



PHOTOCHEMICAL HAZES  
*SARAH HORST*

1  
00:00:12,370 --> 00:00:09,820  
I had the pleasure of talking about

2  
00:00:15,249 --> 00:00:12,380  
Hayes's at the last exit climbs and for

3  
00:00:16,960 --> 00:00:15,259  
those of you who were there I said most

4  
00:00:19,420 --> 00:00:16,970  
of the time just talking about kind of

5  
00:00:21,130 --> 00:00:19,430  
general information about how Hayes

6  
00:00:22,380 --> 00:00:21,140  
pricks in about how we think about Hayes

7  
00:00:25,479 --> 00:00:22,390  
and some of the lessons we've learned

8  
00:00:27,190 --> 00:00:25,489  
from the earth community in part that's

9  
00:00:30,130 --> 00:00:27,200  
because at the time there hadn't really

10  
00:00:32,139 --> 00:00:30,140  
been a lot of work done on trying to

11  
00:00:34,000 --> 00:00:32,149  
understand Hayes and exoplanet

12  
00:00:35,260 --> 00:00:34,010  
atmospheres and I think I ended that

13  
00:00:37,870 --> 00:00:35,270

talk when I went back and looked at my

14

00:00:39,460 --> 00:00:37,880

slides with um this is very like

15

00:00:40,960 --> 00:00:39,470

optimistic if we get these proposals

16

00:00:41,800 --> 00:00:40,970

funded we're actually going to do some

17

00:00:43,870 --> 00:00:41,810

work

18

00:00:45,850 --> 00:00:43,880

we got the proposals funded we did the

19

00:00:47,440 --> 00:00:45,860

work and now I found myself suddenly

20

00:00:50,560 --> 00:00:47,450

trying to figure out how to talk about

21

00:00:52,330 --> 00:00:50,570

all of that in the time allotted so

22

00:00:54,340 --> 00:00:52,340

things have changed quite a bit since

23

00:00:56,200 --> 00:00:54,350

the last Expo climbs I know you all are

24

00:00:58,750 --> 00:00:56,210

familiar with how fast-paced this field

25

00:01:01,330 --> 00:00:58,760

is but I have a lot to tell you about

26

00:01:04,479 --> 00:01:01,340

today first I just want to start off

27

00:01:06,010 --> 00:01:04,489

quickly reminding maybe everybody why we

28

00:01:08,260 --> 00:01:06,020

care about Hayes we've heard it come up

29

00:01:09,880 --> 00:01:08,270

a little bit already today and I'm gonna

30

00:01:11,410 --> 00:01:09,890

use the same definition that everyone

31

00:01:12,820 --> 00:01:11,420

has been using today which is when I'm

32

00:01:14,920 --> 00:01:12,830

talking about Hayes I'm talking about

33

00:01:18,399 --> 00:01:14,930

particles produced by photochemistry

34

00:01:19,719 --> 00:01:18,409

I'm not talking about cloud so we care

35

00:01:21,370 --> 00:01:19,729

about Hayes for lots of reasons in

36

00:01:23,469 --> 00:01:21,380

planetary atmospheres I think the one

37

00:01:25,210 --> 00:01:23,479

that often comes up in this crowd is

38

00:01:26,649 --> 00:01:25,220

that it's signal is present and remote

39

00:01:27,580 --> 00:01:26,659

sensing observations sometimes

40

00:01:29,500 --> 00:01:27,590

frustratingly

41

00:01:31,390 --> 00:01:29,510

but I'm hopeful as Caroline mentioned

42

00:01:33,640 --> 00:01:31,400

this morning that we can start thinking

43

00:01:35,230 --> 00:01:33,650

about these particles as information

44

00:01:36,280 --> 00:01:35,240

rather than frustration that are going

45

00:01:39,310 --> 00:01:36,290

to help us figure out how these

46

00:01:40,810 --> 00:01:39,320

atmospheres work we know that they

47

00:01:42,460 --> 00:01:40,820

affect the radiation budget of the

48

00:01:44,109 --> 00:01:42,470

atmosphere and also the surface if the

49

00:01:45,730 --> 00:01:44,119

planet has a surface because particles

50

00:01:49,929 --> 00:01:45,740

interact with light differently than

51  
00:01:51,700 --> 00:01:49,939  
gases do if we have a surface it's also

52  
00:01:53,560 --> 00:01:51,710  
possible that these particles could be

53  
00:01:55,000 --> 00:01:53,570  
providing a source of organic material

54  
00:01:57,429 --> 00:01:55,010  
to the surface and that might be an

55  
00:01:59,310 --> 00:01:57,439  
important part of the organic inventory

56  
00:02:01,420 --> 00:01:59,320  
for that world and so that might have

57  
00:02:03,340 --> 00:02:01,430  
important consequences for things like

58  
00:02:04,300 --> 00:02:03,350  
the origin or evolution of life if we're

59  
00:02:07,300 --> 00:02:04,310  
thinking about how the bit of

60  
00:02:09,490 --> 00:02:07,310  
habitability and one of the things that

61  
00:02:11,589 --> 00:02:09,500  
I also think is really important not to

62  
00:02:13,269 --> 00:02:11,599  
forget is that these particles are a

63  
00:02:14,199 --> 00:02:13,279

record of the atmosphere and atmospheric

64

00:02:16,089 --> 00:02:14,209

processes

65

00:02:17,410 --> 00:02:16,099

by the time a particle ends up on the

66

00:02:19,240 --> 00:02:17,420

surface of a planet or in the deep

67

00:02:20,800 --> 00:02:19,250

atmosphere of the planet that particle

68

00:02:24,429 --> 00:02:20,810

has experienced every temperature

69

00:02:25,720 --> 00:02:24,439

pressure background gas mixture exposure

70

00:02:27,910 --> 00:02:25,730

to different wavelengths of photons

71

00:02:29,709 --> 00:02:27,920

energetic particles condensation

72

00:02:31,539 --> 00:02:29,719

transport all of these particle all of

73

00:02:33,399 --> 00:02:31,549

these processes have affected the

74

00:02:34,839 --> 00:02:33,409

particles and we think that most of

75

00:02:36,819 --> 00:02:34,849

those processes should leave their

76

00:02:38,319 --> 00:02:36,829

fingerprint on the particles and so if

77

00:02:40,390 --> 00:02:38,329

we can start to really understand how

78

00:02:42,220 --> 00:02:40,400

those processes work we really will have

79

00:02:43,990 --> 00:02:42,230

a good record of the atmosphere and

80

00:02:49,179 --> 00:02:44,000

atmospheric processes encoded in these

81

00:02:51,159 --> 00:02:49,189

particles okay so if you're gonna try to

82

00:02:52,750 --> 00:02:51,169

understand haze and I think a lot of you

83

00:02:53,920 --> 00:02:52,760

know that I mostly study Titan or at

84

00:02:56,050 --> 00:02:53,930

least I did at some point in my career

85

00:02:58,059 --> 00:02:56,060

if you're gonna study haze in the solar

86

00:03:00,069 --> 00:02:58,069

system the best place to do it is Titan

87

00:03:01,449 --> 00:03:00,079

but I think that all of the studying of

88

00:03:03,459 --> 00:03:01,459

Titan has done us a little bit of

89

00:03:04,869 --> 00:03:03,469

disservice and so I'm going to spend a

90

00:03:07,089 --> 00:03:04,879

good chunk of today trying to dissuade

91

00:03:08,649 --> 00:03:07,099

you of some of the lessons that we may

92

00:03:10,720 --> 00:03:08,659

have learned from Titan because we

93

00:03:12,399 --> 00:03:10,730

learned them incorrectly so this is an

94

00:03:14,379 --> 00:03:12,409

image from Voyager as Voyager flew

95

00:03:16,360 --> 00:03:14,389

through the Saturn system and beamed

96

00:03:17,679 --> 00:03:16,370

back this really frustrating image we

97

00:03:20,949 --> 00:03:17,689

were unable to see the surface

98

00:03:22,689 --> 00:03:20,959

everything okay it's free okay

99

00:03:24,610 --> 00:03:22,699

well it's just an orange ball you're not

100

00:03:26,680 --> 00:03:24,620

actually missing anything you're

101  
00:03:28,300 --> 00:03:26,690  
literally missing nothing uh-huh a

102  
00:03:29,439 --> 00:03:28,310  
little bit later you might want to see

103  
00:03:32,710 --> 00:03:29,449  
what's on the slides but at this moment

104  
00:03:35,009 --> 00:03:32,720  
see I told you it's just nothing to see

105  
00:03:39,129 --> 00:03:37,270  
you know we knew that it was this easy

106  
00:03:40,780 --> 00:03:39,139  
world and Voyager was carrying an

107  
00:03:42,969 --> 00:03:40,790  
infrared spectrometer and so we were

108  
00:03:44,259 --> 00:03:42,979  
able to get some composition information

109  
00:03:45,969 --> 00:03:44,269  
and some of these molecules may look

110  
00:03:48,069 --> 00:03:45,979  
familiar to some of you there's hydrogen

111  
00:03:51,460 --> 00:03:48,079  
cyanide there's si and there's propane

112  
00:03:54,280 --> 00:03:51,470  
there's acetylene all kinds of carbon

113  
00:03:56,050 --> 00:03:54,290

containing molecules there was only one

114

00:03:58,179 --> 00:03:56,060

nitrogen kentuc containing molecule

115

00:04:00,099 --> 00:03:58,189

detected by Voyager that was hydrogen

116

00:04:03,969 --> 00:04:00,109

cyanide all of the other molecules that

117

00:04:06,909 --> 00:04:03,979

Voyager found were hydrocarbon and so we

118

00:04:08,679 --> 00:04:06,919

kind of left the Voyager era studying

119

00:04:10,569 --> 00:04:08,689

Titan with this idea in our head that

120

00:04:11,800 --> 00:04:10,579

turned out to not be correct and we've

121

00:04:13,449 --> 00:04:11,810

learned a lot from Cassini but

122

00:04:16,509 --> 00:04:13,459

unfortunately some of these these

123

00:04:18,370 --> 00:04:16,519

messages kind of stuck and so we left

124

00:04:20,199 --> 00:04:18,380

the Voyager air kind of with this idea

125

00:04:22,060 --> 00:04:20,209

that organic haze is produced from

126

00:04:23,379 --> 00:04:22,070

methane photochemistry in mildly

127

00:04:26,890 --> 00:04:23,389

reducing atmospheres tightened

128

00:04:27,790 --> 00:04:26,900

atmospheres a mildly reduced officer and

129

00:04:29,020 --> 00:04:27,800

so

130

00:04:30,580 --> 00:04:29,030

you will often hear and I've already

131

00:04:33,879 --> 00:04:30,590

heard it said multiple times today

132

00:04:35,920 --> 00:04:33,889

tightens hydrocarbon haze sorry Caroline

133

00:04:38,159 --> 00:04:35,930

she's looking at me like was it mean yes

134

00:04:40,809 --> 00:04:38,169

I'm sorry it wasn't just you though

135

00:04:42,610 --> 00:04:40,819

so you know we came out of the voyager

136

00:04:44,379 --> 00:04:42,620

area with this idea right it's hazy we

137

00:04:47,350 --> 00:04:44,389

see hydrocarbons in the gas phase that

138

00:04:48,820 --> 00:04:47,360

the pain must be hydrocarbon and in the

139

00:04:50,830 --> 00:04:48,830

interim we didn't have the opportunity

140

00:04:53,200 --> 00:04:50,840

to get a lot more information about the

141

00:04:55,210 --> 00:04:53,210

haze and so instead we turned to

142

00:04:57,040 --> 00:04:55,220

laboratory experiments tried to try to

143

00:04:59,230 --> 00:04:57,050

study the processes that were resulting

144

00:05:00,760 --> 00:04:59,240

in haze formation while we were waiting

145

00:05:03,249 --> 00:05:00,770

for another mission and we had to wait

146

00:05:05,469 --> 00:05:03,259

quite a number of years and so there

147

00:05:07,659 --> 00:05:05,479

were a number of nitrogen and methane

148

00:05:09,070 --> 00:05:07,669

photo chemistry experiments of the type

149

00:05:10,540 --> 00:05:09,080

that I'm going to describe in

150

00:05:12,520 --> 00:05:10,550

excruciating detail here in a few

151

00:05:14,320 --> 00:05:12,530

minutes that were designed to try to

152

00:05:16,450 --> 00:05:14,330

understand haze formation and type of

153

00:05:18,219 --> 00:05:16,460

atmosphere and I want to tell you two

154

00:05:20,260 --> 00:05:18,229

important takeaway lessons that we learn

155

00:05:21,969 --> 00:05:20,270

from those experiments that turned out

156

00:05:25,119 --> 00:05:21,979

to be really important when we started

157

00:05:27,100 --> 00:05:25,129

getting Cassini data back so one thing

158

00:05:30,010 --> 00:05:27,110

that we learned from experiments done by

159

00:05:32,649 --> 00:05:30,020

multiple groups different different labs

160

00:05:35,260 --> 00:05:32,659

across quite a bit of time is that

161

00:05:38,709 --> 00:05:35,270

nitrogen preferentially partitions into

162

00:05:39,999 --> 00:05:38,719

the solid phase and so the vision we got

163

00:05:42,159 --> 00:05:40,009

from looking at the gas phase was that

164

00:05:44,620 --> 00:05:42,169

the nitrogen wasn't participating in the

165

00:05:46,330 --> 00:05:44,630

chemistry but that was not correct at

166

00:05:48,249 --> 00:05:46,340

all in fact the nitrogen is very

167

00:05:49,570 --> 00:05:48,259

actively participating in the chemistry

168

00:05:51,580 --> 00:05:49,580

and that's something that we've seen

169

00:05:54,760 --> 00:05:51,590

from a lot of data that were taken from

170

00:05:56,080 --> 00:05:54,770

the Cassini mass spectrometer and so one

171

00:05:57,820 --> 00:05:56,090

of the reasons we don't see as much of

172

00:05:59,589 --> 00:05:57,830

it in the gas phase is because when it

173

00:06:01,089 --> 00:05:59,599

participates in the chemistry it wants

174

00:06:02,320 --> 00:06:01,099

to go into the solid and that's

175

00:06:05,050 --> 00:06:02,330

something that we learn from these lab

176

00:06:06,640 --> 00:06:05,060

experiments one of the other things that

177

00:06:08,640 --> 00:06:06,650

we learned from these lab experiments is

178

00:06:10,779 --> 00:06:08,650

that the presence of molecular nitrogen

179

00:06:12,459 --> 00:06:10,789

dramatically increases the production

180

00:06:14,890 --> 00:06:12,469

rate of particles in these experiments

181

00:06:17,050 --> 00:06:14,900

if you switch out molecular nitrogen for

182

00:06:18,820 --> 00:06:17,060

argon in most of these experiments you

183

00:06:21,240 --> 00:06:18,830

decrease your production rate by orders

184

00:06:24,730 --> 00:06:21,250

of magnitude so the nitrogen is very

185

00:06:27,070 --> 00:06:24,740

important it has a role that it plays in

186

00:06:28,869 --> 00:06:27,080

how the energy moves that drives the

187

00:06:30,430 --> 00:06:28,879

chemistry it's also actively

188

00:06:32,050 --> 00:06:30,440

participating in the chemistry itself

189

00:06:34,029 --> 00:06:32,060

partitioning into the salt so the

190

00:06:35,740 --> 00:06:34,039

nitrogen is really important and we tend

191

00:06:37,990 --> 00:06:35,750

to forget about it when we talk about

192

00:06:40,089 --> 00:06:38,000

nitrogen when we talk about Titans

193

00:06:40,380 --> 00:06:40,099

hydrocarbon haze so I prefer Titans or

194

00:06:43,380 --> 00:06:40,390

again

195

00:06:45,690 --> 00:06:43,390

case the decent description Titans very

196

00:06:48,120 --> 00:06:45,700

messy haze Titans whatever is going on

197

00:06:49,350 --> 00:06:48,130

in their haze I don't know it's but the

198

00:06:51,150 --> 00:06:49,360

reason that I want to dissuade you of

199

00:06:53,580 --> 00:06:51,160

this is because carbon because methane

200

00:06:55,260 --> 00:06:53,590

isn't the only important molecule for

201  
00:06:56,700 --> 00:06:55,270  
haze formation and hydrocarbons are not

202  
00:06:58,230 --> 00:06:56,710  
the only important molecules for haze

203  
00:07:00,480 --> 00:06:58,240  
formation and I'm gonna step you through

204  
00:07:02,100 --> 00:07:00,490  
a bunch of experiments that have shown

205  
00:07:05,280 --> 00:07:02,110  
this including the work that we've been

206  
00:07:06,930 --> 00:07:05,290  
doing specifically for exoplanets so I

207  
00:07:09,000 --> 00:07:06,940  
want to show you one more thing that we

208  
00:07:12,090 --> 00:07:09,010  
learned from Titan because I think it's

209  
00:07:13,650 --> 00:07:12,100  
really important Cassini was carrying a

210  
00:07:16,290 --> 00:07:13,660  
mass spectrometer that was designed to

211  
00:07:18,750 --> 00:07:16,300  
study the gas phase composition of

212  
00:07:21,570 --> 00:07:18,760  
Titan's atmosphere in sidhu it had a

213  
00:07:24,530 --> 00:07:21,580

mass range that went up to 99 amu so

214

00:07:27,030 --> 00:07:24,540

that's five or six heavy carbon atoms if

215

00:07:28,710 --> 00:07:27,040

this you know so what we basically

216

00:07:30,210 --> 00:07:28,720

thought was that this was what it was

217

00:07:31,530 --> 00:07:30,220

gonna look like if we looked at a mass

218

00:07:33,210 --> 00:07:31,540

spectrum so this is let's see if I can

219

00:07:35,490 --> 00:07:33,220

work this without poking an eye out um

220

00:07:37,860 --> 00:07:35,500

this is not to charge on the x-axis this

221

00:07:39,450 --> 00:07:37,870

is number on the y-axis and so we would

222

00:07:40,860 --> 00:07:39,460

assume that this is what a mass spectrum

223

00:07:43,590 --> 00:07:40,870

of Titans upper atmosphere might look

224

00:07:45,900 --> 00:07:43,600

like six or seven heavy carbon atoms

225

00:07:47,280 --> 00:07:45,910

going up to a mass of a hundred in fact

226

00:07:49,320 --> 00:07:47,290

the heaviest molecule that had ever been

227

00:07:52,050 --> 00:07:49,330

detected prior to the arrival of Cassini

228

00:07:55,800 --> 00:07:52,060

was benzene just  $C_6H_6$  that has a mass of

229

00:07:57,450 --> 00:07:55,810

78 so it turns out that we were really

230

00:07:59,430 --> 00:07:57,460

lucky because in addition to the mass

231

00:08:01,050 --> 00:07:59,440

spectrometer that was very carefully

232

00:08:03,360 --> 00:08:01,060

designed to study Titan's atmosphere in

233

00:08:04,950 --> 00:08:03,370

great detail Cassini was also carrying a

234

00:08:06,750 --> 00:08:04,960

plasma spectrometer that wasn't meant to

235

00:08:09,090 --> 00:08:06,760

study Titan at all it was meant to

236

00:08:10,770 --> 00:08:09,100

characterize the small energetic ions in

237

00:08:13,620 --> 00:08:10,780

the Saturnia mini magnetosphere things

238

00:08:14,940 --> 00:08:13,630

like okhla but they didn't turn it off

239

00:08:17,250 --> 00:08:14,950

when it flew through Titan's atmosphere

240

00:08:21,990 --> 00:08:17,260

and then we saw data those like this

241

00:08:24,900 --> 00:08:22,000

instead so that's a log axis so Cassini

242

00:08:27,840 --> 00:08:24,910

detected ions in this case negative ions

243

00:08:30,090 --> 00:08:27,850

with a master charge up to 10,000 amu in

244

00:08:33,300 --> 00:08:30,100

Titan's atmosphere that's more like six

245

00:08:36,690 --> 00:08:33,310

or seven or eight hundred heavy atom not

246

00:08:38,490 --> 00:08:36,700

six or seven six or 700 so we were wrong

247

00:08:40,320 --> 00:08:38,500

by a couple orders of magnitude and our

248

00:08:42,000 --> 00:08:40,330

understanding of how complicated the

249

00:08:44,430 --> 00:08:42,010

chemistry is in Titan's atmosphere and

250

00:08:47,730 --> 00:08:44,440

this is at an altitude of 950 kilometers

251  
00:08:49,020 --> 00:08:47,740  
above the surface the mean free path in

252  
00:08:51,540 --> 00:08:49,030  
this region of the atmosphere is about a

253  
00:08:53,490 --> 00:08:51,550  
kilometer so we're still trying to sort

254  
00:08:54,240 --> 00:08:53,500  
out exactly how one goes about building

255  
00:08:56,040 --> 00:08:54,250  
something that has

256  
00:08:58,550 --> 00:08:56,050  
six or seven hundred carbon atoms when

257  
00:09:00,690 --> 00:08:58,560  
you barely ever interact with anything

258  
00:09:01,680 --> 00:09:00,700  
just to give you a sense of scale for

259  
00:09:03,300 --> 00:09:01,690  
those of you who don't think about

260  
00:09:06,150 --> 00:09:03,310  
chemistry very often there's our friend

261  
00:09:07,650 --> 00:09:06,160  
benzene massive 78 i sat in chem draw

262  
00:09:09,540 --> 00:09:07,660  
one day and it took me a full day

263  
00:09:11,520 --> 00:09:09,550

because programs don't like drawing

264

00:09:14,130 --> 00:09:11,530

molecules this big to draw something

265

00:09:15,480 --> 00:09:14,140

that is not a real chemistry thing but

266

00:09:17,400 --> 00:09:15,490

that's just to give you a sense of scale

267

00:09:20,730 --> 00:09:17,410

of how wrong we were about the

268

00:09:22,650 --> 00:09:20,740

complexity and so we had this idea

269

00:09:24,960 --> 00:09:22,660

before Cassini that the haze particles

270

00:09:27,810 --> 00:09:24,970

formed where we see them because that's

271

00:09:29,220 --> 00:09:27,820

how it works on earth and in Titan's

272

00:09:31,190 --> 00:09:29,230

atmosphere where we really see the

273

00:09:33,780 --> 00:09:31,200

particles as deep in the stratosphere

274

00:09:35,400 --> 00:09:33,790

but this is in the ionosphere and this

275

00:09:38,400 --> 00:09:35,410

is where the processes that leads to

276

00:09:40,050 --> 00:09:38,410

haze formation on Titan start and if you

277

00:09:41,700 --> 00:09:40,060

look in the ultraviolet in this region

278

00:09:43,710 --> 00:09:41,710

of the atmosphere you can already see

279

00:09:45,030 --> 00:09:43,720

that there are particles in the

280

00:09:46,380 --> 00:09:45,040

atmosphere that are interacting with

281

00:09:49,020 --> 00:09:46,390

light of the third particle and not a

282

00:09:52,770 --> 00:09:49,030

gas so this has really changed our

283

00:09:54,510 --> 00:09:52,780

understanding of aerosol formation we

284

00:09:56,280 --> 00:09:54,520

thought then ok Titan must be this

285

00:09:58,500 --> 00:09:56,290

unique unicorn and it has this really

286

00:10:00,560 --> 00:09:58,510

weird chemistry but it turned out that

287

00:10:03,660 --> 00:10:00,570

Cassini had a few more surprises for us

288

00:10:05,190 --> 00:10:03,670

so we think that maybe Titan is not the

289

00:10:06,900 --> 00:10:05,200

exception and it's possible that it may

290

00:10:08,790 --> 00:10:06,910

be the rule for a lot of these types of

291

00:10:10,800 --> 00:10:08,800

atmospheres so this is Saturn now

292

00:10:12,480 --> 00:10:10,810

similar to the spectrum that I showed

293

00:10:14,280 --> 00:10:12,490

you a few minutes ago of Titan you'll

294

00:10:15,960 --> 00:10:14,290

see similar molecules so just to give

295

00:10:17,400 --> 00:10:15,970

you a sense of scale of the types of

296

00:10:20,010 --> 00:10:17,410

things we're seeing in the gas phase we

297

00:10:21,360 --> 00:10:20,020

see methane we see a tiny sea acetylene

298

00:10:24,570 --> 00:10:21,370

again these hydrocarbons

299

00:10:26,730 --> 00:10:24,580

so Cassini's last act was to be

300

00:10:28,920 --> 00:10:26,740

intentionally crashed into saturn and

301

00:10:31,520 --> 00:10:28,930

one of the main goals of the end of

302

00:10:34,950 --> 00:10:31,530

mission was send back mass spectral data

303

00:10:38,700 --> 00:10:34,960

of Saturn's upper atmosphere and this is

304

00:10:40,380 --> 00:10:38,710

what they look like so we thought with

305

00:10:42,329 --> 00:10:40,390

our understanding of how Saturn worked

306

00:10:44,310 --> 00:10:42,339

that the only thing we were going to see

307

00:10:46,710 --> 00:10:44,320

we're right here are hydrogen and helium

308

00:10:48,090 --> 00:10:46,720

that's it the only thing that we should

309

00:10:50,190 --> 00:10:48,100

see in that region the atmosphere based

310

00:10:51,720 --> 00:10:50,200

on our understanding of Saturn but

311

00:10:54,410 --> 00:10:51,730

instead we see all of these so that's

312

00:10:57,390 --> 00:10:54,420

methane there's ammonia there's water

313

00:11:01,020 --> 00:10:57,400

this is what's the molecular nitrogen

314

00:11:03,540 --> 00:11:01,030

and carbon monoxide there's CO<sub>2</sub> this one

315

00:11:05,710 --> 00:11:03,550

over here is benzene there's potentially

316

00:11:07,840 --> 00:11:05,720

some toluene hiding over here

317

00:11:09,460 --> 00:11:07,850

so the chemistry occurring in Saturn's

318

00:11:10,750 --> 00:11:09,470

atmosphere is also very complicated

319

00:11:12,970 --> 00:11:10,760

again this is at the top of the

320

00:11:14,650 --> 00:11:12,980

atmosphere and so we really had to

321

00:11:17,080 --> 00:11:14,660

rethink a lot of our ideas about how

322

00:11:18,670 --> 00:11:17,090

these processes work and so of course

323

00:11:21,430 --> 00:11:18,680

when these data came back from from

324

00:11:23,860 --> 00:11:21,440

Cassini especially from Titan we were

325

00:11:26,800 --> 00:11:23,870

kind of flummoxed at the time I was a

326

00:11:29,170 --> 00:11:26,810

photochemical modeler with my primary

327

00:11:31,420 --> 00:11:29,180

expertise being Titan and we looked at

328

00:11:33,130 --> 00:11:31,430

those data and thought there's no way we

329

00:11:35,260 --> 00:11:33,140

can use a photochemical model to figure

330

00:11:36,730 --> 00:11:35,270

out what these molecules are and we

331

00:11:38,680 --> 00:11:36,740

wanted to know because we're interested

332

00:11:40,450 --> 00:11:38,690

in prebiotic chemistry for Titan and so

333

00:11:42,130 --> 00:11:40,460

we couldn't figure it out from the data

334

00:11:44,020 --> 00:11:42,140

the instrument wasn't designed to do it

335

00:11:46,030 --> 00:11:44,030

we couldn't figure it out for models

336

00:11:48,460 --> 00:11:46,040

because models just aren't that good for

337

00:11:49,960 --> 00:11:48,470

lots of reason and so we started working

338

00:11:52,150 --> 00:11:49,970

on some of these questions in the lab

339

00:11:54,160 --> 00:11:52,160

and so all the experiments that I'm

340

00:11:55,540 --> 00:11:54,170

going to talk to you about and the

341

00:11:57,520 --> 00:11:55,550

experiments that I mentioned a few

342

00:12:00,670 --> 00:11:57,530

minutes ago I'll operate on the same

343

00:12:02,410 --> 00:12:00,680

principle we take simple abundant

344

00:12:04,450 --> 00:12:02,420

atmospheric gases for the main

345

00:12:06,010 --> 00:12:04,460

constituents of an atmosphere for Titan

346

00:12:07,810 --> 00:12:06,020

the experiments are usually molecular

347

00:12:10,150 --> 00:12:07,820

nitrogen and methane maybe some carbon

348

00:12:12,390 --> 00:12:10,160

monoxide if you were doing Venus you

349

00:12:15,190 --> 00:12:12,400

would have co<sub>2</sub> and so<sub>2</sub> the main

350

00:12:17,860 --> 00:12:15,200

constituents of the atmosphere we expose

351

00:12:20,200 --> 00:12:17,870

them to an energy source we can use

352

00:12:21,880 --> 00:12:20,210

plasma you can use UV photons people

353

00:12:23,410 --> 00:12:21,890

have used if it's an energy source that

354

00:12:24,910 --> 00:12:23,420

exists in a lab people have used it to

355

00:12:27,820 --> 00:12:24,920

do these experiments these are the two

356

00:12:29,770 --> 00:12:27,830

most common at the point the energy

357

00:12:32,260 --> 00:12:29,780

source and source initiates chemistry

358

00:12:35,200 --> 00:12:32,270

that often results in the formation of a

359

00:12:36,550 --> 00:12:35,210

complex organic solid and these are the

360

00:12:38,170 --> 00:12:36,560

particles that were interested in trying

361

00:12:40,030 --> 00:12:38,180

to study so we want to understand this

362

00:12:42,820 --> 00:12:40,040

process of how we're converting the

363

00:12:45,520 --> 00:12:42,830

gases to particles and then everything

364

00:12:46,930 --> 00:12:45,530

that happens after that people often and

365

00:12:48,610 --> 00:12:46,940

I've heard that this word a number of

366

00:12:50,950 --> 00:12:48,620

times especially yesterday people often

367

00:12:52,540 --> 00:12:50,960

refer to this material as Poland which

368

00:12:54,790 --> 00:12:52,550

was a term that was coined by Carl Sagan

369

00:12:56,800 --> 00:12:54,800

in part because they couldn't come up

370

00:13:00,880 --> 00:12:56,810

with an actual word for what they had

371

00:13:02,710 --> 00:13:00,890

made when people say so in almost all of

372

00:13:05,110 --> 00:13:02,720

the time and I think every time it came

373

00:13:07,240 --> 00:13:05,120

up yesterday you actually mean one

374

00:13:11,320 --> 00:13:07,250

specific paper that was published in

375

00:13:13,660 --> 00:13:11,330

1984 his car a 1984 those experiments

376

00:13:15,520 --> 00:13:13,670

were erected specifically for Titan but

377

00:13:16,990 --> 00:13:15,530

they were run at room temperature but

378

00:13:18,069 --> 00:13:17,000

the 90% nitrogen

379

00:13:20,769 --> 00:13:18,079

10% methane

380

00:13:22,479 --> 00:13:20,779

mixture the energy source matters less

381

00:13:24,850 --> 00:13:22,489

to this audience but that's actually a

382

00:13:26,530 --> 00:13:24,860

decent energy source and on top of that

383

00:13:27,939 --> 00:13:26,540

it was a closed experiment which is not

384

00:13:31,600 --> 00:13:27,949

a way that we run experiments anymore

385

00:13:33,999 --> 00:13:31,610

the energy is too high the only reason

386

00:13:35,679 --> 00:13:34,009

that everybody uses this one is because

387

00:13:37,449 --> 00:13:35,689

this is the only one that has optical

388

00:13:40,840 --> 00:13:37,459

constants over the entire wavelength

389

00:13:43,389 --> 00:13:40,850

range that you all want and so I say

390

00:13:45,669 --> 00:13:43,399

this only as a reminder to just not

391

00:13:48,639 --> 00:13:45,679

forget what these particles were made

392

00:13:51,400 --> 00:13:48,649

for they weren't made to be used for

393

00:13:53,049 --> 00:13:51,410

every atmosphere ever in the universe in

394

00:13:58,720 --> 00:13:53,059

part because we didn't know how many

395

00:14:00,519 --> 00:13:58,730

atmospheres there were in 1984 and but

396

00:14:02,439 --> 00:14:00,529

also to say that I understand why people

397

00:14:03,939 --> 00:14:02,449

use them and we're trying to fix the

398

00:14:06,280 --> 00:14:03,949

situation for you but it's a little bit

399

00:14:08,679 --> 00:14:06,290

slow going but it is important not to

400

00:14:11,499 --> 00:14:08,689

forget this because not all organic junk

401  
00:14:13,269 --> 00:14:11,509  
is the same in particular not all

402  
00:14:15,460 --> 00:14:13,279  
organic gunk has the same optical

403  
00:14:19,449 --> 00:14:15,470  
constants so that's just a little

404  
00:14:21,220 --> 00:14:19,459  
disclaimer and I mention again that it

405  
00:14:22,590 --> 00:14:21,230  
well no I'm gonna no I'm not gonna skip

406  
00:14:24,819 --> 00:14:22,600  
this because there's one good answer

407  
00:14:26,499 --> 00:14:24,829  
this is just a schematic of the

408  
00:14:28,119 --> 00:14:26,509  
experiment that we're using to do the

409  
00:14:30,910 --> 00:14:28,129  
exoplanet extract it's just to give you

410  
00:14:32,949 --> 00:14:30,920  
a slightly more detailed picture we can

411  
00:14:34,119 --> 00:14:32,959  
do experiments or science 90 p kelvin

412  
00:14:36,220 --> 00:14:34,129  
i'm going to show you 800 health

413  
00:14:37,539 --> 00:14:36,230

experiments today i'm in addition to the

414

00:14:39,669 --> 00:14:37,549

ones that we published we have two

415

00:14:43,239 --> 00:14:39,679

different energy sources and we can do

416

00:14:44,470 --> 00:14:43,249

basically any atmosphere you watch this

417

00:14:47,739 --> 00:14:44,480

is what the chamber looks like when it's

418

00:14:50,379 --> 00:14:47,749

on sorry Caroline I've never seen

419

00:14:51,939 --> 00:14:50,389

someone so excited to see our experiment

420

00:14:54,639 --> 00:14:51,949

I love this picture so much that you

421

00:14:56,980 --> 00:14:54,649

didn't like all of my talks sorry about

422

00:14:58,329 --> 00:14:56,990

that yeah you can come take another one

423

00:15:00,039 --> 00:14:58,339

if you don't like this one but I think

424

00:15:02,019 --> 00:15:00,049

it has to be you at this point

425

00:15:04,239 --> 00:15:02,029

hey that's what the chamber looks like

426

00:15:05,590 --> 00:15:04,249

when it's running with the plasma and

427

00:15:08,109 --> 00:15:05,600

then one thing I wanted to do quickly is

428

00:15:10,090 --> 00:15:08,119

just let you give you a brief list of

429

00:15:12,039 --> 00:15:10,100

the kind of information that we actually

430

00:15:13,569 --> 00:15:12,049

get from laboratory experiments because

431

00:15:14,619 --> 00:15:13,579

I think you know people don't often

432

00:15:17,799 --> 00:15:14,629

think about the price that we can

433

00:15:19,210 --> 00:15:17,809

actually do planetary scientist lab so

434

00:15:20,769 --> 00:15:19,220

we can measure the gas phase products of

435

00:15:22,389 --> 00:15:20,779

these experiments I think this is

436

00:15:23,889 --> 00:15:22,399

particularly important for this audience

437

00:15:26,199 --> 00:15:23,899

because one of the things that we're

438

00:15:28,359 --> 00:15:26,209

hoping to do in the long run if we could

439

00:15:30,460 --> 00:15:28,369

measure the small space products very

440

00:15:31,900 --> 00:15:30,470

precisely these are things you're going

441

00:15:33,760 --> 00:15:31,910

to be able to get if you

442

00:15:35,710 --> 00:15:33,770

haven't already gotten them from things

443

00:15:37,480 --> 00:15:35,720

like James Webb we can measure the small

444

00:15:40,210 --> 00:15:37,490

gases just like you all will have them

445

00:15:41,770 --> 00:15:40,220

too um then we can measure everything

446

00:15:43,390 --> 00:15:41,780

else because we can measure the

447

00:15:44,710 --> 00:15:43,400

particles and so when I'm hoping long

448

00:15:46,870 --> 00:15:44,720

run is that we'll actually be able to

449

00:15:49,060 --> 00:15:46,880

use the lab experiments to tie your

450

00:15:52,150 --> 00:15:49,070

observations together with them with

451  
00:15:53,710 --> 00:15:52,160  
information we can measure in the lab we

452  
00:15:55,060 --> 00:15:53,720  
can look at gas to solid conversion if

453  
00:15:57,850 --> 00:15:55,070  
it's efficiency which is really

454  
00:15:59,080 --> 00:15:57,860  
important for putting into models we can

455  
00:16:00,880 --> 00:15:59,090  
measure the composition of the particles

456  
00:16:02,710 --> 00:16:00,890  
we can measure the particle size

457  
00:16:04,870 --> 00:16:02,720  
distribution we can measure obstacle

458  
00:16:06,190 --> 00:16:04,880  
properties we can measure particle

459  
00:16:09,040 --> 00:16:06,200  
density which is important for cloud

460  
00:16:10,960 --> 00:16:09,050  
microphysics models we can measure inter

461  
00:16:12,430 --> 00:16:10,970  
particle forces which are also important

462  
00:16:14,920 --> 00:16:12,440  
for micro physics we can look at

463  
00:16:16,360 --> 00:16:14,930

nucleation efficiency we can do things

464

00:16:18,940 --> 00:16:16,370

like figure out whether or not the

465

00:16:20,710 --> 00:16:18,950

particles will interact happily or sadly

466

00:16:22,690 --> 00:16:20,720

with liquids that might be present in

467

00:16:24,250 --> 00:16:22,700

the atmosphere and if you get really

468

00:16:25,150 --> 00:16:24,260

excited like we do for Titan you can

469

00:16:26,710 --> 00:16:25,160

start thinking about things like

470

00:16:28,360 --> 00:16:26,720

mechanical properties because these

471

00:16:29,680 --> 00:16:28,370

particles might end up seeing the same

472

00:16:31,870 --> 00:16:29,690

students on the planet that you're

473

00:16:33,250 --> 00:16:31,880

interested in and so those are the kinds

474

00:16:36,610 --> 00:16:33,260

of things that lab experiments can

475

00:16:37,930 --> 00:16:36,620

provide you so now I'm gonna actually

476

00:16:40,630 --> 00:16:37,940

show you some real experiments and I

477

00:16:43,090 --> 00:16:40,640

have to apologize in advance because I

478

00:16:46,000 --> 00:16:43,100

made this talk on a Mac and we had some

479

00:16:52,540 --> 00:16:46,010

Mac to PC conversion issues and so some

480

00:16:54,640 --> 00:16:52,550

of my slides looked like modern art was

481

00:16:56,850 --> 00:16:54,650

anybody's time to try to sort it out I

482

00:16:59,710 --> 00:16:56,860

think all the science wives are okay so

483

00:17:01,300 --> 00:16:59,720

one of the things that I first kind of

484

00:17:03,160 --> 00:17:01,310

started getting interested in was trying

485

00:17:05,080 --> 00:17:03,170

to step out of our nitrogen methane box

486

00:17:06,670 --> 00:17:05,090

there are so many nitrogen methane

487

00:17:08,380 --> 00:17:06,680

experiments you all like you have no

488

00:17:10,810 --> 00:17:08,390

idea and so we have spent like

489

00:17:13,330 --> 00:17:10,820

legitimately like 30 or 40 years trying

490

00:17:15,430 --> 00:17:13,340

to study how nitrogen methane form pays

491

00:17:17,350 --> 00:17:15,440

and then basically done nothing else

492

00:17:19,840 --> 00:17:17,360

because we had this one place that we

493

00:17:21,340 --> 00:17:19,850

were interested in and so I first got

494

00:17:24,190 --> 00:17:21,350

interested in trying to understand what

495

00:17:26,860 --> 00:17:24,200

carbon monoxide would do because of

496

00:17:29,080 --> 00:17:26,870

Titan but it turns out that Titan isn't

497

00:17:30,640 --> 00:17:29,090

the only hazy methane nitrogen carbon

498

00:17:32,700 --> 00:17:30,650

oxide atmosphere in the solar system

499

00:17:35,470 --> 00:17:32,710

this is cheating because it's just scale

500

00:17:38,410 --> 00:17:35,480

but that's our friend Titan this one's

501  
00:17:40,930 --> 00:17:38,420  
Pluto and this is just here in case some

502  
00:17:43,180 --> 00:17:40,940  
of you have somehow inexplicably never

503  
00:17:45,400 --> 00:17:43,190  
seen this picture before because

504  
00:17:47,260 --> 00:17:45,410  
everybody needs to see this picture and

505  
00:17:48,550 --> 00:17:47,270  
so it was for the solar since the solar

506  
00:17:49,900 --> 00:17:48,560  
system objects that we first got

507  
00:17:51,850 --> 00:17:49,910  
interested in trying to understand

508  
00:17:53,320 --> 00:17:51,860  
carbon monoxide although as we heard

509  
00:17:55,510 --> 00:17:53,330  
about yesterday carbon monoxide is a

510  
00:17:57,160 --> 00:17:55,520  
lovely molecule to search for in

511  
00:17:58,390 --> 00:17:57,170  
exoplanet atmospheres as well and so

512  
00:18:00,280 --> 00:17:58,400  
this is something that we need to think

513  
00:18:02,170 --> 00:18:00,290

about it's also the first oxygen

514

00:18:03,400 --> 00:18:02,180

containing molecule that really start we

515

00:18:05,320 --> 00:18:03,410

really started studying and these

516

00:18:06,850 --> 00:18:05,330

experiments and as you'll see is I

517

00:18:09,280 --> 00:18:06,860

started to talk more about the exoplanet

518

00:18:10,840 --> 00:18:09,290

experiments oxygen bearing molecules

519

00:18:12,940 --> 00:18:10,850

have a really important impact on haze

520

00:18:14,410 --> 00:18:12,950

formation and it really depends which

521

00:18:18,130 --> 00:18:14,420

molecule were talking about what that

522

00:18:19,570 --> 00:18:18,140

impact is so one of the things that we

523

00:18:22,570 --> 00:18:19,580

figured out when we started looking at

524

00:18:24,250 --> 00:18:22,580

Co is that adding co2 these types of

525

00:18:27,370 --> 00:18:24,260

experiments results in an increase in

526

00:18:29,400 --> 00:18:27,380

the in the production rate this happens

527

00:18:33,010 --> 00:18:29,410

for all of the experiments that we did

528

00:18:34,840 --> 00:18:33,020

so we looked at 0.1% methane with a UV

529

00:18:36,880 --> 00:18:34,850

source we looked at 2% methane with the

530

00:18:38,980 --> 00:18:36,890

UV source we switch things up completely

531

00:18:41,410 --> 00:18:38,990

into the same gas mixtures with a plasma

532

00:18:43,000 --> 00:18:41,420

instead just to see if that would have

533

00:18:44,770 --> 00:18:43,010

any effect and the answer was really no

534

00:18:47,200 --> 00:18:44,780

the more carbon monoxide we put into the

535

00:18:49,240 --> 00:18:47,210

experiment the more particles we got

536

00:18:50,950 --> 00:18:49,250

this was really surprising to a lot of

537

00:18:53,440 --> 00:18:50,960

people because we had this idea in our

538

00:18:55,900 --> 00:18:53,450

head that oxygen full-stop whatever

539

00:18:58,360 --> 00:18:55,910

molecule it was contained in was bad for

540

00:19:00,580 --> 00:18:58,370

hay formation and that turned out to

541

00:19:02,110 --> 00:19:00,590

really not be true in fact we have a lot

542

00:19:04,030 --> 00:19:02,120

of reasons now why we think that some

543

00:19:05,320 --> 00:19:04,040

oxygen depending on what molecule it

544

00:19:07,600 --> 00:19:05,330

comes from might actually be really good

545

00:19:10,210 --> 00:19:07,610

for haze formation I'm gonna skip this

546

00:19:12,370 --> 00:19:10,220

slide and it turns out that we could

547

00:19:14,290 --> 00:19:12,380

actually look and see whether this was

548

00:19:17,560 --> 00:19:14,300

from the particles getting bigger which

549

00:19:19,360 --> 00:19:17,570

means that Co makes makes growth more

550

00:19:22,030 --> 00:19:19,370

efficient and it turns out that that's

551  
00:19:23,530 --> 00:19:22,040  
true the particles get bigger so adding

552  
00:19:26,020 --> 00:19:23,540  
co2 the gas mixture makes the particles

553  
00:19:27,910 --> 00:19:26,030  
grow more efficiently but we could also

554  
00:19:29,440 --> 00:19:27,920  
look at the number density and that

555  
00:19:31,390 --> 00:19:29,450  
tells us something about the nucleation

556  
00:19:33,670 --> 00:19:31,400  
efficiency that first step of making a

557  
00:19:35,680 --> 00:19:33,680  
particle and it turns out that Co also

558  
00:19:37,270 --> 00:19:35,690  
increases the nucleation efficiency so

559  
00:19:41,560 --> 00:19:37,280  
this trend we were seeing was a result

560  
00:19:43,780 --> 00:19:41,570  
of both things and it turns out that one

561  
00:19:45,340 --> 00:19:43,790  
of the the key things that I think that

562  
00:19:47,080 --> 00:19:45,350  
we have found from doing this work and

563  
00:19:49,360 --> 00:19:47,090

it's relevant for all the exoplanet

564

00:19:51,100 --> 00:19:49,370

stuff is that when we started looking at

565

00:19:52,300 --> 00:19:51,110

the gas phase and the only thing I

566

00:19:55,090 --> 00:19:52,310

actually want you to look at in this

567

00:19:57,250 --> 00:19:55,100

plot are these red diamonds right here

568

00:19:59,210 --> 00:19:57,260

when we started looking at the gas phase

569

00:20:01,730 --> 00:19:59,220

this is a molecular hydrogen

570

00:20:04,850 --> 00:20:01,740

that 2mu point as we put more CEO in the

571

00:20:07,910 --> 00:20:04,860

gas mixture the molecular hydrogen in

572

00:20:09,260 --> 00:20:07,920

the gas phase decreases and we know from

573

00:20:10,610 --> 00:20:09,270

some of the work that's been done for

574

00:20:13,820 --> 00:20:10,620

Titan that the more molecular hydrogen

575

00:20:15,950 --> 00:20:13,830

is present the less efficient particle

576

00:20:17,930 --> 00:20:15,960

formation is because every time you

577

00:20:20,060 --> 00:20:17,940

break one of those carbon hydrogen bonds

578

00:20:21,650 --> 00:20:20,070

to try to build a bigger molecule you

579

00:20:23,600 --> 00:20:21,660

have the opportunity to molecular

580

00:20:25,610 --> 00:20:23,610

hydrogen and just reform that bond so

581

00:20:27,800 --> 00:20:25,620

getting rid of the molecular hydrogen is

582

00:20:30,020 --> 00:20:27,810

really important to make hey its

583

00:20:32,120 --> 00:20:30,030

formation more efficient and having

584

00:20:34,250 --> 00:20:32,130

oxygen in the gas mixture that came from

585

00:20:36,230 --> 00:20:34,260

that Co seems to be pulling some of that

586

00:20:40,550 --> 00:20:36,240

hydrogen out and forming other molecules

587

00:20:41,660 --> 00:20:40,560

which helps increase the efficiency one

588

00:20:43,310 --> 00:20:41,670

other thing we learned from looking at

589

00:20:44,960 --> 00:20:43,320

the solids is that the oxygen actually

590

00:20:46,610 --> 00:20:44,970

really participates in the chemistry and

591

00:20:49,220 --> 00:20:46,620

so the more Co we put in the gas mixture

592

00:20:51,380 --> 00:20:49,230

the more oxygen-rich the aerosol is and

593

00:20:53,390 --> 00:20:51,390

so this tells us something right away

594

00:20:54,650 --> 00:20:53,400

which is that the optical properties of

595

00:20:56,000 --> 00:20:54,660

these particles are almost certainly

596

00:20:57,830 --> 00:20:56,010

changing their composition is very

597

00:20:59,060 --> 00:20:57,840

different that's going to affect all of

598

00:21:00,320 --> 00:20:59,070

the ways in which they're interacting

599

00:21:03,770 --> 00:21:00,330

with the atmosphere and so this is

600

00:21:05,450 --> 00:21:03,780

really important we also decided to look

601  
00:21:08,270 --> 00:21:05,460  
to see what kinds of oxygen molecules

602  
00:21:09,530 --> 00:21:08,280  
and since we have some some astrobiology

603  
00:21:11,000 --> 00:21:09,540  
interest in this crowd I just thought I

604  
00:21:12,200 --> 00:21:11,010  
would quickly point this out that we've

605  
00:21:14,660 --> 00:21:12,210  
seen that you can make a lot of

606  
00:21:16,880 --> 00:21:14,670  
molecules of astrobiological interest in

607  
00:21:18,590 --> 00:21:16,890  
the gas phase in experiments that

608  
00:21:20,510 --> 00:21:18,600  
include Co so these are the five

609  
00:21:23,180 --> 00:21:20,520  
nucleobases that all of life on Earth

610  
00:21:26,780 --> 00:21:23,190  
uses and the two smallest protein a

611  
00:21:30,260 --> 00:21:26,790  
Jenica amino acid and a glycine and

612  
00:21:31,340 --> 00:21:30,270  
alanine I'm gonna skip that slide one of

613  
00:21:33,230 --> 00:21:31,350

the other things we've discovered more

614

00:21:35,300 --> 00:21:33,240

recently which i think is also really

615

00:21:36,710 --> 00:21:35,310

relevant to thinking about this issue of

616

00:21:39,080 --> 00:21:36,720

where haze formation occurs in different

617

00:21:41,060 --> 00:21:39,090

atmospheres is that we found that the

618

00:21:43,070 --> 00:21:41,070

more energetic environment in our lab

619

00:21:45,050 --> 00:21:43,080

experiments produces more prebiotic

620

00:21:47,000 --> 00:21:45,060

molecules so these are two different

621

00:21:49,430 --> 00:21:47,010

energy sources one of them is a plasma

622

00:21:51,140 --> 00:21:49,440

and one of them is a UV source otherwise

623

00:21:53,150 --> 00:21:51,150

the experiments are effectively the same

624

00:21:55,160 --> 00:21:53,160

you can see just from looking at how

625

00:21:57,050 --> 00:21:55,170

many things are labeled in this column

626  
00:21:59,030 --> 00:21:57,060  
versus this column that we're seeing a

627  
00:22:01,190 --> 00:21:59,040  
lot more of these molecules when we use

628  
00:22:03,770 --> 00:22:01,200  
the plasma energy source that energy

629  
00:22:05,540 --> 00:22:03,780  
source is much more analogous for the

630  
00:22:07,520 --> 00:22:05,550  
upper atmosphere of a planet when we're

631  
00:22:09,050 --> 00:22:07,530  
in the ionosphere and so that's a place

632  
00:22:11,660 --> 00:22:09,060  
for some really interesting chemistry to

633  
00:22:13,130 --> 00:22:11,670  
happen so just to give you a quick

634  
00:22:15,440 --> 00:22:13,140  
summary about what we learned about sea

635  
00:22:16,789 --> 00:22:15,450  
the particle size number densities are

636  
00:22:19,430 --> 00:22:16,799  
for the total amount of stuff that we

637  
00:22:21,860 --> 00:22:19,440  
made increases when we put Co in the in

638  
00:22:23,480 --> 00:22:21,870

the experiments it decreases the gas

639

00:22:26,150 --> 00:22:23,490

phase molecular hydrogen I think that's

640

00:22:28,490 --> 00:22:26,160

really key to what's happening in terms

641

00:22:30,230 --> 00:22:28,500

of the production rate the aerosols

642

00:22:32,720 --> 00:22:30,240

become more oxygen-rich as we put more

643

00:22:34,310 --> 00:22:32,730

co in the gas mixture and we also get

644

00:22:36,169 --> 00:22:34,320

some production of some some molecules

645

00:22:37,400 --> 00:22:36,179

prebiotic interest which is a really

646

00:22:38,720 --> 00:22:37,410

interesting and has important

647

00:22:40,970 --> 00:22:38,730

implications for the role that haze

648

00:22:44,090 --> 00:22:40,980

might play in the origin or evolution of

649

00:22:45,409 --> 00:22:44,100

life so after that we got really excited

650

00:22:48,409 --> 00:22:45,419

about exoplanets cuz when everybody was

651  
00:22:50,419 --> 00:22:48,419  
getting excited about exoplanets so we

652  
00:22:52,789 --> 00:22:50,429  
and we gotta figure out where to start

653  
00:22:55,610 --> 00:22:52,799  
because there's a lot of them I think

654  
00:22:58,250 --> 00:22:55,620  
you all sympathize with that feeling and

655  
00:22:59,810 --> 00:22:58,260  
so we decided to focus on this class of

656  
00:23:02,090 --> 00:22:59,820  
planets that we apparently don't have in

657  
00:23:03,890 --> 00:23:02,100  
our solar system super simony them one

658  
00:23:05,360 --> 00:23:03,900  
of the reasons that we did that aside

659  
00:23:07,850 --> 00:23:05,370  
from the fact that there's so many of

660  
00:23:10,039 --> 00:23:07,860  
them is that I wanted to play with new

661  
00:23:13,789 --> 00:23:10,049  
molecules and so I needed new kinds of

662  
00:23:15,919 --> 00:23:13,799  
planets and so this is one of the

663  
00:23:18,470 --> 00:23:15,929

reasons why the other reason why I think

664

00:23:20,780 --> 00:23:18,480

many of you know know and potentially

665

00:23:23,570 --> 00:23:20,790

hate everyone's favorite problem child

666

00:23:25,549 --> 00:23:23,580

GJ 1214b but it was also the the period

667

00:23:26,900 --> 00:23:25,559

of time when a lot of the supers and

668

00:23:28,730 --> 00:23:26,910

many Neptune's that we weren't able to

669

00:23:30,289 --> 00:23:28,740

get observations up we're turning up

670

00:23:31,549 --> 00:23:30,299

with some kite type of particle in their

671

00:23:35,210 --> 00:23:31,559

atmospheres whether it was paid for

672

00:23:37,280 --> 00:23:35,220

clouds so we decided to focus on this

673

00:23:38,659 --> 00:23:37,290

phase space where we could really look

674

00:23:42,370 --> 00:23:38,669

at the effect of a lot of different

675

00:23:45,500 --> 00:23:42,380

molecules so we started with this matrix

676

00:23:49,010 --> 00:23:45,510

we did experiments at 300 400 and 600

677

00:23:52,039 --> 00:23:49,020

Kelvin at a hundred a thousand and ten

678

00:23:54,049 --> 00:23:52,049

thousand times solar metallicity which

679

00:23:55,430 --> 00:23:54,059

in this audience is probably an OK unit

680

00:23:58,159 --> 00:23:55,440

cheese but you can also think of them as

681

00:24:01,520 --> 00:23:58,169

being hydrogen rich water rich or co2

682

00:24:03,049 --> 00:24:01,530

rich we started with equilibrium

683

00:24:06,680 --> 00:24:03,059

calculations that were done by Julie

684

00:24:08,390 --> 00:24:06,690

Moses we don't actually yet have good

685

00:24:09,680 --> 00:24:08,400

measurements to start from to do these

686

00:24:11,000 --> 00:24:09,690

experiments like we do in the solar

687

00:24:14,150 --> 00:24:11,010

system so we thought this was a good

688

00:24:15,890 --> 00:24:14,160

good starting point and what we found

689

00:24:19,010 --> 00:24:15,900

was that we get all kinds of production

690

00:24:20,060 --> 00:24:19,020

rates so the interesting case there's a

691

00:24:22,419 --> 00:24:20,070

bunch of interesting cases to me

692

00:24:23,769 --> 00:24:22,429

actually the

693

00:24:25,509 --> 00:24:23,779

time is metallicity experiments were

694

00:24:27,519 --> 00:24:25,519

really interesting to us because of the

695

00:24:29,769 --> 00:24:27,529

following thing this grey line right

696

00:24:32,409 --> 00:24:29,779

here is our standard tighten production

697

00:24:34,090 --> 00:24:32,419

rate in our experiment so two of our

698

00:24:36,340 --> 00:24:34,100

experiments are actually have a higher

699

00:24:38,049 --> 00:24:36,350

production rate than tighten which was

700

00:24:39,310 --> 00:24:38,059

fascinating to us I don't think we ever

701  
00:24:41,109 --> 00:24:39,320  
in a million years thought any of these

702  
00:24:42,850 --> 00:24:41,119  
gas mixtures would make particles better

703  
00:24:47,200 --> 00:24:42,860  
than tighten make particles but we were

704  
00:24:48,879 --> 00:24:47,210  
wrong one of the things that these two

705  
00:24:50,919 --> 00:24:48,889  
experiments have in common is that they

706  
00:24:53,739 --> 00:24:50,929  
have quite a bit of methane in them but

707  
00:24:55,989 --> 00:24:53,749  
they also have a lot of water in the gas

708  
00:24:57,519 --> 00:24:55,999  
phase and so we weren't really sure how

709  
00:24:59,859 --> 00:24:57,529  
water was going to be interacting with

710  
00:25:01,930 --> 00:24:59,869  
the chemistry it has oxygen in it and

711  
00:25:03,700 --> 00:25:01,940  
we're still working to sort a lot of the

712  
00:25:07,869 --> 00:25:03,710  
details of this out this didn't really

713  
00:25:09,820 --> 00:25:07,879

surprise me at all actually um in part

714

00:25:11,889 --> 00:25:09,830

because we know from the solar system

715

00:25:13,810 --> 00:25:11,899

and we know from previous experiments

716

00:25:15,340 --> 00:25:13,820

that molecular hydrogen dominated gas

717

00:25:17,859 --> 00:25:15,350

mixtures just aren't as efficient at

718

00:25:19,539 --> 00:25:17,869

producing case we do see particles in

719

00:25:21,009 --> 00:25:19,549

our experiment we also see Hayes's

720

00:25:22,779 --> 00:25:21,019

Jupiter's atmosphere and Saturn's

721

00:25:24,369 --> 00:25:22,789

atmosphere they're just not great places

722

00:25:28,090 --> 00:25:24,379

from doing this type of chemistry

723

00:25:30,519 --> 00:25:28,100

because of the hydrogen this this over

724

00:25:32,019 --> 00:25:30,529

here I still don't understand this

725

00:25:35,470 --> 00:25:32,029

experiment has no methane in it

726

00:25:36,970 --> 00:25:35,480

whatsoever and still managed to convert

727

00:25:38,739 --> 00:25:36,980

some of the carbon monoxide that was in

728

00:25:41,409 --> 00:25:38,749

the gas phase into a solid that contains

729

00:25:43,509 --> 00:25:41,419

carbon which is amazing and so what I

730

00:25:45,220 --> 00:25:43,519

wanted to you to get out of this plot

731

00:25:47,200 --> 00:25:45,230

what I'm going to tell you more as we go

732

00:25:49,539 --> 00:25:47,210

along is that there are many pathways to

733

00:25:51,430 --> 00:25:49,549

making haze there are many pathways to

734

00:25:52,960 --> 00:25:51,440

similar production rates these three

735

00:25:54,909 --> 00:25:52,970

experiments have very similar production

736

00:25:58,269 --> 00:25:54,919

rates and have completely different

737

00:26:00,009 --> 00:25:58,279

chemistry happening we did the same

738

00:26:02,889 --> 00:26:00,019

thing with the UV source we saw a

739

00:26:05,230 --> 00:26:02,899

similar trend in particular this 300

740

00:26:07,119 --> 00:26:05,240

Kelvin thousand times solar metallicity

741

00:26:09,450 --> 00:26:07,129

experiment just really wants to make

742

00:26:11,529 --> 00:26:09,460

particles it's super excited about it

743

00:26:13,359 --> 00:26:11,539

another thing that we found is that the

744

00:26:15,129 --> 00:26:13,369

color of the particle is actually varies

745

00:26:17,440 --> 00:26:15,139

quite a bit depending on what gas

746

00:26:19,629 --> 00:26:17,450

mixture we're looking at I have never

747

00:26:22,180 --> 00:26:19,639

ever seen a lab experiment produce

748

00:26:23,350 --> 00:26:22,190

particles of these two colors we decided

749

00:26:25,299 --> 00:26:23,360

that's olive green and this this

750

00:26:27,070 --> 00:26:25,309

chocolate brown I don't know if I'm not

751  
00:26:28,960 --> 00:26:27,080  
speeding my research group enough or

752  
00:26:30,310 --> 00:26:28,970  
what one of my grad students didn't read

753  
00:26:33,789 --> 00:26:30,320  
that I can't tell she which direction

754  
00:26:35,409 --> 00:26:33,799  
she sees shaking her head these two

755  
00:26:36,100 --> 00:26:35,419  
experiments with the similar production

756  
00:26:38,680 --> 00:26:36,110  
rates

757  
00:26:40,900 --> 00:26:38,690  
to tighten also looks suspiciously

758  
00:26:42,700 --> 00:26:40,910  
tighten color although again I have to

759  
00:26:45,070 --> 00:26:42,710  
tell you their composition is completely

760  
00:26:46,660 --> 00:26:45,080  
different and if you want to know more

761  
00:26:50,230 --> 00:26:46,670  
about the composition you should go see

762  
00:26:52,480 --> 00:26:50,240  
Sarah Moran's poster today and so we

763  
00:26:53,920 --> 00:26:52,490

know the color varies we also know that

764

00:26:55,690 --> 00:26:53,930

the particle diameter varies in

765

00:26:57,010 --> 00:26:55,700

particular the 10,000 times metallicity

766

00:26:59,020 --> 00:26:57,020

experiments like to make much larger

767

00:27:03,220 --> 00:26:59,030

particles than we were seeing with the

768

00:27:04,810 --> 00:27:03,230

other experiments and finally we looked

769

00:27:07,120 --> 00:27:04,820

at the gas phase I promised you we would

770

00:27:10,240 --> 00:27:07,130

do that and we did this is a very busy

771

00:27:11,440 --> 00:27:10,250

plot so you can just listen to me while

772

00:27:13,270 --> 00:27:11,450

I walk you through it for a second this

773

00:27:15,820 --> 00:27:13,280

is all of the experiments I just showed

774

00:27:19,180 --> 00:27:15,830

you so all of the gas mixtures all the

775

00:27:20,860 --> 00:27:19,190

metallicity both energy sources and the

776

00:27:23,110 --> 00:27:20,870

first thing to see is that in every

777

00:27:24,990 --> 00:27:23,120

single experiment we produce organic

778

00:27:27,310 --> 00:27:25,000

molecules in the gas phase all of them

779

00:27:30,250 --> 00:27:27,320

including the one that didn't have any

780

00:27:33,610 --> 00:27:30,260

methane in it to begin with so that was

781

00:27:35,350 --> 00:27:33,620

kind of impressive in quite a few of

782

00:27:37,830 --> 00:27:35,360

them we've produced what we have

783

00:27:40,210 --> 00:27:37,840

described as prebiotic precursors

784

00:27:41,470 --> 00:27:40,220

molecules that the prebiotic chemistry

785

00:27:42,970 --> 00:27:41,480

community tends to think of as being

786

00:27:44,290 --> 00:27:42,980

important precursors things like

787

00:27:46,330 --> 00:27:44,300

hydrogen cyanide things like

788

00:27:48,160 --> 00:27:46,340

formaldehyde on these kind of small

789

00:27:51,580 --> 00:27:48,170

organic molecules that can then slimmer

790

00:27:53,530 --> 00:27:51,590

eyes or participate in other chemistry

791

00:27:55,270 --> 00:27:53,540

and then finally the things that are

792

00:27:58,990 --> 00:27:55,280

stars we actually produced a molecular

793

00:28:01,900 --> 00:27:59,000

oxygen in the gas phase and just to note

794

00:28:03,880 --> 00:28:01,910

that in all of those cases we saw

795

00:28:06,370 --> 00:28:03,890

molecular nitrogen alekhya leur oxygen

796

00:28:08,560 --> 00:28:06,380

in the presence of both these prebiotic

797

00:28:10,330 --> 00:28:08,570

precursor molecules that some people

798

00:28:13,180 --> 00:28:10,340

might also think about as biomarkers and

799

00:28:15,610 --> 00:28:13,190

organics and so that's just something

800

00:28:17,710 --> 00:28:15,620

that we need to think really hard about

801  
00:28:19,420 --> 00:28:17,720  
in terms of our understanding going

802  
00:28:21,820 --> 00:28:19,430  
forward of what of what atmospheres are

803  
00:28:24,520 --> 00:28:21,830  
capable of and so just to give you a

804  
00:28:26,230 --> 00:28:24,530  
quick summary of those experiments we

805  
00:28:28,990 --> 00:28:26,240  
found that the water the water rich or

806  
00:28:31,030 --> 00:28:29,000  
water dominated cases produce the most

807  
00:28:32,590 --> 00:28:31,040  
particles Titan like amounts of

808  
00:28:34,690 --> 00:28:32,600  
particles we know that they're different

809  
00:28:35,770 --> 00:28:34,700  
colors and so we can tell just by

810  
00:28:38,490 --> 00:28:35,780  
looking that they're going to have

811  
00:28:40,540 --> 00:28:38,500  
different different optical properties

812  
00:28:42,160 --> 00:28:40,550  
we also know that metallicity and

813  
00:28:43,870 --> 00:28:42,170

temperature both appear to matter the

814

00:28:45,430 --> 00:28:43,880

way we built this matrix is a little

815

00:28:46,780 --> 00:28:45,440

hard to think about metallicity and

816

00:28:49,630 --> 00:28:46,790

temperature because each of those

817

00:28:51,250 --> 00:28:49,640

experiments is self-consistent we had to

818

00:28:53,140 --> 00:28:51,260

the gas is an equilibrium to start

819

00:28:56,680 --> 00:28:53,150

otherwise we wouldn't have any idea what

820

00:28:57,970 --> 00:28:56,690

we were actually irradiating and so

821

00:29:00,010 --> 00:28:57,980

because of that as you change the

822

00:29:01,330 --> 00:29:00,020

metallicity as you change the

823

00:29:02,530 --> 00:29:01,340

temperature also changing the gas

824

00:29:04,180 --> 00:29:02,540

mixture as you change the metallicity

825

00:29:05,560 --> 00:29:04,190

you're also changing the gas mixture and

826

00:29:07,030 --> 00:29:05,570

so each of those is a discrete gas

827

00:29:09,100 --> 00:29:07,040

mixture so it's a little hard to study

828

00:29:11,760 --> 00:29:09,110

trend but they both seem to have an

829

00:29:14,410 --> 00:29:11,770

effect on what's happening in the

830

00:29:15,820 --> 00:29:14,420

experiment and also we see molecular

831

00:29:19,360 --> 00:29:15,830

oxygen and organics produced

832

00:29:22,030 --> 00:29:19,370

simultaneously in the gas phase so this

833

00:29:23,650 --> 00:29:22,040

is the matrix that we started with and

834

00:29:25,960 --> 00:29:23,660

this is the one that we have published

835

00:29:28,299 --> 00:29:25,970

thus far everything that I just showed

836

00:29:30,250 --> 00:29:28,309

you I'm gonna make the following request

837

00:29:32,530 --> 00:29:30,260

because I want to show you stuff that's

838

00:29:33,850 --> 00:29:32,540

new I realize this is being broadcast so

839

00:29:35,080 --> 00:29:33,860

it feels a little ridiculous but also

840

00:29:36,880 --> 00:29:35,090

those of you who are being broadcast

841

00:29:39,490 --> 00:29:36,890

please don't screenshot or tweet about

842

00:29:41,020 --> 00:29:39,500

my talk thank you please no pictures

843

00:29:43,750 --> 00:29:41,030

please no tweeting and especially no

844

00:29:46,450 --> 00:29:43,760

tweets with pictures thank you okay so

845

00:29:48,789 --> 00:29:46,460

we have been doing experiments at 800

846

00:29:50,140 --> 00:29:48,799

Kelvin um these are the gas mixtures for

847

00:29:52,150 --> 00:29:50,150

the a hundred Kelvin experiments I'm

848

00:29:54,940 --> 00:29:52,160

going to leave you wondering what

849

00:29:57,880 --> 00:29:54,950

happened in these two and focus entirely

850

00:29:59,950 --> 00:29:57,890

on this experiment right here um once we

851

00:30:01,750 --> 00:29:59,960

got up to 800 Kelvin at 10,000 times

852

00:30:04,600 --> 00:30:01,760

solar medalists equilibrium there's a

853

00:30:06,940 --> 00:30:04,610

hydrogen sulfide in the gas mixture and

854

00:30:10,419 --> 00:30:06,950

so we wanted to find out what happens

855

00:30:12,460 --> 00:30:10,429

with sulfur and so we ran these if this

856

00:30:15,880 --> 00:30:12,470

gas mixture that you see right here with

857

00:30:18,010 --> 00:30:15,890

H<sub>2</sub>S with both the plasma and the UV the

858

00:30:19,750 --> 00:30:18,020

way that we've done in the past but we

859

00:30:21,340 --> 00:30:19,760

also did experiments where we swapped

860

00:30:23,560 --> 00:30:21,350

out the height of the hydrogen sulfide

861

00:30:25,990 --> 00:30:23,570

with argon which is inert it won't do

862

00:30:29,310 --> 00:30:26,000

anything just to see what the impact of

863

00:30:32,110 --> 00:30:29,320

adding that h2s was on these experiments

864

00:30:34,360 --> 00:30:32,120

so what we find is that the presence of

865

00:30:37,090 --> 00:30:34,370

hydrogen sulfide increases the particle

866

00:30:40,960 --> 00:30:37,100

production rate in both the plasma and

867

00:30:43,750 --> 00:30:40,970

the UV this is a skinning an electron no

868

00:30:45,039 --> 00:30:43,760

atomic force microscope image of the

869

00:30:46,510 --> 00:30:45,049

disks that are sitting on the bottom of

870

00:30:49,000 --> 00:30:46,520

the chamber that we use for some of our

871

00:30:50,680 --> 00:30:49,010

other measurements you can see what the

872

00:30:54,370 --> 00:30:50,690

plasma that the particle size increased

873

00:30:55,720 --> 00:30:54,380

pretty dramatically too with the UV the

874

00:30:58,030 --> 00:30:55,730

particle the average particle size

875

00:30:59,650 --> 00:30:58,040

didn't actually change that much but the

876

00:31:01,390 --> 00:30:59,660

size distribution changed quite a bit

877

00:31:01,960 --> 00:31:01,400

and also you can see for yourself there

878

00:31:03,730 --> 00:31:01,970

are way more

879

00:31:07,920 --> 00:31:03,740

articles with the h2s them there are way

880

00:31:10,630 --> 00:31:07,930

about I cut off the blank but a blank

881

00:31:12,310 --> 00:31:10,640

disk from our experiment looks like

882

00:31:15,550 --> 00:31:12,320

completely flat there's not a single

883

00:31:16,990 --> 00:31:15,560

particle on it until the presence of h2s

884

00:31:19,510 --> 00:31:17,000

increases the particle production rate

885

00:31:20,500 --> 00:31:19,520

here's the actual measurements just to

886

00:31:22,360 --> 00:31:20,510

give you a sense of how much it's

887

00:31:26,260 --> 00:31:22,370

changing it's pretty substantial

888

00:31:27,520 --> 00:31:26,270

actually so we're you know interested in

889

00:31:29,260 --> 00:31:27,530

trying to understand the sulfur

890

00:31:30,880 --> 00:31:29,270

chemistry more putting that in the

891

00:31:32,410 --> 00:31:30,890

context of the previous work that we've

892

00:31:35,410 --> 00:31:32,420

done this is the plot I showed you with

893

00:31:37,540 --> 00:31:35,420

the original nine plasma experiments and

894

00:31:39,550 --> 00:31:37,550

I've now put the eight hundred Kelvin

895

00:31:42,670 --> 00:31:39,560

experiment on here in a color that

896

00:31:43,660 --> 00:31:42,680

apparently no one can see it goes like

897

00:31:45,130 --> 00:31:43,670

goes right over here

898

00:31:48,220 --> 00:31:45,140

just it looks it's at the bottom of the

899

00:31:51,310 --> 00:31:48,230

K if you can't see it so the interesting

900

00:31:52,930 --> 00:31:51,320

thing that I noticed now when I look at

901  
00:31:54,250 --> 00:31:52,940  
this plot having added this additional

902  
00:31:57,220 --> 00:31:54,260  
data point and also knowing what the

903  
00:31:59,650 --> 00:31:57,230  
answer is for these other suitcases is

904  
00:32:01,360 --> 00:31:59,660  
that it appears that in the 10,000 times

905  
00:32:02,830 --> 00:32:01,370  
metallicity case as we increase

906  
00:32:05,260 --> 00:32:02,840  
temperature were actually increasing

907  
00:32:07,000 --> 00:32:05,270  
production rate just the opposite of

908  
00:32:10,420 --> 00:32:07,010  
what's happening and the other two

909  
00:32:12,070 --> 00:32:10,430  
metallicity that is almost entirely to

910  
00:32:14,710 --> 00:32:12,080  
do with this addition of these extra

911  
00:32:17,680 --> 00:32:14,720  
gases that we weren't using at the lower

912  
00:32:19,030 --> 00:32:17,690  
temperatures and I think that's really

913  
00:32:21,100 --> 00:32:19,040

interesting and there's a lot more work

914

00:32:23,860 --> 00:32:21,110

to do the presence of hydrogen sulfide

915

00:32:26,020 --> 00:32:23,870

doesn't actually substantially affect

916

00:32:28,480 --> 00:32:26,030

the total amount of gas based products

917

00:32:30,340 --> 00:32:28,490

but what it does is it really decreases

918

00:32:32,800 --> 00:32:30,350

the amount of molecular oxygen present

919

00:32:34,810 --> 00:32:32,810

in the gas phase and I assume that

920

00:32:36,520 --> 00:32:34,820

that's partially that's in part due to

921

00:32:38,140 --> 00:32:36,530

the fact that the sulfur is pulling that

922

00:32:40,900 --> 00:32:38,150

out and having it participate in the

923

00:32:42,370 --> 00:32:40,910

chemistry we see all kinds of

924

00:32:45,610 --> 00:32:42,380

interesting molecules in the gas phase

925

00:32:48,160 --> 00:32:45,620

we see our favorite precursors hydrogen

926  
00:32:50,350 --> 00:32:48,170  
cyanide and formaldehyde we see two

927  
00:32:51,820 --> 00:32:50,360  
nitrile then we see a whole bunch of

928  
00:32:55,330 --> 00:32:51,830  
sulfur containing molecules the gas

929  
00:32:57,390 --> 00:32:55,340  
phase so we see methyl mercaptan which

930  
00:32:59,620 --> 00:32:57,400  
is well known for smelling delicious

931  
00:33:02,350 --> 00:32:59,630  
that was sarcasm for those of you who

932  
00:33:05,680 --> 00:33:02,360  
don't know what my captains are we see

933  
00:33:08,500 --> 00:33:05,690  
sulfur oxide we see carbonyl sulfide we

934  
00:33:10,750 --> 00:33:08,510  
see ethylene sulfide we see so<sub>2</sub> we see

935  
00:33:12,460 --> 00:33:10,760  
carbon disulfide we see the sulfur

936  
00:33:15,010 --> 00:33:12,470  
really participating in the gas phase

937  
00:33:15,550 --> 00:33:15,020  
chemistry not seeming to have much of an

938  
00:33:19,150 --> 00:33:15,560

effect

939

00:33:22,030 --> 00:33:19,160

the amount of molecular oxygen present

940

00:33:24,700 --> 00:33:22,040

in the gas phase so we're still working

941

00:33:26,500 --> 00:33:24,710

on trying to understand this and we'll

942

00:33:28,420 --> 00:33:26,510

be finishing working up the other two

943

00:33:30,670 --> 00:33:28,430

experiments this paper will hopefully be

944

00:33:32,710 --> 00:33:30,680

submitted next week so those of you who

945

00:33:34,000 --> 00:33:32,720

have been dying for sulfur experiments

946

00:33:34,770 --> 00:33:34,010

we finally did one for you you're

947

00:33:36,790 --> 00:33:34,780

welcome

948

00:33:38,350 --> 00:33:36,800

so we found that the presence of

949

00:33:40,570 --> 00:33:38,360

hydrogen sulfide increases production

950

00:33:43,030 --> 00:33:40,580

right the pressure of gas phase organics

951  
00:33:45,600 --> 00:33:43,040  
is relatively unaffected but the o2 was

952  
00:33:47,680 --> 00:33:45,610  
changing pretty pretty dramatically and

953  
00:33:49,210 --> 00:33:47,690  
for the 10,000 times metallicity

954  
00:33:50,860 --> 00:33:49,220  
experiments the production rate appears

955  
00:33:52,510 --> 00:33:50,870  
to increase as a function of increasing

956  
00:33:53,980 --> 00:33:52,520  
temperature which we think is the

957  
00:33:57,040 --> 00:33:53,990  
opposite of what's happening with the

958  
00:33:59,350 --> 00:33:57,050  
other two metallicity  $x'$  and so that

959  
00:34:01,690 --> 00:33:59,360  
just goes to show that the composition

960  
00:34:03,670 --> 00:34:01,700  
of the gases in your experiment really

961  
00:34:06,010 --> 00:34:03,680  
matters in terms of what kinds of

962  
00:34:07,570 --> 00:34:06,020  
particles there are and how many but

963  
00:34:10,210 --> 00:34:07,580

that also shows that there are so many

964

00:34:11,980 --> 00:34:10,220

different pathways for haze formation so

965

00:34:13,870 --> 00:34:11,990

real quick just to say what's next for

966

00:34:15,370 --> 00:34:13,880

these experiments I mentioned that you

967

00:34:17,440 --> 00:34:15,380

can go see some of the particle

968

00:34:19,810 --> 00:34:17,450

composition results unfortunately not

969

00:34:22,690 --> 00:34:19,820

the sulphur ones you had the the rest of

970

00:34:24,100 --> 00:34:22,700

the matrix is on Sara's post or at least

971

00:34:25,690 --> 00:34:24,110

the ones that cooperated with our

972

00:34:29,889 --> 00:34:25,700

measurement techniques which was not all

973

00:34:30,760 --> 00:34:29,899

of them she's shaking her head yeah and

974

00:34:32,470 --> 00:34:30,770

then the other thing we're gonna be

975

00:34:34,270 --> 00:34:32,480

doing for these is optical constants

976  
00:34:36,310 --> 00:34:34,280  
measurement so we'll actually do

977  
00:34:38,520 --> 00:34:36,320  
measurements in the UV too but the

978  
00:34:40,960 --> 00:34:38,530  
interwebz showing you right here can do

979  
00:34:42,909 --> 00:34:40,970  
optical constants from 400 nanometers to

980  
00:34:44,440 --> 00:34:42,919  
25 microns and we're gonna be doing the

981  
00:34:47,649 --> 00:34:44,450  
measurements at the temperature that the

982  
00:34:50,380 --> 00:34:47,659  
experiment was run because we have a

983  
00:34:53,770 --> 00:34:50,390  
cryostat on our instrument that can do

984  
00:34:55,480 --> 00:34:53,780  
from 3 to 800 Kelvin and try explaining

985  
00:34:57,070 --> 00:34:55,490  
to a Christ company why you want to

986  
00:34:59,560 --> 00:34:57,080  
Christ out that goes from 3 to 800

987  
00:35:03,010 --> 00:34:59,570  
Kelvin I just want to do a whole solar

988  
00:35:04,570 --> 00:35:03,020

system not too much to ask and so we'll

989

00:35:08,020 --> 00:35:04,580

be doing those a temperature hopefully

990

00:35:10,120 --> 00:35:08,030

that'll be done sometime around the

991

00:35:11,800 --> 00:35:10,130

beginning of next year and so we'll have

992

00:35:17,560 --> 00:35:11,810

optic optical constants from these

993

00:35:20,140 --> 00:35:17,570

particles as well sorry

994

00:35:21,640 --> 00:35:20,150

so I talked to you about experiments

995

00:35:24,760 --> 00:35:21,650

with carbon monoxide I talked you about

996

00:35:26,140 --> 00:35:24,770

experiments with water with  $\text{CO}_2$  and so

997

00:35:27,850 --> 00:35:26,150

that's like a good chunk of our oxygen

998

00:35:29,420 --> 00:35:27,860

containing molecules which I was really

999

00:35:31,760 --> 00:35:29,430

interested in

1000

00:35:33,050 --> 00:35:31,770

but I also wanted to go all the way all

1001  
00:35:35,540 --> 00:35:33,060  
the way to that to the edge of the

1002  
00:35:36,890 --> 00:35:35,550  
oxidation states and so a couple years

1003  
00:35:38,930 --> 00:35:36,900  
ago I did some experiments with

1004  
00:35:41,570 --> 00:35:38,940  
molecular oxygen ray and I collaborated

1005  
00:35:43,700 --> 00:35:41,580  
on this paper to try to actually think

1006  
00:35:45,650 --> 00:35:43,710  
about what was happening in the early

1007  
00:35:47,599 --> 00:35:45,660  
Earth which we heard of some a little

1008  
00:35:49,099 --> 00:35:47,609  
bit about this morning but this is also

1009  
00:35:50,570 --> 00:35:49,109  
relevant for thinking about extrasolar

1010  
00:35:53,480 --> 00:35:50,580  
planets in terms of what might happen

1011  
00:35:56,570 --> 00:35:53,490  
either in atmospheres that have a

1012  
00:35:58,099 --> 00:35:56,580  
nascent biosphere on their surface or

1013  
00:35:59,570 --> 00:35:58,109

thinking about what happens when you

1014

00:36:02,630 --> 00:35:59,580

might see the signal of molecular oxygen

1015

00:36:03,740 --> 00:36:02,640

in an atmosphere so we wanted to know if

1016

00:36:06,050 --> 00:36:03,750

haze could exist during the rise of

1017

00:36:08,240 --> 00:36:06,060

oxygen so this is an early early Earth

1018

00:36:10,450 --> 00:36:08,250

this is like things have started making

1019

00:36:13,490 --> 00:36:10,460

oxygen there's just not a lot of it yet

1020

00:36:14,720 --> 00:36:13,500

and part of the reason again that I was

1021

00:36:16,580 --> 00:36:14,730

interested in trying to do this is

1022

00:36:18,560 --> 00:36:16,590

because we have this idea that oxidized

1023

00:36:21,950 --> 00:36:18,570

atmospheres are less favorable for

1024

00:36:23,900 --> 00:36:21,960

photochemical haze production um and as

1025

00:36:25,370 --> 00:36:23,910

I think I've already shown you not all

1026

00:36:27,170 --> 00:36:25,380

is it all not all oxygen bearing

1027

00:36:29,150 --> 00:36:27,180

molecules are this and so we wanted to

1028

00:36:30,920 --> 00:36:29,160

figure out what happened with o2 this

1029

00:36:32,780 --> 00:36:30,930

next plot is super complicated so I'm

1030

00:36:34,520 --> 00:36:32,790

going to step you through it before just

1031

00:36:37,760 --> 00:36:34,530

throwing the whole thing at you at the

1032

00:36:39,800 --> 00:36:37,770

end so this is this set of experiments

1033

00:36:41,900 --> 00:36:39,810

right here only have methane and

1034

00:36:44,180 --> 00:36:41,910

nitrogen there's no oxygen containing

1035

00:36:47,390 --> 00:36:44,190

molecules new experiment these are the

1036

00:36:49,490 --> 00:36:47,400

methane abundances and you can see the

1037

00:36:51,740 --> 00:36:49,500

production rates there you know doing

1038

00:36:54,500 --> 00:36:51,750

their thing they're doing a well known

1039

00:36:56,480 --> 00:36:54,510

thing in fact we know that in the lab

1040

00:36:59,060 --> 00:36:56,490

with a UV source which is what we're

1041

00:37:00,770 --> 00:36:59,070

using that most people see that there's

1042

00:37:02,270 --> 00:37:00,780

a peak in the aerosol production rate

1043

00:37:05,480 --> 00:37:02,280

somewhere around point one percent

1044

00:37:08,000 --> 00:37:05,490

methane before it turns back over we

1045

00:37:09,260 --> 00:37:08,010

think here this is a lack of carbon and

1046

00:37:11,930 --> 00:37:09,270

so the more you put in the more

1047

00:37:13,400 --> 00:37:11,940

particles you get this is probably to do

1048

00:37:15,650 --> 00:37:13,410

with the fact that you start having

1049

00:37:16,940 --> 00:37:15,660

shielding from methane and so the

1050

00:37:18,260 --> 00:37:16,950

photons can't participate in the

1051  
00:37:20,599 --> 00:37:18,270  
chemistry can't drive the chemistry as

1052  
00:37:22,849 --> 00:37:20,609  
much so this does what we already knew

1053  
00:37:26,180 --> 00:37:22,859  
it would do that was good then we

1054  
00:37:28,190 --> 00:37:26,190  
started adding co2 and in all cases in

1055  
00:37:29,810 --> 00:37:28,200  
these experiments there is more co2 in

1056  
00:37:31,640 --> 00:37:29,820  
the gas phase than there is methane

1057  
00:37:34,010 --> 00:37:31,650  
except for the experiment that didn't

1058  
00:37:35,570 --> 00:37:34,020  
have any co2 and we turn this been

1059  
00:37:36,890 --> 00:37:35,580  
demonstrated before that when you put

1060  
00:37:39,410 --> 00:37:36,900  
co2 in the gas mixture

1061  
00:37:41,270 --> 00:37:39,420  
unlike Co you do decrease particle

1062  
00:37:41,829 --> 00:37:41,280  
formation you do decrease the production

1063  
00:37:43,749 --> 00:37:41,839

rate

1064

00:37:46,299 --> 00:37:43,759

so those are those points so now we have

1065

00:37:48,309 --> 00:37:46,309

only methane and nitrogen then we have

1066

00:37:52,959 --> 00:37:48,319

methane nitrogen co2 and now we're gonna

1067

00:37:54,999 --> 00:37:52,969

add otwo to the gas mixture and we start

1068

00:37:58,199 --> 00:37:55,009

with a very small amount only about two

1069

00:38:01,449 --> 00:37:58,209

parts per million and went up 2.2%

1070

00:38:03,670 --> 00:38:01,459

interestingly putting a tiny amount of

1071

00:38:06,549 --> 00:38:03,680

oxygen in the gas mixture actually makes

1072

00:38:07,959 --> 00:38:06,559

the production rate go up I suspect

1073

00:38:09,969 --> 00:38:07,969

that's to do with this point that I

1074

00:38:11,650 --> 00:38:09,979

already brought up about oxygen

1075

00:38:13,179 --> 00:38:11,660

containing molecules being useful for

1076

00:38:15,880 --> 00:38:13,189

pulling molecular hydrogen out of the

1077

00:38:18,789 --> 00:38:15,890

gas phase and then as we put more

1078

00:38:20,109 --> 00:38:18,799

molecular oxygen into the gas we had a

1079

00:38:21,579 --> 00:38:20,119

decrease in production rate which is

1080

00:38:23,289 --> 00:38:21,589

probably not surprising because it was

1081

00:38:24,459 --> 00:38:23,299

what everybody thought all along but

1082

00:38:26,739 --> 00:38:24,469

nobody had ever actually done the

1083

00:38:28,390 --> 00:38:26,749

experiment to show that but just to give

1084

00:38:30,519 --> 00:38:28,400

you a sense of what the production rates

1085

00:38:31,599 --> 00:38:30,529

look like this is our standard tight in

1086

00:38:34,059 --> 00:38:31,609

the experiment and that in that

1087

00:38:36,519 --> 00:38:34,069

particular setup so actually a bunch of

1088

00:38:38,679 --> 00:38:36,529

these experiments have have a higher

1089

00:38:40,630 --> 00:38:38,689

production rate than Titan which is

1090

00:38:42,699 --> 00:38:40,640

super super interesting because as I

1091

00:38:46,689 --> 00:38:42,709

mentioned there's more co2 in these

1092

00:38:48,189 --> 00:38:46,699

experiments and there is methane this is

1093

00:38:50,650 --> 00:38:48,199

what the lab looked like one of the days

1094

00:38:53,019 --> 00:38:50,660

that I was doing the experiment you can

1095

00:38:56,140 --> 00:38:53,029

see down to the end of the lab so it's

1096

00:38:57,729 --> 00:38:56,150

not particularly hazy which is good

1097

00:39:01,029 --> 00:38:57,739

because I spent three years breathing

1098

00:39:03,549 --> 00:39:01,039

that air for about ten hours a day and

1099

00:39:04,959 --> 00:39:03,559

then just to give you a sense that these

1100

00:39:07,329 --> 00:39:04,969

are these are real we are actually

1101  
00:39:09,069 --> 00:39:07,339  
making particles this is what the gases

1102  
00:39:10,509 --> 00:39:09,079  
look like when they ran all the way

1103  
00:39:12,640 --> 00:39:10,519  
through the experiment without the

1104  
00:39:14,289 --> 00:39:12,650  
energy source on and so in every single

1105  
00:39:16,689 --> 00:39:14,299  
one of these experiments including the

1106  
00:39:18,880 --> 00:39:16,699  
ones that had point 2% molecular oxygen

1107  
00:39:19,390 --> 00:39:18,890  
we were still making particles in the

1108  
00:39:21,339 --> 00:39:19,400  
atmosphere

1109  
00:39:23,319 --> 00:39:21,349  
I hope the take-home message from that

1110  
00:39:25,359 --> 00:39:23,329  
is particles like atmospheres really

1111  
00:39:27,429 --> 00:39:25,369  
want to make particles like you give

1112  
00:39:29,019 --> 00:39:27,439  
gases photons and they want to they want

1113  
00:39:31,269 --> 00:39:29,029

to convert some of those gases into

1114

00:39:33,789 --> 00:39:31,279

solid it's just a question of how much

1115

00:39:35,049 --> 00:39:33,799

and by which pathways it turns out a lot

1116

00:39:38,229 --> 00:39:35,059

of really interesting things happen when

1117

00:39:40,150 --> 00:39:38,239

we look at the particles too so when we

1118

00:39:41,739 --> 00:39:40,160

looked at the composition of the

1119

00:39:44,319 --> 00:39:41,749

particles we see that the addition of

1120

00:39:46,599 --> 00:39:44,329

molecular oxygen increases nitrogen

1121

00:39:48,549 --> 00:39:46,609

fixation and so all of a sudden the

1122

00:39:51,429 --> 00:39:48,559

nitrogen is participating more actively

1123

00:39:53,169 --> 00:39:51,439

in the solid phase and so we're actually

1124

00:39:54,930 --> 00:39:53,179

I see one person really appreciating

1125

00:39:57,240 --> 00:39:54,940

what I'm saying right now thank you

1126

00:39:59,400 --> 00:39:57,250

maybe the recipe r2 but if someone

1127

00:40:00,809 --> 00:39:59,410

really got what I was about to say and

1128

00:40:02,400 --> 00:40:00,819

so what we see in these particles that

1129

00:40:04,799 --> 00:40:02,410

are produced as much oxygen factual

1130

00:40:07,920 --> 00:40:04,809

information of organic nitrate in the

1131

00:40:09,150 --> 00:40:07,930

atmosphere from photochemistry and

1132

00:40:11,160 --> 00:40:09,160

actually during a period of Earth's

1133

00:40:13,020 --> 00:40:11,170

history when organic nitrate may have

1134

00:40:16,380 --> 00:40:13,030

been a useful thing to have raining from

1135

00:40:17,789 --> 00:40:16,390

the sky so that's cool and then one of

1136

00:40:20,370 --> 00:40:17,799

the other things that I really want to

1137

00:40:21,720 --> 00:40:20,380

emphasize about this work because I

1138

00:40:24,750 --> 00:40:21,730

think it's important for this discussion

1139

00:40:26,609 --> 00:40:24,760

discussion of optical properties for

1140

00:40:29,010 --> 00:40:26,619

those of you think about nnk I put this

1141

00:40:30,690 --> 00:40:29,020

here for you and this here for you for

1142

00:40:32,480 --> 00:40:30,700

those who don't think about nnk I'm

1143

00:40:35,910 --> 00:40:32,490

going to tell you what you are seeing

1144

00:40:37,859 --> 00:40:35,920

when we put oxygen into these

1145

00:40:40,020 --> 00:40:37,869

experiments even relatively small

1146

00:40:42,569 --> 00:40:40,030

amounts of oxygen we converted these

1147

00:40:44,099 --> 00:40:42,579

Brown gunky particles that everyone is

1148

00:40:45,960 --> 00:40:44,109

familiar with that I already showed you

1149

00:40:49,230 --> 00:40:45,970

a bunch of pictures of into particles

1150

00:40:51,569 --> 00:40:49,240

that do not absorb photons period end of

1151

00:40:53,970 --> 00:40:51,579

discussion like they are highly

1152

00:40:55,380 --> 00:40:53,980

reflective effectively having teeny tiny

1153

00:40:58,170 --> 00:40:55,390

mirrors floating around in the

1154

00:41:00,029 --> 00:40:58,180

atmosphere just with the addition of a

1155

00:41:02,640 --> 00:41:00,039

little bit of molecular oxygen into the

1156

00:41:03,930 --> 00:41:02,650

gas phase this is super important for

1157

00:41:05,940 --> 00:41:03,940

this period of time in early Earth's

1158

00:41:08,190 --> 00:41:05,950

history but it's also just to

1159

00:41:10,440 --> 00:41:08,200

demonstrate that small changes in the

1160

00:41:12,180 --> 00:41:10,450

composition of the atmosphere can result

1161

00:41:14,130 --> 00:41:12,190

in huge changes in the optical

1162

00:41:15,779 --> 00:41:14,140

properties of the particles which is one

1163

00:41:17,220 --> 00:41:15,789

of the reasons why we need more optical

1164

00:41:19,170 --> 00:41:17,230

constants measurements so that you're

1165

00:41:21,420 --> 00:41:19,180

not all stuck with that one paper from

1166

00:41:22,980 --> 00:41:21,430

1984 which I suspect in this audience

1167

00:41:26,670 --> 00:41:22,990

may actually have been before quite a

1168

00:41:27,779 --> 00:41:26,680

few of you were born yeah no I know some

1169

00:41:31,289 --> 00:41:27,789

of you are laughing uncomfortably you

1170

00:41:32,700 --> 00:41:31,299

know it's true and so just to give you a

1171

00:41:35,039 --> 00:41:32,710

quick summary of what we learned for the

1172

00:41:36,480 --> 00:41:35,049

like Euler oxygen experiment we know

1173

00:41:39,269 --> 00:41:36,490

that with relatively small amounts of

1174

00:41:40,799 --> 00:41:39,279

methane we can produce aerosol in the

1175

00:41:43,260 --> 00:41:40,809

lab with up to 200 parts per million

1176

00:41:45,029 --> 00:41:43,270

oxygen present in the gas mixture in

1177

00:41:48,150 --> 00:41:45,039

those experiments not only is there more

1178

00:41:50,309 --> 00:41:48,160

co2 present in the gas mixture than

1179

00:41:52,049 --> 00:41:50,319

methane there is more Oh to present in

1180

00:41:54,960 --> 00:41:52,059

the gas mixture than methane and we're

1181

00:41:56,819 --> 00:41:54,970

still making particles as the oxygen

1182

00:41:58,620 --> 00:41:56,829

concentration increases the aerosol

1183

00:42:01,890 --> 00:41:58,630

becomes increasingly oxygen and nitrogen

1184

00:42:03,150 --> 00:42:01,900

rich and then the addition of oxygen

1185

00:42:05,099 --> 00:42:03,160

results in an increase in nitrogen

1186

00:42:08,059 --> 00:42:05,109

fixation which is cool so the chemistry

1187

00:42:09,229 --> 00:42:08,069

is really changing and

1188

00:42:10,910 --> 00:42:09,239

finally the addition of this small

1189

00:42:12,739 --> 00:42:10,920

amount of o2 results in particles that

1190

00:42:14,749 --> 00:42:12,749

don't absorb photons which is super

1191

00:42:16,130 --> 00:42:14,759

weird like we didn't believe it so we

1192

00:42:19,609 --> 00:42:16,140

checked it with another technique just

1193

00:42:21,439 --> 00:42:19,619

to be sure and that said the same thing

1194

00:42:24,289 --> 00:42:21,449

so I want to go back to this picture

1195

00:42:27,349 --> 00:42:24,299

that we started with that we kind of

1196

00:42:29,870 --> 00:42:27,359

came out of this you know era of Titan

1197

00:42:32,449 --> 00:42:29,880

with this idea that organic haze is

1198

00:42:37,640 --> 00:42:32,459

produced from methane photochemistry it

1199

00:42:38,900 --> 00:42:37,650

mildly reduced atmospheres I hope after

1200

00:42:40,549 --> 00:42:38,910

telling you about all of those

1201  
00:42:42,229 --> 00:42:40,559  
experiments which I actually got through

1202  
00:42:45,769 --> 00:42:42,239  
miraculously probably because I talked

1203  
00:42:46,999 --> 00:42:45,779  
to you fast there are many many pathways

1204  
00:42:49,309 --> 00:42:47,009  
for the generation of photochemical

1205  
00:42:51,739 --> 00:42:49,319  
Hayes's some of those pathways don't

1206  
00:42:55,699 --> 00:42:51,749  
even require there to be methane in the

1207  
00:42:57,979 --> 00:42:55,709  
gas mixture to begin with some of those

1208  
00:43:00,380 --> 00:42:57,989  
pathways go against all conventional

1209  
00:43:02,660 --> 00:43:00,390  
wisdom that we have ever had about how

1210  
00:43:06,349 --> 00:43:02,670  
chemistry works in terms of converting

1211  
00:43:07,400 --> 00:43:06,359  
gases into particles like I said there

1212  
00:43:10,370 --> 00:43:07,410  
appeared to be a pathways that don't

1213  
00:43:12,769 --> 00:43:10,380

require methane oxygen very molecules

1214

00:43:15,799 --> 00:43:12,779

each play a really unique role in haze

1215

00:43:19,069 --> 00:43:15,809

formation I think this is happening for

1216

00:43:20,569 --> 00:43:19,079

a few different reasons I think one of

1217

00:43:22,699 --> 00:43:20,579

the main reasons that it's happening is

1218

00:43:24,829 --> 00:43:22,709

because if you look at the absorption

1219

00:43:27,380 --> 00:43:24,839

spectra of oxygen containing molecules

1220

00:43:29,959 --> 00:43:27,390

we've seen a couple of them over the

1221

00:43:32,779 --> 00:43:29,969

past day and a half they all interact

1222

00:43:34,279 --> 00:43:32,789

with light very very differently and so

1223

00:43:36,229 --> 00:43:34,289

the fact that they're absorbing photons

1224

00:43:38,959 --> 00:43:36,239

of different wavelengths really affects

1225

00:43:40,459 --> 00:43:38,969

how the photochemistry proceed in part

1226

00:43:41,839 --> 00:43:40,469

because we need both the short

1227

00:43:44,180 --> 00:43:41,849

wavelength photons to start the

1228

00:43:46,969 --> 00:43:44,190

chemistry to break things like molecular

1229

00:43:48,910 --> 00:43:46,979

nitrogen which has a triple bond but we

1230

00:43:51,890 --> 00:43:48,920

also need a longer wavelength photons to

1231

00:43:53,660 --> 00:43:51,900

keep the chemistry going so to take

1232

00:43:56,239 --> 00:43:53,670

things like ethane and acetylene and

1233

00:43:58,009 --> 00:43:56,249

benzene and break them up and continue

1234

00:44:00,439 --> 00:43:58,019

the chemistry so we need we need all of

1235

00:44:01,910 --> 00:44:00,449

the photons we need all the UV photons

1236

00:44:03,229 --> 00:44:01,920

anyway I don't care about the visible

1237

00:44:06,499 --> 00:44:03,239

ones they can go do whatever they want

1238

00:44:08,959 --> 00:44:06,509

to do I want all the UV photon and so

1239

00:44:10,699 --> 00:44:08,969

the way in which that the gases interact

1240

00:44:12,769 --> 00:44:10,709

with the UV photons really matters and

1241

00:44:15,739 --> 00:44:12,779

this is also a really important lesson

1242

00:44:16,729 --> 00:44:15,749

for thinking about exoplanets because we

1243

00:44:19,549 --> 00:44:16,739

have all these different kinds of

1244

00:44:20,989 --> 00:44:19,559

stuffers which is really annoying I'm

1245

00:44:21,920 --> 00:44:20,999

super excited about it because they're

1246

00:44:23,599 --> 00:44:21,930

each their own little

1247

00:44:25,000 --> 00:44:23,609

experiment about what happens when you

1248

00:44:27,140 --> 00:44:25,010

were radiate with different way looks

1249

00:44:29,059 --> 00:44:27,150

but that's very hard to replicate in the

1250

00:44:30,890 --> 00:44:29,069

lab and it says something that we have

1251  
00:44:32,660 --> 00:44:30,900  
to think about I think the other reason

1252  
00:44:34,309 --> 00:44:32,670  
that the Austin Berry molecules each do

1253  
00:44:35,930 --> 00:44:34,319  
something really different is because

1254  
00:44:39,620 --> 00:44:35,940  
once they are fragmented once they do

1255  
00:44:41,390 --> 00:44:39,630  
interact with photon the pieces that

1256  
00:44:42,799 --> 00:44:41,400  
produced are very different chemically

1257  
00:44:45,260 --> 00:44:42,809  
and are going to participate in

1258  
00:44:46,220 --> 00:44:45,270  
chemistry in very different ways one of

1259  
00:44:47,750 --> 00:44:46,230  
the reasons that I really want to

1260  
00:44:50,059 --> 00:44:47,760  
emphasize the oxygen bearing molecules

1261  
00:44:51,740 --> 00:44:50,069  
also is that we have a habit and this

1262  
00:44:53,359 --> 00:44:51,750  
happens in the solar system to of

1263  
00:44:56,240 --> 00:44:53,369

thinking about Hayes formation in terms

1264

00:44:57,920 --> 00:44:56,250  
of the sitio ratio in the gases and

1265

00:45:00,740 --> 00:44:57,930  
there's lots of different ways to get

1266

00:45:02,329 --> 00:45:00,750  
specific field ratios depending on which

1267

00:45:05,620 --> 00:45:02,339  
oxygen containing molecules are looking

1268

00:45:07,910 --> 00:45:05,630  
at and so that probably isn't the best

1269

00:45:09,740 --> 00:45:07,920  
metric for thinking about whether or not

1270

00:45:12,680 --> 00:45:09,750  
an atmosphere would be favorable for

1271

00:45:14,420 --> 00:45:12,690  
hayes formation it turned out that

1272

00:45:16,700 --> 00:45:14,430  
oxidized atmospheres may also be

1273

00:45:19,670 --> 00:45:16,710  
favorable for his formation depending on

1274

00:45:21,349 --> 00:45:19,680  
other things about them what is the

1275

00:45:24,740 --> 00:45:21,359  
temperature what does their star look

1276

00:45:26,089 --> 00:45:24,750

like what other gases are present like I

1277

00:45:28,880 --> 00:45:26,099

said with this hydrogen sulfide

1278

00:45:31,039 --> 00:45:28,890

experiment now we're seeing that you can

1279

00:45:32,660 --> 00:45:31,049

have a co2 dominated atmosphere that

1280

00:45:34,700 --> 00:45:32,670

still actually is pretty efficient at

1281

00:45:38,000 --> 00:45:34,710

producing particles because we have this

1282

00:45:41,020 --> 00:45:38,010

new atom in the gas mixture that's

1283

00:45:44,210 --> 00:45:41,030

really good at building things and

1284

00:45:46,490 --> 00:45:44,220

finally one other thing to point out and

1285

00:45:48,200 --> 00:45:46,500

we had a discussion about the the ways

1286

00:45:50,720 --> 00:45:48,210

in which Earth's atmosphere has been up

1287

00:45:52,220 --> 00:45:50,730

to shenanigans over its history earlier

1288

00:45:55,490 --> 00:45:52,230

today but as the planet atmosphere

1289

00:45:56,690 --> 00:45:55,500

evolves its haze will - and one of the

1290

00:45:57,890 --> 00:45:56,700

things that we know about planetary

1291

00:46:00,650 --> 00:45:57,900

atmospheres is that they're constantly

1292

00:46:02,390 --> 00:46:00,660

evolving over time because they are

1293

00:46:04,940 --> 00:46:02,400

undergoing atmospheric escape because

1294

00:46:06,319 --> 00:46:04,950

there may be changes from volcanism or

1295

00:46:08,299 --> 00:46:06,329

from impacts or all these other things

1296

00:46:10,039 --> 00:46:08,309

so the composition is always changing

1297

00:46:12,200 --> 00:46:10,049

and that means that the possibility that

1298

00:46:13,970 --> 00:46:12,210

there's going to be a haze layer present

1299

00:46:15,859 --> 00:46:13,980

or not will also change over time and

1300

00:46:18,470 --> 00:46:15,869

that's something really complicated that

1301

00:46:22,039 --> 00:46:18,480

we have to think about so the moral of

1302

00:46:24,309 --> 00:46:22,049

the story for this slide is basically

1303

00:46:26,690 --> 00:46:24,319

that there's still a lot of work to do

1304

00:46:28,880 --> 00:46:26,700

and in part the reason that there's

1305

00:46:30,440 --> 00:46:28,890

still so much work to do is that we

1306

00:46:34,460 --> 00:46:30,450

can't calculate any of these things from

1307

00:46:35,170 --> 00:46:34,470

first principles and so we really need a

1308

00:46:36,880 --> 00:46:35,180

robust

1309

00:46:39,609 --> 00:46:36,890

experimental and theoretical framework

1310

00:46:42,190 --> 00:46:39,619

to try to understand how gases convert

1311

00:46:43,630 --> 00:46:42,200

into particles and right now the only

1312

00:46:45,760 --> 00:46:43,640

place that we really have a good

1313

00:46:47,290 --> 00:46:45,770

framework for that is Earth and the

1314

00:46:49,710 --> 00:46:47,300

reason for that is because the earth

1315

00:46:52,450 --> 00:46:49,720

community has spent so much time

1316

00:46:53,790 --> 00:46:52,460

meticulously figuring out how every gas

1317

00:46:56,049 --> 00:46:53,800

that matters in Earth's atmosphere

1318

00:46:58,420 --> 00:46:56,059

interacts with every particle that

1319

00:46:59,710 --> 00:46:58,430

matters in Earth's atmosphere I've asked

1320

00:47:01,000 --> 00:46:59,720

them if they could do it for the rest of

1321

00:47:02,670 --> 00:47:01,010

the universe and they kind of rolled

1322

00:47:05,799 --> 00:47:02,680

their eyes at me

1323

00:47:07,270 --> 00:47:05,809

but this is kind of I think you know our

1324

00:47:09,549 --> 00:47:07,280

first baby steps forward and she's

1325

00:47:11,890 --> 00:47:09,559

trying to understand bigger picture how

1326  
00:47:15,370 --> 00:47:11,900  
haze formation precedes so that we are

1327  
00:47:17,500 --> 00:47:15,380  
able to actually bridge this gap that we

1328  
00:47:19,900 --> 00:47:17,510  
have between the small molecules that

1329  
00:47:21,190 --> 00:47:19,910  
we're pretty good at modeling and the

1330  
00:47:22,990 --> 00:47:21,200  
particles that are large enough that we

1331  
00:47:24,880 --> 00:47:23,000  
can start thinking about them in terms

1332  
00:47:27,130 --> 00:47:24,890  
of micro physics rather than chemistry

1333  
00:47:29,859 --> 00:47:27,140  
but there's a huge gap between those

1334  
00:47:31,540 --> 00:47:29,869  
those two things we haven't solved it in

1335  
00:47:34,270 --> 00:47:31,550  
the solar system we don't know how that

1336  
00:47:36,579 --> 00:47:34,280  
works on Titan I'm hoping that something

1337  
00:47:37,780 --> 00:47:36,589  
that is happening soon see I was going

1338  
00:47:41,079 --> 00:47:37,790

to sneak it in you all knew I was gonna

1339

00:47:43,420 --> 00:47:41,089

stick it in will help us to bridge that

1340

00:47:46,750 --> 00:47:43,430

gap by actually measuring the real

1341

00:47:48,220 --> 00:47:46,760

particles in a real place but until then

1342

00:47:50,980 --> 00:47:48,230

we don't really have that framework

1343

00:47:52,299 --> 00:47:50,990

anywhere not just for exoplanets but

1344

00:47:53,500 --> 00:47:52,309

also in the solar system and so

1345

00:47:55,720 --> 00:47:53,510

something that we have to keep in mind

1346

00:48:00,700 --> 00:47:55,730

when we're thinking about haze formation

1347

00:48:06,099 --> 00:48:00,710

and I think I'm almost out of time well

1348

00:48:07,660 --> 00:48:06,109

I could tap dance before you know I am

1349

00:48:11,640 --> 00:48:07,670

good I would love to take questions

1350

00:48:11,650 --> 00:48:15,220

[Music]

1351

00:48:15,230 --> 00:48:21,700

so we have a lot of questions so yeah

1352

00:48:26,120 --> 00:48:24,530

naked main university Rickster sorry

1353

00:48:28,460 --> 00:48:26,130

this is a really basic question about

1354

00:48:30,800 --> 00:48:28,470

the experimental setup I think I was

1355

00:48:32,420 --> 00:48:30,810

misled a little bit at one point so when

1356

00:48:34,970 --> 00:48:32,430

you were showing the images of particles

1357

00:48:37,520 --> 00:48:34,980

on the surface when you're forming these

1358

00:48:39,530 --> 00:48:37,530

things do they form on the surfaces

1359

00:48:41,270 --> 00:48:39,540

inside the experiment is that acting as

1360

00:48:42,980 --> 00:48:41,280

a catalyst accelerate it was it straight

1361

00:48:45,200 --> 00:48:42,990

out of the ground so one of the things

1362

00:48:47,030 --> 00:48:45,210

that determines the pressure in our

1363

00:48:49,040 --> 00:48:47,040

experiment which I didn't say which is a

1364

00:48:51,620 --> 00:48:49,050

millibar so there you go now you know

1365

00:48:53,660 --> 00:48:51,630

that - it's trying to make sure that all

1366

00:48:56,150 --> 00:48:53,670

of the chemistry all the molecules as

1367

00:48:58,010 --> 00:48:56,160

they're participating chemistry are

1368

00:49:00,140 --> 00:48:58,020

colliding more often with themselves in

1369

00:49:01,940 --> 00:49:00,150

the wall but also make sure that the

1370

00:49:03,440 --> 00:49:01,950

particles are actually forming not on

1371

00:49:05,420 --> 00:49:03,450

the wall but in the experiments

1372

00:49:07,130 --> 00:49:05,430

themselves so something that people have

1373

00:49:09,050 --> 00:49:07,140

spent a lot of time and effort trying to

1374

00:49:11,510 --> 00:49:09,060

make sure if we don't actually have like

1375

00:49:13,490 --> 00:49:11,520

giant stainless steel surfaces I'm in

1376  
00:49:15,620 --> 00:49:13,500  
real atmosphere but that is something

1377  
00:49:16,940 --> 00:49:15,630  
that we have to think about quite a bit

1378  
00:49:19,089 --> 00:49:16,950  
and do spend a lot of time worrying

1379  
00:49:21,410 --> 00:49:19,099  
about but the particles are made

1380  
00:49:22,880 --> 00:49:21,420  
effectively in suspension and that's

1381  
00:49:24,500 --> 00:49:22,890  
part of actually what sets their size so

1382  
00:49:26,450 --> 00:49:24,510  
I meant to say this earlier it came up

1383  
00:49:27,710 --> 00:49:26,460  
this morning I think this morning I'm

1384  
00:49:30,710 --> 00:49:27,720  
trying to lose track of time I'm a

1385  
00:49:32,420 --> 00:49:30,720  
little jet-lagged but one of the one of

1386  
00:49:34,700 --> 00:49:32,430  
the things that is challenging is that

1387  
00:49:36,500 --> 00:49:34,710  
although we're trying very very hard to

1388  
00:49:38,450 --> 00:49:36,510

mimic the chemical processes correctly

1389

00:49:40,819 --> 00:49:38,460

we're not bothering with the physical

1390

00:49:42,380 --> 00:49:40,829

processes they're all and so when we

1391

00:49:43,849 --> 00:49:42,390

look at the size distributions one of

1392

00:49:46,160 --> 00:49:43,859

this that we're really concerned about

1393

00:49:48,109 --> 00:49:46,170

the size distributions is to compare

1394

00:49:49,220 --> 00:49:48,119

them to other experiments to say okay

1395

00:49:51,410 --> 00:49:49,230

these particles are bigger these

1396

00:49:52,760 --> 00:49:51,420

particles are smaller in a real

1397

00:49:55,670 --> 00:49:52,770

atmosphere the particles have the

1398

00:49:57,589 --> 00:49:55,680

opportunity to stick they can form

1399

00:49:58,910 --> 00:49:57,599

larger spherical particles or they may

1400

00:50:00,440 --> 00:49:58,920

stick and form these beautiful fractal

1401  
00:50:02,240 --> 00:50:00,450  
aggregates that we think are present in

1402  
00:50:03,620 --> 00:50:02,250  
Titan's atmosphere none of that happens

1403  
00:50:05,180 --> 00:50:03,630  
in these experiments because we're not

1404  
00:50:08,569 --> 00:50:05,190  
seeing them a thousand kilometers to

1405  
00:50:10,339 --> 00:50:08,579  
fall um I keep asking Hopkins if they

1406  
00:50:13,040 --> 00:50:10,349  
could build me a thousand kilometer tall

1407  
00:50:14,809 --> 00:50:13,050  
lab and they can't even build me one

1408  
00:50:21,010 --> 00:50:14,819  
that functions correctly that has you

1409  
00:50:23,089 --> 00:50:21,020  
know eight-foot ceilings so but what I

1410  
00:50:25,460 --> 00:50:23,099  
couldn't hear what I couldn't hear was

1411  
00:50:27,370 --> 00:50:25,470  
it oh yeah no it's fine I talked about

1412  
00:50:29,140 --> 00:50:27,380  
on Twitter all the time my

1413  
00:50:30,730 --> 00:50:29,150

alarms went off two minutes before we

1414

00:50:37,630 --> 00:50:30,740

started this talk so we could go down

1415

00:50:40,690 --> 00:50:37,640

that road I Sarah I wanted to ask you a

1416

00:50:42,519 --> 00:50:40,700

bit of details and how do you choose the

1417

00:50:44,859 --> 00:50:42,529

actuator the gases you put in because

1418

00:50:47,319 --> 00:50:44,869

you're bad you're seven matee sitar but

1419

00:50:49,240 --> 00:50:47,329

you're showing that things like h2s even

1420

00:50:50,859 --> 00:50:49,250

as small quantities kind of strong

1421

00:50:53,079 --> 00:50:50,869

effect but you don't put them under

1422

00:50:55,749 --> 00:50:53,089

hundred times Felicity or as very steady

1423

00:50:57,249 --> 00:50:55,759

yeah it should still be some absolutely

1424

00:51:03,870 --> 00:50:57,259

okay that's like that's a great point

1425

00:51:07,089 --> 00:51:03,880

and we chose a cut-off for sanity so the

1426

00:51:09,220 --> 00:51:07,099

thousand times experiments have like six

1427

00:51:10,690 --> 00:51:09,230

or seven gases in them which are the

1428

00:51:13,029 --> 00:51:10,700

most complex experiments of this type

1429

00:51:15,240 --> 00:51:13,039

that anyone had ever done we decided

1430

00:51:19,539 --> 00:51:15,250

that was the most we were going to use

1431

00:51:21,700 --> 00:51:19,549

that put us at a 1% mixing ratio cup so

1432

00:51:24,579 --> 00:51:21,710

we used one percent across the board for

1433

00:51:27,849 --> 00:51:24,589

all of the experiment so it's certainly

1434

00:51:30,759 --> 00:51:27,859

true that in some of those cases there

1435

00:51:33,249 --> 00:51:30,769

were gases at like 0.9% that we did not

1436

00:51:35,109 --> 00:51:33,259

include so if you look at the hundred

1437

00:51:37,720 --> 00:51:35,119

times metallicity case only the lowest

1438

00:51:39,279 --> 00:51:37,730

temperature has ammonia in it it's not

1439

00:51:41,650 --> 00:51:39,289

that there isn't ammonia and those other

1440

00:51:44,799 --> 00:51:41,660

gases it's just that like it was it's

1441

00:51:46,420 --> 00:51:44,809

below the 1% level so what we're gonna

1442

00:51:49,690 --> 00:51:46,430

do is figure out how each of these gases

1443

00:51:51,970 --> 00:51:49,700

matter now we know that sulfur matters

1444

00:51:54,460 --> 00:51:51,980

and so if we go back through and look at

1445

00:51:56,799 --> 00:51:54,470

the ten thousand times cases I think

1446

00:51:58,690 --> 00:51:56,809

hydrogen sulfide is it's still in those

1447

00:52:00,670 --> 00:51:58,700

gas mixtures it's just at a lower level

1448

00:52:02,769 --> 00:52:00,680

the thing that I will tell you is the

1449

00:52:04,779 --> 00:52:02,779

only direction in which this is going to

1450

00:52:06,549 --> 00:52:04,789

impact the production rate if we start

1451

00:52:08,589 --> 00:52:06,559

adding those trace gases is to make the

1452

00:52:10,509 --> 00:52:08,599

production rates higher nothing that is

1453

00:52:12,720 --> 00:52:10,519

lurking below that cutoff is going to

1454

00:52:16,509 --> 00:52:12,730

make any of these production rates lower

1455

00:52:18,789 --> 00:52:16,519

and so that was you know that was a

1456

00:52:19,990 --> 00:52:18,799

choice we made I think depending on what

1457

00:52:21,130 --> 00:52:20,000

we want to do next we might be able to

1458

00:52:23,680 --> 00:52:21,140

go back through and add some of these

1459

00:52:25,990 --> 00:52:23,690

trace gases in and see you know if that

1460

00:52:28,180 --> 00:52:26,000

would have a big impact on some of them

1461

00:52:31,420 --> 00:52:28,190

but it was you know entirely a choice

1462

00:52:36,910 --> 00:52:31,430

made for sanity unfortunately or

1463

00:52:42,050 --> 00:52:36,920

fortunately I'm not sure which I think

1464

00:52:46,200 --> 00:52:42,060

stood for the dragonfly plug Sarah Moore

1465

00:52:49,800 --> 00:52:46,210

thank you the conventional wisdom that

1466

00:52:52,020 --> 00:52:49,810

that I think I learned and maybe it's

1467

00:52:53,550 --> 00:52:52,030

one of those myths that you've you know

1468

00:52:56,460 --> 00:52:53,560

some of the others of which you've been

1469

00:52:58,800 --> 00:52:56,470

dispelling is that in tighten the

1470

00:53:01,530 --> 00:52:58,810

nitrogen nitrogen bond is largely broken

1471

00:53:04,260 --> 00:53:01,540

by the magnetospheric electrons and the

1472

00:53:05,280 --> 00:53:04,270

more abundant UV can only break up the

1473

00:53:08,010 --> 00:53:05,290

CH bonds

1474

00:53:10,350 --> 00:53:08,020

is there anything we've learned from the

1475

00:53:13,650 --> 00:53:10,360

new horizons encounter with Pluto the

1476  
00:53:16,860 --> 00:53:13,660  
challenges or augments that picture yeah

1477  
00:53:19,800 --> 00:53:16,870  
so the extreme UV photons can break up

1478  
00:53:21,060 --> 00:53:19,810  
molecular nitrogen in sum total and I

1479  
00:53:22,410 --> 00:53:21,070  
have to go back and look at the paper to

1480  
00:53:25,770 --> 00:53:22,420  
see what the breakdown is between

1481  
00:53:27,210 --> 00:53:25,780  
nitrogen methane but in sum total 90% of

1482  
00:53:30,150 --> 00:53:27,220  
the chemistry and Titan's atmosphere is

1483  
00:53:32,970 --> 00:53:30,160  
driven by UV photons and only 10% comes

1484  
00:53:35,550 --> 00:53:32,980  
from the input of energetic ions of

1485  
00:53:39,480 --> 00:53:35,560  
whatever flavor they are into the top of

1486  
00:53:41,370 --> 00:53:39,490  
the atmosphere with New Horizons there

1487  
00:53:43,710 --> 00:53:41,380  
there's still a lot of work to do in

1488  
00:53:46,230 --> 00:53:43,720

terms of trying to understand exactly

1489

00:53:48,450 --> 00:53:46,240

what's happening in that atmosphere

1490

00:53:51,300 --> 00:53:48,460

there's an ongoing debate about whether

1491

00:53:52,770 --> 00:53:51,310

the haze particles are very simple and

1492

00:53:56,070 --> 00:53:52,780

then they're actually just condensate of

1493

00:53:58,530 --> 00:53:56,080

things like I don't know acetylene or

1494

00:54:01,760 --> 00:53:58,540

whether they are more complicated in the

1495

00:54:03,840 --> 00:54:01,770

way that we think of Titan's atmosphere

1496

00:54:06,780 --> 00:54:03,850

my personal feeling is that they're

1497

00:54:08,160 --> 00:54:06,790

actually very analogous to Titan in part

1498

00:54:10,380 --> 00:54:08,170

because the pressures that we're

1499

00:54:12,000 --> 00:54:10,390

thinking about for Pluto are actually

1500

00:54:13,320 --> 00:54:12,010

the exact same pressures where we see

1501  
00:54:14,960 --> 00:54:13,330  
this chemistry happening on Titan's

1502  
00:54:18,360 --> 00:54:14,970  
atmosphere because it happened so high

1503  
00:54:19,680 --> 00:54:18,370  
and so there's still a lot of work to be

1504  
00:54:22,230 --> 00:54:19,690  
done there but I think there's some some

1505  
00:54:23,070 --> 00:54:22,240  
beautiful comparative planetology that

1506  
00:54:26,010 --> 00:54:23,080  
it's going to be done with the New

1507  
00:54:27,390 --> 00:54:26,020  
Horizons data I'm we're starting to

1508  
00:54:29,010 --> 00:54:27,400  
think more about Triton a little bit too

1509  
00:54:30,750 --> 00:54:29,020  
I think those three atmospheres are

1510  
00:54:32,460 --> 00:54:30,760  
going to be really interesting test

1511  
00:54:34,010 --> 00:54:32,470  
cases going forwards in terms of at

1512  
00:54:36,540 --> 00:54:34,020  
least trying to see if we can sort out

1513  
00:54:45,540 --> 00:54:36,550

nitrogen CO methane atmosphere haze

1514

00:54:48,300 --> 00:54:45,550

formation but it's complicated thank you

1515

00:54:50,760 --> 00:54:48,310

for this very beautiful talk um I still

1516

00:54:53,460 --> 00:54:50,770

remain confused about the particle sizes

1517

00:54:54,340 --> 00:54:53,470

you are quoting on these bubble plots um

1518

00:54:56,560 --> 00:54:54,350

the

1519

00:54:58,240 --> 00:54:56,570

at which stage our kite are you

1520

00:55:00,340 --> 00:54:58,250

measuring the particle sizes or which

1521

00:55:02,230 --> 00:55:00,350

particle sizes you gave you gave

1522

00:55:04,330 --> 00:55:02,240

definite numbers for particle size right

1523

00:55:07,360 --> 00:55:04,340

yeah so are these the particle sizes on

1524

00:55:10,150 --> 00:55:07,370

these bubbly surfaces or are these mean

1525

00:55:12,910 --> 00:55:10,160

particle sizes of a distribution there

1526

00:55:15,280 --> 00:55:12,920

so the the particle sizes that I showed

1527

00:55:17,470 --> 00:55:15,290

oh it depends on which experiment I was

1528

00:55:20,440 --> 00:55:17,480

talking about but the exoplanet

1529

00:55:22,450 --> 00:55:20,450

experiment those are disks that are in

1530

00:55:24,070 --> 00:55:22,460

the chamber so those are particles that

1531

00:55:26,200 --> 00:55:24,080

have sedimented out of the experiment

1532

00:55:27,490 --> 00:55:26,210

and deposited on the chamber on the on

1533

00:55:28,930 --> 00:55:27,500

these disks in the chamber and then we

1534

00:55:32,110 --> 00:55:28,940

use those just to do atomic force

1535

00:55:34,540 --> 00:55:32,120

microscopy so we measure the particle

1536

00:55:36,520 --> 00:55:34,550

size distribution I didn't I probably

1537

00:55:38,020 --> 00:55:36,530

skipped over one of them breaks but we

1538

00:55:39,190 --> 00:55:38,030

measure the particle size distribution

1539

00:55:42,220 --> 00:55:39,200

and then what we were quoting was the

1540

00:55:43,960 --> 00:55:42,230

mean particle size but we also look at

1541

00:55:45,130 --> 00:55:43,970

how the size distribution itself changes

1542

00:56:00,640 --> 00:55:45,140

because there's information there as

1543

00:56:03,010 --> 00:56:00,650

well two small questions so firstly so

1544

00:56:04,900 --> 00:56:03,020

does this case form only in the upper

1545

00:56:08,050 --> 00:56:04,910

levels of the of the Titan's atmosphere

1546

00:56:10,630 --> 00:56:08,060

is it too cold for the highest form like

1547

00:56:13,180 --> 00:56:10,640

close to the surface at the production

1548

00:56:15,310 --> 00:56:13,190

rates too small that's a really

1549

00:56:17,590 --> 00:56:15,320

interesting question that I don't think

1550

00:56:19,390 --> 00:56:17,600

we actually know the answer to UM we

1551  
00:56:21,130 --> 00:56:19,400  
know that the chemistry that leads to

1552  
00:56:23,110 --> 00:56:21,140  
particle formation starts at the top of

1553  
00:56:26,980 --> 00:56:23,120  
the atmosphere we can see the particles

1554  
00:56:29,920 --> 00:56:26,990  
grow as we look deeper in the atmosphere

1555  
00:56:32,110 --> 00:56:29,930  
they get larger by the time we get to

1556  
00:56:35,770 --> 00:56:32,120  
the top of the stratosphere how the

1557  
00:56:37,630 --> 00:56:35,780  
start in the stratosphere we see that the

1558  
00:56:40,930 --> 00:56:37,640  
the spectra of the particles don't

1559  
00:56:43,420 --> 00:56:40,940  
change and so we interpret that to mean

1560  
00:56:44,380 --> 00:56:43,430  
that whatever the dynamical processes

1561  
00:56:46,660 --> 00:56:44,390  
are they're happening in the atmosphere

1562  
00:56:48,400 --> 00:56:46,670  
they're overwhelming any possible

1563  
00:56:50,200 --> 00:56:48,410

chemical processes that are spending at

1564

00:56:52,540 --> 00:56:50,210

that point and so there's no ket there's

1565

00:56:55,570 --> 00:56:52,550

chemical difference between about 300

1566

00:56:57,250 --> 00:56:55,580

kilometers above the surface and and the

1567

00:56:59,200 --> 00:56:57,260

data that we get right below the the

1568

00:57:01,090 --> 00:56:59,210

surface but we do think there's physical

1569

00:57:02,470 --> 00:57:01,100

things happening there three to the

1570

00:57:03,940 --> 00:57:02,480

atmosphere where condensation should be

1571

00:57:05,590 --> 00:57:03,950

occurring it's a little bit surprising

1572

00:57:07,270 --> 00:57:05,600

that we don't seem to see the spectra

1573

00:57:10,180 --> 00:57:07,280

change very much

1574

00:57:13,780 --> 00:57:10,190

but to say where the chemistry starts

1575

00:57:17,500 --> 00:57:13,790

and stops is is very challenging yeah

1576

00:57:20,470 --> 00:57:17,510

and what's the role of ozone in in the

1577

00:57:22,930 --> 00:57:20,480

haze production experiments to include

1578

00:57:26,080 --> 00:57:22,940

that does it form yeah yeah

1579

00:57:29,080 --> 00:57:26,090

so in the early Earth experiments we

1580

00:57:30,310 --> 00:57:29,090

definitely were making ozone I can tell

1581

00:57:31,960 --> 00:57:30,320

you that because I end up having to run

1582

00:57:35,470 --> 00:57:31,970

those experiments for time because I was

1583

00:57:38,560 --> 00:57:35,480

on is not good and it was causing us all

1584

00:57:41,920 --> 00:57:38,570

kinds of challenges oh then we'll

1585

00:57:44,050 --> 00:57:41,930

certainly start to reverse the process a

1586

00:57:46,240 --> 00:57:44,060

little bit by scavenging organics and

1587

00:57:48,850 --> 00:57:46,250

converting them back into something

1588

00:57:50,140 --> 00:57:48,860

smaller so I think at some point what

1589

00:57:52,090 --> 00:57:50,150

starts to happen when we put more and

1590

00:57:54,040 --> 00:57:52,100

more o to into these experiments is the

1591

00:57:55,900 --> 00:57:54,050

combination of two things one the

1592

00:57:57,520 --> 00:57:55,910

oxygens eating a bunch of the photons

1593

00:58:00,070 --> 00:57:57,530

that we want to use for particle

1594

00:58:01,600 --> 00:58:00,080

formation and to in doing that it starts

1595

00:58:04,930 --> 00:58:01,610

creating a bunch of ozone which also

1596

00:58:06,940 --> 00:58:04,940

tamp down the production rates it's hard

1597

00:58:08,740 --> 00:58:06,950

because um you can't really measure

1598

00:58:10,270 --> 00:58:08,750

ozone because it's so reactive and you

1599

00:58:11,860 --> 00:58:10,280

would need to do it spectroscopically in

1600

00:58:13,960 --> 00:58:11,870

that particular setup we didn't have a

1601  
00:58:15,670 --> 00:58:13,970  
way to measure ozone and so I don't

1602  
00:58:17,290 --> 00:58:15,680  
actually have any measurements of the

1603  
00:58:24,190 --> 00:58:17,300  
gas composition from those experiments

1604  
00:58:26,140 --> 00:58:24,200  
yeah : Gold let you Vic thank you Sarah

1605  
00:58:30,940 --> 00:58:26,150  
for totally rad talk which changed how I

1606  
00:58:33,210 --> 00:58:30,950  
think about hazers a couple of questions

1607  
00:58:36,130 --> 00:58:33,220  
are singing right to mine the first is

1608  
00:58:39,430 --> 00:58:36,140  
for your neo Archaean experiment you

1609  
00:58:43,240 --> 00:58:39,440  
used a quite low co2 use 400 ppm so what

1610  
00:58:46,390 --> 00:58:43,250  
would happen if you use say 10,000 ppm

1611  
00:58:48,660 --> 00:58:46,400  
of co2 um I think that it would probably

1612  
00:58:50,650 --> 00:58:48,670  
follow the trends that we've seen before

1613  
00:58:53,350 --> 00:58:50,660

which is that it would decrease the

1614

00:58:55,180 --> 00:58:53,360

particle production but I don't actually

1615

00:58:57,370 --> 00:58:55,190

know that for sure and the other thing

1616

00:58:58,630 --> 00:58:57,380

that is now super important that I

1617

00:58:59,830 --> 00:58:58,640

should have mentioned that I talked

1618

00:59:01,480 --> 00:58:59,840

about the earth experiments there was a

1619

00:59:03,610 --> 00:59:01,490

very important molecule missing from

1620

00:59:05,170 --> 00:59:03,620

those experiments that nobody ever did

1621

00:59:06,820 --> 00:59:05,180

any of this chemistry with before until

1622

00:59:08,440 --> 00:59:06,830

we did the exoplanet experiments but

1623

00:59:12,100 --> 00:59:08,450

there is definitely water in that

1624

00:59:13,720 --> 00:59:12,110

atmosphere and we've seen in the

1625

00:59:15,250 --> 00:59:13,730

exoplanet experiments that the water

1626  
00:59:17,080 --> 00:59:15,260  
dominated experiments have very high

1627  
00:59:19,120 --> 00:59:17,090  
production rates so I would love to go

1628  
00:59:21,130 --> 00:59:19,130  
back and redo those early Earth

1629  
00:59:23,410 --> 00:59:21,140  
experiments and actually include water

1630  
00:59:24,849 --> 00:59:23,420  
in the gas phase to see what would

1631  
00:59:26,950 --> 00:59:24,859  
happen in terms of page production there

1632  
00:59:29,140 --> 00:59:26,960  
too so I think if the co2 is higher the

1633  
00:59:30,250 --> 00:59:29,150  
particle production would go down but I

1634  
00:59:31,420 --> 00:59:30,260  
don't know what would happen if we

1635  
00:59:34,000 --> 00:59:31,430  
actually put water into those

1636  
00:59:36,220 --> 00:59:34,010  
experiments the ratios by the way were

1637  
00:59:39,460 --> 00:59:36,230  
the output of a model that was looking

1638  
00:59:41,980 --> 00:59:39,470

at what types of gases we might expect

1639

00:59:43,779 --> 00:59:41,990

to see outgassing from like mid-ocean

1640

00:59:45,370 --> 00:59:43,789

ridges and volcanoes and stuff like that

1641

00:59:48,670 --> 00:59:45,380

so that's why there were very oddly

1642

00:59:49,990 --> 00:59:48,680

specific ratios of gases and those

1643

00:59:52,660 --> 00:59:50,000

experiments because they were the output

1644

00:59:54,339 --> 00:59:52,670

of a model my follow-up question would

1645

00:59:57,279 --> 00:59:54,349

be could you describe what you think the

1646

00:59:59,819 --> 00:59:57,289

history of behave in Earth has but they

1647

01:00:04,720 --> 00:59:59,829

have been to all of us history

1648

01:00:06,549 --> 01:00:04,730

buy me a drink later I think I think a

1649

01:00:08,140 --> 01:00:06,559

big picture you know I think Earth

1650

01:00:11,259 --> 01:00:08,150

probably did have a haze layer for a

1651

01:00:13,750 --> 01:00:11,269

good chunk of its early history I think

1652

01:00:16,329 --> 01:00:13,760

that the period of time that you showed

1653

01:00:18,279 --> 01:00:16,339

today in which the atmosphere is going

1654

01:00:21,190 --> 01:00:18,289

through all kinds of shenanigans in the

1655

01:00:22,630 --> 01:00:21,200

gas phase there were probably all kinds

1656

01:00:24,819 --> 01:00:22,640

of shenanigans going on with the haze

1657

01:00:26,710 --> 01:00:24,829

layer - in particular if we start

1658

01:00:28,690 --> 01:00:26,720

changing things like optical properties

1659

01:00:29,829 --> 01:00:28,700

then you start changing the way that the

1660

01:00:31,599 --> 01:00:29,839

rate of balance is working in the

1661

01:00:33,849 --> 01:00:31,609

atmosphere I give you a lot of feedbacks

1662

01:00:36,730 --> 01:00:33,859

that way volcanoes erupting I think that

1663

01:00:39,130 --> 01:00:36,740

period of time was really unstable and

1664

01:00:40,660 --> 01:00:39,140

so I suspect what was happening is that

1665

01:00:42,069 --> 01:00:40,670

sometimes there was a thicker haze layer

1666

01:00:44,140 --> 01:00:42,079

and sometimes there was a thinner haze

1667

01:00:45,880 --> 01:00:44,150

layer but I'm guessing that it took

1668

01:00:48,220 --> 01:00:45,890

quite a bit of time before it actually

1669

01:00:50,890 --> 01:00:48,230

fully dissipated if there was a thick

1670

01:00:52,420 --> 01:00:50,900

haze layer at the beginning which is not

1671

01:00:53,829 --> 01:00:52,430

the picture that we tend to think of

1672

01:00:55,630 --> 01:00:53,839

people tend to think of it more as a

1673

01:00:57,130 --> 01:00:55,640

light switch that once there was any

1674

01:00:58,480 --> 01:00:57,140

oxygen in the atmosphere that was it the

1675

01:01:03,630 --> 01:00:58,490

haze was gone and I don't think that's

1676

01:01:09,700 --> 01:01:07,289

hi my name is r.j. and I'm from here

1677

01:01:12,700 --> 01:01:09,710

this question comes from a place of

1678

01:01:14,799 --> 01:01:12,710

total ignorance did you said that you

1679

01:01:17,019 --> 01:01:14,809

all of the experiments were conducted at

1680

01:01:18,849 --> 01:01:17,029

one millibar of pressure all the

1681

01:01:21,549 --> 01:01:18,859

exoplanet experiments for Tamila Varia

1682

01:01:24,789 --> 01:01:21,559

do you expect that burying that would

1683

01:01:28,120 --> 01:01:24,799

matter at all yes that's not an ignorant

1684

01:01:29,410 --> 01:01:28,130

question at all so I mentioned that the

1685

01:01:31,180 --> 01:01:29,420

chemistry starts very high in Titan's

1686

01:01:34,359 --> 01:01:31,190

atmosphere that's a very challenging

1687

01:01:36,400 --> 01:01:34,369

region to access experimental ii

1688

01:01:38,979 --> 01:01:36,410

we try to have our chamber be many times

1689

01:01:40,209 --> 01:01:38,989

the mean free path of the gases again so

1690

01:01:42,429 --> 01:01:40,219

they're colliding more frequently with

1691

01:01:43,870 --> 01:01:42,439

each other than the wall to do that for

1692

01:01:46,509 --> 01:01:43,880

Titan atmosphere we would need a many

1693

01:01:47,739 --> 01:01:46,519

many kilometer box people don't like it

1694

01:01:49,479 --> 01:01:47,749

when I start talking about filling a

1695

01:01:51,969 --> 01:01:49,489

mini kilometer box with methane and then

1696

01:01:53,469 --> 01:01:51,979

I mean hating it on earth maybe someday

1697

01:01:56,739 --> 01:01:53,479

I'll get a moon base and then I do

1698

01:01:58,839 --> 01:01:56,749

sermons there so the pressure has chosen

1699

01:02:00,459 --> 01:01:58,849

in part because we know that that is a

1700

01:02:01,660 --> 01:02:00,469

region of atmospheres where a lot of

1701

01:02:03,489 --> 01:02:01,670

really interesting chemistry is

1702

01:02:05,679 --> 01:02:03,499

happening but it's also chosen in part

1703

01:02:07,749 --> 01:02:05,689

for reasons that are to do with being

1704

01:02:08,920 --> 01:02:07,759

practical in a lab and that's one of the

1705

01:02:10,569 --> 01:02:08,930

things that's frustrating about lab

1706

01:02:11,799 --> 01:02:10,579

experiments and so it's really

1707

01:02:14,019 --> 01:02:11,809

appreciated the point that was made this

1708

01:02:16,509 --> 01:02:14,029

morning about how we really have to work

1709

01:02:19,150 --> 01:02:16,519

together with experiments and models and

1710

01:02:21,099 --> 01:02:19,160

observations to actually figure out

1711

01:02:23,019 --> 01:02:21,109

what's going on because individually all