Fraction of time planet would spend in CHZ_2 vs. entire MS Lifetime

Composition	0.5 $M_\odot$	0.8 $M_\odot$	1.2 $M_\odot$
0.1 $Z_\odot$, 0.44 $O/Fe_\odot$	85.8	69.0	0.0
0.1 $Z_\odot$, $O/Fe_\odot$	86.8	71.5	0.0
0.1 $Z_\odot$, 2.28 $O/Fe_\odot$	88.7	75.9	0.0
$Z_\odot$, 0.44 $O/Fe_\odot$	91.5	82.6	59.5
$Z_\odot$, $O/Fe_\odot$	91.8	83.9	62.2
$Z_\odot$, 2.28 $O/Fe_\odot$	92.7	86.0	65.2
1.5 $Z_\odot$, 0.44 $O/Fe_\odot$	92.0	84.5	63.4
1.5 $Z_\odot$, $O/Fe_\odot$	92.7	85.6	65.1
1.5 $Z_\odot$, 2.28 $O/Fe_\odot$	92.8	86.8	65.7

1
00:00:11,749 --> 00:00:08,629
so

2
00:00:13,430 --> 00:00:11,759
first i will just talk briefly about

3
00:00:14,910 --> 00:00:13,440
habitable zones and how i'm defining

4
00:00:17,830 --> 00:00:14,920
them for this talk

5
00:00:19,429 --> 00:00:17,840
my and um

6
00:00:22,230 --> 00:00:19,439
basically there are obviously a lot of

7
00:00:23,670 --> 00:00:22,240
factors that could go into play when you

8
00:00:26,790 --> 00:00:23,680
discuss what

9
00:00:28,830 --> 00:00:26,800
defines a habitable zone

10
00:00:33,110 --> 00:00:28,840
it's like i feel like it's

11
00:00:33,120 --> 00:00:36,150
okay

12
00:00:39,030 --> 00:00:37,910
i'll choke

13
00:00:40,310 --> 00:00:39,040

all right

14
00:00:41,750 --> 00:00:40,320
is that better

15
00:00:45,510 --> 00:00:41,760
okay

16
00:00:47,029 --> 00:00:45,520
um basically we're approaching this idea

17
00:00:49,270 --> 00:00:47,039
of habitable zones from the

18
00:00:52,150 --> 00:00:49,280
astrophysical side so

19
00:00:52,950 --> 00:00:52,160
you know we have different stars that

20
00:00:54,389 --> 00:00:52,960
are

21
00:00:55,910 --> 00:00:54,399
different masses and different

22
00:00:57,830 --> 00:00:55,920
temperatures and so that's going to

23
00:01:00,790 --> 00:00:57,840
directly affect the location of a

24
00:01:03,029 --> 00:01:00,800
habitable zone around the star

25
00:01:04,390 --> 00:01:03,039
and

26
00:01:06,550 --> 00:01:04,400
four stars of different mass these

27
00:01:08,630 --> 00:01:06,560
habitable zones also

28
00:01:10,310 --> 00:01:08,640
expand outward at different rates based

29
00:01:12,710 --> 00:01:10,320
on the stellar evolution

30
00:01:13,910 --> 00:01:12,720
so we're trying to basically quantify

31
00:01:15,910 --> 00:01:13,920
how these

32
00:01:18,710 --> 00:01:15,920
stars change over time and thus how the

33
00:01:21,510 --> 00:01:18,720
habitable zones change over time

34
00:01:23,429 --> 00:01:21,520
so the two physical

35
00:01:25,749 --> 00:01:23,439
parameters that we can measure about

36
00:01:27,990 --> 00:01:25,759
stars are their mass

37
00:01:29,270 --> 00:01:28,000
and that affects its rate of hydrogen

38
00:01:31,270 --> 00:01:29,280

fusion

39
00:01:33,910 --> 00:01:31,280
and thus the main sequence lifetime so

40
00:01:35,429 --> 00:01:33,920
that is main sequence and so the more

41
00:01:36,870 --> 00:01:35,439
massive a star

42
00:01:38,390 --> 00:01:36,880
the shorter

43
00:01:40,390 --> 00:01:38,400
life span it's going to have on the main

44
00:01:42,469 --> 00:01:40,400
sequence and the main sequence for

45
00:01:45,670 --> 00:01:42,479
non-astronomers is basically just when a

46
00:01:48,230 --> 00:01:45,680
star is burning hydrogen in its core so

47
00:01:51,190 --> 00:01:48,240
it's about 90 of a star's lifetime it's

48
00:01:53,030 --> 00:01:51,200
really stable and long

49
00:01:56,069 --> 00:01:53,040
also composition so what the star is

50
00:01:58,149 --> 00:01:56,079
actually made of now stars are mostly

51
00:01:58,870 --> 00:01:58,159
hydrogen helium but they're also made up

52
00:02:00,870 --> 00:01:58,880
of

53
00:02:01,749 --> 00:02:00,880
other heavier elements

54
00:02:03,510 --> 00:02:01,759
and

55
00:02:06,310 --> 00:02:03,520
differing combinations of these elements

56
00:02:07,270 --> 00:02:06,320
actually affect the opacity in the star

57
00:02:08,869 --> 00:02:07,280
which

58
00:02:09,749 --> 00:02:08,879
affects the energy transport so if you

59
00:02:14,150 --> 00:02:09,759
have

60
00:02:15,670 --> 00:02:14,160
know photons being generated in the

61
00:02:17,990 --> 00:02:15,680
center of the star

62
00:02:20,390 --> 00:02:18,000
running into more material as they try

63
00:02:22,470 --> 00:02:20,400

to get out so if you have a higher

64
00:02:24,790 --> 00:02:22,480
opacity you're going to have

65
00:02:26,070 --> 00:02:24,800
less efficient energy escape

66
00:02:27,350 --> 00:02:26,080
so

67
00:02:29,030 --> 00:02:27,360
if you have less metal you're going to

68
00:02:31,830 --> 00:02:29,040
have lower opacity and more efficient

69
00:02:34,630 --> 00:02:31,840
energy escape and so two stars of equal

70
00:02:37,030 --> 00:02:34,640
mass if they have different compositions

71
00:02:38,309 --> 00:02:37,040
can actually you know change

72
00:02:40,470 --> 00:02:38,319
the lifetime of the main sequence

73
00:02:42,949 --> 00:02:40,480
significantly

74
00:02:44,229 --> 00:02:42,959
so basically this is just to show how

75
00:02:46,229 --> 00:02:44,239
the stars

76
00:02:47,110 --> 00:02:46,239
change over the main sequence

77
00:02:48,949 --> 00:02:47,120
so

78
00:02:50,869 --> 00:02:48,959
this is time in billions of years and

79
00:02:53,910 --> 00:02:50,879
this is luminosity so luminosity is just

80
00:02:55,750 --> 00:02:53,920
the brightness of the star so four five

81
00:02:58,790 --> 00:02:55,760
different compositions here

82
00:03:00,710 --> 00:02:58,800
black is just um solar composition you

83
00:03:02,710 --> 00:03:00,720
actually see that

84
00:03:04,229 --> 00:03:02,720
the lifetime can be significantly

85
00:03:06,630 --> 00:03:04,239
truncated

86
00:03:08,229 --> 00:03:06,640
versus you know a sun lives about 10

87
00:03:10,710 --> 00:03:08,239
billion years

88
00:03:13,110 --> 00:03:10,720

so something with um

89
00:03:14,470 --> 00:03:13,120
you know about half the oxygen of our

90
00:03:16,869 --> 00:03:14,480
sun let's say

91
00:03:19,430 --> 00:03:16,879
lives about half as long so

92
00:03:21,270 --> 00:03:19,440
really we're seeing and it's uh much

93
00:03:23,110 --> 00:03:21,280
brighter so there's a lot of different

94
00:03:25,589 --> 00:03:23,120
things that come into play here and i'll

95
00:03:28,869 --> 00:03:25,599
talk more about that

96
00:03:30,869 --> 00:03:28,879
so to model cellar evolution usually

97
00:03:33,509 --> 00:03:30,879
astronomers say

98
00:03:36,309 --> 00:03:33,519
okay there's metallicity in the star and

99
00:03:38,390 --> 00:03:36,319
they compare it to the sun so if you

100
00:03:40,149 --> 00:03:38,400
measure the iron abundance they just

101
00:03:41,670 --> 00:03:40,159
assume that all the other elements scale

102
00:03:44,710 --> 00:03:41,680
in the same proportions that are found

103
00:03:47,030 --> 00:03:44,720
in our own sun but that's actually

104
00:03:50,789 --> 00:03:47,040
not correct specific elemental

105
00:03:53,190 --> 00:03:50,799
abundances vary drastically

106
00:03:55,270 --> 00:03:53,200
between stars in particular oxygen we

107
00:03:56,710 --> 00:03:55,280
found significantly affects the stellar

108
00:03:58,710 --> 00:03:56,720
evolution

109
00:04:00,550 --> 00:03:58,720
so you know the location and lifetime of

110
00:04:02,550 --> 00:04:00,560
the habitable zones are dependent on the

111
00:04:04,949 --> 00:04:02,560
host star like i was saying

112
00:04:06,789 --> 00:04:04,959
so if we take into account this extra

113
00:04:08,710 --> 00:04:06,799

oxygen factor

114
00:04:10,309 --> 00:04:08,720
that's going to play a big role

115
00:04:12,309 --> 00:04:10,319
so what i've been doing is just use the

116
00:04:14,470 --> 00:04:12,319
stellar evolution code tycho

117
00:04:16,229 --> 00:04:14,480
i've been creating a big catalog of all

118
00:04:17,830 --> 00:04:16,239
these different kinds of stars

119
00:04:19,670 --> 00:04:17,840
evolutionary tracks

120
00:04:23,030 --> 00:04:19,680
um for different compositions i've made

121
00:04:26,310 --> 00:04:23,040
a grid of 376 so far

122
00:04:27,909 --> 00:04:26,320
mass is between 0.5 and 1.2 so kind of

123
00:04:29,510 --> 00:04:27,919
sun-like

124
00:04:31,749 --> 00:04:29,520
mass stars

125
00:04:33,030 --> 00:04:31,759
at different metallicities so that's

126
00:04:33,749 --> 00:04:33,040
that

127
00:04:34,950 --> 00:04:33,759
just

128
00:04:37,830 --> 00:04:34,960
solar

129
00:04:40,390 --> 00:04:37,840
abundance value scaled and then oxygen

130
00:04:42,390 --> 00:04:40,400
values i have two depleted values and

131
00:04:46,710 --> 00:04:42,400
two enriched values and those are based

132
00:04:50,950 --> 00:04:49,189
so we get something like this if i

133
00:04:52,550 --> 00:04:50,960
uh put something

134
00:04:54,150 --> 00:04:52,560
all together some of my output this is

135
00:04:56,710 --> 00:04:54,160
called a hertzsprung russell diagram

136
00:04:59,350 --> 00:04:56,720
it's just temperature versus brightness

137
00:05:02,070 --> 00:04:59,360
or the luminosity and we have my cool

138
00:05:03,749 --> 00:05:02,080

low mass stars on this side and my hot

139
00:05:06,070 --> 00:05:03,759
high mass stars

140
00:05:08,710 --> 00:05:06,080
on this side and even within each of

141
00:05:11,430 --> 00:05:08,720
these colors represents a different mass

142
00:05:13,909 --> 00:05:11,440
you can see that there's a large spread

143
00:05:17,430 --> 00:05:13,919
in the temperature and the brightness

144
00:05:18,950 --> 00:05:17,440
based on individual compositions so

145
00:05:21,270 --> 00:05:18,960
you have to look at both you can't just

146
00:05:23,990 --> 00:05:21,280
look at mass or composition to really

147
00:05:26,390 --> 00:05:24,000
get a full idea of

148
00:05:29,029 --> 00:05:26,400
how a star is going to evolve in its

149
00:05:30,790 --> 00:05:29,039
temperature and brightness over time

150
00:05:33,029 --> 00:05:30,800
so you know we care about temperature

151
00:05:35,909 --> 00:05:33,039
and brightness oh this is just my little

152
00:05:38,710 --> 00:05:35,919
test to show that this is the sun

153
00:05:40,950 --> 00:05:38,720
and it falls right on

154
00:05:43,029 --> 00:05:40,960
the solar

155
00:05:46,070 --> 00:05:43,039
track so that's a good test for our code

156
00:05:47,990 --> 00:05:46,080
make sure that it's outputting properly

157
00:05:51,029 --> 00:05:48,000
but we care about you know temperature

158
00:05:52,950 --> 00:05:51,039
and luminosity because

159
00:05:55,510 --> 00:05:52,960
at each time step taiko outputs these

160
00:05:57,270 --> 00:05:55,520
surface temperatures and luminosities

161
00:05:58,150 --> 00:05:57,280
and we put them in

162
00:06:02,070 --> 00:05:58,160
to

163
00:06:04,230 --> 00:06:02,080

habitable distances based on equations

164
00:06:06,309 --> 00:06:04,240
from ravi kaparapu's group

165
00:06:08,469 --> 00:06:06,319
and i won't go too much into this but

166
00:06:10,469 --> 00:06:08,479
basically i just wanted to show that

167
00:06:11,990 --> 00:06:10,479
these equations take in an effective

168
00:06:14,710 --> 00:06:12,000
temperature and a luminosity and that's

169
00:06:17,029 --> 00:06:14,720
what our code outputs at each time step

170
00:06:19,350 --> 00:06:17,039
of its evolution so we can actually

171
00:06:22,230 --> 00:06:19,360
calculate this d value this habitable

172
00:06:23,590 --> 00:06:22,240
zone distance for every

173
00:06:26,230 --> 00:06:23,600
point

174
00:06:28,550 --> 00:06:26,240
in a stellar evolution track based on

175
00:06:30,950 --> 00:06:28,560
these two parameters and so we

176
00:06:32,870 --> 00:06:30,960
ultimately end up with

177
00:06:34,790 --> 00:06:32,880
habitable zone limits the optimistic

178
00:06:36,710 --> 00:06:34,800
cases we don't really consider because

179
00:06:38,790 --> 00:06:36,720
they're optimistic we want to be more

180
00:06:40,550 --> 00:06:38,800
conservative so we take the runaway

181
00:06:41,670 --> 00:06:40,560
greenhouse to the maximum greenhouse

182
00:06:43,510 --> 00:06:41,680
cases

183
00:06:45,189 --> 00:06:43,520
and that's just um

184
00:06:47,430 --> 00:06:45,199
inner and outer habitable zone limits

185
00:06:49,749 --> 00:06:47,440
based on

186
00:06:52,150 --> 00:06:49,759
atmospheric properties of hypothetical

187
00:06:55,189 --> 00:06:52,160
planets that would be there so so if i

188
00:06:56,550 --> 00:06:55,199

plot my results based on those limit

189
00:06:58,230 --> 00:06:56,560
equations

190
00:07:00,629 --> 00:06:58,240
i get something like this so this is

191
00:07:03,749 --> 00:07:00,639
again age in billion years

192
00:07:06,390 --> 00:07:03,759
and distance along this axis

193
00:07:08,150 --> 00:07:06,400
and blue represents the sun or like

194
00:07:10,150 --> 00:07:08,160
solar composition so we have inner

195
00:07:12,710 --> 00:07:10,160
limits and outer limits

196
00:07:14,550 --> 00:07:12,720
so 1au is plot of reference so earth is

197
00:07:16,550 --> 00:07:14,560
about right there

198
00:07:18,150 --> 00:07:16,560
and so we're at the very inner limit of

199
00:07:21,909 --> 00:07:18,160
the habitable zone

200
00:07:24,390 --> 00:07:21,919
the red is for um

201
00:07:26,950 --> 00:07:24,400
about half the oxygen value

202
00:07:30,710 --> 00:07:26,960
so if you know if the sun had less

203
00:07:33,749 --> 00:07:30,720
oxygen we would actually be too close

204
00:07:36,070 --> 00:07:33,759
so this limit would be outward and we

205
00:07:37,510 --> 00:07:36,080
would be too close to the sun

206
00:07:40,710 --> 00:07:37,520
to

207
00:07:41,510 --> 00:07:40,720
maybe host liquid water on the surface

208
00:07:47,189 --> 00:07:41,520
so

209
00:07:48,870 --> 00:07:47,199
start problem which is that we don't we

210
00:07:51,670 --> 00:07:48,880
want to avoid planets that have recently

211
00:07:53,909 --> 00:07:51,680
entered the habitable zone because if

212
00:07:56,830 --> 00:07:53,919
something was frozen and then the star

213
00:07:59,110 --> 00:07:56,840

moved its boundaries outward and then it

214
00:08:01,350 --> 00:07:59,120
was at the right temperature to host

215
00:08:02,790 --> 00:08:01,360
liquid water on a planetary surface we

216
00:08:05,589 --> 00:08:02,800
don't know if that planet would have the

217
00:08:07,990 --> 00:08:05,599
impetus to maybe unfreeze itself

218
00:08:09,990 --> 00:08:08,000
and host liquid water so

219
00:08:12,230 --> 00:08:10,000
this prompts us to constrain the

220
00:08:13,589 --> 00:08:12,240
habitable zone with time criteria as

221
00:08:14,869 --> 00:08:13,599
well

222
00:08:16,869 --> 00:08:14,879
um

223
00:08:19,350 --> 00:08:16,879
so this was our first kind of iteration

224
00:08:20,790 --> 00:08:19,360
of this idea so we have the zero h main

225
00:08:23,430 --> 00:08:20,800
sequence and the terminal age main

226
00:08:25,029 --> 00:08:23,440
sequence that's just beginning and end

227
00:08:26,950 --> 00:08:25,039
of the main sequence

228
00:08:29,749 --> 00:08:26,960
and that's in blue and red

229
00:08:32,070 --> 00:08:29,759
and then the inner boundaries are solid

230
00:08:35,350 --> 00:08:32,080
the outer boundaries are dashed so this

231
00:08:37,430 --> 00:08:35,360
overlapping green shaded area is what

232
00:08:39,350 --> 00:08:37,440
would be called a continuously habitable

233
00:08:40,870 --> 00:08:39,360
zone so where

234
00:08:43,029 --> 00:08:40,880
the

235
00:08:45,030 --> 00:08:43,039
a planet in this green shaded area would

236
00:08:46,949 --> 00:08:45,040
remain habitable for its entire main

237
00:08:48,150 --> 00:08:46,959
sequence lifetime

238
00:08:50,389 --> 00:08:48,160

um

239
00:08:52,550 --> 00:08:50,399
however if we plot earth on this

240
00:08:54,150 --> 00:08:52,560
plot it doesn't

241
00:08:56,070 --> 00:08:54,160
quite fall into that region so we

242
00:08:57,350 --> 00:08:56,080
figured that that's not really a robust

243
00:08:59,670 --> 00:08:57,360
enough

244
00:09:02,710 --> 00:08:59,680
method of trying to understand

245
00:09:05,750 --> 00:09:02,720
habitability so instead we consider

246
00:09:08,790 --> 00:09:05,760
this uh continuously habitable zone of

247
00:09:10,230 --> 00:09:08,800
um a two billion year minimum so now the

248
00:09:13,750 --> 00:09:10,240
shaded green

249
00:09:15,269 --> 00:09:13,760
represents a planet at a distance

250
00:09:17,750 --> 00:09:15,279
in this green area would remain

251
00:09:19,030 --> 00:09:17,760
habitable for at least two billion years

252
00:09:21,110 --> 00:09:19,040
and so that's obviously an

253
00:09:23,110 --> 00:09:21,120
anthropomorphic

254
00:09:25,110 --> 00:09:23,120
boundary condition that we've imposed

255
00:09:26,150 --> 00:09:25,120
because it took earth about two billion

256
00:09:27,910 --> 00:09:26,160
years

257
00:09:31,590 --> 00:09:27,920
to

258
00:09:33,430 --> 00:09:31,600
biosignature

259
00:09:34,470 --> 00:09:33,440
but it's a starting place at least so we

260
00:09:36,310 --> 00:09:34,480
can now

261
00:09:38,070 --> 00:09:36,320
plot earth and it falls nicely in our

262
00:09:40,790 --> 00:09:38,080
little

263
00:09:43,430 --> 00:09:40,800

shaded area so basically this is just to

264
00:09:47,430 --> 00:09:45,190
how we're trying to constrain our

265
00:09:49,590 --> 00:09:47,440
habitable zone time limits

266
00:09:51,430 --> 00:09:49,600
now this is just a little overwhelming

267
00:09:53,509 --> 00:09:51,440
but it's basically the same thing as

268
00:09:56,550 --> 00:09:53,519
last plot

269
00:09:57,670 --> 00:09:56,560
except that this is for all of my 376

270
00:10:00,230 --> 00:09:57,680
stars

271
00:10:02,470 --> 00:10:00,240
so each line is a different data point

272
00:10:06,070 --> 00:10:02,480
and this is just again to reinforce the

273
00:10:07,829 --> 00:10:06,080
idea that composition really affects

274
00:10:09,910 --> 00:10:07,839
where your habitable zone distance is

275
00:10:11,030 --> 00:10:09,920
going to be so if you have a distance

276
00:10:12,870 --> 00:10:11,040
here

277
00:10:15,350 --> 00:10:12,880
and

278
00:10:17,269 --> 00:10:15,360
you have oxygen

279
00:10:18,550 --> 00:10:17,279
and okay so let's just look at the solid

280
00:10:21,110 --> 00:10:18,560
lines even

281
00:10:23,269 --> 00:10:21,120
there's a span in these elongated solid

282
00:10:25,509 --> 00:10:23,279
lines and that represents

283
00:10:27,829 --> 00:10:25,519
that spread and oxygen values that we're

284
00:10:29,509 --> 00:10:27,839
looking at so even a star of the same

285
00:10:30,949 --> 00:10:29,519
mass with different oxygen is going to

286
00:10:32,630 --> 00:10:30,959
have a habitable zone that's at a

287
00:10:33,829 --> 00:10:32,640
different distance

288
00:10:36,710 --> 00:10:33,839

and so that would affect where the

289
00:10:37,430 --> 00:10:36,720
planets could be habitable

290
00:10:38,310 --> 00:10:37,440
so

291
00:10:41,030 --> 00:10:38,320
um

292
00:10:42,710 --> 00:10:41,040
this i just wanted to point out that

293
00:10:45,030 --> 00:10:42,720
the fraction of time a planet would

294
00:10:47,269 --> 00:10:45,040
spend in the continuously habitable zone

295
00:10:49,350 --> 00:10:47,279
versus the entire main sequence

296
00:10:51,350 --> 00:10:49,360
is much higher

297
00:10:56,069 --> 00:10:51,360
for

298
00:10:57,110 --> 00:10:56,079
we actually don't see any

299
00:10:59,110 --> 00:10:57,120
because

300
00:11:00,949 --> 00:10:59,120
these stars are so short-lived that

301
00:11:02,790 --> 00:11:00,959
there's no continuously habitable zone

302
00:11:05,110 --> 00:11:02,800
for two billion years

303
00:11:07,670 --> 00:11:05,120
so that's one of the reasons why looking

304
00:11:08,949 --> 00:11:07,680
at low-mass stars is really

305
00:11:10,710 --> 00:11:08,959
important

306
00:11:12,310 --> 00:11:10,720
and it's going to help you know further

307
00:11:15,110 --> 00:11:12,320
quantify what kinds of stars we should

308
00:11:16,710 --> 00:11:15,120
actually focus on in the future with

309
00:11:18,710 --> 00:11:16,720
upcoming

310
00:11:20,230 --> 00:11:18,720
missions you know to try to look at

311
00:11:22,069 --> 00:11:20,240
planets and

312
00:11:24,069 --> 00:11:22,079
search for possibly

313
00:11:27,750 --> 00:11:24,079

inhabited exoplanets

314
00:11:28,949 --> 00:11:27,760
so my next steps are basically just

315
00:11:30,230 --> 00:11:28,959
creating

316
00:11:31,829 --> 00:11:30,240
more

317
00:11:33,590 --> 00:11:31,839
data points to put in this catalog we've

318
00:11:35,430 --> 00:11:33,600
made this catalog

319
00:11:36,560 --> 00:11:35,440
available online

320
00:11:37,750 --> 00:11:36,570
and

321
00:11:40,389 --> 00:11:37,760
[Music]

322
00:11:41,990 --> 00:11:40,399
you can basically go on and

323
00:11:43,430 --> 00:11:42,000
put whatever tracks you want and it'll

324
00:11:44,870 --> 00:11:43,440
interpolate

325
00:11:46,470 --> 00:11:44,880
um different masses or different

326
00:11:48,790 --> 00:11:46,480
compositions and give you a habitable

327
00:11:51,030 --> 00:11:48,800
zone based on whatever input parameters

328
00:11:51,990 --> 00:11:51,040
you want i'm also going to do the same

329
00:11:53,829 --> 00:11:52,000
kind of

330
00:11:56,550 --> 00:11:53,839
calculations for carbon and magnesium

331
00:11:57,430 --> 00:11:56,560
because those are also really important

332
00:11:59,030 --> 00:11:57,440
for

333
00:12:00,470 --> 00:11:59,040
stellar evolution

334
00:12:02,550 --> 00:12:00,480
and we're also going to look at the late

335
00:12:03,990 --> 00:12:02,560
stage evolution beyond the main sequence

336
00:12:05,030 --> 00:12:04,000
because that should be really important

337
00:12:06,949 --> 00:12:05,040
as well

338
00:12:08,870 --> 00:12:06,959

and we're also going to expand the

339
00:12:11,350 --> 00:12:08,880
catalog to include stars of even lower

340
00:12:13,990 --> 00:12:11,360
mass so down to even

341
00:12:15,910 --> 00:12:14,000
like the brown dwarf limit because

342
00:12:16,710 --> 00:12:15,920
they're very abundant and they're very

343
00:12:18,389 --> 00:12:16,720
good

344
00:12:19,350 --> 00:12:18,399
they're very easy to detect plants

345
00:12:21,190 --> 00:12:19,360
around

346
00:12:23,030 --> 00:12:21,200
so those are really good candidates to

347
00:12:25,269 --> 00:12:23,040
look for

348
00:12:28,360 --> 00:12:25,279
habitable planets so

349
00:12:32,470 --> 00:12:28,370
uh thank you for your attention

350
00:12:34,069 --> 00:12:32,480
[Applause]

351
00:12:40,629 --> 00:12:34,079
all right

352
00:12:43,910 --> 00:12:41,750
so um

353
00:12:47,430 --> 00:12:43,920
two questions what was the time

354
00:12:50,629 --> 00:12:47,440
difference from your highest mass

355
00:12:52,790 --> 00:12:50,639
i guess entire main sequence lifetime

356
00:12:54,710 --> 00:12:52,800
to your lowest mass what was the the

357
00:12:56,389 --> 00:12:54,720
time difference

358
00:12:58,550 --> 00:12:56,399
uh so how long is the main sequence

359
00:13:00,949 --> 00:12:58,560
lifetime for like a 1.2 solar mass

360
00:13:04,150 --> 00:13:00,959
versus 0.5 solar mass yeah so it's on

361
00:13:04,829 --> 00:13:04,160
the order of like 5 billion years for

362
00:13:08,310 --> 00:13:04,839
the

363
00:13:10,550 --> 00:13:08,320

1.2 up to about 100 billion years

364
00:13:12,470 --> 00:13:10,560
for the 0.5

365
00:13:15,269 --> 00:13:12,480
and then my second point was that

366
00:13:17,430 --> 00:13:15,279
actually if you do look at the

367
00:13:18,550 --> 00:13:17,440
evolution of the solar luminosity with

368
00:13:19,990 --> 00:13:18,560
time

369
00:13:21,350 --> 00:13:20,000
there is some suggestion that after

370
00:13:23,269 --> 00:13:21,360
about a billion years the carbonate

371
00:13:25,670 --> 00:13:23,279
silicate feedback cycle on the earth

372
00:13:27,269 --> 00:13:25,680
will be insufficient to maintain

373
00:13:29,509 --> 00:13:27,279
uh clement conditions on the earth so

374
00:13:31,190 --> 00:13:29,519
that's why after you know the entirety

375
00:13:33,590 --> 00:13:31,200
of the main sequence lifetime of the sun

376
00:13:36,870 --> 00:13:33,600
the earth is not in the habitable zone

377
00:13:38,870 --> 00:13:36,880
right and yeah and that's i mean

378
00:13:40,470 --> 00:13:38,880
obviously it's a very complex problem

379
00:13:42,230 --> 00:13:40,480
and we're just trying to approach it

380
00:13:43,110 --> 00:13:42,240
kind of from the bottom

381
00:13:44,629 --> 00:13:43,120
like

382
00:13:46,710 --> 00:13:44,639
you know constrain it from the

383
00:13:48,710 --> 00:13:46,720
astrophysical point and then

384
00:13:51,350 --> 00:13:48,720
kind of collaborate with

385
00:13:53,670 --> 00:13:51,360
geophysicists and people who could tell

386
00:13:54,949 --> 00:13:53,680
us more about the actual planet side as

387
00:13:57,110 --> 00:13:54,959
opposed to we're just coming at it from

388
00:13:58,470 --> 00:13:57,120

the star side

389
00:14:00,150 --> 00:13:58,480
but yeah it's

390
00:14:03,590 --> 00:14:00,160
there's a lot to consider with

391
00:14:06,470 --> 00:14:03,600
habitability so uh it's here uh really

392
00:14:08,550 --> 00:14:06,480
nice work i have two questions um i've

393
00:14:10,310 --> 00:14:08,560
seen some of the happy zone gets really

394
00:14:12,310 --> 00:14:10,320
close to central star when the stellar

395
00:14:14,310 --> 00:14:12,320
mass is small i was wondering do you

396
00:14:17,350 --> 00:14:14,320
need to worry about the irrigation of

397
00:14:20,310 --> 00:14:17,360
high energy photons in that situation

398
00:14:22,069 --> 00:14:20,320
yeah um we're actually part of our next

399
00:14:24,069 --> 00:14:22,079
steps that i didn't

400
00:14:25,990 --> 00:14:24,079
include on the slide was actually

401
00:14:28,470 --> 00:14:26,000
looking at um

402
00:14:31,110 --> 00:14:28,480
m dwarf age versus activity and so that

403
00:14:34,069 --> 00:14:31,120
would be the lower mass stars and then

404
00:14:35,750 --> 00:14:34,079
looking at how that activity

405
00:14:36,790 --> 00:14:35,760
you know changes over time and how that

406
00:14:38,949 --> 00:14:36,800
could really

407
00:14:41,430 --> 00:14:38,959
affect if there's a big flux of uv

408
00:14:43,509 --> 00:14:41,440
radiation or something

409
00:14:45,269 --> 00:14:43,519
even if the star lives a hundred billion

410
00:14:47,670 --> 00:14:45,279
years it's not going to be conducive for

411
00:14:50,150 --> 00:14:47,680
life if you have those big

412
00:14:52,150 --> 00:14:50,160
uv pulses happening all the time so that

413
00:14:54,790 --> 00:14:52,160

is something that we're going to

414
00:14:57,350 --> 00:14:54,800
consider cool so the second question is

415
00:14:59,910 --> 00:14:57,360
when you change the oxygen abandons

416
00:15:02,230 --> 00:14:59,920
does it affect your stellar evolution

417
00:15:04,230 --> 00:15:02,240
model or will that effect

418
00:15:06,949 --> 00:15:04,240
affect your um say

419
00:15:08,710 --> 00:15:06,959
planet atmosphere model as well

420
00:15:10,069 --> 00:15:08,720
sorry would it affect what um so you

421
00:15:13,030 --> 00:15:10,079
change the oxygen abundance in your

422
00:15:15,829 --> 00:15:13,040
model am i getting this right yes so so

423
00:15:17,750 --> 00:15:15,839
if we change the actual amount of oxygen

424
00:15:19,670 --> 00:15:17,760
and nothing else so everything else

425
00:15:22,150 --> 00:15:19,680
stays

426
00:15:24,949 --> 00:15:22,160
maybe solar yeah

427
00:15:27,670 --> 00:15:24,959
sorry sorry and then the major effect is

428
00:15:30,310 --> 00:15:27,680
on the stellar evolution

429
00:15:32,550 --> 00:15:30,320
yeah so the major effect is um

430
00:15:34,150 --> 00:15:32,560
the lifetime and the

431
00:15:35,750 --> 00:15:34,160
luminosity so

432
00:15:37,509 --> 00:15:35,760
and that's just due to what i was

433
00:15:40,230 --> 00:15:37,519
talking about with the opacity and the

434
00:15:42,470 --> 00:15:40,240
energy transport if you have more oxygen

435
00:15:44,470 --> 00:15:42,480
you're going to have more

436
00:15:46,230 --> 00:15:44,480
stuff bumping into the photons as it

437
00:15:48,310 --> 00:15:46,240
tries to escape so you're going to have

438
00:15:49,590 --> 00:15:48,320

less efficient energy escape and so the

439
00:15:51,509 --> 00:15:49,600
energy is going to stay in the star

440
00:15:52,870 --> 00:15:51,519
longer so it's actually going to let the

441
00:15:54,870 --> 00:15:52,880
star live

442
00:15:56,870 --> 00:15:54,880
longer than it would if it was just all

443
00:15:59,269 --> 00:15:56,880
radiating away really quickly yeah i was

444
00:16:00,949 --> 00:15:59,279
wondering would that change your planet

445
00:16:03,749 --> 00:16:00,959
atmosphere and the efficiency of

446
00:16:05,829 --> 00:16:03,759
trapping heat as well

447
00:16:09,509 --> 00:16:05,839
i guess i'm not sure i guess that would

448
00:16:11,350 --> 00:16:09,519
depend on the planet atmosphere right

449
00:16:13,110 --> 00:16:11,360
so i don't know if

450
00:16:15,590 --> 00:16:13,120
that would directly

451
00:16:18,069 --> 00:16:15,600
affect it would just from

452
00:16:19,269 --> 00:16:18,079
from this kind of analysis it would

453
00:16:22,310 --> 00:16:19,279
affect

454
00:16:23,509 --> 00:16:22,320
the temperature for sure so the surface

455
00:16:25,269 --> 00:16:23,519
temperature of the planet but then it

456
00:16:27,269 --> 00:16:25,279
would also depend on

457
00:16:29,910 --> 00:16:27,279
whatever atmosphere properties the

458
00:16:32,310 --> 00:16:29,920
planet had i i guess um i don't know if

459
00:16:33,110 --> 00:16:32,320
that answers your question

460
00:16:36,960 --> 00:16:33,120
but