26,230 --> 00:57:25,200
okay and sun's moving at what what's the

1494
00:57:27,990 --> 00:57:26,240
the do you know do you remember the

1495
00:57:30,309 --> 00:57:28,000
current velocity that we ain't know what

1496
00:57:32,309 --> 00:57:30,319
the sun's motion is

1497
00:57:33,589 --> 00:57:32,319
in the galaxy uh

1498
00:57:37,030 --> 00:57:33,599
i don't

1499
00:57:38,950 --> 00:57:37,040
about 300 meters per second yeah it's

1500
00:57:42,309 --> 00:57:38,960
it's been over over my career it's been

1501
00:57:44,230 --> 00:57:42,319
down about 200 and as high as 250 300 or

1502
00:57:45,270 --> 00:57:44,240
something like that

1503
00:57:46,710 --> 00:57:45,280
okay

1504
00:57:48,390 --> 00:57:46,720
all right and that is actually kind of

1505
00:57:49,910 --> 00:57:48,400
interesting to note that it takes a

1506
00:57:52,630 --> 00:57:49,920
couple hundred million years for the sun

1507
00:57:54,470 --> 00:57:52,640
to orbit the galaxy once too

1508
00:57:56,710 --> 00:57:54,480
all right so grant justice has been

1509
00:57:59,109 --> 00:57:56,720
following uh the questions uh along with

1510
00:58:01,750 --> 00:57:59,119
me in the youtube chat grant you want to

1511
00:58:03,829 --> 00:58:01,760
join in and uh ask some of the fit your

1512
00:58:05,670 --> 00:58:03,839
favorite questions from the chat

1513
00:58:07,670 --> 00:58:05,680

yeah absolutely we've had a good

1514
00:58:09,349 --> 00:58:07,680
audience and i have to say like most of

1515
00:58:10,470 --> 00:58:09,359
the questions i've seen in the chat so

1516
00:58:15,109 --> 00:58:10,480
far have been answered by the

1517
00:58:20,069 --> 00:58:17,349
all right um the first one off i like

1518
00:58:21,430 --> 00:58:20,079
this um how is your work going to be

1519
00:58:24,069 --> 00:58:21,440
affected by

1520
00:58:26,870 --> 00:58:24,079
jwst coming online and then after if we

1521
00:58:28,230 --> 00:58:26,880
get to the roman um what do you see the

1522
00:58:31,109 --> 00:58:28,240
future of your work with the new

1523
00:58:32,710 --> 00:58:31,119
instrumentation coming online

1524
00:58:34,470 --> 00:58:32,720
yeah that's a great question and

1525
00:58:37,030 --> 00:58:34,480
something i think the whole field is

1526
00:58:40,470 --> 00:58:37,040
thinking about now um

1527
00:58:42,390 --> 00:58:40,480
so this technique of measuring uh the

1528
00:58:44,150 --> 00:58:42,400
masses of planets will continue to be

1529
00:58:46,150 --> 00:58:44,160
useful but we're always trying to push

1530
00:58:48,150 --> 00:58:46,160
our instruments to do a little bit more

1531
00:58:49,829 --> 00:58:48,160
and so now that we're

1532
00:58:52,549 --> 00:58:49,839
you know sort of able to routinely

1533
00:58:54,710 --> 00:58:52,559
measure small planet masses um one thing

1534
00:58:56,789 --> 00:58:54,720
i'm really interested in is studying

1535
00:58:59,829 --> 00:58:56,799
exoplanet atmospheres with these

1536
00:59:03,430 --> 00:58:59,839
instruments um and so there is a little

1537
00:59:05,910 --> 00:59:03,440
bit a very challenging but a small

1538
00:59:07,910 --> 00:59:05,920

path forward in measuring directly

1539
00:59:10,630 --> 00:59:07,920
trying to measure planetary photons

1540
00:59:12,870 --> 00:59:10,640
while measuring the stellar spectra

1541
00:59:14,470 --> 00:59:12,880
but that is a that is a incredibly

1542
00:59:16,829 --> 00:59:14,480
difficult way of measuring stellar

1543
00:59:19,510 --> 00:59:16,839
atmospheres that are actually

1544
00:59:22,069 --> 00:59:19,520
slightly well not easier but different

1545
00:59:24,390 --> 00:59:22,079
ways uh like like building a 10 billion

1546
00:59:28,069 --> 00:59:24,400
dollar space telescope and sending it to

1547
00:59:30,789 --> 00:59:28,079
l2 um and so jwst will also study

1548
00:59:32,470 --> 00:59:30,799
planetary atmospheres um via the transit

1549
00:59:34,069 --> 00:59:32,480
technique so it will look at the

1550
00:59:36,230 --> 00:59:34,079
difference between

1551
00:59:39,349 --> 00:59:36,240
stars that have planets in front of them

1552
00:59:41,349 --> 00:59:39,359
and stars that don't um and this is

1553
00:59:43,349 --> 00:59:41,359
going to be another question from the

1554
00:59:45,030 --> 00:59:43,359
chat so if you want to elaborate a

1555
00:59:47,430 --> 00:59:45,040
little bit more about how you can

1556
00:59:48,630 --> 00:59:47,440
actually tell the atmosphere and what's

1557
00:59:50,470 --> 00:59:48,640
like what

1558
00:59:51,750 --> 00:59:50,480
how precise the instruments have to be

1559
00:59:53,270 --> 00:59:51,760
in order for you to get that sort of a

1560
00:59:54,789 --> 00:59:53,280
determination that was another question

1561
00:59:57,589 --> 00:59:54,799
i was going to ask you just phased right

1562
01:00:00,950 --> 00:59:57,599
into it uh great so that that question

1563
01:00:02,789 --> 01:00:00,960

was about jwst or just in general

1564
01:00:04,950 --> 01:00:02,799
uh more of a general statement how do

1565
01:00:07,109 --> 01:00:04,960
you get the accuracy necessary to view

1566
01:00:08,630 --> 01:00:07,119
atmospheres and composition in addition

1567
01:00:09,990 --> 01:00:08,640
to like what it can do for your work

1568
01:00:11,270 --> 01:00:10,000
with the new telescope so i'm just kind

1569
01:00:15,430 --> 01:00:11,280
of piggybacking yeah

1570
01:00:18,470 --> 01:00:15,440
yes uh yes okay great um right so so in

1571
01:00:20,470 --> 01:00:18,480
studying atmospheres um jwst will study

1572
01:00:22,549 --> 01:00:20,480
atmospheres um

1573
01:00:24,710 --> 01:00:22,559
roman will try and study atmospheres and

1574
01:00:26,950 --> 01:00:24,720
so really all of these instruments are

1575
01:00:30,309 --> 01:00:26,960
telling different chapters of the same

1576
01:00:32,390 --> 01:00:30,319
story and so to understand a planet a

1577
01:00:33,990 --> 01:00:32,400
planetary system really holistically we

1578
01:00:35,750 --> 01:00:34,000
need all of these pieces we need to

1579
01:00:38,870 --> 01:00:35,760
understand the star we need to

1580
01:00:41,270 --> 01:00:38,880
understand um the size of the planet the

1581
01:00:42,549 --> 01:00:41,280
the mass of the planet the composition

1582
01:00:44,950 --> 01:00:42,559
of the planet the atmosphere of the

1583
01:00:47,910 --> 01:00:44,960
planet and so these are all sort of

1584
01:00:49,510 --> 01:00:47,920
patchwork uh parts of the same story

1585
01:00:51,109 --> 01:00:49,520
um okay so let me break in here let me

1586
01:00:52,789 --> 01:00:51,119
just break in here so just to answer

1587
01:00:54,710 --> 01:00:52,799
some one question right

1588
01:00:57,109 --> 01:00:54,720

you said that jwst will use the transit

1589
01:00:58,870 --> 01:00:57,119
method but jwst will not be using the

1590
01:01:01,109 --> 01:00:58,880
radial velocity method which is what you

1591
01:01:02,549 --> 01:01:01,119
focused on here and i presume it's

1592
01:01:05,910 --> 01:01:02,559
because you don't have astronauts up

1593
01:01:08,390 --> 01:01:05,920
there to wiggle the fibers you know

1594
01:01:10,470 --> 01:01:08,400
yeah so we actually don't fly any radio

1595
01:01:12,789 --> 01:01:10,480
velocity measurement instruments because

1596
01:01:14,630 --> 01:01:12,799
they need to be so stable

1597
01:01:16,230 --> 01:01:14,640
and right now at least the technology

1598
01:01:19,190 --> 01:01:16,240
that we have is also very large and

1599
01:01:21,589 --> 01:01:19,200
heavy uh and so there are there are also

1600
01:01:23,030 --> 01:01:21,599
people trying to build smaller versions

1601
01:01:25,349 --> 01:01:23,040
of these that could be flown in the

1602
01:01:27,430 --> 01:01:25,359
future um but we cannot do precision

1603
01:01:29,190 --> 01:01:27,440
spectroscopy from space right right so

1604
01:01:30,630 --> 01:01:29,200
great so that establishes an answer to

1605
01:01:32,630 --> 01:01:30,640
another to it's one of the things is

1606
01:01:34,470 --> 01:01:32,640
that radial velocity technique is

1607
01:01:36,470 --> 01:01:34,480
actually best from the ground that's

1608
01:01:38,870 --> 01:01:36,480
right but you still have to deal with

1609
01:01:40,230 --> 01:01:38,880
atmospheric distortions

1610
01:01:41,589 --> 01:01:40,240
and if we could get it into space we

1611
01:01:44,150 --> 01:01:41,599
could do it but right now that's not

1612
01:01:46,470 --> 01:01:44,160
technologically useful great right right

1613
01:01:48,549 --> 01:01:46,480

so that there actually is a is a couple

1614
01:01:50,789 --> 01:01:48,559
of teams working on making these smaller

1615
01:01:52,470 --> 01:01:50,799
versions um that where the whole

1616
01:01:54,230 --> 01:01:52,480
argument is that we're we're above the

1617
01:01:55,910 --> 01:01:54,240
atmosphere and so we don't have to worry

1618
01:01:58,470 --> 01:01:55,920
about what we call telluric lines from

1619
01:02:01,190 --> 01:01:58,480
the atmosphere right um but

1620
01:02:03,990 --> 01:02:01,200
but there is still uh i think some some

1621
01:02:05,910 --> 01:02:04,000
gaps there in space technology in

1622
01:02:07,349 --> 01:02:05,920
managing stability and focusing on the

1623
01:02:09,589 --> 01:02:07,359
star etc

1624
01:02:11,029 --> 01:02:09,599
um

1625
01:02:12,630 --> 01:02:11,039
okay this is i'm trying to answer a lot

1626
01:02:14,390 --> 01:02:12,640
of questions okay no no no no then

1627
01:02:16,309 --> 01:02:14,400
that's why that's why we're interrupting

1628
01:02:18,309 --> 01:02:16,319
and pausing and making yeah

1629
01:02:21,829 --> 01:02:18,319
thank you for speaking out the threads

1630
01:02:25,430 --> 01:02:23,670
what's the next thing is is is

1631
01:02:27,029 --> 01:02:25,440
discussing the transiting method or

1632
01:02:29,670 --> 01:02:27,039
what's the next thing she needs yeah so

1633
01:02:31,670 --> 01:02:29,680
let me let me talk about atmospheres

1634
01:02:33,510 --> 01:02:31,680
from both both of these points of view

1635
01:02:35,029 --> 01:02:33,520
so with spectroscopy and then with

1636
01:02:37,750 --> 01:02:35,039
transits which is what we call

1637
01:02:39,990 --> 01:02:37,760
photometry um which is so not spreading

1638
01:02:40,870 --> 01:02:40,000

out the light but just looking at a a

1639
01:02:43,109 --> 01:02:40,880
small

1640
01:02:45,029 --> 01:02:43,119
range of wavelengths of light together

1641
01:02:46,950 --> 01:02:45,039
um so in the transit method of course

1642
01:02:48,549 --> 01:02:46,960
you're the the

1643
01:02:50,309 --> 01:02:48,559
you're lucky enough that the planet is

1644
01:02:52,150 --> 01:02:50,319
passing in front of the star from your

1645
01:02:54,390 --> 01:02:52,160
point of view and so it's basically

1646
01:02:55,990 --> 01:02:54,400
blocking a part of the star for a short

1647
01:02:58,789 --> 01:02:56,000
part of the time and then going behind

1648
01:03:00,630 --> 01:02:58,799
the star um and so you could take this

1649
01:03:02,549 --> 01:03:00,640
this is more like the imaging that i was

1650
01:03:03,829 --> 01:03:02,559
talking about early on in astronomy

1651
01:03:05,990 --> 01:03:03,839
where you can take

1652
01:03:08,069 --> 01:03:06,000
essentially an image when the planet is

1653
01:03:10,710 --> 01:03:08,079
in front of the star and an image when

1654
01:03:12,870 --> 01:03:10,720
the planet is behind the star um and the

1655
01:03:14,870 --> 01:03:12,880
difference between those gives you the

1656
01:03:17,190 --> 01:03:14,880
effect of the planet right how is planet

1657
01:03:19,750 --> 01:03:17,200
plus star versus just star

1658
01:03:21,589 --> 01:03:19,760
um and that difference comes from the

1659
01:03:22,950 --> 01:03:21,599
little bit of starlight that passes

1660
01:03:24,069 --> 01:03:22,960
through the limb of the planet's

1661
01:03:25,430 --> 01:03:24,079
atmosphere

1662
01:03:26,950 --> 01:03:25,440
and picks up a little bit of the

1663
01:03:28,950 --> 01:03:26,960

signature of the the planet's

1664
01:03:31,910 --> 01:03:28,960
atmospheric composition

1665
01:03:33,670 --> 01:03:31,920
and so that is a a very nifty way really

1666
01:03:35,829 --> 01:03:33,680
to try and study the planet's atmosphere

1667
01:03:39,029 --> 01:03:35,839
and has been very successful and that's

1668
01:03:40,950 --> 01:03:39,039
that's what jwst will do as well um it

1669
01:03:42,150 --> 01:03:40,960
seems very round about coming from the

1670
01:03:44,470 --> 01:03:42,160
outside

1671
01:03:48,069 --> 01:03:44,480
catching the little lip of the planet

1672
01:03:49,670 --> 01:03:48,079
and the transit yeah right and so um

1673
01:03:51,510 --> 01:03:49,680
so let's think about a more

1674
01:03:53,109 --> 01:03:51,520
straightforward way to do that how would

1675
01:03:54,870 --> 01:03:53,119
you look at the

1676
01:03:57,750 --> 01:03:54,880
light from a planet you would take a

1677
01:03:59,829 --> 01:03:57,760
picture of the planet right um and so

1678
01:04:00,710 --> 01:03:59,839
that that has been

1679
01:04:02,710 --> 01:04:00,720
um

1680
01:04:05,190 --> 01:04:02,720
very challenging because stars are very

1681
01:04:07,589 --> 01:04:05,200
bright and so if you take a picture all

1682
01:04:10,150 --> 01:04:07,599
you see is the star and not the planet

1683
01:04:12,549 --> 01:04:10,160
and that's where roman comes in uh and

1684
01:04:15,670 --> 01:04:12,559
so roman will have the technology to try

1685
01:04:17,750 --> 01:04:15,680
and block out the light from the star um

1686
01:04:19,990 --> 01:04:17,760
kind of like shading your eyes from

1687
01:04:22,549 --> 01:04:20,000
sunlight to see you know things

1688
01:04:24,470 --> 01:04:22,559

that are that are close to the the sun

1689
01:04:26,390 --> 01:04:24,480
in the sky um

1690
01:04:27,990 --> 01:04:26,400
and so by blocking out the starlight we

1691
01:04:30,069 --> 01:04:28,000
will be able to see a little bit of

1692
01:04:32,549 --> 01:04:30,079
light from the planet and directly image

1693
01:04:34,870 --> 01:04:32,559
the planet itself um this is still

1694
01:04:36,870 --> 01:04:34,880
difficult to do even with roman for

1695
01:04:38,230 --> 01:04:36,880
close-in planets so earth earth-like

1696
01:04:40,470 --> 01:04:38,240
planets are still too close they're

1697
01:04:42,470 --> 01:04:40,480
overwhelmed by starlight but you can get

1698
01:04:44,069 --> 01:04:42,480
planets that are further out or planets

1699
01:04:45,990 --> 01:04:44,079
that are hot themselves and have a

1700
01:04:48,150 --> 01:04:46,000
little bit of their own light

1701
01:04:49,910 --> 01:04:48,160
those are the ones you can study and

1702
01:04:52,549 --> 01:04:49,920
that's important to do that in the

1703
01:04:54,950 --> 01:04:52,559
infrared because the planets glow

1704
01:04:56,630 --> 01:04:54,960
brightest in the infrared right yeah the

1705
01:04:58,870 --> 01:04:56,640
hot young planets are bright in the

1706
01:05:00,710 --> 01:04:58,880
infrared right so i mean one of the one

1707
01:05:02,710 --> 01:05:00,720
of the reasons why jwst is going to be

1708
01:05:05,029 --> 01:05:02,720
such an exoplanet machine

1709
01:05:07,990 --> 01:05:05,039
is because if you're uh hubble could

1710
01:05:09,750 --> 01:05:08,000
look at at um planets but they aren't

1711
01:05:12,309 --> 01:05:09,760
bright in the visible you really want to

1712
01:05:14,630 --> 01:05:12,319
get the uh brightness coming from them

1713
01:05:15,510 --> 01:05:14,640

you're going to need the j2st

1714
01:05:17,430 --> 01:05:15,520
that's right

1715
01:05:19,589 --> 01:05:17,440
for red light um

1716
01:05:21,589 --> 01:05:19,599
but then there is a third and very new

1717
01:05:22,710 --> 01:05:21,599
way of studying planetary atmospheres

1718
01:05:25,190 --> 01:05:22,720
with these

1719
01:05:26,710 --> 01:05:25,200
extreme precision spectrographs that i i

1720
01:05:29,670 --> 01:05:26,720
use

1721
01:05:31,670 --> 01:05:29,680
and there instead of trying to separate

1722
01:05:34,069 --> 01:05:31,680
the planet and the star spatially which

1723
01:05:36,630 --> 01:05:34,079
is what imaging does

1724
01:05:38,950 --> 01:05:36,640
or waiting for a transit to happen

1725
01:05:40,710 --> 01:05:38,960
you separate them in velocity space

1726
01:05:43,029 --> 01:05:40,720
because we're we're all about looking at

1727
01:05:45,349 --> 01:05:43,039
the shifting spectra and so the the

1728
01:05:46,789 --> 01:05:45,359
planet and the star move differently

1729
01:05:48,390 --> 01:05:46,799
when the planet is moving towards you

1730
01:05:49,910 --> 01:05:48,400
the star is moving away from you and

1731
01:05:51,829 --> 01:05:49,920
vice versa

1732
01:05:54,390 --> 01:05:51,839
and so they separate out in their blue

1733
01:05:57,109 --> 01:05:54,400
shift and redshift and so really when

1734
01:05:59,910 --> 01:05:57,119
you look at this system you're getting a

1735
01:06:01,910 --> 01:05:59,920
lot of photons from the star a billion

1736
01:06:03,750 --> 01:06:01,920
10 billion photons from the star and one

1737
01:06:06,150 --> 01:06:03,760
photon from the planet but you are

1738
01:06:08,789 --> 01:06:06,160

getting that one photon from the planet

1739
01:06:11,109 --> 01:06:08,799
and so if you observe for long enough

1740
01:06:13,750 --> 01:06:11,119
you can try to build up that the

1741
01:06:15,910 --> 01:06:13,760
planetary contribution and uh

1742
01:06:18,390 --> 01:06:15,920
disentangle them by their motion it's

1743
01:06:21,670 --> 01:06:18,400
very challenging it hasn't been done i'm

1744
01:06:23,829 --> 01:06:21,680
trying really hard to do it right now um

1745
01:06:25,589 --> 01:06:23,839
but but again i'm so i'm trying to do it

1746
01:06:27,109 --> 01:06:25,599
in the optical it's a little bit easier

1747
01:06:29,029 --> 01:06:27,119
in the near infrared especially if the

1748
01:06:30,549 --> 01:06:29,039
planet is bright there and so it has

1749
01:06:32,150 --> 01:06:30,559
been done in the near infrared for a

1750
01:06:34,470 --> 01:06:32,160
handful of planets uh even

1751
01:06:36,390 --> 01:06:34,480
non-transiting planets so this is

1752
01:06:38,950 --> 01:06:36,400
uh one of the only ways to study the

1753
01:06:40,630 --> 01:06:38,960
atmospheres of non-transiting planets um

1754
01:06:43,270 --> 01:06:40,640
so yeah there's a lot of exciting

1755
01:06:44,829 --> 01:06:43,280
atmospheric work coming up

1756
01:06:50,549 --> 01:06:44,839
yeah

1757
01:06:53,109 --> 01:06:50,559
um it is um as i i've presented to kids

1758
01:06:55,109 --> 01:06:53,119
um that uh when i grew up you know we

1759
01:06:57,829 --> 01:06:55,119
had star trek that was going around

1760
01:06:59,829 --> 01:06:57,839
exploring other planetary systems and

1761
01:07:02,150 --> 01:06:59,839
now the kids growing up these days they

1762
01:07:03,750 --> 01:07:02,160
get to explore them for real

1763
01:07:05,829 --> 01:07:03,760

unfortunately they just don't get to go

1764
01:07:08,549 --> 01:07:05,839
go there they can explore them by these

1765
01:07:10,470 --> 01:07:08,559
things and to have that come to life in

1766
01:07:11,990 --> 01:07:10,480
in my time in my lifetime is really

1767
01:07:13,190 --> 01:07:12,000
wonderful

1768
01:07:14,549 --> 01:07:13,200
because we are

1769
01:07:16,710 --> 01:07:14,559
we've got four thousand planetary

1770
01:07:18,549 --> 01:07:16,720
systems out there that we we know right

1771
01:07:20,789 --> 01:07:18,559
that's right i i think the thing that

1772
01:07:23,270 --> 01:07:20,799
still blows my mind is is that when you

1773
01:07:25,349 --> 01:07:23,280
look up at the at the night sky a lot of

1774
01:07:27,910 --> 01:07:25,359
the stars that you see maybe most of the

1775
01:07:30,309 --> 01:07:27,920
stars that you see have planets

1776
01:07:32,549 --> 01:07:30,319
and maybe habitable planets

1777
01:07:34,390 --> 01:07:32,559
which kind of makes it all seem very

1778
01:07:36,390 --> 01:07:34,400
close

1779
01:07:37,430 --> 01:07:36,400
all right so one person

1780
01:07:38,789 --> 01:07:37,440
obviously

1781
01:07:41,190 --> 01:07:38,799
thinks about

1782
01:07:44,069 --> 01:07:41,200
media delivery says your modal noise

1783
01:07:45,990 --> 01:07:44,079
actuator could help the fiber internet

1784
01:07:48,549 --> 01:07:46,000
delivery to improve the signal its

1785
01:07:49,990 --> 01:07:48,559
signal to noise ratio um but can you

1786
01:07:52,549 --> 01:07:50,000
figure out how to wiggle fibers that

1787
01:07:54,710 --> 01:07:52,559
they're buried underground

1788
01:07:57,349 --> 01:07:54,720

yeah so actually the the telecom

1789
01:08:00,950 --> 01:07:57,359
industry is far ahead of us in thinking

1790
01:08:05,990 --> 01:08:03,270
yeah i think there are already uh model

1791
01:08:08,309 --> 01:08:06,000
noise solutions for those fibers so

1792
01:08:10,069 --> 01:08:08,319
since even since we built that motor

1793
01:08:11,829 --> 01:08:10,079
noise agitator which was a few years ago

1794
01:08:14,789 --> 01:08:11,839
now you can now buy

1795
01:08:16,950 --> 01:08:14,799
just tiny off the shelf parts that will

1796
01:08:19,510 --> 01:08:16,960
like very softly squeeze and wiggle the

1797
01:08:21,910 --> 01:08:19,520
fiber um because the less you wiggle it

1798
01:08:23,590 --> 01:08:21,920
the less you damage the fiber also so

1799
01:08:25,910 --> 01:08:23,600
you don't you don't want to go swinging

1800
01:08:28,870 --> 01:08:25,920
it around too much um

1801
01:08:31,349 --> 01:08:28,880
but but yeah you can buy agitators that

1802
01:08:33,269 --> 01:08:31,359
are really small and so um you know we

1803
01:08:34,870 --> 01:08:33,279
we did patent the scrambler we probably

1804
01:08:37,349 --> 01:08:34,880
should have happened to the agitator as

1805
01:08:40,789 --> 01:08:39,110
but astronomers are generally not in it

1806
01:08:42,870 --> 01:08:40,799
for the money unfortunately we don't

1807
01:08:45,189 --> 01:08:42,880
think like that

1808
01:08:47,510 --> 01:08:45,199
grant thank you for bearing with me on

1809
01:08:49,510 --> 01:08:47,520
the deluge of questions but they were

1810
01:08:51,269 --> 01:08:49,520
all loosely related and i needed you to

1811
01:08:53,349 --> 01:08:51,279
bring them together for both me and the

1812
01:08:55,430 --> 01:08:53,359
audience

1813
01:08:57,510 --> 01:08:55,440

um all right so i'm gonna take a slight

1814
01:08:59,430 --> 01:08:57,520
departure from the science here and a

1815
01:09:01,189 --> 01:08:59,440
lot of the audience is very interested

1816
01:09:02,630 --> 01:09:01,199
in you because you are very

1817
01:09:03,990 --> 01:09:02,640
knowledgeable and have given such a good

1818
01:09:05,749 --> 01:09:04,000
talk like why don't you talk a little

1819
01:09:07,189 --> 01:09:05,759
bit about what got you interested into

1820
01:09:08,709 --> 01:09:07,199
this and a little bit of your journey

1821
01:09:10,149 --> 01:09:08,719
into astronomy

1822
01:09:12,070 --> 01:09:10,159
sure um

1823
01:09:14,950 --> 01:09:12,080
so i was always interested

1824
01:09:16,870 --> 01:09:14,960
in astronomy um and so i

1825
01:09:18,630 --> 01:09:16,880
without quite knowing what it meant to

1826
01:09:21,110 --> 01:09:18,640
be an astronomer

1827
01:09:24,229 --> 01:09:21,120
i think i was you know taking classes in

1828
01:09:26,709 --> 01:09:24,239
undergrad and um

1829
01:09:28,709 --> 01:09:26,719
trying to get closer to to professional

1830
01:09:29,669 --> 01:09:28,719
astronomy to see what it might be like

1831
01:09:32,709 --> 01:09:29,679
um

1832
01:09:34,950 --> 01:09:32,719
and i i i remember i decided to take a

1833
01:09:36,309 --> 01:09:34,960
gap year after undergrad to think about

1834
01:09:39,430 --> 01:09:36,319
whether to go to grad school since

1835
01:09:42,070 --> 01:09:39,440
that's that can be a bit of a commitment

1836
01:09:44,149 --> 01:09:42,080
and i i spent that year at penn state

1837
01:09:46,550 --> 01:09:44,159
where they had just started the center

1838
01:09:48,870 --> 01:09:46,560

for exoplanets and habitable worlds and

1839
01:09:50,309 --> 01:09:48,880
i had never studied exoplanets before in

1840
01:09:52,390 --> 01:09:50,319
undergrad i worked on gravitational

1841
01:09:53,990 --> 01:09:52,400
waves um

1842
01:09:55,910 --> 01:09:54,000
which you know were still in the

1843
01:09:58,709 --> 01:09:55,920
pre-discovery year so everyone was

1844
01:10:01,350 --> 01:09:58,719
racing to find gravitational waves

1845
01:10:03,910 --> 01:10:01,360
and exoplanets i feel like i just took

1846
01:10:05,669 --> 01:10:03,920
to it very naturally exoplanets are

1847
01:10:07,750 --> 01:10:05,679
are

1848
01:10:10,550 --> 01:10:07,760
so much easier to get excited about than

1849
01:10:12,870 --> 01:10:10,560
some of the more uh obtuse parts of

1850
01:10:15,189 --> 01:10:12,880
astronomy because they're

1851
01:10:17,189 --> 01:10:15,199
i have i have an astronomy professor who

1852
01:10:19,669 --> 01:10:17,199
who said that you know these are other

1853
01:10:22,310 --> 01:10:19,679
worlds they remind us of our home and we

1854
01:10:23,990 --> 01:10:22,320
can we can imagine them um

1855
01:10:25,750 --> 01:10:24,000
and and we

1856
01:10:27,430 --> 01:10:25,760
we relate to them and we care about them

1857
01:10:29,430 --> 01:10:27,440
and we like to you know we have so many

1858
01:10:32,229 --> 01:10:29,440
stories about who else could be living

1859
01:10:33,750 --> 01:10:32,239
on them and looking down on us um and so

1860
01:10:35,510 --> 01:10:33,760
i think it's very easy to get excited

1861
01:10:38,070 --> 01:10:35,520
about explanation and life in the

1862
01:10:39,910 --> 01:10:38,080
universe and um i i was lucky to join

1863
01:10:42,709 --> 01:10:39,920

the field at a time when it was sort of

1864
01:10:45,030 --> 01:10:42,719
exploding with activity and and funding

1865
01:10:47,990 --> 01:10:45,040
which is important as a grad student and

1866
01:10:50,550 --> 01:10:48,000
new instruments to be built and um i

1867
01:10:52,390 --> 01:10:50,560
think what i what i discovered is that i

1868
01:10:54,470 --> 01:10:52,400
really enjoy making

1869
01:10:56,229 --> 01:10:54,480
making precision measurements so you

1870
01:10:58,070 --> 01:10:56,239
know kind of digging down into the data

1871
01:10:58,790 --> 01:10:58,080
to get that last bit of precision and

1872
01:11:01,189 --> 01:10:58,800
then

1873
01:11:03,510 --> 01:11:01,199
seeing these tiny wobbles of stars that

1874
01:11:04,390 --> 01:11:03,520
are light years away was just incredible

1875
01:11:05,910 --> 01:11:04,400
and so

1876
01:11:07,350 --> 01:11:05,920
um i

1877
01:11:09,270 --> 01:11:07,360
yeah i've stayed i've stayed in

1878
01:11:12,390 --> 01:11:09,280
exoplanets and and built several

1879
01:11:13,990 --> 01:11:12,400
instruments since then and it's i think

1880
01:11:15,750 --> 01:11:14,000
this is maybe true of all astronomers

1881
01:11:17,350 --> 01:11:15,760
but for the days when i can step back

1882
01:11:19,110 --> 01:11:17,360
from the you know

1883
01:11:21,110 --> 01:11:19,120
curious coding and think about what

1884
01:11:23,830 --> 01:11:21,120
we're actually doing it still is still

1885
01:11:25,510 --> 01:11:23,840
amazing to me that we can do it at all

1886
01:11:29,590 --> 01:11:25,520
you may be drowning in python but you're

1887
01:11:34,149 --> 01:11:31,750
i will say that you remind me of a lot

1888
01:11:37,270 --> 01:11:34,159

of other astronomers in that

1889
01:11:40,149 --> 01:11:37,280
you have a zeal for best basic problem

1890
01:11:41,990 --> 01:11:40,159
solving you know i think um

1891
01:11:43,189 --> 01:11:42,000
that error chart that you give which by

1892
01:11:45,270 --> 01:11:43,199
the way for the public i just want to

1893
01:11:47,350 --> 01:11:45,280
say that astronomers and scientists call

1894
01:11:48,630 --> 01:11:47,360
it an error budget but it's not really

1895
01:11:51,669 --> 01:11:48,640
errors that we're making it's just the

1896
01:11:54,229 --> 01:11:51,679
uncertainty that's natural in it okay

1897
01:11:55,990 --> 01:11:54,239
we do the public they go oh you're

1898
01:11:58,229 --> 01:11:56,000
you're planning on making errors

1899
01:12:00,950 --> 01:11:58,239
these are just uncertainties that are

1900
01:12:03,189 --> 01:12:00,960
inherent in what we're doing um but in

1901
01:12:05,110 --> 01:12:03,199
in that chart you know going through

1902
01:12:07,510 --> 01:12:05,120
that and trying to solve each block of

1903
01:12:11,030 --> 01:12:07,520
that you know trying to do come up with

1904
01:12:13,350 --> 01:12:11,040
a way to address this problem um i see

1905
01:12:15,030 --> 01:12:13,360
that in you and it's it's it's you know

1906
01:12:16,310 --> 01:12:15,040
it's kind of the thing that kind of

1907
01:12:17,990 --> 01:12:16,320
drove me but in a totally different

1908
01:12:19,669 --> 01:12:18,000
totally different way uh through

1909
01:12:21,669 --> 01:12:19,679
astronomy and i think a lot of

1910
01:12:23,189 --> 01:12:21,679
astronomers are you know an a lot of

1911
01:12:25,030 --> 01:12:23,199
scientists just inherently problem

1912
01:12:27,990 --> 01:12:25,040
solvers at heart that's right that's

1913
01:12:30,390 --> 01:12:28,000

right and i think that's what makes

1914
01:12:31,830 --> 01:12:30,400
being an astronomer not a really scary

1915
01:12:33,350 --> 01:12:31,840
intimidating thing right because at the

1916
01:12:35,590 --> 01:12:33,360
end of the day you still the problems

1917
01:12:37,350 --> 01:12:35,600
you solve are still small there's just

1918
01:12:40,550 --> 01:12:37,360
so many of them that they they stack

1919
01:12:43,910 --> 01:12:40,560
together and solve a big problem

1920
01:12:45,990 --> 01:12:43,920
okay um grant i am out of the questions

1921
01:12:47,350 --> 01:12:46,000
that i i had written down how about you

1922
01:12:48,790 --> 01:12:47,360
do you have any other questions for our

1923
01:12:50,390 --> 01:12:48,800
absolutely do we have time for more than

1924
01:12:52,390 --> 01:12:50,400
one or i have a good one at least we

1925
01:12:53,910 --> 01:12:52,400
might get we we might have time for two

1926
01:12:56,070 --> 01:12:53,920
yeah we could have time for two two more

1927
01:12:58,070 --> 01:12:56,080
okay all right well i'm gonna throw this

1928
01:13:00,550 --> 01:12:58,080
one out there this is a great question

1929
01:13:02,310 --> 01:13:00,560
uh what determines where to look in the

1930
01:13:03,270 --> 01:13:02,320
universe we've talked about this in

1931
01:13:05,590 --> 01:13:03,280
other

1932
01:13:07,430 --> 01:13:05,600
discussions before but specifically for

1933
01:13:09,590 --> 01:13:07,440
you what is it that stands out to you

1934
01:13:11,430 --> 01:13:09,600
that tells you oh i want to look at this

1935
01:13:13,750 --> 01:13:11,440
particular planet this particular galaxy

1936
01:13:15,270 --> 01:13:13,760
this particular star what what calls to

1937
01:13:18,790 --> 01:13:15,280
you and your work

1938
01:13:20,790 --> 01:13:18,800

yeah that's a great question so um

1939
01:13:22,470 --> 01:13:20,800
this actually is a it's a really

1940
01:13:25,030 --> 01:13:22,480
fundamental question to designing

1941
01:13:26,709 --> 01:13:25,040
surveys for for planet hunting because

1942
01:13:29,669 --> 01:13:26,719
what do we what do we care about right

1943
01:13:32,070 --> 01:13:29,679
so firstly we care about nearby systems

1944
01:13:34,550 --> 01:13:32,080
uh because there is maybe a shadow of a

1945
01:13:36,310 --> 01:13:34,560
chance that we can send something there

1946
01:13:38,070 --> 01:13:36,320
or eventually go there right so the

1947
01:13:40,070 --> 01:13:38,080
closer it is the easier it is for us to

1948
01:13:41,990 --> 01:13:40,080
study the more light we get from it the

1949
01:13:44,709 --> 01:13:42,000
easier it is for us to study

1950
01:13:47,669 --> 01:13:44,719
uh but but another strategy that i

1951
01:13:50,070 --> 01:13:47,679
really like um you know we we can was

1952
01:13:52,950 --> 01:13:50,080
broader than this but this subset of of

1953
01:13:55,189 --> 01:13:52,960
systems is very interesting is other

1954
01:13:57,830 --> 01:13:55,199
systems where earth would be transiting

1955
01:13:59,030 --> 01:13:57,840
to them uh and so they are trans they

1956
01:14:01,430 --> 01:13:59,040
are transiting to us and we are

1957
01:14:04,149 --> 01:14:01,440
transiting to them uh and so they are

1958
01:14:05,750 --> 01:14:04,159
possibly studying us and so

1959
01:14:08,149 --> 01:14:05,760
in thinking about set your you know

1960
01:14:11,189 --> 01:14:08,159
searches for for any kinds of uh techno

1961
01:14:13,510 --> 01:14:11,199
signatures uh we're calling them now um

1962
01:14:15,189 --> 01:14:13,520
they're looking at us uh and so it's

1963
01:14:17,510 --> 01:14:15,199

it's interesting to think about what

1964
01:14:19,590 --> 01:14:17,520
they would see um and therefore to think

1965
01:14:21,830 --> 01:14:19,600
about the ones that we see uh in that

1966
01:14:24,630 --> 01:14:21,840
context um so i yeah i really like to

1967
01:14:27,750 --> 01:14:24,640
think about other other uh

1968
01:14:29,030 --> 01:14:27,760
beings uh checking our transit patterns

1969
01:14:30,790 --> 01:14:29,040
all the time

1970
01:14:33,270 --> 01:14:30,800
and um could you mention a little bit

1971
01:14:35,430 --> 01:14:33,280
about tess because the transiting

1972
01:14:38,229 --> 01:14:35,440
exoplanet survey satellite is sort of a

1973
01:14:40,070 --> 01:14:38,239
precursor mission to find places that

1974
01:14:41,669 --> 01:14:40,080
things like jwst or other missions might

1975
01:14:43,830 --> 01:14:41,679
want to look at

1976
01:14:45,750 --> 01:14:43,840
just as a shameless plug before we begin

1977
01:14:47,350 --> 01:14:45,760
yeah absolutely i'm not a burst of

1978
01:14:49,270 --> 01:14:47,360
shameless plugs

1979
01:14:51,430 --> 01:14:49,280
we have an entire public lecture about

1980
01:14:53,189 --> 01:14:51,440
tess it's awesome if there's anything in

1981
01:14:55,189 --> 01:14:53,199
these discussions that you guys don't

1982
01:14:56,950 --> 01:14:55,199
see or necessarily understand or we

1983
01:14:59,030 --> 01:14:56,960
don't get time to check or go into the

1984
01:15:00,950 --> 01:14:59,040
questions look at the public talks

1985
01:15:03,350 --> 01:15:00,960
they're quest chances are we've talked

1986
01:15:05,910 --> 01:15:03,360
about it before we have over 100 public

1987
01:15:07,669 --> 01:15:05,920
talks on on our youtube channel

1988
01:15:09,750 --> 01:15:07,679

it's true when i was uh picking the

1989
01:15:10,870 --> 01:15:09,760
topic i kind of had to not pick some of

1990
01:15:13,189 --> 01:15:10,880
the topics because there were already

1991
01:15:14,950 --> 01:15:13,199
great talks on them um

1992
01:15:17,270 --> 01:15:14,960
sorry yeah so tess is uh tess is

1993
01:15:18,390 --> 01:15:17,280
fantastic tess is in the sky right now

1994
01:15:20,870 --> 01:15:18,400
um

1995
01:15:22,790 --> 01:15:20,880
tess in some ways is a is a follow-up to

1996
01:15:24,550 --> 01:15:22,800
the kepler space mission where kepler

1997
01:15:27,750 --> 01:15:24,560
was the first

1998
01:15:29,430 --> 01:15:27,760
space mission to do transits uh at very

1999
01:15:31,510 --> 01:15:29,440
very high precision

2000
01:15:34,229 --> 01:15:31,520
but kepler's strategy was to look at one

2001
01:15:37,350 --> 01:15:34,239
patch of the sky for five years and so

2002
01:15:39,510 --> 01:15:37,360
to go really deep on some systems on a

2003
01:15:41,430 --> 01:15:39,520
patch of systems there's hundreds of

2004
01:15:43,750 --> 01:15:41,440
thousands of systems in there but

2005
01:15:45,270 --> 01:15:43,760
it's still a limited patch of sky

2006
01:15:46,950 --> 01:15:45,280
what tess is doing is a little bit

2007
01:15:49,669 --> 01:15:46,960
different where it's scanning the whole

2008
01:15:51,350 --> 01:15:49,679
sky uh but not with the same baseline so

2009
01:15:53,189 --> 01:15:51,360
it comes back to the systems over and

2010
01:15:54,149 --> 01:15:53,199
over again but then it moves on from

2011
01:15:55,110 --> 01:15:54,159
them

2012
01:15:58,149 --> 01:15:55,120
and so

2013
01:16:00,149 --> 01:15:58,159

tess is great for finding a lot of

2014
01:16:01,830 --> 01:16:00,159
planets that kepler would never would

2015
01:16:04,149 --> 01:16:01,840
have because it didn't look in the sky

2016
01:16:04,870 --> 01:16:04,159
in those regions

2017
01:16:11,270 --> 01:16:04,880
but

2018
01:16:14,070 --> 01:16:11,280
very different uh

2019
01:16:16,550 --> 01:16:14,080
but just as fruitful strategy and so

2020
01:16:19,590 --> 01:16:16,560
tess is finding new planet candidates

2021
01:16:21,750 --> 01:16:19,600
every day um and part of why we're

2022
01:16:23,990 --> 01:16:21,760
building all of these extreme precision

2023
01:16:26,070 --> 01:16:24,000
spectrographs there's about i didn't

2024
01:16:28,630 --> 01:16:26,080
mention this but there's about 23 new

2025
01:16:30,229 --> 01:16:28,640
instruments on the ground uh coming up

2026
01:16:33,189 --> 01:16:30,239
that have been coming up in the in the

2027
01:16:34,870 --> 01:16:33,199
last decade um is because we are we knew

2028
01:16:37,270 --> 01:16:34,880
we were going to be rushed off our feet

2029
01:16:39,270 --> 01:16:37,280
trying to follow up the test discoveries

2030
01:16:41,750 --> 01:16:39,280
and so test discoveries need to usually

2031
01:16:44,070 --> 01:16:41,760
be uh confirmed and so if you can

2032
01:16:46,790 --> 01:16:44,080
measure the mass of it you can be 100

2033
01:16:49,510 --> 01:16:46,800
sure it's a planet um and having the

2034
01:16:51,030 --> 01:16:49,520
mass and the radius gives you some hint

2035
01:16:53,910 --> 01:16:51,040
of composition which is also very

2036
01:16:56,229 --> 01:16:53,920
interesting and so um these all these

2037
01:16:58,470 --> 01:16:56,239
instruments are again working uh

2038
01:17:01,430 --> 01:16:58,480

together to try and get a comprehensive

2039
01:17:02,950 --> 01:17:01,440
view of the the extra solar system so

2040
01:17:04,390 --> 01:17:02,960
and yeah we just want to make a point

2041
01:17:06,390 --> 01:17:04,400
that you know sometimes you have to do

2042
01:17:08,070 --> 01:17:06,400
an entire mission just to get the

2043
01:17:09,990 --> 01:17:08,080
candidates from which to follow up on

2044
01:17:12,149 --> 01:17:10,000
other missions or other instruments and

2045
01:17:13,669 --> 01:17:12,159
such and so this is this is not

2046
01:17:16,390 --> 01:17:13,679
something you do in the life of a

2047
01:17:17,350 --> 01:17:16,400
graduate student okay it's it's my

2048
01:17:18,550 --> 01:17:17,360
career

2049
01:17:20,470 --> 01:17:18,560
you're not you're not going to get out

2050
01:17:22,470 --> 01:17:20,480
of this field

2051
01:17:24,149 --> 01:17:22,480
yes that's right and so all of the

2052
01:17:25,510 --> 01:17:24,159
information that we have from tess and

2053
01:17:28,070 --> 01:17:25,520
kepler and the ground-based

2054
01:17:31,750 --> 01:17:28,080
spectrographs are all part of what goes

2055
01:17:33,990 --> 01:17:31,760
into selecting targets um for jwst and

2056
01:17:36,149 --> 01:17:34,000
for next for roman um and then

2057
01:17:38,470 --> 01:17:36,159
eventually for for the next great

2058
01:17:40,550 --> 01:17:38,480
observatory which will be either

2059
01:17:43,350 --> 01:17:40,560
i guess we're calling it loop x now uh

2060
01:17:45,350 --> 01:17:43,360
but it's it's really to be named um

2061
01:17:47,669 --> 01:17:45,360
but that that great mission in the

2062
01:17:49,990 --> 01:17:47,679
future will will try to do will

2063
01:17:51,750 --> 01:17:50,000

basically try to be the the defining

2064
01:17:53,590 --> 01:17:51,760
point where we start looking for life

2065
01:17:55,189 --> 01:17:53,600
where we start taking images of

2066
01:17:57,189 --> 01:17:55,199
earth-like planets so

2067
01:17:59,830 --> 01:17:57,199
you know i said we can't we can't take

2068
01:18:01,830 --> 01:17:59,840
images of of uh planets yet but we might

2069
01:18:03,590 --> 01:18:01,840
be able to in the future and

2070
01:18:05,990 --> 01:18:03,600
this will sort of bring us full circle

2071
01:18:07,669 --> 01:18:06,000
in astronomy in the in the story that i

2072
01:18:09,830 --> 01:18:07,679
was telling where we started by just

2073
01:18:12,070 --> 01:18:09,840
looking at pictures of things and and

2074
01:18:13,990 --> 01:18:12,080
figuring out what was going on

2075
01:18:15,910 --> 01:18:14,000
and planets have been so far beyond our

2076
01:18:18,229 --> 01:18:15,920
reach but but in the you know in the

2077
01:18:19,830 --> 01:18:18,239
next few decades we will be able to take

2078
01:18:22,070 --> 01:18:19,840
if we really want we will be able to

2079
01:18:25,189 --> 01:18:22,080
take images of earth-like planets and

2080
01:18:27,510 --> 01:18:25,199
study their atmospheres and

2081
01:18:29,669 --> 01:18:27,520
really ask questions about bio

2082
01:18:31,110 --> 01:18:29,679
signatures and habitability and be able

2083
01:18:33,590 --> 01:18:31,120
to answer them not just ask the

2084
01:18:35,510 --> 01:18:33,600
questions um so there is a there is

2085
01:18:36,470 --> 01:18:35,520
quite a tremendous arc ahead for this

2086
01:18:37,830 --> 01:18:36,480
field

2087
01:18:39,350 --> 01:18:37,840
absolutely

2088
01:18:41,030 --> 01:18:39,360

one of the grants

2089
01:18:41,830 --> 01:18:41,040
um one of the ways i like to think about

2090
01:18:45,910 --> 01:18:41,840
tess

2091
01:18:47,910 --> 01:18:45,920
kind of like a spotter

2092
01:18:49,590 --> 01:18:47,920
like it's not going to actually do

2093
01:18:51,110 --> 01:18:49,600
whatever it is or do the science or look

2094
01:18:52,149 --> 01:18:51,120
hard at it but it's just saying hey

2095
01:18:55,669 --> 01:18:52,159
there's

2096
01:18:57,910 --> 01:18:55,679
at it like it's a candidate yeah it's

2097
01:18:59,350 --> 01:18:57,920
kind of scouting it out ahead of time

2098
01:19:01,110 --> 01:18:59,360
yeah yeah

2099
01:19:03,189 --> 01:19:01,120
and that's cool i genuinely didn't know

2100
01:19:04,550 --> 01:19:03,199
that that many that many uh

2101
01:19:05,669 --> 01:19:04,560
installations were coming online with

2102
01:19:07,669 --> 01:19:05,679
instruments

2103
01:19:08,870 --> 01:19:07,679
that's wild um all right this is a good

2104
01:19:12,870 --> 01:19:08,880
question

2105
01:19:15,030 --> 01:19:12,880
i like this let's go for it yep um

2106
01:19:16,950 --> 01:19:15,040
how have you found your collaboration

2107
01:19:19,110 --> 01:19:16,960
like across the world on this sort of

2108
01:19:21,990 --> 01:19:19,120
stuff do you work often with other teams

2109
01:19:23,750 --> 01:19:22,000
who are outside of the us the eu that

2110
01:19:26,550 --> 01:19:23,760
sort of thing like talk a little bit

2111
01:19:29,510 --> 01:19:26,560
about like the multinational like world

2112
01:19:33,110 --> 01:19:29,520
scale of the science being done

2113
01:19:35,590 --> 01:19:33,120

yes that's a that's a great question um

2114
01:19:37,830 --> 01:19:35,600
i have had a fantastic experience with

2115
01:19:39,990 --> 01:19:37,840
the with the rv community that we are

2116
01:19:41,750 --> 01:19:40,000
spread out around the world um so

2117
01:19:44,870 --> 01:19:41,760
there's a there's a lot of activity in

2118
01:19:46,870 --> 01:19:44,880
the us there's a lot in europe uh

2119
01:19:49,669 --> 01:19:46,880
there's some in india and part of a team

2120
01:19:52,550 --> 01:19:49,679
there there's some in south africa

2121
01:19:54,950 --> 01:19:52,560
there's some in china now um yeah it is

2122
01:19:57,110 --> 01:19:54,960
it is absolutely a global effort and

2123
01:20:00,070 --> 01:19:57,120
um actually this field the radio

2124
01:20:03,750 --> 01:20:00,080
velocity field does does have a history

2125
01:20:05,430 --> 01:20:03,760
of a more contentious atmosphere uh

2126
01:20:07,270 --> 01:20:05,440
because just because the stakes were

2127
01:20:10,149 --> 01:20:07,280
high and people were kind of competing

2128
01:20:11,990 --> 01:20:10,159
to claim these first planets um but

2129
01:20:14,950 --> 01:20:12,000
turns out there's plenty of planets to

2130
01:20:17,830 --> 01:20:14,960
go around and so people are are

2131
01:20:20,470 --> 01:20:17,840
much much more open and uh share you

2132
01:20:22,950 --> 01:20:20,480
know from from software to hardware to

2133
01:20:24,470 --> 01:20:22,960
you know secrets in figuring out the

2134
01:20:27,270 --> 01:20:24,480
errors

2135
01:20:28,470 --> 01:20:27,280
and so i i do i do collaborate with and

2136
01:20:29,910 --> 01:20:28,480
i'm part of

2137
01:20:31,669 --> 01:20:29,920
several teams

2138
01:20:34,470 --> 01:20:31,679

some of which used to be

2139
01:20:36,790 --> 01:20:34,480
kind of sworn enemies but but now works

2140
01:20:38,709 --> 01:20:36,800
together just fine and um

2141
01:20:41,510 --> 01:20:38,719
and it's better for all of us because

2142
01:20:44,550 --> 01:20:41,520
the challenges are the same right um

2143
01:20:47,189 --> 01:20:44,560
the the data is complementary and so

2144
01:20:49,350 --> 01:20:47,199
everybody can help each other and so i

2145
01:20:52,470 --> 01:20:49,360
yeah i have really enjoyed being part of

2146
01:20:54,950 --> 01:20:52,480
this field and it really feels like a

2147
01:20:57,110 --> 01:20:54,960
a large scientific family where you know

2148
01:20:59,430 --> 01:20:57,120
the stars are our nemesis or our friends

2149
01:21:01,430 --> 01:20:59,440
and not not each other

2150
01:21:03,270 --> 01:21:01,440
that's great to hear because

2151
01:21:06,149 --> 01:21:03,280
sometimes you will see depictions in the

2152
01:21:07,830 --> 01:21:06,159
media of scientists uh in these these

2153
01:21:10,229 --> 01:21:07,840
hard pitched battles against each other

2154
01:21:12,070 --> 01:21:10,239
but the inherent nature of science as it

2155
01:21:14,470 --> 01:21:12,080
progresses over the centuries is

2156
01:21:16,790 --> 01:21:14,480
collaborative right yeah you know yeah

2157
01:21:19,430 --> 01:21:16,800
you stand on the shoulders of time of

2158
01:21:21,430 --> 01:21:19,440
giants and without

2159
01:21:24,310 --> 01:21:21,440
many people attacking these really

2160
01:21:26,229 --> 01:21:24,320
really really hard problems uh you're

2161
01:21:28,149 --> 01:21:26,239
not gonna get a lot of solutions first

2162
01:21:29,910 --> 01:21:28,159
of all and also you want there to be

2163
01:21:31,990 --> 01:21:29,920

other teams so they can verify your

2164
01:21:33,990 --> 01:21:32,000
results because if you put out a result

2165
01:21:37,430 --> 01:21:34,000
and nobody can verify it

2166
01:21:39,510 --> 01:21:37,440
it just sits there right so um i i the

2167
01:21:41,030 --> 01:21:39,520
collaborative nature of science really

2168
01:21:43,350 --> 01:21:41,040
was the internet

2169
01:21:45,510 --> 01:21:43,360
has totally transformed it and made it

2170
01:21:47,669 --> 01:21:45,520
so much easier to work cross-country i

2171
01:21:48,310 --> 01:21:47,679
mean i've never met you and yet here we

2172
01:21:50,550 --> 01:21:48,320
are

2173
01:21:52,229 --> 01:21:50,560
in this uh talk together right right

2174
01:21:53,830 --> 01:21:52,239
right and i will say also you know i was

2175
01:21:55,669 --> 01:21:53,840
reading all these historic papers for

2176
01:21:57,590 --> 01:21:55,679
this talk and it used to be that one or

2177
01:21:59,669 --> 01:21:57,600
two people would write a seminal paper

2178
01:22:00,950 --> 01:21:59,679
and that's just that just never happens

2179
01:22:03,430 --> 01:22:00,960
anymore because

2180
01:22:04,950 --> 01:22:03,440
we're at such a such a more challenging

2181
01:22:06,709 --> 01:22:04,960
point that you can't just look at the

2182
01:22:08,790 --> 01:22:06,719
sky and discover things there's a lot of

2183
01:22:10,950 --> 01:22:08,800
work that goes into it and it takes a

2184
01:22:12,390 --> 01:22:10,960
large team for every result it's you

2185
01:22:14,070 --> 01:22:12,400
know it's marginal

2186
01:22:16,629 --> 01:22:14,080
uh

2187
01:22:19,590 --> 01:22:16,639
advances at this point um i will also

2188
01:22:20,709 --> 01:22:19,600

say in terms of uh

2189
01:22:22,390 --> 01:22:20,719
sort of

2190
01:22:25,030 --> 01:22:22,400
teams that are publishing or checking

2191
01:22:27,030 --> 01:22:25,040
your result before i found a planet i

2192
01:22:30,790 --> 01:22:27,040
killed like several planets before i

2193
01:22:32,790 --> 01:22:30,800
ever found one um and so that you know

2194
01:22:34,310 --> 01:22:32,800
again can be a little bit contentious

2195
01:22:35,669 --> 01:22:34,320
for the people who discovered those

2196
01:22:37,510 --> 01:22:35,679
planets but really it's the field

2197
01:22:39,030 --> 01:22:37,520
self-correcting right it's like we have

2198
01:22:41,270 --> 01:22:39,040
a little bit more information we can

2199
01:22:42,870 --> 01:22:41,280
understand better what's going on and so

2200
01:22:45,030 --> 01:22:42,880
um

2201
01:22:46,870 --> 01:22:45,040
now we kill off less planets within the

2202
01:22:49,110 --> 01:22:46,880
field because we are more careful when

2203
01:22:51,510 --> 01:22:49,120
we claim planets and so okay and just to

2204
01:22:53,910 --> 01:22:51,520
clarify killing a planet means saying no

2205
01:22:55,750 --> 01:22:53,920
no no that that detection wasn't real

2206
01:22:58,229 --> 01:22:55,760
isn't real right yeah okay let's go and

2207
01:22:59,830 --> 01:22:58,239
say we're not out

2208
01:23:03,750 --> 01:22:59,840
we don't have our own little death star

2209
01:23:07,189 --> 01:23:05,590
all right grant any last comments from

2210
01:23:10,310 --> 01:23:07,199
you

2211
01:23:13,030 --> 01:23:10,320
no no less comments um everyone

2212
01:23:14,149 --> 01:23:13,040
says thank you for the talk and

2213
01:23:15,910 --> 01:23:14,159

all right

2214
01:23:18,870 --> 01:23:15,920
well i will thank you again for the talk

2215
01:23:21,189 --> 01:23:18,880
for uh for our audience and for me um i

2216
01:23:22,149 --> 01:23:21,199
will remind our audience that on march

2217
01:23:24,470 --> 01:23:22,159
1st

2218
01:23:26,870 --> 01:23:24,480
hubble from space and integral field

2219
01:23:29,990 --> 01:23:26,880
spectroscopy from the ground seeing both

2220
01:23:31,990 --> 01:23:30,000
the forests and the trees mark sasi arma

2221
01:23:34,149 --> 01:23:32,000
observatory and planetarium

2222
01:23:36,790 --> 01:23:34,159
another talk that actually will show you

2223
01:23:38,870 --> 01:23:36,800
the benefits of both ground-based and

2224
01:23:41,669 --> 01:23:38,880
space-based i i gotta say we're at the

2225
01:23:44,229 --> 01:23:41,679
space telescope science institute we put

2226
01:23:45,430 --> 01:23:44,239
forward the space telescope aspect of it

2227
01:23:47,750 --> 01:23:45,440
but it's

2228
01:23:49,669 --> 01:23:47,760
always good to understand just how the

2229
01:23:51,990 --> 01:23:49,679
space observatories and the ground-based

2230
01:23:54,149 --> 01:23:52,000
observatories work together and you'll