



# ABSciCON 2017

MESA, ARIZONA

1  
00:00:12,250 --> 00:00:06,150

you

2  
00:00:17,800 --> 00:00:15,119

[Music]

3  
00:00:20,320 --> 00:00:17,810

well thanks to the conference organizers

4  
00:00:22,120 --> 00:00:20,330

and the session chairs for giving me the

5  
00:00:26,050 --> 00:00:22,130

opportunity to talk today so that's some

6  
00:00:29,769 --> 00:00:26,060

of my thesis work so some motivating

7  
00:00:31,900 --> 00:00:29,779

questions for this talk or how to stars

8  
00:00:33,970 --> 00:00:31,910

of different math and composition

9  
00:00:36,040 --> 00:00:33,980

evolved how does this impact the

10  
00:00:38,890 --> 00:00:36,050

location of the habitable zone around

11  
00:00:41,049 --> 00:00:38,900

the star how does the habitable zone

12  
00:00:43,170 --> 00:00:41,059

co-evolved with the star over time and

13  
00:00:46,030 --> 00:00:43,180

how will utilizing this knowledge apply

14

00:00:47,500 --> 00:00:46,040

in the continued search for potentially

15

00:00:52,959 --> 00:00:47,510

habitable earth-like planets in the

16

00:00:54,610 --> 00:00:52,969

future so I know I don't need to you

17

00:00:56,080 --> 00:00:54,620

know belabor the point that habitable

18

00:00:57,520 --> 00:00:56,090

zones are complicated concepts but I

19

00:00:59,790 --> 00:00:57,530

just want to emphasize that for the

20

00:01:02,170 --> 00:00:59,800

context of this work we're approaching

21

00:01:04,119 --> 00:01:02,180

habitability or the habitable zone from

22

00:01:08,230 --> 00:01:04,129

the Astrophysical perspective in terms

23

00:01:11,139 --> 00:01:08,240

of thinking about how stars of different

24

00:01:16,389 --> 00:01:11,149

math and temperature how they're

25

00:01:17,950 --> 00:01:16,399

habitable zones differ and also make the

26

00:01:19,570 --> 00:01:17,960

point that for different math stars not

27

00:01:23,200 --> 00:01:19,580

only are the distances of the habitable

28

00:01:26,980 --> 00:01:23,210

zones variable but they expand outward

29

00:01:29,109 --> 00:01:26,990

at different rates so the two main

30

00:01:33,190 --> 00:01:29,119

measurable parameters that I look at our

31

00:01:36,999 --> 00:01:33,200

math which impacts the rate of hydrogen

32

00:01:38,859 --> 00:01:37,009

fusion in the star which thus impacts

33

00:01:41,649 --> 00:01:38,869

the main sequence lifetime of the star

34

00:01:43,510 --> 00:01:41,659

as well as the composition which affects

35

00:01:46,870 --> 00:01:43,520

the opacity energy transport within the

36

00:01:48,850 --> 00:01:46,880

star so something with a star with lower

37

00:01:51,340 --> 00:01:48,860

opacity for example would have more

38

00:01:53,020 --> 00:01:51,350

efficient energy escapes and a shorter

39

00:01:59,170 --> 00:01:53,030

main sequence lifetime than a star of

40

00:02:00,870 --> 00:01:59,180

equal mass so what I do to model stellar

41

00:02:03,969 --> 00:02:00,880

evolution is I use Tycho a

42

00:02:05,620 --> 00:02:03,979

one-dimensional hydrodynamic alcoa which

43

00:02:07,990 --> 00:02:05,630

outputs stellar surface quantities of

44

00:02:09,669 --> 00:02:08,000

interest for each time step of the

45

00:02:11,920 --> 00:02:09,679

evolution so typically temperature and

46

00:02:15,030 --> 00:02:11,930

luminosity or what we're primarily

47

00:02:17,590 --> 00:02:15,040

interested in and I've created an online

48

00:02:19,180 --> 00:02:17,600

database for the evolutionary tracks

49

00:02:22,510 --> 00:02:19,190

that's available it has an interactive

50

00:02:25,180 --> 00:02:22,520

interpolation tool as well and primarily

51  
00:02:26,190 --> 00:02:25,190  
what we want from these evolutionary

52  
00:02:28,530 --> 00:02:26,200  
tracks is to look

53  
00:02:31,530 --> 00:02:28,540  
at how the location and lifetime of the

54  
00:02:35,309 --> 00:02:31,540  
habitable zone depends on the changes

55  
00:02:38,820 --> 00:02:35,319  
over the stars made sequence lifetime as

56  
00:02:41,580 --> 00:02:38,830  
it goes so looking at the temperature in

57  
00:02:45,059 --> 00:02:41,590  
luminosity you have the HR diagram even

58  
00:02:46,080 --> 00:02:45,069  
just for looking at oxygen if we have

59  
00:02:48,930 --> 00:02:46,090  
depleted oxygen

60  
00:02:51,930 --> 00:02:48,940  
- enriched oxygen compared to the Sun

61  
00:02:54,720 --> 00:02:51,940  
and dots you can see that there's quite

62  
00:02:56,820 --> 00:02:54,730  
a significant spread in the temperature

63  
00:02:59,990 --> 00:02:56,830

in luminosity outputs for the HR

64

00:03:04,500 --> 00:03:00,000

diagrams for each mass in our range and

65

00:03:07,610 --> 00:03:04,510

if we plot the Sun on our tracks you can

66

00:03:10,860 --> 00:03:07,620

see that this is a good estimate of the

67

00:03:13,949 --> 00:03:10,870

current Sun temperature and luminosity

68

00:03:16,170 --> 00:03:13,959

so just believable estimates for what

69

00:03:18,240 --> 00:03:16,180

we're getting here so the limit

70

00:03:23,190 --> 00:03:18,250

equations that we use also come from

71

00:03:25,410 --> 00:03:23,200

Ravi copper Rafi's 2013-2014 papers what

72

00:03:26,940 --> 00:03:25,420

we're focused on here again the

73

00:03:29,190 --> 00:03:26,950

temperature and luminosity so we take

74

00:03:32,610 --> 00:03:29,200

that from Tyco and input this into these

75

00:03:34,800 --> 00:03:32,620

equations that calculate the habitable

76  
00:03:38,520 --> 00:03:34,810  
zone distance at each time step in our

77  
00:03:42,090 --> 00:03:38,530  
evolution and this is the program that I

78  
00:03:44,250 --> 00:03:42,100  
use that I wrote to do these radii

79  
00:03:46,050 --> 00:03:44,260  
calculations are easily upgradeable for

80  
00:03:48,000 --> 00:03:46,060  
any particular habitable zone

81  
00:03:50,729 --> 00:03:48,010  
prescriptions that you want to use but

82  
00:03:53,400 --> 00:03:50,739  
we chose the conservative cases from

83  
00:03:55,289 --> 00:03:53,410  
copper abu which are the runaway

84  
00:03:58,680 --> 00:03:55,299  
greenhouse and the maximum greenhouse

85  
00:04:01,590 --> 00:03:58,690  
cases and that's where total ocean

86  
00:04:04,349 --> 00:04:01,600  
evaporation to the point at which

87  
00:04:05,940 --> 00:04:04,359  
Rayleigh scattering by co2 starts out

88  
00:04:09,720 --> 00:04:05,950

with a greenhouse effect on the outer

89

00:04:11,190 --> 00:04:09,730

edge so with elemental abundances what

90

00:04:13,470 --> 00:04:11,200

we're thinking about is that usually

91

00:04:15,150 --> 00:04:13,480

only iron is measured in stars because

92

00:04:17,219 --> 00:04:15,160

it's easy there are lots of lines and

93

00:04:19,140 --> 00:04:17,229

other elements are just assumed to scale

94

00:04:23,640 --> 00:04:19,150

in the same proportions that are

95

00:04:26,790 --> 00:04:23,650

observed at the Sun but as in natalie

96

00:04:29,520 --> 00:04:26,800

Hinkle's 2014 papers especially we see

97

00:04:33,180 --> 00:04:29,530

that specific chemical abundances can

98

00:04:35,130 --> 00:04:33,190

vary significantly among stars and also

99

00:04:37,640 --> 00:04:35,140

previous work by patrick Young has shown

100

00:04:39,620 --> 00:04:37,650

that oxygen specifically has

101  
00:04:44,060 --> 00:04:39,630  
a really strong impact to the stellar

102  
00:04:46,070 --> 00:04:44,070  
evolution so my database that I put

103  
00:04:49,370 --> 00:04:46,080  
together for the stellar evolution

104  
00:04:51,740 --> 00:04:49,380  
tracks in 2015 paper I discussed a grid

105  
00:04:54,770 --> 00:04:51,750  
of three hundred and seventy-six models

106  
00:04:57,140 --> 00:04:54,780  
that range from 0.5 to 1.2 solar masses

107  
00:04:59,180 --> 00:04:57,150  
it has a scaled overall metallicity

108  
00:05:01,430 --> 00:04:59,190  
relative to the Sun so just scaling all

109  
00:05:04,370 --> 00:05:01,440  
the elements proportionally from point 1

110  
00:05:07,879 --> 00:05:04,380  
to 1.5 solar metallicity and then a

111  
00:05:09,260 --> 00:05:07,889  
specific oxygen abundance values ranging

112  
00:05:12,500 --> 00:05:09,270  
from point four four to two point two

113  
00:05:16,909 --> 00:05:12,510

eight solar oxygen and in my recent

114

00:05:19,610 --> 00:05:16,919

paper we added additional 528 models so

115

00:05:23,150 --> 00:05:19,620

that's four carbon magnesium and neon

116

00:05:24,860 --> 00:05:23,160

and neon is an artificial range here

117

00:05:27,320 --> 00:05:24,870

just because it's very difficult to

118

00:05:29,090 --> 00:05:27,330

accurately measure in stars but we want

119

00:05:32,320 --> 00:05:29,100

to include it even hypothetically

120

00:05:33,890 --> 00:05:32,330

because it's important for

121

00:05:37,879 --> 00:05:33,900

considerations into the stellar

122

00:05:39,529 --> 00:05:37,889

evolution so what we were plotting here

123

00:05:43,040 --> 00:05:39,539

is how does one distance versus stellar

124

00:05:44,270 --> 00:05:43,050

age days age and distance and we have

125

00:05:47,180 --> 00:05:44,280

the inner limits and the outer limits

126

00:05:50,029 --> 00:05:47,190

here each color represents a different

127

00:05:51,980 --> 00:05:50,039

elemental abundance so we have oxygen in

128

00:05:54,290 --> 00:05:51,990

red and purple and you can see that they

129

00:05:57,350 --> 00:05:54,300

make the most difference versus the

130

00:06:00,110 --> 00:05:57,360

black line which is solar then orange

131

00:06:02,180 --> 00:06:00,120

and blue or magnesium and yellow and

132

00:06:04,370 --> 00:06:02,190

green or carbon and interestingly Carvin

133

00:06:05,540 --> 00:06:04,380

actually makes less of the difference

134

00:06:08,210 --> 00:06:05,550

than magnesium even though it's

135

00:06:10,189 --> 00:06:08,220

relatively more abundant in stars the

136

00:06:13,450 --> 00:06:10,199

magnesium has a higher opacity per gram

137

00:06:15,230 --> 00:06:13,460

so it impacts the difference in

138

00:06:19,129 --> 00:06:15,240

evolution the temperature and luminosity

139

00:06:22,189 --> 00:06:19,139

outputs and not only do the Hobbit alone

140

00:06:23,450 --> 00:06:22,199

distances differ with variable

141

00:06:26,000 --> 00:06:23,460

composition we also see that the

142

00:06:28,610 --> 00:06:26,010

lifetimes again can be significantly

143

00:06:31,670 --> 00:06:28,620

truncated for example if we're looking

144

00:06:33,770 --> 00:06:31,680

at depleted oxygen here versus enriched

145

00:06:37,640 --> 00:06:33,780

oxygen there's a difference of maybe

146

00:06:41,750 --> 00:06:37,650

three billion years so it's quite a big

147

00:06:44,270 --> 00:06:41,760

difference if we plot the earth here you

148

00:06:46,610 --> 00:06:44,280

can see that Earth is on the inner edge

149

00:06:47,899 --> 00:06:46,620

of the habitable zone currently however

150

00:06:48,920 --> 00:06:47,909

for thinking about some sort of

151  
00:06:49,679 --> 00:06:48,930  
hypothetical

152  
00:06:53,850 --> 00:06:49,689  
X

153  
00:06:55,649 --> 00:06:53,860  
planet at the same current time then you

154  
00:06:58,949 --> 00:06:55,659  
can see that it's only recently entered

155  
00:07:01,019 --> 00:06:58,959  
the habitable zone so up until this

156  
00:07:04,109 --> 00:07:01,029  
point it's been what we would maybe

157  
00:07:06,089 --> 00:07:04,119  
consider outside and we don't know now

158  
00:07:08,999 --> 00:07:06,099  
what implications that would have for

159  
00:07:10,499 --> 00:07:09,009  
this planet so generally though we want

160  
00:07:17,129 --> 00:07:10,509  
to avoid planets that have only recently

161  
00:07:19,379 --> 00:07:17,139  
entered the habitable zone this table is

162  
00:07:21,959 --> 00:07:19,389  
showing the fraction of orbital radii

163  
00:07:24,600 --> 00:07:21,969

that do enter after the mid point I want

164

00:07:26,219 --> 00:07:24,610

to highlight is that up to a third to a

165

00:07:28,229 --> 00:07:26,229

half of all orbits in the habitable zone

166

00:07:32,329 --> 00:07:28,239

only become so in the second half of

167

00:07:36,449 --> 00:07:34,709

additionally a trend that we see is that

168

00:07:39,149 --> 00:07:36,459

with increasing composition a higher

169

00:07:41,279 --> 00:07:39,159

percentage of planets are not in the

170

00:07:43,919 --> 00:07:41,289

habitable zone until the second half of

171

00:07:46,319 --> 00:07:43,929

the stars main sequence lifetime so this

172

00:07:48,779 --> 00:07:46,329

prompts us to constrain with a time

173

00:07:53,069 --> 00:07:48,789

criteria our consideration of the

174

00:07:55,409 --> 00:07:53,079

habitable zones so I wanted to show this

175

00:07:57,689 --> 00:07:55,419

it's kind of a complicated figure but

176

00:08:00,329 --> 00:07:57,699

mostly what we're looking at is distance

177

00:08:03,239 --> 00:08:00,339

here versus stellar mass and this is for

178

00:08:05,269 --> 00:08:03,249

all of the 376 grid

179

00:08:08,759 --> 00:08:05,279

it just basically is meant to illustrate

180

00:08:11,369 --> 00:08:08,769

that we see a wide range of habitable

181

00:08:14,999 --> 00:08:11,379

distances based on the stellar

182

00:08:17,339 --> 00:08:15,009

composition so it can really impact what

183

00:08:20,159 --> 00:08:17,349

we're seeing in terms of distance based

184

00:08:25,780 --> 00:08:20,169

on the wide variety of stellar

185

00:08:33,260 --> 00:08:29,930

okay okay so if we pick out one which is

186

00:08:34,670 --> 00:08:33,270

just the solar value and we look at what

187

00:08:37,370 --> 00:08:34,680

we would think of as a continuously

188

00:08:42,110 --> 00:08:37,380

habitable zone the green shaded region

189

00:08:45,590 --> 00:08:42,120

here is what we would think of as the CH

190

00:08:48,230 --> 00:08:45,600

Z 1 which is the where something would

191

00:08:50,030 --> 00:08:48,240

be continuously habitable for the Stars

192

00:08:54,860 --> 00:08:50,040

entire main sequence lifetime so you see

193

00:08:56,420 --> 00:08:54,870

that that's not a very comprehensive way

194

00:09:02,840 --> 00:08:56,430

to think about it because if we plot

195

00:09:06,230 --> 00:09:02,850

earth on here that doesn't find earth so

196

00:09:07,970 --> 00:09:06,240

we we know that Earth is in what we

197

00:09:09,920 --> 00:09:07,980

would consider the habitable zone so we

198

00:09:11,630 --> 00:09:09,930

need to be more careful about how we

199

00:09:14,180 --> 00:09:11,640

define is continuously habitable zone

200

00:09:16,870 --> 00:09:14,190

instead if we use a 2 billion year

201

00:09:22,250 --> 00:09:16,880

criteria which is based on obviously

202

00:09:26,660 --> 00:09:22,260

earth took about 2 billion years to

203

00:09:29,060 --> 00:09:26,670

produce enough biogenic gases that would

204

00:09:33,110 --> 00:09:29,070

be detectable with something in the most

205

00:09:36,140 --> 00:09:33,120

recent decade all survey then we have

206

00:09:38,300 --> 00:09:36,150

that earth does fall into this range of

207

00:09:40,370 --> 00:09:38,310

orbits that would be continuously

208

00:09:42,910 --> 00:09:40,380

habitable for at least two billion years

209

00:09:46,490 --> 00:09:42,920

so anything within this green range

210

00:09:48,470 --> 00:09:46,500

would meet that criteria now here's a

211

00:09:50,450 --> 00:09:48,480

table illustrating that and what I want

212

00:09:52,580 --> 00:09:50,460

to draw the attention to here is that

213

00:09:56,720 --> 00:09:52,590

for low mass stars obviously they have a

214

00:09:59,750 --> 00:09:56,730

very high percent of time that a planet

215

00:10:01,220 --> 00:09:59,760

would spend in the continuously have 2

216

00:10:03,860 --> 00:10:01,230

billion year continuously have it alone

217

00:10:06,200 --> 00:10:03,870

versus the entire main sequence whereas

218

00:10:08,450 --> 00:10:06,210

something with lower composition at

219

00:10:10,280 --> 00:10:08,460

higher mass don't have any orbits that

220

00:10:13,520 --> 00:10:10,290

are continuously habitable for 2 billion

221

00:10:14,990 --> 00:10:13,530

years just because of the main short

222

00:10:17,150 --> 00:10:15,000

main sequence lifetime so that could

223

00:10:20,540 --> 00:10:17,160

help us constrain maybe the types of

224

00:10:24,770 --> 00:10:20,550

stars we want to focus on as well we can

225

00:10:29,150 --> 00:10:24,780

provide accurate time evolution of a

226

00:10:30,920 --> 00:10:29,160

wider array of stars to better evaluate

227

00:10:34,670 --> 00:10:30,930

individual cases of interest as they

228

00:10:35,850 --> 00:10:34,680

arise so the current work that I've been

229

00:10:37,860 --> 00:10:35,860

doing

230

00:10:41,760 --> 00:10:37,870

is expanding a catalogue to also include

231

00:10:44,310 --> 00:10:41,770

a grid of M dwarf stars which utilize

232

00:10:47,520 --> 00:10:44,320

the same range of abundances for oxygen

233

00:10:49,050 --> 00:10:47,530

carbon magnesium etc except for now we

234

00:10:50,030 --> 00:10:49,060

have from point one to point four five

235

00:10:52,890 --> 00:10:50,040

solar masses

236

00:10:55,350 --> 00:10:52,900

- hopefully incorporate all the interest

237

00:10:57,510 --> 00:10:55,360

for M dwarf habitability and I'm also

238

00:10:59,220 --> 00:10:57,520

writing a type of subroutine that will

239

00:11:02,760 --> 00:10:59,230

be able to estimate the activity versus

240

00:11:04,440 --> 00:11:02,770

age for each star in our catalog this is

241

00:11:07,830 --> 00:11:04,450

based on a minimalist couple evolution

242

00:11:10,770 --> 00:11:07,840

model from Blackmon and O in 2016 and

243

00:11:13,410 --> 00:11:10,780

I'm also working on keeping the database

244

00:11:15,570 --> 00:11:13,420

updated it's designed for the

245

00:11:18,300 --> 00:11:15,580

astrobiology exoplanet communities to

246

00:11:20,400 --> 00:11:18,310

basically characterize any particular

247

00:11:23,970 --> 00:11:20,410

system that we're interested in any new

248

00:11:26,190 --> 00:11:23,980

discoveries that are coming up planetary

249

00:11:28,530 --> 00:11:26,200

candidates so we can look at the host

250

00:11:32,120 --> 00:11:28,540

star characterization and try to get an

251

00:11:35,100 --> 00:11:32,130

idea of what's going on with that so

252

00:11:50,730 --> 00:11:35,110

with that I will stop I'll take

253

00:11:53,010 --> 00:11:50,740

questions questions for Amanda so Amanda

254

00:11:55,320 --> 00:11:53,020

this is really cool and I was curious if

255

00:11:57,690 --> 00:11:55,330

you had so you said you were going to

256

00:12:01,280 --> 00:11:57,700

these smaller stars and I was curious if

257

00:12:03,030 --> 00:12:01,290

you had any intuition as to what the

258

00:12:04,620 --> 00:12:03,040

essentially certain you start forming

259

00:12:07,260 --> 00:12:04,630

molecular species in their atmospheres

260

00:12:09,920 --> 00:12:07,270

and what that might say for your stellar

261

00:12:15,480 --> 00:12:09,930

effective temperatures and luminosities

262

00:12:17,130 --> 00:12:15,490

I think that would you mean I mean it's

263

00:12:19,500 --> 00:12:17,140

just generally lower but are you bring

264

00:12:21,690 --> 00:12:19,510

like different species could yeah

265

00:12:23,640 --> 00:12:21,700

differently right so is that going to

266

00:12:25,980 --> 00:12:23,650

affect your your luminosity of it'll I

267

00:12:27,780 --> 00:12:25,990

think yeah definitely will but I'm not

268

00:12:29,850 --> 00:12:27,790

sure I can say anything about specific

269

00:12:31,800 --> 00:12:29,860

species like how how particular

270

00:12:33,660 --> 00:12:31,810

molecules might affect but I think

271

00:12:36,810 --> 00:12:33,670

absolutely that yes

272

00:12:39,450 --> 00:12:36,820

having having that and at the lower

273

00:12:41,490 --> 00:12:39,460

effective temperatures will impact the

274

00:12:43,350 --> 00:12:41,500

stellar evolution but I'm not I'm not

275

00:12:45,840 --> 00:12:43,360

exactly sure because I don't know how

276

00:12:47,699 --> 00:12:45,850

each specific species will interact in

277

00:12:52,410 --> 00:12:47,709

the whole process so

278

00:12:55,889 --> 00:12:52,420

Thanks I guess the idea that I've heard

279

00:12:58,290 --> 00:12:55,899

around that is that by increasing the

280

00:13:00,780 --> 00:12:58,300

amount of absorption towards the red you

281

00:13:03,359 --> 00:13:00,790

effectively widened a half zone a little

282

00:13:06,059 --> 00:13:03,369

further out and that especially around M

283

00:13:08,879 --> 00:13:06,069

dwarfs hey where the light is redder

284

00:13:13,109 --> 00:13:08,889

right in planetary albedo is smaller at

285

00:13:15,509 --> 00:13:13,119

those wavelengths I guess that I was

286

00:13:18,329 --> 00:13:15,519

thinking about you know the minimum age

287

00:13:21,059 --> 00:13:18,339

or the minimum continuously habitable

288

00:13:23,249 --> 00:13:21,069

time you know in terms of setting

289

00:13:24,900 --> 00:13:23,259

constraints on which types of stars

290

00:13:27,150 --> 00:13:24,910

could absolute habitable planets around

291

00:13:28,889 --> 00:13:27,160

them yeah we have fun too

292

00:13:32,609 --> 00:13:28,899

I mean we thought about this you know a

293

00:13:35,040 --> 00:13:32,619

lot but it would be fun to translate you

294

00:13:38,009 --> 00:13:35,050

know what if you wanted planets that are

295

00:13:40,710 --> 00:13:38,019

at least 1 billion years habitable or to

296

00:13:43,679 --> 00:13:40,720

really into actual mission detection

297

00:13:45,900 --> 00:13:43,689

parameters because planets in the

298

00:13:48,389 --> 00:13:45,910

habitable zones around a stars for

299

00:13:50,489 --> 00:13:48,399

example have a much steeper contrast

300

00:13:52,470 --> 00:13:50,499

rate rate that you have to reach then to

301  
00:13:55,829 --> 00:13:52,480  
detect those than in the half zone

302  
00:13:58,110 --> 00:13:55,839  
around a G Star by K star and M star and

303  
00:13:59,879 --> 00:13:58,120  
then but then also they're further out

304  
00:14:01,919 --> 00:13:59,889  
so it's a little easier in terms of

305  
00:14:03,780 --> 00:14:01,929  
interworking angle but it would be fun

306  
00:14:06,179 --> 00:14:03,790  
to actually try to map that out in terms

307  
00:14:09,210 --> 00:14:06,189  
of contrast interworking angle as well

308  
00:14:11,160 --> 00:14:09,220  
as that the actual apparent magnitude of

309  
00:14:12,660 --> 00:14:11,170  
the planet you have to get down to four

310  
00:14:14,100 --> 00:14:12,670  
specific stars yeah that's really

311  
00:14:16,559 --> 00:14:14,110  
interesting I've had discussions about

312  
00:14:18,780 --> 00:14:16,569  
kind of doing contour type plots even

313  
00:14:21,360 --> 00:14:18,790

with like different ages or different

314

00:14:24,059 --> 00:14:21,370

time criteria so like 1 billion years or

315

00:14:25,829 --> 00:14:24,069

two or five or whatever so that's also

316

00:14:27,449 --> 00:14:25,839

really interesting at the end one day

317

00:14:29,850 --> 00:14:27,459

you kind of have to do it star by star

318

00:14:31,799 --> 00:14:29,860

so right super time-consuming but it has