



ALIEN SULFUR CYCLES  
SULFATE HAZE & SO<sub>2</sub> GAS AS CONSTRAINTS  
ON SURFACE LIQUID WATER  
*KAITLYN LOFTUS*

1  
00:00:08,450 --> 00:00:06,760

[Music]

2  
00:00:10,520 --> 00:00:08,460

so thanks Laura

3  
00:00:13,549 --> 00:00:10,530

my name is Caitlin Loftus I'm a PhD

4  
00:00:17,179 --> 00:00:13,559

student at Harvard and today I go talk

5  
00:00:18,859 --> 00:00:17,189

to you about some work on trying to

6  
00:00:21,950 --> 00:00:18,869

constrain the presence of surface liquid

7  
00:00:24,710 --> 00:00:21,960

water via oxidized sulfur in the

8  
00:00:27,590 --> 00:00:24,720

atmosphere and this has been done with

9  
00:00:32,330 --> 00:00:27,600

my PhD advisor Robin Wordsworth as well

10  
00:00:36,619 --> 00:00:32,340

as Caroline Morley okay that's not

11  
00:00:39,080 --> 00:00:36,629

working okay so starting big picture one

12  
00:00:41,569 --> 00:00:39,090

of the big sparkly questions kind of

13  
00:00:45,680 --> 00:00:41,579

driving exoplanet science is a question

14

00:00:47,420 --> 00:00:45,690

of how common is life in the universe so

15

00:00:50,540 --> 00:00:47,430

very traditionally perhaps we have to

16

00:00:53,060 --> 00:00:50,550

rethink this a bit and secrets talk

17

00:00:54,680 --> 00:00:53,070

about this water paradox but we consider

18

00:00:56,420 --> 00:00:54,690

its surface liquid water pretty crucial

19

00:00:58,310 --> 00:00:56,430

for the development of life because of

20

00:00:59,959 --> 00:00:58,320

its kazmo chemical abundance and also

21

00:01:01,790 --> 00:00:59,969

because it's a really great solvent to

22

00:01:05,270 --> 00:01:01,800

get these kind of organic materials

23

00:01:06,889 --> 00:01:05,280

started so one way we can try to track

24

00:01:08,990 --> 00:01:06,899

tably try to think about how common is

25

00:01:11,330 --> 00:01:09,000

life in the universe is how common is

26  
00:01:12,950 --> 00:01:11,340  
surface of the water in the universe we

27  
00:01:15,950 --> 00:01:12,960  
want to answer this via observations

28  
00:01:20,080 --> 00:01:15,960  
because water distribution during

29  
00:01:22,160 --> 00:01:20,090  
planetary formation via models is a bit

30  
00:01:24,170 --> 00:01:22,170  
so we really want to constrain this

31  
00:01:25,640 --> 00:01:24,180  
observational e but first we kind of

32  
00:01:30,200 --> 00:01:25,650  
need to figure out how we can actually

33  
00:01:31,820 --> 00:01:30,210  
observe these EXO oceans so basically

34  
00:01:33,380 --> 00:01:31,830  
just from the phrase surface like a

35  
00:01:34,490 --> 00:01:33,390  
water if we look at these individual

36  
00:01:36,530 --> 00:01:34,500  
words we can put pretty basic

37  
00:01:38,840 --> 00:01:36,540  
constraints on where we could possibly

38  
00:01:40,160 --> 00:01:38,850

find surface water first we're talking

39

00:01:42,679 --> 00:01:40,170

about a surface so we want a rocky

40

00:01:44,810 --> 00:01:42,689

planet and second we want liquid water

41

00:01:47,139 --> 00:01:44,820

so that tells us about a temperature

42

00:01:51,050 --> 00:01:47,149

regime we expect the planet to be in

43

00:01:52,310 --> 00:01:51,060

based on stellar insulation so this is

44

00:01:54,050 --> 00:01:52,320

kind of the state of the art of

45

00:01:56,440 --> 00:01:54,060

observations right now what we can tell

46

00:02:00,530 --> 00:01:56,450

about the potential for liquid water

47

00:02:02,450 --> 00:02:00,540

looking farther to the future trying to

48

00:02:04,999 --> 00:02:02,460

actually detect service like a water is

49

00:02:07,010 --> 00:02:05,009

non-trivial we're gonna be getting our

50

00:02:09,770 --> 00:02:07,020

information from various forms of

51  
00:02:12,289 --> 00:02:09,780  
spectroscopy right now all of the method

52  
00:02:13,820 --> 00:02:12,299  
methods proposed for detecting liquid

53  
00:02:15,210 --> 00:02:13,830  
water have to do with the radiative

54  
00:02:17,130 --> 00:02:15,220  
properties

55  
00:02:18,630 --> 00:02:17,140  
these are theoretically observable but

56  
00:02:20,730 --> 00:02:18,640  
are going to require very far away

57  
00:02:22,440 --> 00:02:20,740  
instrumentation they have some false

58  
00:02:24,750 --> 00:02:22,450  
positive concerns and also they're not

59  
00:02:26,160 --> 00:02:24,760  
going to work for every planet so if we

60  
00:02:28,380 --> 00:02:26,170  
want to learn about liquid water we

61  
00:02:30,450 --> 00:02:28,390  
really need to develop some more methods

62  
00:02:32,340 --> 00:02:30,460  
to constrain its presence or absence and

63  
00:02:35,070 --> 00:02:32,350

today I'm going to discuss how we can

64

00:02:40,230 --> 00:02:35,080

use the sulfur cycle to propose to new

65

00:02:42,810 --> 00:02:40,240

observational methods so detecting

66

00:02:45,480 --> 00:02:42,820

liquid water via liquid water radiative

67

00:02:46,710 --> 00:02:45,490

properties makes a lot of sense now

68

00:02:48,630 --> 00:02:46,720

we're trying to throw in the sulfur

69

00:02:50,280 --> 00:02:48,640

cycle there's actually two really good

70

00:02:52,140 --> 00:02:50,290

reasons why we want to use the sulfur

71

00:02:56,160 --> 00:02:52,150

cycle to probe the presence or absence

72

00:02:57,870 --> 00:02:56,170

of oceans the first is that atmospheric

73

00:02:58,950 --> 00:02:57,880

features of the silver atmospheric

74

00:03:01,320 --> 00:02:58,960

features of the sulfur cycle are

75

00:03:03,720 --> 00:03:01,330

observable and the second which is kind

76

00:03:06,380 --> 00:03:03,730

of physically how we can tie these two

77

00:03:09,150 --> 00:03:06,390

ideas together is via aqueous chemistry

78

00:03:10,260 --> 00:03:09,160

so first I'm gonna talk about very

79

00:03:12,420 --> 00:03:10,270

briefly because I'm sure it doesn't

80

00:03:13,890 --> 00:03:12,430

surprise the majority of people in this

81

00:03:16,740 --> 00:03:13,900

room that we can observe these kind of

82

00:03:19,940 --> 00:03:16,750

we can observe the sulfur cycle and the

83

00:03:23,490 --> 00:03:19,950

atmosphere we can think about how

84

00:03:26,730 --> 00:03:23,500

sulfate haze is very clearly distinct

85

00:03:28,650 --> 00:03:26,740

from clear atmosphere so here we're

86

00:03:31,650 --> 00:03:28,660

gonna look at transmission spectra and

87

00:03:35,640 --> 00:03:31,660

increase as the blue gets darker the

88

00:03:38,910 --> 00:03:35,650

optical depth of the haze present and as

89

00:03:40,590 --> 00:03:38,920

we kind of know and love or hate we see

90

00:03:42,960 --> 00:03:40,600

this kind of distinct flattening of the

91

00:03:45,120 --> 00:03:42,970

spectra very broadly and these

92

00:03:49,640 --> 00:03:45,130

simulations were done by Carol and

93

00:03:51,750 --> 00:03:49,650

Morley additionally we can think about

94

00:03:54,350 --> 00:03:51,760

atmospheric gases and how they affect

95

00:03:57,420 --> 00:03:54,360

spectra via specific absorption lines

96

00:04:00,000 --> 00:03:57,430

so2 it's also possible to detect as we

97

00:04:02,390 --> 00:04:00,010

start adding it in high quantities or

98

00:04:05,340 --> 00:04:02,400

high trace quantities into an atmosphere

99

00:04:07,890 --> 00:04:05,350

so if we can detect it for now we need

100

00:04:09,660 --> 00:04:07,900

to couple it to the amount of water we

101  
00:04:11,270 --> 00:04:09,670  
have present and we can do that via

102  
00:04:17,430 --> 00:04:11,280  
aqueous chemistry

103  
00:04:21,150 --> 00:04:17,440  
so first so<sub>2</sub> is dissolving into water in

104  
00:04:23,040 --> 00:04:21,160  
an amount that's proportional directly

105  
00:04:25,980 --> 00:04:23,050  
proportional to the partial pressure of

106  
00:04:28,830 --> 00:04:25,990  
so<sub>2</sub> at the surface that will give us a

107  
00:04:31,470 --> 00:04:28,840  
concentration of aqueous so<sub>2</sub>

108  
00:04:33,720 --> 00:04:31,480  
so that's telling us in a in a unit of

109  
00:04:36,000 --> 00:04:33,730  
water how much so<sub>2</sub> is present as we

110  
00:04:37,980 --> 00:04:36,010  
scale up that amount of water and

111  
00:04:39,510 --> 00:04:37,990  
maintain the same concentration that

112  
00:04:42,930 --> 00:04:39,520  
requires we have more and more sulfur

113  
00:04:45,300 --> 00:04:42,940

present in the ocean additionally we

114

00:04:48,720 --> 00:04:45,310

have further disproportion Asian

115

00:04:51,300 --> 00:04:48,730

reactions of that aqueous so<sub>2</sub> with water

116

00:04:53,040 --> 00:04:51,310

to get some other sulfur bearing species

117

00:04:55,440 --> 00:04:53,050

that are all in equilibrium with that

118

00:04:57,240 --> 00:04:55,450

aqueous so<sub>2</sub> which is the only sulfur

119

00:05:01,170 --> 00:04:57,250

species that's an equilibrium with the

120

00:05:02,370 --> 00:05:01,180

atmosphere these kind of other sulfur

121

00:05:04,980 --> 00:05:02,380

bearing species that I've highlight an

122

00:05:08,190 --> 00:05:04,990

orange I'm gonna be referring to just

123

00:05:11,879 --> 00:05:08,200

kind of collectively as s<sub>4</sub> sulfur in the

124

00:05:13,320 --> 00:05:11,889

fourth oxidation state or sulfite what's

125

00:05:16,020 --> 00:05:13,330

kind of key here is that you can see

126

00:05:17,580 --> 00:05:16,030

this H<sup>+</sup> ion and that's gonna make this

127

00:05:22,020 --> 00:05:17,590

whole system very dependent on the pH of

128

00:05:24,540 --> 00:05:22,030

the water so if we want to see how

129

00:05:26,490 --> 00:05:24,550

sulfur is stored in the ocean over the

130

00:05:29,610 --> 00:05:26,500

atmosphere we can put some numbers

131

00:05:32,190 --> 00:05:29,620

behind these reactions and equations and

132

00:05:36,510 --> 00:05:32,200

plot out so on the on the bottom panel I

133

00:05:38,310 --> 00:05:36,520

have pH and then on the y-axis log we

134

00:05:42,840 --> 00:05:38,320

have the amount of atmospheric sulfur

135

00:05:47,070 --> 00:05:42,850

and so<sub>2</sub> over the amount of sulfur in the

136

00:05:50,070 --> 00:05:47,080

ocean that those s<sub>4</sub> or aqueous so<sub>2</sub>

137

00:05:51,510 --> 00:05:50,080

products and then in blue we're going to

138

00:05:57,510 --> 00:05:51,520

be varying the amount of liquid water

139

00:06:00,210 --> 00:05:57,520

present and as we can see as you as you

140

00:06:01,860 --> 00:06:00,220

add more liquid water and the spa's the

141

00:06:04,500 --> 00:06:01,870

smallest line here is just a thousandth

142

00:06:07,980 --> 00:06:04,510

of an earth some ount of water in the

143

00:06:10,020 --> 00:06:07,990

ocean and go to kind of more realistic

144

00:06:11,790 --> 00:06:10,030

neutral pH as you're driving the amount

145

00:06:14,670 --> 00:06:11,800

of sulfur that's in the atmosphere

146

00:06:17,760 --> 00:06:14,680

compared to the ocean down to very small

147

00:06:19,860 --> 00:06:17,770

quantities so down to trillions billions

148

00:06:23,400 --> 00:06:19,870

those kinds of numbers that means if we

149

00:06:24,960 --> 00:06:23,410

want to get if we want to get sulfur

150

00:06:27,480 --> 00:06:24,970

into the atmosphere in the presence of

151

00:06:29,460 --> 00:06:27,490

an ocean we have to have a lot more

152

00:06:30,360 --> 00:06:29,470

sulfur lurking in the ocean versus what

153

00:06:33,090 --> 00:06:30,370

we're actually observing in the

154

00:06:36,360 --> 00:06:33,100

atmosphere and kind of to further

155

00:06:38,040 --> 00:06:36,370

emphasize this inability to get sulfur

156

00:06:39,440 --> 00:06:38,050

into the atmosphere in the presence of

157

00:06:41,690 --> 00:06:39,450

water

158

00:06:43,700 --> 00:06:41,700

as we're kind of pumping all the sulfur

159

00:06:47,630 --> 00:06:43,710

into the ocean because of this aqueous

160

00:06:50,390 --> 00:06:47,640

chemistry these  $S_4$  or aqueous  $SO_2$

161

00:06:51,770 --> 00:06:50,400

products are being destroyed in the

162

00:06:56,240 --> 00:06:51,780

water because they're thermodynamically

163

00:06:58,940 --> 00:06:56,250

unstable so that means that we're kind

164

00:07:03,520 --> 00:06:58,950

of limited to having so2 to make those

165

00:07:05,840 --> 00:07:03,530

observable sulfate aerosols and so2 gas

166

00:07:09,020 --> 00:07:05,850

all that sulfur has to be supplied by

167

00:07:10,220 --> 00:07:09,030

recent outgassing and so in ocean and

168

00:07:11,780 --> 00:07:10,230

that is fundamentally limiting the

169

00:07:15,380 --> 00:07:11,790

buildup of so2 that's needed for

170

00:07:17,270 --> 00:07:15,390

fundamental atmospheric sulfur so now

171

00:07:18,890 --> 00:07:17,280

what we want to do is kind of put

172

00:07:20,930 --> 00:07:18,900

forward this hypothesis that if we can

173

00:07:22,760 --> 00:07:20,940

observe us o2 or sulfate haze

174

00:07:24,590 --> 00:07:22,770

we don't have an ocean or a large

175

00:07:26,600 --> 00:07:24,600

significant quantity of surface of the

176

00:07:28,520 --> 00:07:26,610

water present on that planet

177

00:07:30,160 --> 00:07:28,530

of course anecdotally in the solar

178

00:07:32,810 --> 00:07:30,170

system we know this is true with Venus

179

00:07:35,240 --> 00:07:32,820

but one example does not a very

180

00:07:37,100 --> 00:07:35,250

convincing Theory make so we test this

181

00:07:41,240 --> 00:07:37,110

via quantitative model of the sulfur

182

00:07:42,530 --> 00:07:41,250

cycle so some of you who think about

183

00:07:44,300 --> 00:07:42,540

sulfur a lot might have noticed that

184

00:07:47,330 --> 00:07:44,310

I've kind of been ignoring a lot of

185

00:07:49,490 --> 00:07:47,340

sulfur species and that's because sulfur

186

00:07:52,100 --> 00:07:49,500

can occupy a ton of different redox

187

00:07:54,950 --> 00:07:52,110

States and so they kind of tend to group

188

00:07:57,080 --> 00:07:54,960

collectively what's present on a planet

189

00:07:59,290 --> 00:07:57,090

based on the red ox state right now

190

00:08:01,910 --> 00:07:59,300

we're only interested in the oxidized

191

00:08:04,070 --> 00:08:01,920

surface so we're only looking at a

192

00:08:09,590 --> 00:08:04,080

system that has sulfate aerosols so2 gas

193

00:08:11,330 --> 00:08:09,600

and leads us for aqueous products then

194

00:08:13,670 --> 00:08:11,340

how we kind of set up our model as we

195

00:08:16,130 --> 00:08:13,680

say okay in order to have an

196

00:08:17,960 --> 00:08:16,140

observational sulfur detection we have

197

00:08:20,060 --> 00:08:17,970

to have a critical amount of sulfur in

198

00:08:22,250 --> 00:08:20,070

the atmosphere for that observation we

199

00:08:25,610 --> 00:08:22,260

track that down to how much water or how

200

00:08:27,410 --> 00:08:25,620

much sulfur needs to be present both in

201  
00:08:30,530 --> 00:08:27,420  
the atmosphere and the assumed amount of

202  
00:08:32,270 --> 00:08:30,540  
water present to say this is the total

203  
00:08:35,810 --> 00:08:32,280  
amount of sulfur in the atmosphere ocean

204  
00:08:38,150 --> 00:08:35,820  
system that we need to see sulfur to

205  
00:08:39,680 --> 00:08:38,160  
observe that sulfur and then we need to

206  
00:08:40,940 --> 00:08:39,690  
say that this amount around servation

207  
00:08:43,190 --> 00:08:40,950  
needs to be less than our expected

208  
00:08:45,770 --> 00:08:43,200  
amount of sulfur which we can get very

209  
00:08:48,680 --> 00:08:45,780  
easily from an assumed outgassing rate

210  
00:08:50,900 --> 00:08:48,690  
of sulfur and an assumed decay timescale

211  
00:08:52,610 --> 00:08:50,910  
of sulfur it should make you kind of

212  
00:08:53,860 --> 00:08:52,620  
nervous and I just kind of said the word

213  
00:08:55,240 --> 00:08:53,870

assumed

214

00:08:56,910 --> 00:08:55,250

that's because a lot of elements of the

215

00:09:00,610 --> 00:08:56,920

system have very very large

216

00:09:03,640 --> 00:09:00,620

uncertainties and we try to do our best

217

00:09:08,380 --> 00:09:03,650

to account for the very many ways a

218

00:09:11,500 --> 00:09:08,390

planetary system could could could could

219

00:09:13,600 --> 00:09:11,510

develop a sulfur cycle so first kind of

220

00:09:16,150 --> 00:09:13,610

a really big problem is that while it's

221

00:09:18,010 --> 00:09:16,160

very robustly demonstrated that these s4

222

00:09:21,070 --> 00:09:18,020

silver products are thermodynamically

223

00:09:25,210 --> 00:09:21,080

unstable in water we don't really have a

224

00:09:28,750 --> 00:09:25,220

good idea of either the kinetics or a

225

00:09:32,230 --> 00:09:28,760

lot of times the mechanisms for this s4

226

00:09:35,020 --> 00:09:32,240

decay so in the modern earth ocean this

227

00:09:37,870 --> 00:09:35,030

decay happens basically so fast that you

228

00:09:41,440 --> 00:09:37,880

can't measure it but as you go to more

229

00:09:44,820 --> 00:09:41,450

limited oxygen regimes were a bit less

230

00:09:47,470 --> 00:09:44,830

sure about how fast this reaction occurs

231

00:09:50,860 --> 00:09:47,480

so in order to kind of couch for that

232

00:09:52,390 --> 00:09:50,870

because that's a huge part of how we're

233

00:09:55,690 --> 00:09:52,400

doing these the calculations of what

234

00:09:57,730 --> 00:09:55,700

some silver you can observe we kind of

235

00:10:01,810 --> 00:09:57,740

put all our results in terms of this

236

00:10:04,030 --> 00:10:01,820

decay timescale and we calculate that in

237

00:10:05,890 --> 00:10:04,040

terms of our ocean parameters which

238

00:10:08,260 --> 00:10:05,900

which are pH because of how sensitive

239

00:10:11,080 --> 00:10:08,270

the system is the pH of the ocean and

240

00:10:12,970 --> 00:10:11,090

also the size of the ocean and we're

241

00:10:15,070 --> 00:10:12,980

getting that decay timescale such that

242

00:10:16,660 --> 00:10:15,080

we can have the condition here that are

243

00:10:18,070 --> 00:10:16,670

there are critical amount of silver for

244

00:10:21,880 --> 00:10:18,080

observation as people which are expected

245

00:10:23,590 --> 00:10:21,890

amount of sulfur and then other key but

246

00:10:27,460 --> 00:10:23,600

poorly constrained model parameters that

247

00:10:29,950 --> 00:10:27,470

we have inner system are set first kind

248

00:10:32,320 --> 00:10:29,960

of realistically or our best guess is

249

00:10:35,830 --> 00:10:32,330

right now from kind of Earth Venus

250

00:10:37,300 --> 00:10:35,840

analogs and then second we do runs with

251

00:10:38,920 --> 00:10:37,310

physically limited scenarios so

252

00:10:41,110 --> 00:10:38,930

basically we say we look at each

253

00:10:44,440 --> 00:10:41,120

parameter individually and set that

254

00:10:46,570 --> 00:10:44,450

parameter to the to the value that will

255

00:10:48,310 --> 00:10:46,580

make it most hard to prove our

256

00:10:51,780 --> 00:10:48,320

hypothesis so will most encourage the

257

00:10:54,070 --> 00:10:51,790

build-up of sulfur in the atmosphere

258

00:10:56,320 --> 00:10:54,080

okay so now we can start looking at the

259

00:11:00,250 --> 00:10:56,330

results so we're gonna have contour

260

00:11:02,620 --> 00:11:00,260

plots and our x axis here is pH our Y

261

00:11:04,549 --> 00:11:02,630

axis we have two options for thinking

262

00:11:07,159 --> 00:11:04,559

about the size of these oceans

263

00:11:10,039 --> 00:11:07,169

first we have just in terms of number of

264

00:11:12,499 --> 00:11:10,049

Earth oceans and this isn't log and then

265

00:11:14,419 --> 00:11:12,509

we also have a global equivalent ocean

266

00:11:15,739 --> 00:11:14,429

layer in meters just because I think

267

00:11:17,379 --> 00:11:15,749

that's kind of an easier way sometimes

268

00:11:21,829 --> 00:11:17,389

to think about the quantity of water

269

00:11:23,779 --> 00:11:21,839

involved next we kind of put this box of

270

00:11:26,029 --> 00:11:23,789

around what our kind of our ocean

271

00:11:30,139 --> 00:11:26,039

parameters of interest they kind of say

272

00:11:31,999 --> 00:11:30,149

if you have less than a thousandth of an

273

00:11:34,279 --> 00:11:32,009

earth ocean we're kind of getting it's a

274

00:11:35,869 --> 00:11:34,289

regime where we're not really willing to

275

00:11:39,919 --> 00:11:35,879

call that significant liquid water

276  
00:11:42,049 --> 00:11:39,929  
anymore we also set upper limit of kind

277  
00:11:46,279 --> 00:11:42,059  
of PHS we we think are reasonable to

278  
00:11:48,699 --> 00:11:46,289  
occur because at six basically just

279  
00:11:51,439 --> 00:11:48,709  
because of how water rock interactions

280  
00:11:53,899 --> 00:11:51,449  
we would expect to buffer the pH to

281  
00:11:55,849 --> 00:11:53,909  
higher values but of course we plot the

282  
00:11:57,769 --> 00:11:55,859  
rest of of the parameters you have

283  
00:12:01,849 --> 00:11:57,779  
interest just so if you don't trust our

284  
00:12:03,169 --> 00:12:01,859  
box you can see the rest next the we

285  
00:12:04,729 --> 00:12:03,179  
have the blooming of like what we're

286  
00:12:07,579 --> 00:12:04,739  
contouring in color

287  
00:12:10,809 --> 00:12:07,589  
and this is the log of the critical

288  
00:12:14,749 --> 00:12:10,819

decay timescale of these s four products

289

00:12:17,359 --> 00:12:14,759

and I'll note this is this is a log and

290

00:12:21,169 --> 00:12:17,369

this is in in log years so at the very

291

00:12:22,669 --> 00:12:21,179

end of of this this light blue it's

292

00:12:24,619 --> 00:12:22,679

getting to ten to the ten years so we're

293

00:12:27,499 --> 00:12:24,629

getting to the timescale of the length

294

00:12:29,210 --> 00:12:27,509

of the universe and we kind of divided

295

00:12:32,809 --> 00:12:29,220

between orange and blue saying or

296

00:12:35,299 --> 00:12:32,819

interest where we kind of are saying

297

00:12:37,429 --> 00:12:35,309

okay this is kind of a reasonable decay

298

00:12:39,259 --> 00:12:37,439

time scale of these s4 products from

299

00:12:41,509 --> 00:12:39,269

what we know right now about these

300

00:12:43,849 --> 00:12:41,519

reactions hope they will be able to get

301  
00:12:45,499 --> 00:12:43,859  
better experimental data to constrain

302  
00:12:47,089 --> 00:12:45,509  
this a little better as we got to

303  
00:12:49,189 --> 00:12:47,099  
lighter and lighter blue on the other

304  
00:12:51,559 --> 00:12:49,199  
side we're saying becomes less and less

305  
00:12:54,710 --> 00:12:51,569  
feasible or sober to build up to an

306  
00:12:58,129 --> 00:12:54,720  
observable letter level and then finally

307  
00:13:01,639 --> 00:12:58,139  
kind of mark a - grade point at where we

308  
00:13:04,429 --> 00:13:01,649  
see pH equals 6 and this decay timescale

309  
00:13:06,469 --> 00:13:04,439  
at kind of what we pick as this white

310  
00:13:08,629 --> 00:13:06,479  
line here at a tenth of the year to give

311  
00:13:12,589 --> 00:13:08,639  
a kind of a baseline of what we could

312  
00:13:15,049 --> 00:13:12,599  
say I'm a maximum ocean size would be so

313  
00:13:17,570 --> 00:13:15,059

first looking at observable so2 for our

314

00:13:21,560 --> 00:13:17,580

realistic model parameters

315

00:13:23,930 --> 00:13:21,570

you need less than three microns Gogol

316

00:13:27,740 --> 00:13:23,940

equivalent ocean layer in order to start

317

00:13:29,840 --> 00:13:27,750

seeing observable so2 with these

318

00:13:31,490 --> 00:13:29,850

realistic parameters for contacts we

319

00:13:35,300 --> 00:13:31,500

have about a global current layer of

320

00:13:39,140 --> 00:13:35,310

three kilometers on earth today we can

321

00:13:41,300 --> 00:13:39,150

push into our very limiting or Lemmy

322

00:13:44,030 --> 00:13:41,310

parameter so basically basically the

323

00:13:47,260 --> 00:13:44,040

system that can help this observable a

324

00:13:49,460 --> 00:13:47,270

so to build up as much as possible

325

00:13:51,880 --> 00:13:49,470

obviously the system is a bit less

326

00:13:54,230 --> 00:13:51,890

favorable but we're still very clearly

327

00:13:59,080 --> 00:13:54,240

the are regime of interest is still very

328

00:14:01,850 --> 00:13:59,090

clearly in kind of many many years of

329

00:14:05,810 --> 00:14:01,860

decay before it starts becoming feasible

330

00:14:08,630 --> 00:14:05,820

that we would get observable so2 with

331

00:14:11,960 --> 00:14:08,640

those ocean parameters next we can look

332

00:14:15,290 --> 00:14:11,970

at sulphate Hayes's so for our realistic

333

00:14:18,710 --> 00:14:15,300

model parameters we see that to get an

334

00:14:21,530 --> 00:14:18,720

observable sulfate haze layer would

335

00:14:23,660 --> 00:14:21,540

require an ocean of less than 70 microns

336

00:14:26,240 --> 00:14:23,670

global equivalent layer again this is

337

00:14:29,060 --> 00:14:26,250

really small and you can note that kind

338

00:14:32,000 --> 00:14:29,070

of at our ten to the negative three

339

00:14:35,329 --> 00:14:32,010

ocean mass threshold that whole regime

340

00:14:37,940 --> 00:14:35,339

is is still blue and finally we can look

341

00:14:41,630 --> 00:14:37,950

at our limiting parameters for sulfate

342

00:14:44,860 --> 00:14:41,640

aerosols this is a a bit less favourable

343

00:14:47,660 --> 00:14:44,870

because we're basically inconsistently

344

00:14:50,360 --> 00:14:47,670

studying every single parameter to be

345

00:14:52,220 --> 00:14:50,370

limiting when really that wouldn't

346

00:14:55,040 --> 00:14:52,230

really be physically consistent we still

347

00:14:56,360 --> 00:14:55,050

find that for our regime of interest we

348

00:14:58,790 --> 00:14:56,370

still see that as like that's

349

00:15:00,590 --> 00:14:58,800

predominantly blue and still is less

350

00:15:03,770 --> 00:15:00,600

than 5 meters both will clip on layer of

351

00:15:05,960 --> 00:15:03,780

water so to kind of wrap up with what

352

00:15:07,910 --> 00:15:05,970

I've just shown via quantitative model

353

00:15:10,610 --> 00:15:07,920

of the solar cycle either observable

354

00:15:12,800 --> 00:15:10,620

sulfate haze layers nor observable

355

00:15:14,980 --> 00:15:12,810

levels of so2 are likely compatible with

356

00:15:17,360 --> 00:15:14,990

surface significant service liquid water

357

00:15:19,730 --> 00:15:17,370

this incompatibility seems to persist

358

00:15:22,730 --> 00:15:19,740

even in the most extreme conditions to

359

00:15:24,590 --> 00:15:22,740

promote observable sulphur and therefore

360

00:15:26,780 --> 00:15:24,600

we propose the observational detection

361

00:15:29,690 --> 00:15:26,790

of sulfate haze and as such a gas as two

362

00:15:31,130 --> 00:15:29,700

new constraints on surface liquid water

363

00:15:32,840 --> 00:15:31,140

and we've submitted the paper and it's

364

00:15:34,100 --> 00:15:32,850

up on archive here you want to check it

365

00:15:45,440 --> 00:15:34,110

out and with that I can take any

366

00:15:49,519 --> 00:15:45,450

questions Thank You Caitlin let's start

367

00:15:51,199 --> 00:15:49,529

with Sara over the wall didn't realize I

368

00:15:52,310 --> 00:15:51,209

was gonna ask questions in the session

369

00:15:52,610 --> 00:15:52,320

otherwise I would have that somewhere

370

00:15:54,710 --> 00:15:52,620

else

371

00:15:55,759 --> 00:15:54,720

um this is really interesting I'm just

372

00:15:57,319 --> 00:15:55,769

wondering if you could tell us a little

373

00:15:59,120 --> 00:15:57,329

bit more about how you're actually

374

00:16:00,470 --> 00:15:59,130

deciding like when there's haze and when

375

00:16:03,139 --> 00:16:00,480

there's not haze under certain

376

00:16:08,350 --> 00:16:05,960

so basically we're making a really

377

00:16:10,819 --> 00:16:08,360

really simple model all we're saying is

378

00:16:13,730 --> 00:16:10,829

we're kind of testing via transit

379

00:16:15,620 --> 00:16:13,740

spectra what's an observable optical

380

00:16:17,960 --> 00:16:15,630

depth of haze when can we start to see a

381

00:16:20,449 --> 00:16:17,970

significant difference in our transit

382

00:16:23,300 --> 00:16:20,459

spectra by just increasing optical depth

383

00:16:24,949 --> 00:16:23,310

and then trying to setting that as how

384

00:16:26,660 --> 00:16:24,959

much haze is present in the atmosphere

385

00:16:29,150 --> 00:16:26,670

to be observable and kind of working

386

00:16:34,189 --> 00:16:29,160

backwards from that so it's entirely

387

00:16:35,810 --> 00:16:34,199

driven by kind of a guess at kind of the

388

00:16:45,800 --> 00:16:35,820

amount of hazy depressing the atmosphere

389

00:16:48,100 --> 00:16:45,810

to observe this atom I was wondering if

390

00:16:50,569 --> 00:16:48,110

you'd comment slightly more on Venus the

391

00:16:52,130 --> 00:16:50,579

units of our remember numbers correctly

392

00:16:53,990 --> 00:16:52,140

it's got sort of were 20 parts per

393

00:16:56,560 --> 00:16:54,000

million water in the atmosphere I'm not

394

00:17:00,290 --> 00:16:56,570

sure if your constraint on the 70 micro

395

00:17:02,480 --> 00:17:00,300

meters of precipitable would include

396

00:17:04,280 --> 00:17:02,490

yeah would include if that includes gas

397

00:17:06,049 --> 00:17:04,290

than beams yeah so I shouldn't I should

398

00:17:07,610 --> 00:17:06,059

clarify that doesn't include any gas at

399

00:17:08,780 --> 00:17:07,620

all that's just liquid water yeah yeah

400

00:17:11,179 --> 00:17:08,790

because Venus is actually quite a bit

401  
00:17:13,100 --> 00:17:11,189  
above that if you do yeah yeah yeah yeah

402  
00:17:14,720 --> 00:17:13,110  
you actually you need to have liquid you

403  
00:17:16,159 --> 00:17:14,730  
need to have I should say you need to

404  
00:17:17,390 --> 00:17:16,169  
have water vapor present in the

405  
00:17:27,919 --> 00:17:17,400  
atmosphere in order to start making

406  
00:17:32,380 --> 00:17:27,929  
those soul phases RJ hi RJ Oxford um

407  
00:17:34,820 --> 00:17:32,390  
I've read a paper - that argued that

408  
00:17:37,549 --> 00:17:34,830  
there you might be able to like support

409  
00:17:42,049 --> 00:17:37,559  
a a negative geochemical negative

410  
00:17:43,490 --> 00:17:42,059  
feedback on early Mars with sulphate so2

411  
00:17:44,690 --> 00:17:43,500  
as a greenhouse gas but then there's

412  
00:17:47,450 --> 00:17:44,700  
other paper than argue it's infeasible

413  
00:17:50,660 --> 00:17:47,460

because of the haze formation but this

414

00:17:52,850 --> 00:17:50,670

kind of just like kill that down the

415

00:17:56,300 --> 00:17:52,860

water I think it makes it really

416

00:17:58,970 --> 00:17:56,310

difficult if you have liquid water to

417

00:18:01,790 --> 00:17:58,980

build up a pre Schabel amounts of so<sub>2</sub>

418

00:18:04,460 --> 00:18:01,800

for a long period of time all of this is

419

00:18:05,510 --> 00:18:04,470

assuming equilibrium conditions so just

420

00:18:08,050 --> 00:18:05,520

like on earth and we have like very

421

00:18:11,240 --> 00:18:08,060

large volcanic eruptions and you inject

422

00:18:12,890 --> 00:18:11,250

so<sub>2</sub> way up into the stratosphere there's

423

00:18:15,740 --> 00:18:12,900

a period of time where you can form kind

424

00:18:17,660 --> 00:18:15,750

of optically significant cases but it

425

00:18:22,400 --> 00:18:17,670

doesn't take very long to get back into

426

00:18:29,360 --> 00:18:22,410

equi Librium I think Daniel have the

427

00:18:33,640 --> 00:18:29,370

last question very naive question but is

428

00:18:38,510 --> 00:18:33,650

there sulphur on Mars today that we see

429

00:18:41,110 --> 00:18:38,520

yes we see a lot of sulphur in the in

430

00:18:43,730 --> 00:18:41,120

the minerals on the surface at least

431

00:18:45,290 --> 00:18:43,740

lucky looking from orbiters looking at

432

00:18:46,250 --> 00:18:45,300

subject rasca P but no one's really sure

433

00:18:50,120 --> 00:18:46,260

how they got there

434

00:18:53,090 --> 00:18:50,130

so is Mars than like another data point

435

00:18:54,800 --> 00:18:53,100

besides Venus that favours this so I

436

00:18:56,630 --> 00:18:54,810

guess I guess I should clarify the

437

00:18:58,940 --> 00:18:56,640

mechanism works in the sense of if you

438

00:19:00,530 --> 00:18:58,950

observe sulfur you can say that there's

439

00:19:02,120 --> 00:19:00,540

probably not for you observed these

440

00:19:04,460 --> 00:19:02,130

atmospheric sulfur you can say there's

441

00:19:05,870 --> 00:19:04,470

probably not liquid water significant

442

00:19:07,160 --> 00:19:05,880

quantities have liquid water present it

443

00:19:09,950 --> 00:19:07,170

doesn't go the other way and say if you

444

00:19:12,290 --> 00:19:09,960

don't observe sulfur that there is water

445

00:19:16,880 --> 00:19:12,300

present liquid water present if I

446

00:19:18,890 --> 00:19:16,890

clarifies all right let's think Caitlin