

NEXSS & NFOLD

STANDARDS OF EVIDENCE FOR LIFE
DETECTION COMMUNITY WORKSHOP

DR. SHAWN DOMAGAL-GOLDMAN
BIOSIGNATURES DETECTION VIA
REMOTE SENSING



1
00:00:04,950 --> 00:00:03,030
hi my name is sean domigal goldman i'm

2
00:00:06,630 --> 00:00:04,960
at nasa's goddard space flight center

3
00:00:08,710 --> 00:00:06,640
although obviously not literally since

4
00:00:10,310 --> 00:00:08,720
i'm recording this from my home office

5
00:00:11,749 --> 00:00:10,320
on microsoft teams

6
00:00:13,669 --> 00:00:11,759
and today i'll be talking about

7
00:00:15,669 --> 00:00:13,679
biosignatures uh

8
00:00:16,870 --> 00:00:15,679
biosignature detection i should say via

9
00:00:18,630 --> 00:00:16,880
remote sensing

10
00:00:20,470 --> 00:00:18,640
i'll be focusing on exoplanets because

11
00:00:23,910 --> 00:00:20,480
that's where my expertise lies

12
00:00:26,870 --> 00:00:23,920
um although some of this will apply to

13
00:00:29,750 --> 00:00:26,880

ins i'm sorry solar system biosignature

14

00:00:32,630 --> 00:00:29,760

remote sensing as well

15

00:00:33,990 --> 00:00:32,640

if you want a more in-depth uh version

16

00:00:36,069 --> 00:00:34,000

of what i'm going to say today

17

00:00:37,830 --> 00:00:36,079

or if you'd like a broader cross-section

18

00:00:39,590 --> 00:00:37,840

of the community's opinions on this or

19

00:00:40,150 --> 00:00:39,600

take on this i would direct you towards

20

00:00:43,110 --> 00:00:40,160

this

21

00:00:45,830 --> 00:00:43,120

special issue of astrobiology volume 18

22

00:00:47,750 --> 00:00:45,840

number six that's the june 2018 issue

23

00:00:49,750 --> 00:00:47,760

which was uh an issue that published the

24

00:00:51,270 --> 00:00:49,760

work from our of the findings from a

25

00:00:54,150 --> 00:00:51,280

workshop we hosted

26
00:00:55,110 --> 00:00:54,160
on exoplanet biosignatures um i really

27
00:00:56,389 --> 00:00:55,120
would would

28
00:00:58,790 --> 00:00:56,399
can't recommend that strongly enough

29
00:01:00,549 --> 00:00:58,800
like it you it has a really good

30
00:01:01,990 --> 00:01:00,559
cross-section of community opinions

31
00:01:03,750 --> 00:01:02,000
incorporated into it

32
00:01:05,270 --> 00:01:03,760
uh and like i said much more detail that

33
00:01:07,030 --> 00:01:05,280
i'm gonna go into today

34
00:01:08,630 --> 00:01:07,040
i will try to update things a little bit

35
00:01:10,230 --> 00:01:08,640
at the end of my talk today from where

36
00:01:10,630 --> 00:01:10,240
we were at the end of that workshop with

37
00:01:14,390 --> 00:01:10,640
my

38
00:01:16,149 --> 00:01:14,400

future i mean here are the questions

39

00:01:17,749 --> 00:01:16,159

that was asked by the science organizing

40

00:01:18,710 --> 00:01:17,759

committee who i first of all i'd like to

41

00:01:20,870 --> 00:01:18,720

thank for

42

00:01:22,630 --> 00:01:20,880

uh inviting me to give this talk i'm

43

00:01:24,710 --> 00:01:22,640

really happy to be giving this talk to

44

00:01:25,990 --> 00:01:24,720

this audience at this time i'm glad this

45

00:01:27,830 --> 00:01:26,000

workshop is happening and i'm

46

00:01:29,510 --> 00:01:27,840

i'm really honored to be a part of it so

47

00:01:31,190 --> 00:01:29,520

thank you very much for inviting me

48

00:01:32,950 --> 00:01:31,200

and also thanks for these questions

49

00:01:33,990 --> 00:01:32,960

which which really helped frame this

50

00:01:35,749 --> 00:01:34,000

talk for me

51
00:01:37,429 --> 00:01:35,759
um and i'm not going to go over them all

52
00:01:39,350 --> 00:01:37,439
now i'll just cover them one by one

53
00:01:40,870 --> 00:01:39,360
starting with the top what do we think

54
00:01:43,109 --> 00:01:40,880
we are looking for when it comes to

55
00:01:45,270 --> 00:01:43,119
remote detection of biosignatures

56
00:01:46,789 --> 00:01:45,280
and what we think we're looking for is a

57
00:01:48,230 --> 00:01:46,799
number of different kinds of bio

58
00:01:50,149 --> 00:01:48,240
signatures and i'm

59
00:01:52,469 --> 00:01:50,159
going to demonstrate them with examples

60
00:01:54,069 --> 00:01:52,479
from earth now for exoplanets we're not

61
00:01:54,789 --> 00:01:54,079
going to get this level of spatial

62
00:01:59,350 --> 00:01:54,799
resolution

63
00:02:01,109 --> 00:01:59,360

just to demonstrate that yeah we can

64

00:02:02,789 --> 00:02:01,119

we can see the life does remotely

65

00:02:04,630 --> 00:02:02,799

because we're remotely observing this

66

00:02:06,870 --> 00:02:04,640

stuff on earth today

67

00:02:08,150 --> 00:02:06,880

this first example is a map of methane

68

00:02:10,869 --> 00:02:08,160

on earth which

69

00:02:12,710 --> 00:02:10,879

is predominantly produced by life and

70

00:02:12,949 --> 00:02:12,720

which we can sense remotely by building

71

00:02:15,510 --> 00:02:12,959

an

72

00:02:17,589 --> 00:02:15,520

orbiter that has instruments that have

73

00:02:19,030 --> 00:02:17,599

spectrographs that that can detect the

74

00:02:20,309 --> 00:02:19,040

wavelengths of light that nothing

75

00:02:22,150 --> 00:02:20,319

absorbs

76

00:02:24,309 --> 00:02:22,160

and methane is one biosignature you

77

00:02:25,910 --> 00:02:24,319

could do this with uh for exoplanets

78

00:02:27,430 --> 00:02:25,920

we've also talked about doing it for

79

00:02:29,350 --> 00:02:27,440

oxygen or ozone

80

00:02:31,350 --> 00:02:29,360

for solar system planets methane has

81

00:02:31,830 --> 00:02:31,360

been proposed as a biosignature as well

82

00:02:36,070 --> 00:02:31,840

as

83

00:02:37,110 --> 00:02:36,080

to phosphine which we've heard discussed

84

00:02:39,589 --> 00:02:37,120

in the literature

85

00:02:41,509 --> 00:02:39,599

recently and another kind of

86

00:02:42,949 --> 00:02:41,519

biosignature in addition to the gases

87

00:02:44,390 --> 00:02:42,959

that light produces

88

00:02:46,229 --> 00:02:44,400

are the ways that life affects the

89

00:02:47,030 --> 00:02:46,239
spectrum or the reflectivity of the

90

00:02:48,949 --> 00:02:47,040
surface

91

00:02:50,150 --> 00:02:48,959
and that could come in two forms both

92

00:02:52,309 --> 00:02:50,160
shown here on this

93

00:02:54,150 --> 00:02:52,319
this one movie um the first is in the

94

00:02:56,710 --> 00:02:54,160
oceans you could see chlorophyll which

95

00:02:59,750 --> 00:02:56,720
is a molecule inside the organism

96

00:03:01,350 --> 00:02:59,760
in this case used for photosynthesis um

97

00:03:02,790 --> 00:03:01,360
and on land you're seeing what's called

98

00:03:05,509 --> 00:03:02,800
the red edge effect that's

99

00:03:07,830 --> 00:03:05,519
associated with the the jump and

100

00:03:09,990 --> 00:03:07,840
reflectivity caused by plants

101
00:03:11,750 --> 00:03:10,000
in either case you're kind of detecting

102
00:03:13,270 --> 00:03:11,760
the organism itself a molecule the

103
00:03:14,149 --> 00:03:13,280
organism is made of in the case of

104
00:03:16,710 --> 00:03:14,159
chlorophyll

105
00:03:18,630 --> 00:03:16,720
or the structure or color of the of the

106
00:03:21,430 --> 00:03:18,640
organism in the case of the green

107
00:03:23,430 --> 00:03:21,440
on on land and either way again you can

108
00:03:25,830 --> 00:03:23,440
detect this remotely if you've got

109
00:03:27,589 --> 00:03:25,840
a telescope or in this case an orbiter

110
00:03:29,350 --> 00:03:27,599
that that includes a spectrograph that's

111
00:03:31,830 --> 00:03:29,360
got the right resolution and

112
00:03:33,350 --> 00:03:31,840
uh spectral resolution and wavelength

113
00:03:34,710 --> 00:03:33,360

range to detect the features you're

114

00:03:36,789 --> 00:03:34,720

looking for

115

00:03:38,550 --> 00:03:36,799

and then lastly you could in addition to

116

00:03:39,509 --> 00:03:38,560

looking for the things that life is made

117

00:03:41,750 --> 00:03:39,519

of or the

118

00:03:43,110 --> 00:03:41,760

byproducts of metabolism from the

119

00:03:44,550 --> 00:03:43,120

biosphere that's present

120

00:03:46,309 --> 00:03:44,560

you could also look for things that a

121

00:03:48,630 --> 00:03:46,319

civilization that is present on that

122

00:03:50,390 --> 00:03:48,640

planet isn't uh doing intentionally

123

00:03:52,390 --> 00:03:50,400

um some of these would use the same

124

00:03:53,910 --> 00:03:52,400

kinds of techniques and tools

125

00:03:55,429 --> 00:03:53,920

and platforms that the prior

126

00:03:57,509 --> 00:03:55,439

biosignatures would use

127

00:03:59,110 --> 00:03:57,519

uh such as looking for light coming from

128

00:04:01,350 --> 00:03:59,120

the night side of a planet or looking

129

00:04:02,869 --> 00:04:01,360

for the industrial pollutants that are

130

00:04:05,910 --> 00:04:02,879

clearly non-natural or

131

00:04:07,429 --> 00:04:05,920

perhaps even not uh clearly not from a a

132

00:04:09,270 --> 00:04:07,439

biosphere but are clearly from an

133

00:04:11,190 --> 00:04:09,280

industrialized civilization

134

00:04:12,630 --> 00:04:11,200

um you could look for those things um

135

00:04:13,990 --> 00:04:12,640

and there's there's other kinds of

136

00:04:14,869 --> 00:04:14,000

techno signatures you could look for as

137

00:04:16,629 --> 00:04:14,879

well including

138

00:04:17,909 --> 00:04:16,639

communication that's intentional or

139

00:04:19,909 --> 00:04:17,919

that's leakage

140

00:04:21,430 --> 00:04:19,919

from internal communication inside that

141

00:04:23,110 --> 00:04:21,440

civilization

142

00:04:25,430 --> 00:04:23,120

what's interesting to me is a lot of

143

00:04:27,590 --> 00:04:25,440

those are also

144

00:04:28,710 --> 00:04:27,600

require some sort of spectroscopy or

145

00:04:31,670 --> 00:04:28,720

understanding of

146

00:04:32,710 --> 00:04:31,680

of radiation of different wavelengths

147

00:04:34,629 --> 00:04:32,720

now i'm going to focus

148

00:04:35,909 --> 00:04:34,639

on the gaseous pile signatures for two

149

00:04:37,510 --> 00:04:35,919

reasons one that's

150

00:04:39,110 --> 00:04:37,520

where my history is and it's where i

151
00:04:41,270 --> 00:04:39,120
feel it got the most

152
00:04:42,469 --> 00:04:41,280
uh sort of authority or experience to

153
00:04:44,310 --> 00:04:42,479
speak from

154
00:04:45,749 --> 00:04:44,320
and secondly to be frank that's where a

155
00:04:48,550 --> 00:04:45,759
lot of the

156
00:04:49,110 --> 00:04:48,560
past history of research has been um i

157
00:04:52,230 --> 00:04:49,120
want to

158
00:04:53,510 --> 00:04:52,240
give the impression that i think that

159
00:04:55,670 --> 00:04:53,520
that's all we should

160
00:04:56,870 --> 00:04:55,680
focus on in fact i do think there's a

161
00:04:58,790 --> 00:04:56,880
case to be made to

162
00:05:00,870 --> 00:04:58,800
focus more on some of the other kinds of

163
00:05:02,469 --> 00:05:00,880

biosignatures i just mentioned

164

00:05:04,070 --> 00:05:02,479

but i won't give a lot of attention to

165

00:05:05,670 --> 00:05:04,080

you later today that's just not

166

00:05:07,110 --> 00:05:05,680

where my background isn't and it's not

167

00:05:07,909 --> 00:05:07,120

where a lot of the history in the field

168

00:05:09,830 --> 00:05:07,919

has been

169

00:05:11,189 --> 00:05:09,840

so i'm going to dive deeper into gaseous

170

00:05:13,270 --> 00:05:11,199

biosignatures

171

00:05:15,029 --> 00:05:13,280

and i'm going to start with just this

172

00:05:15,909 --> 00:05:15,039

these two takes which are very similar

173

00:05:17,110 --> 00:05:15,919

to each other but we're done

174

00:05:18,790 --> 00:05:17,120

independently

175

00:05:20,150 --> 00:05:18,800

on what makes a good gaseous

176

00:05:23,270 --> 00:05:20,160

biosignature

177

00:05:23,670 --> 00:05:23,280

um in both cases you're both in both of

178

00:05:25,830 --> 00:05:23,680

these

179

00:05:27,590 --> 00:05:25,840

papers which as far as i know are were

180

00:05:29,189 --> 00:05:27,600

considered fairly independently

181

00:05:31,830 --> 00:05:29,199

you've got a number of considerations

182

00:05:33,909 --> 00:05:31,840

you want the guests um to to pass

183

00:05:35,590 --> 00:05:33,919

for lack of a better word to to be a

184

00:05:37,029 --> 00:05:35,600

good biosignature you want it to be

185

00:05:39,270 --> 00:05:37,039

something that life makes

186

00:05:41,029 --> 00:05:39,280

you want it to last in the atmosphere

187

00:05:42,310 --> 00:05:41,039

long enough so that it could build up to

188

00:05:44,070 --> 00:05:42,320

detectable levels

189

00:05:45,909 --> 00:05:44,080

and then you want it to be something

190

00:05:48,150 --> 00:05:45,919

that it either is not made by

191

00:05:49,749 --> 00:05:48,160

non-biological processes or is all

192

00:05:51,029 --> 00:05:49,759

discussed in detail later

193

00:05:53,110 --> 00:05:51,039

where you can rule out the

194

00:05:55,430 --> 00:05:53,120

non-biological processes that make that

195

00:05:57,270 --> 00:05:55,440

gas

196

00:05:58,790 --> 00:05:57,280

the canonical biosignature that's kind

197

00:05:59,909 --> 00:05:58,800

of historically made it through all of

198

00:06:02,710 --> 00:05:59,919

those considerations

199

00:06:05,029 --> 00:06:02,720

is oxygen along with the photochemical

200

00:06:06,870 --> 00:06:05,039

byproduct of oxygen which is ozone

201
00:06:08,469 --> 00:06:06,880
it's made by plants you can see it here

202
00:06:10,150 --> 00:06:08,479
literally bubbling up from a leaf that's

203
00:06:11,189 --> 00:06:10,160
put under water for a kid's science

204
00:06:12,629 --> 00:06:11,199
experiment which

205
00:06:14,309 --> 00:06:12,639
you can do with your kids at home i'm

206
00:06:16,870 --> 00:06:14,319
planning to do that with mine

207
00:06:18,790 --> 00:06:16,880
later this summer um and that oxygen

208
00:06:20,230 --> 00:06:18,800
once it's made by plants can accumulate

209
00:06:22,790 --> 00:06:20,240
in the atmosphere to

210
00:06:23,590 --> 00:06:22,800
very high concentrations like to 20

211
00:06:25,350 --> 00:06:23,600
which is what it

212
00:06:27,270 --> 00:06:25,360
what it is in today's atmosphere on

213
00:06:28,469 --> 00:06:27,280

earth and that's detectable across

214

00:06:30,710 --> 00:06:28,479

interstellar space

215

00:06:31,510 --> 00:06:30,720

it's also very hard to make oxygen or

216

00:06:33,990 --> 00:06:31,520

ozone

217

00:06:35,590 --> 00:06:34,000

without biology producing it because

218

00:06:36,550 --> 00:06:35,600

it's rapidly destroyed both by

219

00:06:39,749 --> 00:06:36,560

photochemistry

220

00:06:41,430 --> 00:06:39,759

and by by photolysis directly and also

221

00:06:43,110 --> 00:06:41,440

from reaction with other chemicals in

222

00:06:45,270 --> 00:06:43,120

the atmosphere and if it's being

223

00:06:47,590 --> 00:06:45,280

destroyed rapidly it needs to be

224

00:06:48,710 --> 00:06:47,600

produced rapidly to replenish it that

225

00:06:50,870 --> 00:06:48,720

high flux

226
00:06:53,029 --> 00:06:50,880
of oxygen to the atmosphere required to

227
00:06:54,390 --> 00:06:53,039
sustain oxygen or ozone

228
00:06:56,469 --> 00:06:54,400
at high enough concentrations for

229
00:06:57,909 --> 00:06:56,479
detection that flux is orders of

230
00:07:00,870 --> 00:06:57,919
magnitude higher

231
00:07:02,230 --> 00:07:00,880
than the non-biological fluxes you get

232
00:07:03,589 --> 00:07:02,240
of oxygen and ozone

233
00:07:05,350 --> 00:07:03,599
and it's that orders of magnitude

234
00:07:07,029 --> 00:07:05,360
difference in flux that we think is the

235
00:07:08,950 --> 00:07:07,039
true biosignature

236
00:07:10,150 --> 00:07:08,960
now that said there have been some folks

237
00:07:11,909 --> 00:07:10,160
including myself

238
00:07:13,510 --> 00:07:11,919

that have tried to look at ways you

239

00:07:15,110 --> 00:07:13,520

could do that that where you could make

240

00:07:16,710 --> 00:07:15,120

enough oxygen or ozone

241

00:07:18,390 --> 00:07:16,720

so that you can detect it across the

242

00:07:20,309 --> 00:07:18,400

interstellar space

243

00:07:21,430 --> 00:07:20,319

without any biosphere being present on

244

00:07:23,270 --> 00:07:21,440

the planet

245

00:07:25,589 --> 00:07:23,280

uh there's a nice actually that meadows

246

00:07:29,270 --> 00:07:25,599

paper i quoted a couple slides ago

247

00:07:31,589 --> 00:07:29,280

uh from 2016 had a nice review

248

00:07:32,870 --> 00:07:31,599

of the the research into oxygen as a

249

00:07:34,790 --> 00:07:32,880

biosignature

250

00:07:35,990 --> 00:07:34,800

and into all these mechanisms that can

251
00:07:38,150 --> 00:07:36,000
make oxygen

252
00:07:39,589 --> 00:07:38,160
abiotically without a biosphere present

253
00:07:41,270 --> 00:07:39,599
on the planet this is the cover image

254
00:07:43,749 --> 00:07:41,280
from the issue of astrobiology

255
00:07:44,790 --> 00:07:43,759
in which that appeared and i recommend

256
00:07:46,790 --> 00:07:44,800
you take a look at that

257
00:07:48,550 --> 00:07:46,800
now the reason we did that the the that

258
00:07:49,350 --> 00:07:48,560
we looked at oxygen and ozone we weren't

259
00:07:51,430 --> 00:07:49,360
just trying to take

260
00:07:53,909 --> 00:07:51,440
the canonical biosignature down a few

261
00:07:55,670 --> 00:07:53,919
pegs we were doing it because we wanted

262
00:07:57,350 --> 00:07:55,680
to understand what the implications of

263
00:08:00,230 --> 00:07:57,360

that would be for emissions

264

00:08:02,790 --> 00:08:00,240

oxygen being the canonical biosignature

265

00:08:05,029 --> 00:08:02,800

along with its its byproduct ozone

266

00:08:06,629 --> 00:08:05,039

we're kind of at the heart of all all

267

00:08:08,790 --> 00:08:06,639

the past mission and all the current

268

00:08:11,589 --> 00:08:08,800

mission designs that we've been making

269

00:08:11,990 --> 00:08:11,599

for exoplanet spectroscopy missions

270

00:08:13,350 --> 00:08:12,000

basically

271

00:08:15,749 --> 00:08:13,360

if you're if you're designing a mission

272

00:08:18,309 --> 00:08:15,759

to find biosignatures on exoplanets

273

00:08:18,950 --> 00:08:18,319

you kind of start with uh can it detect

274

00:08:21,670 --> 00:08:18,960

oxygen

275

00:08:23,589 --> 00:08:21,680

and or ozone and what we wanted to do is

276

00:08:25,189 --> 00:08:23,599

if those missions were going to be

277

00:08:27,350 --> 00:08:25,199

designed around that at least as a

278

00:08:28,629 --> 00:08:27,360

starting point we'd want them to also be

279

00:08:31,430 --> 00:08:28,639

able to discriminate

280

00:08:32,310 --> 00:08:31,440

between planets that had oxygen or ozone

281

00:08:34,149 --> 00:08:32,320

but were dead

282

00:08:35,909 --> 00:08:34,159

and those that had oxygen or ozone that

283

00:08:37,990 --> 00:08:35,919

originated from a biosphere

284

00:08:39,829 --> 00:08:38,000

and we were able to do that so oxygen

285

00:08:41,990 --> 00:08:39,839

and ozone we now know that there are

286

00:08:45,590 --> 00:08:42,000

ways to make it but they're fairly

287

00:08:47,590 --> 00:08:45,600

um limited in the in the the planetary

288

00:08:48,630 --> 00:08:47,600

context and the stellar context in which

289

00:08:50,389 --> 00:08:48,640

that can occur

290

00:08:52,710 --> 00:08:50,399

and let that lets us do things like this

291

00:08:54,310 --> 00:08:52,720

which you don't have to read in detail

292

00:08:55,910 --> 00:08:54,320

but i put it up here to point out that

293

00:08:58,389 --> 00:08:55,920

because we thought

294

00:09:00,310 --> 00:08:58,399

about the ways that a dead planet could

295

00:09:01,190 --> 00:09:00,320

make that canonical biosignature of

296

00:09:03,269 --> 00:09:01,200

oxygen

297

00:09:04,870 --> 00:09:03,279

we now know what other observations we

298

00:09:05,350 --> 00:09:04,880

need to make what order we can make them

299

00:09:07,110 --> 00:09:05,360

in

300

00:09:08,310 --> 00:09:07,120

what wavelength range that implies for

301
00:09:09,430 --> 00:09:08,320
the mission we're looking at and the

302
00:09:10,870 --> 00:09:09,440
spectral resolution for the

303
00:09:13,190 --> 00:09:10,880
instrumentation on that

304
00:09:15,269 --> 00:09:13,200
that that mission as well which means

305
00:09:16,630 --> 00:09:15,279
that if we were to find oxygen or ozone

306
00:09:18,630 --> 00:09:16,640
on an exoplanet

307
00:09:20,150 --> 00:09:18,640
we could have the same mission do a

308
00:09:23,030 --> 00:09:20,160
follow-up observation

309
00:09:25,190 --> 00:09:23,040
to rule out the non-biological pathways

310
00:09:26,630 --> 00:09:25,200
for making oxygen or ozone

311
00:09:28,630 --> 00:09:26,640
and as i'll talk about later we've done

312
00:09:30,310 --> 00:09:28,640
that for other gases as well we've done

313
00:09:31,670 --> 00:09:30,320

it for methane for example

314

00:09:33,590 --> 00:09:31,680

and i think we should continue to do

315

00:09:36,230 --> 00:09:33,600

that as we move forward consider those

316

00:09:37,750 --> 00:09:36,240

non-biological production mechanisms and

317

00:09:39,670 --> 00:09:37,760

then figure out how to discriminate

318

00:09:42,150 --> 00:09:39,680

between the dead planet that makes that

319

00:09:44,630 --> 00:09:42,160

putative biosignature gas and the true

320

00:09:46,790 --> 00:09:44,640

living biosphere that does

321

00:09:48,389 --> 00:09:46,800

and so the next question is where are we

322

00:09:49,990 --> 00:09:48,399

exploring again i'm focused on

323

00:09:52,150 --> 00:09:50,000

exoplanets here in this talk you could

324

00:09:54,070 --> 00:09:52,160

look for remote biosignatures on well

325

00:09:55,750 --> 00:09:54,080

just about any any planet in the solar

326

00:09:56,470 --> 00:09:55,760

system especially the atmosphere bearing

327

00:09:58,310 --> 00:09:56,480

ones

328

00:10:00,150 --> 00:09:58,320

for exoplanets we've got a lot of

329

00:10:02,389 --> 00:10:00,160

choices in in some sense we've got

330

00:10:04,150 --> 00:10:02,399

thousands of exoplanets we've discovered

331

00:10:06,069 --> 00:10:04,160

and there's two considerations that we

332

00:10:08,150 --> 00:10:06,079

put into which ones would be the best

333

00:10:09,829 --> 00:10:08,160

to do to conduct a search for for

334

00:10:11,269 --> 00:10:09,839

biosignatures on

335

00:10:13,430 --> 00:10:11,279

the first is with regards to

336

00:10:16,150 --> 00:10:13,440

habitability and not habitability in a

337

00:10:18,550 --> 00:10:16,160

theoretical sense but in a practical one

338

00:10:19,190 --> 00:10:18,560

i know that the habitable zone term can

339

00:10:22,389 --> 00:10:19,200

be

340

00:10:22,949 --> 00:10:22,399

a little bit um uh of uh off-putting one

341

00:10:25,110 --> 00:10:22,959

to our

342

00:10:27,110 --> 00:10:25,120

colleagues that look uh for for signs of

343

00:10:28,790 --> 00:10:27,120

life or habitable environments

344

00:10:31,590 --> 00:10:28,800

in parts of our solar system that are

345

00:10:33,430 --> 00:10:31,600

beyond that technical habitable zone

346

00:10:35,590 --> 00:10:33,440

um but the reason that the habitable

347

00:10:37,590 --> 00:10:35,600

zone exists is really about

348

00:10:39,190 --> 00:10:37,600

global biospheres we want to look for

349

00:10:41,750 --> 00:10:39,200

global biospheres because

350

00:10:43,509 --> 00:10:41,760

we think that to detect a biosphere

351
00:10:45,750 --> 00:10:43,519
across interstellar space it's going to

352
00:10:46,870 --> 00:10:45,760
have to have a really robust signature

353
00:10:48,550 --> 00:10:46,880
um have to have pro

354
00:10:49,990 --> 00:10:48,560
and for that we think it will have had

355
00:10:52,310 --> 00:10:50,000
to proliferate it all

356
00:10:54,069 --> 00:10:52,320
all across the surface of the world um

357
00:10:55,509 --> 00:10:54,079
and and to be in close contact with the

358
00:10:57,750 --> 00:10:55,519
atmosphere

359
00:10:59,190 --> 00:10:57,760
and so that's why we want a global

360
00:11:01,269 --> 00:10:59,200
liquid water

361
00:11:03,509 --> 00:11:01,279
bearing planet which is what the

362
00:11:05,110 --> 00:11:03,519
habitable zone is really about so if

363
00:11:07,030 --> 00:11:05,120

that term bugs you just do a search

364

00:11:09,350 --> 00:11:07,040

replace of habitable zone four

365

00:11:11,350 --> 00:11:09,360

global biosphere zone or global liquid

366

00:11:13,269 --> 00:11:11,360

water zone and that that's really what

367

00:11:14,630 --> 00:11:13,279

we mean it's about that global

368

00:11:16,710 --> 00:11:14,640

habitability

369

00:11:18,230 --> 00:11:16,720

and so only as some a subset of these

370

00:11:19,990 --> 00:11:18,240

thousands of planets that we found

371

00:11:21,990 --> 00:11:20,000

with kepler and test and ground-based

372

00:11:23,350 --> 00:11:22,000

observations and other observatories

373

00:11:25,030 --> 00:11:23,360

only a fraction are in the habitable

374

00:11:26,470 --> 00:11:25,040

zone and only a fraction are

375

00:11:28,310 --> 00:11:26,480

of the right size to allow for that

376

00:11:31,110 --> 00:11:28,320

global habitability

377

00:11:32,150 --> 00:11:31,120

additionally only some of these planets

378

00:11:34,389 --> 00:11:32,160

are going to be

379

00:11:35,509 --> 00:11:34,399

amenable to follow-up observations and

380

00:11:37,910 --> 00:11:35,519

spectroscopy

381

00:11:40,310 --> 00:11:37,920

the stars are billions of times brighter

382

00:11:42,230 --> 00:11:40,320

than the planets that we want to look at

383

00:11:44,069 --> 00:11:42,240

and in addition to that the planets are

384

00:11:45,590 --> 00:11:44,079

really dim because they're small

385

00:11:47,350 --> 00:11:45,600

not just dim compared to the star

386

00:11:49,590 --> 00:11:47,360

they're just dim overall

387

00:11:51,430 --> 00:11:49,600

period full stop which means you need a

388

00:11:53,509 --> 00:11:51,440

telescope that's really big to collect

389

00:11:56,629 --> 00:11:53,519

the light from that very dim planet

390

00:11:57,670 --> 00:11:56,639

or and or you need a way to leverage the

391

00:11:59,350 --> 00:11:57,680

light of the star

392

00:12:01,990 --> 00:11:59,360

which is brighter to get some

393

00:12:03,829 --> 00:12:02,000

information from the planet itself

394

00:12:05,269 --> 00:12:03,839

all right so ultimately you really need

395

00:12:05,910 --> 00:12:05,279

three things in a mission that's going

396

00:12:08,470 --> 00:12:05,920

to look

397

00:12:09,829 --> 00:12:08,480

at spectroscopy from exo habitable

398

00:12:11,829 --> 00:12:09,839

exoplanets

399

00:12:13,430 --> 00:12:11,839

you need a big telescope you need a way

400

00:12:14,389 --> 00:12:13,440

to cancel out the starlight and then you

401
00:12:16,710 --> 00:12:14,399
need a way

402
00:12:17,430 --> 00:12:16,720
to analyze the spectrum of the light

403
00:12:19,110 --> 00:12:17,440
that has

404
00:12:20,790 --> 00:12:19,120
interacted with the planet somehow its

405
00:12:22,629 --> 00:12:20,800
atmosphere and or its

406
00:12:24,150 --> 00:12:22,639
surface i'll come to the different

407
00:12:25,829 --> 00:12:24,160
techniques for that in a bit

408
00:12:27,590 --> 00:12:25,839
now if you ask me five years ago i would

409
00:12:29,350 --> 00:12:27,600
have said that that we didn't have many

410
00:12:31,190 --> 00:12:29,360
near-term prospects for this

411
00:12:33,670 --> 00:12:31,200
because although we had jwst on the

412
00:12:34,629 --> 00:12:33,680
horizon none of the targets we had were

413
00:12:36,310 --> 00:12:34,639

good enough for that and

414

00:12:37,910 --> 00:12:36,320

we it really would have required perfect

415

00:12:39,670 --> 00:12:37,920

targets and they didn't anticipate us

416

00:12:42,790 --> 00:12:39,680

getting those perfect targets

417

00:12:44,790 --> 00:12:42,800

well about five years ago we did we got

418

00:12:46,470 --> 00:12:44,800

this trappist-1 system which is amazing

419

00:12:48,629 --> 00:12:46,480

in so many ways it has

420

00:12:49,910 --> 00:12:48,639

first off a number of planets which

421

00:12:51,829 --> 00:12:49,920

opens it up to some comparative

422

00:12:53,110 --> 00:12:51,839

planetology investigations which are

423

00:12:54,949 --> 00:12:53,120

really fun regardless of the

424

00:12:57,190 --> 00:12:54,959

biosignature search

425

00:12:58,470 --> 00:12:57,200

it also has a couple of those worlds a

426

00:13:00,629 --> 00:12:58,480

few of those worlds

427

00:13:02,310 --> 00:13:00,639

potentially in the habitable zone or or

428

00:13:04,629 --> 00:13:02,320

that are potentially habitable

429

00:13:07,030 --> 00:13:04,639

and then lastly the system itself is

430

00:13:07,829 --> 00:13:07,040

very close to us and it has a star at

431

00:13:10,550 --> 00:13:07,839

its center an

432

00:13:11,190 --> 00:13:10,560

m type star that's not too bright which

433

00:13:13,110 --> 00:13:11,200

which

434

00:13:14,310 --> 00:13:13,120

lowers the planet the stark contrast

435

00:13:16,069 --> 00:13:14,320

ratio and

436

00:13:18,470 --> 00:13:16,079

all of that makes it really favorable

437

00:13:19,350 --> 00:13:18,480

for observation um again five years ago

438

00:13:21,430 --> 00:13:19,360

i would have told you

439

00:13:23,350 --> 00:13:21,440

i'm not counting on us being successful

440

00:13:25,190 --> 00:13:23,360

here in the near term because

441

00:13:26,550 --> 00:13:25,200

we would have needed pretty much perfect

442

00:13:28,470 --> 00:13:26,560

targets and then

443

00:13:29,829 --> 00:13:28,480

like i said we got these targets which

444

00:13:31,990 --> 00:13:29,839

are pretty much perfect

445

00:13:33,670 --> 00:13:32,000

so that's trappist-1 is probably the

446

00:13:35,030 --> 00:13:33,680

most famous of these systems but there's

447

00:13:36,790 --> 00:13:35,040

a handful of other ones

448

00:13:39,110 --> 00:13:36,800

that are really really good that we we

449

00:13:41,509 --> 00:13:39,120

should be able to get some information

450

00:13:43,189 --> 00:13:41,519

from potentially habitable worlds in the

451

00:13:45,430 --> 00:13:43,199

near-term future with either

452

00:13:48,069 --> 00:13:45,440

the james webb space telescope or

453

00:13:49,750 --> 00:13:48,079

ground-based extremely large telescopes

454

00:13:51,110 --> 00:13:49,760

now there's two ways to get the spectral

455

00:13:52,230 --> 00:13:51,120

information i talked about you need a

456

00:13:54,310 --> 00:13:52,240

big telescope

457

00:13:55,910 --> 00:13:54,320

you need a way to get spectra from the

458

00:13:58,230 --> 00:13:55,920

planet and you need to block out the

459

00:13:59,750 --> 00:13:58,240

starlight or account for the starlight

460

00:14:02,069 --> 00:13:59,760

the two methods i'm going to talk about

461

00:14:04,230 --> 00:14:02,079

real quick are transit spectroscopy

462

00:14:05,189 --> 00:14:04,240

which is what jwst will use and the

463

00:14:07,430 --> 00:14:05,199

first generation

464

00:14:09,030 --> 00:14:07,440

of the extremely large telescopes on the

465

00:14:11,350 --> 00:14:09,040

ground we'll use to analyze

466

00:14:12,550 --> 00:14:11,360

rocky exoplanets in the habitable zones

467

00:14:14,629 --> 00:14:12,560

of other stars

468

00:14:16,150 --> 00:14:14,639

now the transit technique works it gets

469

00:14:18,389 --> 00:14:16,160

the spectra from the planet

470

00:14:20,389 --> 00:14:18,399

by separating out the planet spectrum

471

00:14:22,470 --> 00:14:20,399

basically by time you you look at

472

00:14:23,750 --> 00:14:22,480

what the spectrum of the star planet

473

00:14:25,189 --> 00:14:23,760

system is

474

00:14:27,350 --> 00:14:25,199

when the planet's at different points in

475

00:14:28,870 --> 00:14:27,360

the orbit most notably when it's

476
00:14:30,470 --> 00:14:28,880
in front of or behind the star when

477
00:14:31,910 --> 00:14:30,480
you're not getting as much uh

478
00:14:33,910 --> 00:14:31,920
when it's in front of her behind the

479
00:14:34,870 --> 00:14:33,920
star compared to when the planet's on

480
00:14:36,710 --> 00:14:34,880
the side

481
00:14:38,150 --> 00:14:36,720
if you look at kind of those three cases

482
00:14:39,670 --> 00:14:38,160
in general and you can do some things

483
00:14:41,110 --> 00:14:39,680
with the full orbit that are that are

484
00:14:43,030 --> 00:14:41,120
a little bit more nuanced but if you

485
00:14:44,150 --> 00:14:43,040
look at those three cases you can

486
00:14:46,470 --> 00:14:44,160
isolate

487
00:14:48,310 --> 00:14:46,480
the the spectrum or the part the part of

488
00:14:50,230 --> 00:14:48,320

the spectrum that's being filtered

489

00:14:51,910 --> 00:14:50,240

through the planet's atmosphere and that

490

00:14:53,590 --> 00:14:51,920

lets you basically get a spectrum of the

491

00:14:55,670 --> 00:14:53,600

planet's atmosphere

492

00:14:57,350 --> 00:14:55,680

now this is best for planets around

493

00:14:59,189 --> 00:14:57,360

m-type stars which are cooler and

494

00:15:00,949 --> 00:14:59,199

smaller than sun type stars

495

00:15:03,030 --> 00:15:00,959

it's most sensitive to the upper parts

496

00:15:04,790 --> 00:15:03,040

of the planet's atmosphere

497

00:15:06,949 --> 00:15:04,800

and it's also severely impacted by

498

00:15:08,069 --> 00:15:06,959

clouds now the other technique which is

499

00:15:10,870 --> 00:15:08,079

a little bit further off

500

00:15:11,829 --> 00:15:10,880

um for the last bullet it is direct

501
00:15:13,670 --> 00:15:11,839
imaging now direct

502
00:15:16,230 --> 00:15:13,680
imaging the downside is it requires

503
00:15:17,829 --> 00:15:16,240
significant technology development

504
00:15:19,590 --> 00:15:17,839
that we haven't done yet we know how to

505
00:15:20,389 --> 00:15:19,600
do it we're investing in it we expect to

506
00:15:21,990 --> 00:15:20,399
have it

507
00:15:24,310 --> 00:15:22,000
online for the next generation

508
00:15:26,790 --> 00:15:24,320
observatories but it as of today

509
00:15:28,389 --> 00:15:26,800
it's not sufficient for the the mission

510
00:15:30,710 --> 00:15:28,399
the observatories that are using direct

511
00:15:32,710 --> 00:15:30,720
imaging or high contrast imaging

512
00:15:34,629 --> 00:15:32,720
to to get the earth-like planets and the

513
00:15:37,350 --> 00:15:34,639

habitable zones around sun-like stars

514

00:15:39,110 --> 00:15:37,360

now unlike the transit spectroscopy case

515

00:15:41,670 --> 00:15:39,120

these are better for sun-like stars

516

00:15:43,430 --> 00:15:41,680

they work worse for m-type stars and on

517

00:15:43,990 --> 00:15:43,440

and vice versa the transit technique is

518

00:15:46,069 --> 00:15:44,000

worse

519

00:15:47,110 --> 00:15:46,079

and might not even ever work for fgk

520

00:15:49,430 --> 00:15:47,120

type stars

521

00:15:50,949 --> 00:15:49,440

high contrast direct imaging also probes

522

00:15:52,949 --> 00:15:50,959

the entire atmosphere effectively

523

00:15:55,350 --> 00:15:52,959

because the light you're seeing has

524

00:15:57,350 --> 00:15:55,360

originated at the star um at least for

525

00:15:59,509 --> 00:15:57,360

the uv to near ir versions of these

526

00:16:01,509 --> 00:15:59,519

it bounces off the surface of the planet

527

00:16:03,749 --> 00:16:01,519

and passes through the atmosphere twice

528

00:16:05,189 --> 00:16:03,759

it's also less sensitive to clouds

529

00:16:06,230 --> 00:16:05,199

for that reason clouds are always going

530

00:16:08,150 --> 00:16:06,240

to be an issue but

531

00:16:09,749 --> 00:16:08,160

they're not sort of a show stopper for

532

00:16:11,749 --> 00:16:09,759

direct imaging in the same way they can

533

00:16:13,430 --> 00:16:11,759

be for transit uh spectroscopy at least

534

00:16:14,949 --> 00:16:13,440

for near-term missions

535

00:16:16,230 --> 00:16:14,959

uh but that downside is they're further

536

00:16:17,590 --> 00:16:16,240

off because we're still developing the

537

00:16:18,389 --> 00:16:17,600

technologies to the levels they're

538

00:16:20,550 --> 00:16:18,399

needed for

539

00:16:22,069 --> 00:16:20,560

for the habitable worlds now the cool

540

00:16:23,910 --> 00:16:22,079

thing about transit spectroscopy

541

00:16:25,430 --> 00:16:23,920

that the best in my opinion is that we

542

00:16:26,550 --> 00:16:25,440

can do it sooner because the

543

00:16:28,470 --> 00:16:26,560

technologies

544

00:16:30,310 --> 00:16:28,480

uh are basically there they've been

545

00:16:32,230 --> 00:16:30,320

incorporated into a telescope

546

00:16:35,110 --> 00:16:32,240

um even though the telescope was not

547

00:16:38,069 --> 00:16:35,120

designed to do exoplanet spectroscopy of

548

00:16:39,350 --> 00:16:38,079

of rocky habitable zone worlds jwst is

549

00:16:42,069 --> 00:16:39,360

such an awesome

550

00:16:42,629 --> 00:16:42,079

piece of machinery that exists and has

551
00:16:44,949 --> 00:16:42,639
been built

552
00:16:46,870 --> 00:16:44,959
and tested and is about to launch um

553
00:16:48,470 --> 00:16:46,880
that we're going to pretty soon have

554
00:16:50,629 --> 00:16:48,480
some kind of information from these

555
00:16:54,310 --> 00:16:50,639
worlds with that transit spectroscopy

556
00:16:57,590 --> 00:16:54,320
technique um and and here's a simulation

557
00:16:59,350 --> 00:16:57,600
of both what's promising about

558
00:17:01,350 --> 00:16:59,360
that kind of observation but also what's

559
00:17:04,630 --> 00:17:01,360
perilous and challenging about them

560
00:17:06,949 --> 00:17:04,640
uh this is worked by thomas what he's

561
00:17:08,549 --> 00:17:06,959
done is he's he's made a a spectrum here

562
00:17:10,949 --> 00:17:08,559
actually two versions of

563
00:17:12,230 --> 00:17:10,959

the same planet and and a simulation of

564

00:17:14,549 --> 00:17:12,240

what jwst

565

00:17:15,429 --> 00:17:14,559

might see for that planet the first

566

00:17:18,470 --> 00:17:15,439

which i'm going to show

567

00:17:20,150 --> 00:17:18,480

in black is uh basically the spectrum

568

00:17:22,870 --> 00:17:20,160

for a planet with a clear sky

569

00:17:23,669 --> 00:17:22,880

no clouds in and you can see these peaks

570

00:17:26,230 --> 00:17:23,679

are from

571

00:17:28,549 --> 00:17:26,240

uh water or carbon dioxide absorption in

572

00:17:30,950 --> 00:17:28,559

the atmosphere and transit spectroscopy

573

00:17:31,990 --> 00:17:30,960

peaks are are what result from

574

00:17:34,870 --> 00:17:32,000

absorption

575

00:17:35,669 --> 00:17:34,880

he then adds clouds to the model and and

576

00:17:37,510 --> 00:17:35,679

any

577

00:17:39,830 --> 00:17:37,520

world that's habitable is almost certain

578

00:17:40,950 --> 00:17:39,840

to have clouds and this is the bad news

579

00:17:42,950 --> 00:17:40,960

when you add the clouds to the

580

00:17:43,990 --> 00:17:42,960

simulation you get this blue line which

581

00:17:45,430 --> 00:17:44,000

is much flatter

582

00:17:47,350 --> 00:17:45,440

you don't see all these absorption

583

00:17:48,870 --> 00:17:47,360

features from water and carbon dioxide

584

00:17:51,830 --> 00:17:48,880

like you do in the black curve

585

00:17:52,390 --> 00:17:51,840

um and it's it's pretty dim um and and

586

00:17:54,070 --> 00:17:52,400

this is

587

00:17:55,590 --> 00:17:54,080

bad because it means that we're we might

588

00:17:57,190 --> 00:17:55,600

be able to see whether or not this

589

00:17:58,549 --> 00:17:57,200

planet has an atmosphere according to

590

00:18:00,070 --> 00:17:58,559

these simulations but

591

00:18:02,070 --> 00:18:00,080

it's going to be really really hard to

592

00:18:04,230 --> 00:18:02,080

see the bio signatures themselves

593

00:18:05,830 --> 00:18:04,240

um jake lustig yeager also did similar

594

00:18:08,070 --> 00:18:05,840

calculations on what we

595

00:18:10,070 --> 00:18:08,080

you know how how many transits how much

596

00:18:11,430 --> 00:18:10,080

of jwst time would it take for the

597

00:18:12,630 --> 00:18:11,440

different trappist worlds and for

598

00:18:15,190 --> 00:18:12,640

different versions

599

00:18:16,950 --> 00:18:15,200

different model versions of those worlds

600

00:18:17,990 --> 00:18:16,960

um and and for some of them you don't

601
00:18:20,630 --> 00:18:18,000
need a lot

602
00:18:22,150 --> 00:18:20,640
um but but but this is really just to

603
00:18:23,669 --> 00:18:22,160
detect the presence of the atmosphere

604
00:18:24,310 --> 00:18:23,679
it's to know that the spectrum isn't

605
00:18:26,230 --> 00:18:24,320
flat

606
00:18:27,590 --> 00:18:26,240
uh you would need more this is just the

607
00:18:29,270 --> 00:18:27,600
number of transits you need for each of

608
00:18:30,789 --> 00:18:29,280
these permutations

609
00:18:33,830 --> 00:18:30,799
for some you only need a few and this is

610
00:18:35,430 --> 00:18:33,840
quite affordable for the one bar water

611
00:18:36,950 --> 00:18:35,440
rich atmosphere or the habitable

612
00:18:38,549 --> 00:18:36,960
atmosphere with clouds it's going to

613
00:18:39,830 --> 00:18:38,559

take dozens of spectra that's going to

614

00:18:41,909 --> 00:18:39,840

be expensive

615

00:18:43,669 --> 00:18:41,919

it's probably worth doing just because

616

00:18:46,150 --> 00:18:43,679

we're going to learn a lot there

617

00:18:47,590 --> 00:18:46,160

but this is not enough to get us the

618

00:18:49,750 --> 00:18:47,600

biosignatures themselves

619

00:18:51,590 --> 00:18:49,760

the bios signatures are going to be hard

620

00:18:53,590 --> 00:18:51,600

uh they're going to take a lot of time

621

00:18:55,190 --> 00:18:53,600

um and it's worth looking at these

622

00:18:56,549 --> 00:18:55,200

worlds and getting the spectra of these

623

00:18:58,549 --> 00:18:56,559

worlds and and we

624

00:19:00,070 --> 00:18:58,559

might find something interesting there

625

00:19:03,029 --> 00:19:00,080

but i will tell you

626
00:19:04,150 --> 00:19:03,039
my honest expectation is that we're not

627
00:19:06,549 --> 00:19:04,160
going to see

628
00:19:08,390 --> 00:19:06,559
the level of us the we're not going to

629
00:19:09,750 --> 00:19:08,400
get good enough signal to noise to to be

630
00:19:11,590 --> 00:19:09,760
able to search for or detect

631
00:19:14,630 --> 00:19:11,600
biosignatures on these worlds

632
00:19:16,789 --> 00:19:14,640
and that's not a knock on jwst in fact

633
00:19:17,669 --> 00:19:16,799
it i'm i'm impressed that it can do any

634
00:19:19,669 --> 00:19:17,679
of this at all

635
00:19:21,750 --> 00:19:19,679
without being purpose built for this

636
00:19:24,630 --> 00:19:21,760
kind of thing and this is where myself

637
00:19:26,310 --> 00:19:24,640
and the rest of the exoplanet rocky uh

638
00:19:29,430 --> 00:19:26,320

uh habitable zone

639

00:19:31,190 --> 00:19:29,440

uh community turns into aid simpson

640

00:19:33,029 --> 00:19:31,200

shaking our fist of clouds because it's

641

00:19:33,510 --> 00:19:33,039

the clouds that really are the problem

642

00:19:35,669 --> 00:19:33,520

here

643

00:19:37,590 --> 00:19:35,679

um the transit technique also has uh is

644

00:19:38,230 --> 00:19:37,600

not as good as direct imaging in many

645

00:19:40,070 --> 00:19:38,240

ways

646

00:19:41,510 --> 00:19:40,080

um but especially if you've got clouds

647

00:19:43,270 --> 00:19:41,520

just not good

648

00:19:44,549 --> 00:19:43,280

so that was kind of both how we'll

649

00:19:45,990 --> 00:19:44,559

explore but also what our current

650

00:19:48,310 --> 00:19:46,000

limitations are

651
00:19:49,830 --> 00:19:48,320
to get around those limitations i i

652
00:19:51,510 --> 00:19:49,840
think we need to go to direct imaging

653
00:19:52,950 --> 00:19:51,520
and it has those advantages i mentioned

654
00:19:54,470 --> 00:19:52,960
earlier you can look at the

655
00:19:55,990 --> 00:19:54,480
earth-like planets around the sun like

656
00:19:57,750 --> 00:19:56,000
stars you don't have

657
00:19:59,510 --> 00:19:57,760
as many issues with clouds they're not

658
00:20:01,990 --> 00:19:59,520
showstoppers um

659
00:20:03,430 --> 00:20:02,000
and we can do this for quite a large

660
00:20:04,390 --> 00:20:03,440
number of worlds as i'll get to in a

661
00:20:06,549 --> 00:20:04,400
little bit

662
00:20:08,310 --> 00:20:06,559
now we have two mission concepts for

663
00:20:09,830 --> 00:20:08,320

flagship scale observatories that would

664

00:20:11,990 --> 00:20:09,840

do this at different levels of ambition

665

00:20:14,230 --> 00:20:12,000

that's shown on the left this is luvoir

666

00:20:16,789 --> 00:20:14,240

on on the top and have x on the bottom

667

00:20:17,590 --> 00:20:16,799

this is not to scale luvoir is by design

668

00:20:20,230 --> 00:20:17,600

much bigger

669

00:20:20,950 --> 00:20:20,240

it's more ambitious than have x ex both

670

00:20:23,110 --> 00:20:20,960

missions

671

00:20:24,470 --> 00:20:23,120

though like regardless of ambition it's

672

00:20:26,230 --> 00:20:24,480

really about how many times they would

673

00:20:28,310 --> 00:20:26,240

do this kind of observation

674

00:20:30,149 --> 00:20:28,320

both missions would be able to do the

675

00:20:30,710 --> 00:20:30,159

direct imaging observation i talked

676
00:20:32,830 --> 00:20:30,720
about

677
00:20:34,230 --> 00:20:32,840
earlier the the reflected light

678
00:20:35,830 --> 00:20:34,240
spectroscopy

679
00:20:37,590 --> 00:20:35,840
and the way that works is you block out

680
00:20:39,750 --> 00:20:37,600
the star physically with some

681
00:20:41,990 --> 00:20:39,760
coronagraph or star shade

682
00:20:44,310 --> 00:20:42,000
and then the light that's left over is

683
00:20:45,990 --> 00:20:44,320
is from either the dust in the planetary

684
00:20:47,990 --> 00:20:46,000
system or from the planets

685
00:20:49,350 --> 00:20:48,000
themselves and this is what you really

686
00:20:50,870 --> 00:20:49,360
want to see you want to see a bright

687
00:20:51,830 --> 00:20:50,880
thing in the habitable zone and get a

688
00:20:54,230 --> 00:20:51,840

spectrum of it

689

00:20:55,270 --> 00:20:54,240

this is a simulation of what that image

690

00:20:57,510 --> 00:20:55,280

would look like

691

00:20:59,350 --> 00:20:57,520

using the bigger version of luvoir

692

00:21:00,630 --> 00:20:59,360

looking back at the solar system from 12

693

00:21:02,630 --> 00:21:00,640

and a half par 6 away

694

00:21:04,310 --> 00:21:02,640

you get a similar image uh with a

695

00:21:06,310 --> 00:21:04,320

smaller version of luvoir

696

00:21:08,470 --> 00:21:06,320

or or with habex if you were looking at

697

00:21:09,830 --> 00:21:08,480

it at a solar system twin that's that's

698

00:21:11,909 --> 00:21:09,840

closer to us

699

00:21:12,870 --> 00:21:11,919

than 12 and a half par 6 away so this

700

00:21:14,789 --> 00:21:12,880

image would still be

701
00:21:16,310 --> 00:21:14,799
quote unquote true um just for a

702
00:21:18,870 --> 00:21:16,320
different a different system that you'd

703
00:21:20,789 --> 00:21:18,880
be targeting

704
00:21:22,070 --> 00:21:20,799
now this is a a simulation of what the

705
00:21:23,590 --> 00:21:22,080
spectrum would look like because you

706
00:21:25,750 --> 00:21:23,600
don't just want those points of light

707
00:21:27,990 --> 00:21:25,760
you want to spread that pale blue dot

708
00:21:28,870 --> 00:21:28,000
out into its constituent colors to look

709
00:21:30,870 --> 00:21:28,880
for those

710
00:21:33,029 --> 00:21:30,880
features from the biosignature gases and

711
00:21:34,870 --> 00:21:33,039
now just think about before i had those

712
00:21:36,549 --> 00:21:34,880
just water and co2 and it was really

713
00:21:38,549 --> 00:21:36,559

flat if you included the clouds

714

00:21:41,669 --> 00:21:38,559

here's a simulation of what luvoir might

715

00:21:43,190 --> 00:21:41,679

see for a planet that's 10 parsecs away

716

00:21:45,270 --> 00:21:43,200

and you can see absorption features

717

00:21:46,310 --> 00:21:45,280

which are now down this is confusing and

718

00:21:48,789 --> 00:21:46,320

i apologize for

719

00:21:50,710 --> 00:21:48,799

for what the exoplanet community does to

720

00:21:53,430 --> 00:21:50,720

spectra and flipping their axes but

721

00:21:54,630 --> 00:21:53,440

for a direct imaging reflected light uh

722

00:21:57,110 --> 00:21:54,640

observation

723

00:21:59,669 --> 00:21:57,120

you have uh absorption associated with

724

00:22:00,870 --> 00:21:59,679

being is shown as being down on the on

725

00:22:02,310 --> 00:22:00,880

the diagram as opposed to

726

00:22:03,909 --> 00:22:02,320

up which is what i was showing before so

727

00:22:04,870 --> 00:22:03,919

that now the valleys are absorption

728

00:22:06,789 --> 00:22:04,880

features

729

00:22:08,149 --> 00:22:06,799

so for for this for this simulated

730

00:22:10,230 --> 00:22:08,159

spectrum you can see

731

00:22:12,149 --> 00:22:10,240

absorption from ozone you can see a

732

00:22:14,149 --> 00:22:12,159

broad feet i'm sorry from oxygen here a

733

00:22:15,590 --> 00:22:14,159

broad feature from ozone over here

734

00:22:17,270 --> 00:22:15,600

there's a shoulder feature here from the

735

00:22:19,110 --> 00:22:17,280

methane you can start to accumulate a

736

00:22:20,870 --> 00:22:19,120

library of gases that you know are in

737

00:22:22,549 --> 00:22:20,880

that planet's atmosphere

738

00:22:24,310 --> 00:22:22,559

and the signal to noise on the detection

739

00:22:25,750 --> 00:22:24,320

of those gases is quite good

740

00:22:27,669 --> 00:22:25,760

um and this is a simulation that

741

00:22:29,510 --> 00:22:27,679

included clouds in it so the clouds

742

00:22:31,029 --> 00:22:29,520

it impacts the the continuum but it

743

00:22:31,990 --> 00:22:31,039

doesn't impact your ability to get at

744

00:22:33,590 --> 00:22:32,000

these gases

745

00:22:35,750 --> 00:22:33,600

by the way i should mention that this is

746

00:22:37,669 --> 00:22:35,760

a simulation for luvoir but again

747

00:22:38,789 --> 00:22:37,679

havex could also do something like this

748

00:22:41,590 --> 00:22:38,799

for a different

749

00:22:42,950 --> 00:22:41,600

system that's closer up and bonus an

750

00:22:46,470 --> 00:22:42,960

awesome telescope

751

00:22:47,909 --> 00:22:46,480

out that if you can do

752

00:22:49,510 --> 00:22:47,919

if you build the observatory that's

753

00:22:50,230 --> 00:22:49,520

required to do the exoplanet direct

754

00:22:52,149 --> 00:22:50,240

imaging

755

00:22:53,830 --> 00:22:52,159

that observatory and this would also be

756

00:22:54,870 --> 00:22:53,840

true for have x would also be

757

00:22:57,590 --> 00:22:54,880

outstanding for

758

00:22:58,630 --> 00:22:57,600

remote sensing inside our solar system

759

00:23:00,390 --> 00:22:58,640

so if you're into

760

00:23:02,470 --> 00:23:00,400

a biosignature search remotely in the

761

00:23:05,110 --> 00:23:02,480

solar system levoir or habex would be

762

00:23:07,110 --> 00:23:05,120

excellent for that as well

763

00:23:08,390 --> 00:23:07,120

now for both of these we we leveraged

764

00:23:10,390 --> 00:23:08,400

the work or or

765

00:23:12,470 --> 00:23:10,400

or built off the work that jada arne and

766

00:23:14,470 --> 00:23:12,480

colleagues did on how we would detect

767

00:23:16,230 --> 00:23:14,480

not just the biosignatures from modern

768

00:23:18,149 --> 00:23:16,240

day earth but throughout earth's history

769

00:23:18,470 --> 00:23:18,159

for example archaean earth we think had

770

00:23:20,470 --> 00:23:18,480

no

771

00:23:21,510 --> 00:23:20,480

oxygen or very little oxygen in its

772

00:23:24,630 --> 00:23:21,520

atmosphere

773

00:23:26,070 --> 00:23:24,640

and no detectable ozone or oxygen

774

00:23:27,669 --> 00:23:26,080

but it had life for about a third of the

775

00:23:29,510 --> 00:23:27,679

history of life on earth

776

00:23:31,830 --> 00:23:29,520

and and we wanted to be able to detect

777

00:23:33,350 --> 00:23:31,840

that kind of world so we built luvoir

778

00:23:34,789 --> 00:23:33,360

and havoc or should say we didn't build

779

00:23:37,669 --> 00:23:34,799

it yet gosh wish we had

780

00:23:39,350 --> 00:23:37,679

we design or conceptualize luf and habex

781

00:23:41,190 --> 00:23:39,360

to be able to detect

782

00:23:43,909 --> 00:23:41,200

not just the bio signatures on our key

783

00:23:45,909 --> 00:23:43,919

and earth we're without oxygen but also

784

00:23:46,950 --> 00:23:45,919

to discriminate between an arcane

785

00:23:48,950 --> 00:23:46,960

earth-like world

786

00:23:51,269 --> 00:23:48,960

and a planet like titan that has methane

787

00:23:52,789 --> 00:23:51,279

that comes from we think non-biological

788

00:23:54,310 --> 00:23:52,799

sources

789

00:23:56,149 --> 00:23:54,320

now as we're thinking about those future

790

00:23:57,669 --> 00:23:56,159

emissions i also want us to think about

791

00:23:59,510 --> 00:23:57,679

what we need to do in the future

792

00:24:01,350 --> 00:23:59,520

for research and for the theory of

793

00:24:02,630 --> 00:24:01,360

biosignatures which is what my last few

794

00:24:04,789 --> 00:24:02,640

slides will be on

795

00:24:07,350 --> 00:24:04,799

um the first i'm going to just talk to

796

00:24:09,029 --> 00:24:07,360

jake lustig yeager's work as an example

797

00:24:10,549 --> 00:24:09,039

of us doing a more thorough

798

00:24:12,630 --> 00:24:10,559

consideration of

799

00:24:14,230 --> 00:24:12,640

surface biosignatures because basically

800

00:24:15,510 --> 00:24:14,240

everything i've been talking about as i

801

00:24:17,669 --> 00:24:15,520

alluded to earlier

802

00:24:19,669 --> 00:24:17,679

is about gaseous spout signatures now

803

00:24:20,630 --> 00:24:19,679

there is work on surface file signatures

804

00:24:22,549 --> 00:24:20,640

but i don't think

805

00:24:24,070 --> 00:24:22,559

um as broad of a community has looked at

806

00:24:24,950 --> 00:24:24,080

it especially on the the side of

807

00:24:27,350 --> 00:24:24,960

simulating

808

00:24:28,870 --> 00:24:27,360

what a luvor or havex might see and i

809

00:24:30,710 --> 00:24:28,880

think we could do a lot more there

810

00:24:32,149 --> 00:24:30,720

um i think i think the same thing is

811

00:24:33,750 --> 00:24:32,159

true for techno signatures there's a

812

00:24:34,710 --> 00:24:33,760

couple papers just coming out the last

813

00:24:36,230 --> 00:24:34,720

few years

814

00:24:37,830 --> 00:24:36,240

on what we could do with luvoir or

815

00:24:39,110 --> 00:24:37,840

have-ex for techno signatures and i

816

00:24:40,630 --> 00:24:39,120

think we need to see more of that as

817

00:24:42,630 --> 00:24:40,640

well

818

00:24:44,310 --> 00:24:42,640

uh there's also this excellent work by

819

00:24:46,789 --> 00:24:44,320

tessa fisher which is uh

820

00:24:48,390 --> 00:24:46,799

taking us in a uh i would say it's

821

00:24:50,310 --> 00:24:48,400

quantifying our intuition

822

00:24:52,310 --> 00:24:50,320

i think there's a lot of good intuition

823

00:24:53,909 --> 00:24:52,320

and consistent intuition we've built up

824

00:24:55,990 --> 00:24:53,919

as a community of

825

00:24:57,110 --> 00:24:56,000

uh of exoplanet biosignatures

826
00:24:58,870 --> 00:24:57,120
researchers

827
00:25:00,149 --> 00:24:58,880
and and we we might all nod our heads

828
00:25:02,310 --> 00:25:00,159
and agree with each other but it'd be

829
00:25:04,870 --> 00:25:02,320
better if we had a way to quantify that

830
00:25:05,669 --> 00:25:04,880
consensus intuition and and test tessa

831
00:25:08,710 --> 00:25:05,679
fisher's work

832
00:25:10,549 --> 00:25:08,720
which which is about uh

833
00:25:12,230 --> 00:25:10,559
analyzing the complexity of the

834
00:25:13,430 --> 00:25:12,240
photochemical network in the atmosphere

835
00:25:15,669 --> 00:25:13,440
as a proxy

836
00:25:17,990 --> 00:25:15,679
for whether or not life is present there

837
00:25:19,990 --> 00:25:18,000
um is one way to do that and i think in

838
00:25:20,470 --> 00:25:20,000

an awesome way i think we need other i

839

00:25:23,350 --> 00:25:20,480

think we

840

00:25:25,190 --> 00:25:23,360

need to develop others because these

841

00:25:25,909 --> 00:25:25,200

quantified methods are really really

842

00:25:27,990 --> 00:25:25,919

important

843

00:25:29,669 --> 00:25:28,000

for for the eventual observation and our

844

00:25:31,190 --> 00:25:29,679

discussion thereof with the

845

00:25:32,789 --> 00:25:31,200

other scientists and with the general

846

00:25:34,310 --> 00:25:32,799

public

847

00:25:35,510 --> 00:25:34,320

and then the last thing so that the

848

00:25:36,230 --> 00:25:35,520

things i just mentioned are kind of at

849

00:25:37,669 --> 00:25:36,240

the top

850

00:25:39,990 --> 00:25:37,679

for the future i think we need more

851
00:25:41,830 --> 00:25:40,000
research into non-gaseous biosignatures

852
00:25:43,269 --> 00:25:41,840
um just because we've we've really

853
00:25:45,590 --> 00:25:43,279
focused on those in

854
00:25:46,870 --> 00:25:45,600
in in history the second thing is as i

855
00:25:48,630 --> 00:25:46,880
mentioned we need to quantify our

856
00:25:49,110 --> 00:25:48,640
intuition and come up with ways to do

857
00:25:50,630 --> 00:25:49,120
that

858
00:25:52,470 --> 00:25:50,640
and then the last thing is i think we

859
00:25:55,430 --> 00:25:52,480
need to look at

860
00:25:57,269 --> 00:25:55,440
earth science as and and specifically

861
00:25:57,669 --> 00:25:57,279
into climate change as a guide to how to

862
00:26:00,950 --> 00:25:57,679
be

863
00:26:03,909 --> 00:26:00,960

and i'm going to just take

864

00:26:05,190 --> 00:26:03,919

a minute here for my last slide to talk

865

00:26:06,710 --> 00:26:05,200

about that

866

00:26:09,029 --> 00:26:06,720

and this is in my opinion one of the

867

00:26:10,070 --> 00:26:09,039

most important figures or series of

868

00:26:12,470 --> 00:26:10,080

figures that that have

869

00:26:13,350 --> 00:26:12,480

has come out in the last 100 years of of

870

00:26:15,909 --> 00:26:13,360

research

871

00:26:16,789 --> 00:26:15,919

in the sciences and what this is is it's

872

00:26:18,470 --> 00:26:16,799

three plots

873

00:26:19,909 --> 00:26:18,480

one is i'm going to start with the black

874

00:26:20,950 --> 00:26:19,919

line the black line in each of these is

875

00:26:23,029 --> 00:26:20,960

for land

876

00:26:24,870 --> 00:26:23,039

ocean and land and ocean surface the

877

00:26:27,029 --> 00:26:24,880

black line is our planet's

878

00:26:28,390 --> 00:26:27,039

surface temperature history for the last

879

00:26:31,990 --> 00:26:28,400

hundred years or in the case of the

880

00:26:34,950 --> 00:26:32,000

ocean heat content for the last 50 or so

881

00:26:35,830 --> 00:26:34,960

the pink uh range is a is the range of

882

00:26:38,070 --> 00:26:35,840

model

883

00:26:39,110 --> 00:26:38,080

uh predictions of that temperature

884

00:26:40,710 --> 00:26:39,120

evolution

885

00:26:42,470 --> 00:26:40,720

which you can see is quite good and

886

00:26:44,230 --> 00:26:42,480

what's key about this pink is it

887

00:26:46,470 --> 00:26:44,240

includes everything we know

888

00:26:47,990 --> 00:26:46,480

about earth all the comp all the complex

889

00:26:50,630 --> 00:26:48,000

forcings on climate

890

00:26:53,110 --> 00:26:50,640

including the stellar variations the the

891

00:26:55,190 --> 00:26:53,120

volcanic forcings human emissions

892

00:26:57,190 --> 00:26:55,200

biological emissions that are not human

893

00:26:58,070 --> 00:26:57,200

induced everything is included in this

894

00:27:00,549 --> 00:26:58,080

pink chart

895

00:27:02,470 --> 00:27:00,559

or this this this pink line that's sort

896

00:27:03,110 --> 00:27:02,480

of the range of outcomes we get from the

897

00:27:04,710 --> 00:27:03,120

models

898

00:27:06,390 --> 00:27:04,720

and what's really good is it matches the

899

00:27:08,070 --> 00:27:06,400

temperature record really well

900

00:27:09,430 --> 00:27:08,080

well so what's up with the blue line why

901
00:27:11,669 --> 00:27:09,440
doesn't that match

902
00:27:13,909 --> 00:27:11,679
the answer to that question is that

903
00:27:15,830 --> 00:27:13,919
that's the same models where we've taken

904
00:27:18,070 --> 00:27:15,840
out the natural forcings

905
00:27:19,350 --> 00:27:18,080
and i think that's just first of all

906
00:27:21,430 --> 00:27:19,360
it's profound

907
00:27:23,029 --> 00:27:21,440
how well we can capture the increase in

908
00:27:24,470 --> 00:27:23,039
temperature over time

909
00:27:26,710 --> 00:27:24,480
when we include the anthropogenic

910
00:27:27,590 --> 00:27:26,720
forcings but how poorly we capture it

911
00:27:31,590 --> 00:27:27,600
when we don't

912
00:27:33,909 --> 00:27:31,600
that that a clean very clean a b result

913
00:27:36,549 --> 00:27:33,919

in the context of all the theory and

914

00:27:38,789 --> 00:27:36,559

complex interactions of earth's climate

915

00:27:39,590 --> 00:27:38,799

is just it's beautiful it's just a

916

00:27:41,909 --> 00:27:39,600

beautiful

917

00:27:42,630 --> 00:27:41,919

model experiment and to me it's one of

918

00:27:45,669 --> 00:27:42,640

the more

919

00:27:47,669 --> 00:27:45,679

convincing sets of evidence that climate

920

00:27:48,950 --> 00:27:47,679

change is not just real but caused by

921

00:27:50,870 --> 00:27:48,960

humans

922

00:27:52,870 --> 00:27:50,880

and i think with something that could be

923

00:27:54,789 --> 00:27:52,880

as contentious and controversial as the

924

00:27:57,990 --> 00:27:54,799

statement we are not alone

925

00:28:00,310 --> 00:27:58,000

in the context of context of something

926
00:28:02,070 --> 00:28:00,320
that is also complex because you're also

927
00:28:03,750 --> 00:28:02,080
talking about looking at one data set

928
00:28:06,470 --> 00:28:03,760
like a spectrum

929
00:28:07,510 --> 00:28:06,480
in in that results from a set of complex

930
00:28:10,149 --> 00:28:07,520
interactions between

931
00:28:11,750 --> 00:28:10,159
multiple systems at the surface of a of

932
00:28:13,269 --> 00:28:11,760
a ocean-bearing world

933
00:28:15,110 --> 00:28:13,279
and you want to know is that one

934
00:28:16,710 --> 00:28:15,120
spectrum or that's that

935
00:28:18,630 --> 00:28:16,720
that time varying spectrum whatever that

936
00:28:20,389 --> 00:28:18,640
that data set is you want to know is

937
00:28:22,950 --> 00:28:20,399
that caused by biology

938
00:28:24,149 --> 00:28:22,960

and i think like just as one of many

939

00:28:25,350 --> 00:28:24,159

examples we could take from climate

940

00:28:28,070 --> 00:28:25,360

science it would be

941

00:28:28,710 --> 00:28:28,080

super powerful if we had models like

942

00:28:31,269 --> 00:28:28,720

this

943

00:28:32,470 --> 00:28:31,279

that a captured the complexity of

944

00:28:35,510 --> 00:28:32,480

interactions

945

00:28:37,909 --> 00:28:35,520

in that habitable planet and b

946

00:28:40,630 --> 00:28:37,919

gave us sort of the ability to turn the

947

00:28:42,070 --> 00:28:40,640

biological fluxes the ecosystem fluxes

948

00:28:44,549 --> 00:28:42,080

at the global scale

949

00:28:45,430 --> 00:28:44,559

on and off so we could do this clean

950

00:28:47,029 --> 00:28:45,440

experiment

951
00:28:49,110 --> 00:28:47,039
where we say can we reproduce the data

952
00:28:50,310 --> 00:28:49,120
with biology and can we not reproduce it

953
00:28:52,950 --> 00:28:50,320
without the biology

954
00:28:53,750 --> 00:28:52,960
that kind of experiment was so critical

955
00:28:56,389 --> 00:28:53,760
to at least

956
00:28:57,350 --> 00:28:56,399
in my opinion to to our arguments and

957
00:29:00,070 --> 00:28:57,360
our understanding

958
00:29:00,789 --> 00:29:00,080
of attributing climate change to human

959
00:29:02,630 --> 00:29:00,799
activity

960
00:29:04,710 --> 00:29:02,640
and i think the same thing could be true

961
00:29:06,470 --> 00:29:04,720
if we can develop this kind of model

962
00:29:08,389 --> 00:29:06,480
for the future for for the exoplanet

963
00:29:10,870 --> 00:29:08,399

file signature search but that's just

964

00:29:11,909 --> 00:29:10,880

one example of the broader set of i

965

00:29:13,590 --> 00:29:11,919

think there's other things we could do

966

00:29:15,190 --> 00:29:13,600

with their model comparisons and

967

00:29:17,430 --> 00:29:15,200

the way that those folks use language

968

00:29:19,190 --> 00:29:17,440

and such i am well past time and

969

00:29:20,710 --> 00:29:19,200

apologies for taking up more

970

00:29:22,149 --> 00:29:20,720

of your time than i was supposed to i

971

00:29:23,909 --> 00:29:22,159

think i was supposed to come in at 25

972

00:29:25,269 --> 00:29:23,919

but i've been at 30 but i thank you so

973

00:29:26,950 --> 00:29:25,279

much for your time

974

00:29:28,630 --> 00:29:26,960

and i really appreciate it and i look

975

00:29:29,110 --> 00:29:28,640

forward to discussing this and other

