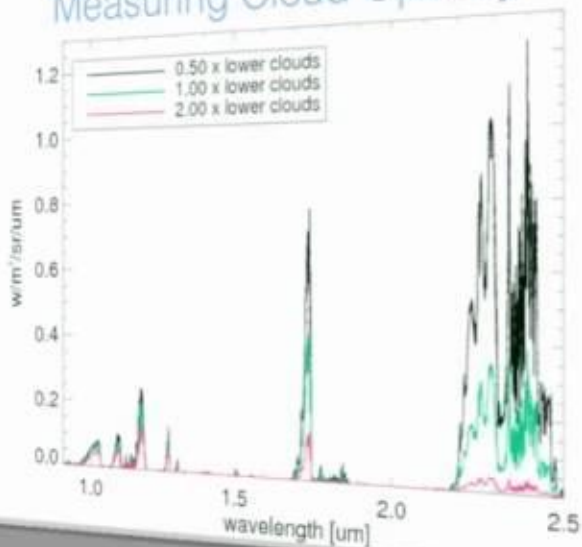


## Measuring Cloud Opacity



1  
00:00:10,560 --> 00:00:08,790  
alright hi everybody I'm Giada from the

2  
00:00:12,180 --> 00:00:10,570  
University of Washington I want to say

3  
00:00:17,820 --> 00:00:12,190  
thank you to the organizers for putting

4  
00:00:19,320 --> 00:00:17,830  
together this whole conference okay so I

5  
00:00:20,519 --> 00:00:19,330  
feel like I need to justify talking

6  
00:00:22,200 --> 00:00:20,529  
about Venus at an astrobiology

7  
00:00:23,939 --> 00:00:22,210  
conference because Venus is extremely

8  
00:00:26,730 --> 00:00:23,949  
inhospitable has a surface temperature

9  
00:00:28,290 --> 00:00:26,740  
that's high enough to melt lead so

10  
00:00:29,970 --> 00:00:28,300  
there's two questions that come to my

11  
00:00:33,180 --> 00:00:29,980  
mind when I think about why Venus is

12  
00:00:35,190 --> 00:00:33,190  
relevant to astrobiologists one is what

13  
00:00:37,410 --> 00:00:35,200

can Venus tell us about earth some

14

00:00:38,910 --> 00:00:37,420

people think that measuring the ratio of

15

00:00:42,299 --> 00:00:38,920

deuterium to hydrogen and menaces

16

00:00:44,340 --> 00:00:42,309

atmosphere that Venus oops the Venus

17

00:00:46,950 --> 00:00:44,350

once was more earth-like and maybe have

18

00:00:48,450 --> 00:00:46,960

had a lot of water on its surface but

19

00:00:50,040 --> 00:00:48,460

over time and underwent this ronery

20

00:00:52,380 --> 00:00:50,050

greenhouse process and lost its water

21

00:00:54,599 --> 00:00:52,390

people think that in the future earth

22

00:00:56,670 --> 00:00:54,609

will undergo a similar process an earth

23

00:00:58,259 --> 00:00:56,680

will become Venus like so Venus's

24

00:01:00,689 --> 00:00:58,269

present state may be Earth's future

25

00:01:02,669 --> 00:01:00,699

state and then the second question is

26

00:01:04,410 --> 00:01:02,679

how can Venus import exoplanet studies

27

00:01:07,080 --> 00:01:04,420

esso planets are something near and dear

28

00:01:08,310 --> 00:01:07,090

to my heart i love exoplanets so i'm

29

00:01:10,580 --> 00:01:08,320

always thinking about that in the back

30

00:01:12,720 --> 00:01:10,590

of my mind when I study these planets I

31

00:01:14,370 --> 00:01:12,730

think the Venus like planets are

32

00:01:17,640 --> 00:01:14,380

probably common in the exoplanet

33

00:01:19,890 --> 00:01:17,650

population because I imagine it sort of

34

00:01:21,240 --> 00:01:19,900

like Venus's are the end state of

35

00:01:23,370 --> 00:01:21,250

earth-like planets so they would

36

00:01:25,610 --> 00:01:23,380

presumably collect and exoplanet

37

00:01:28,050 --> 00:01:25,620

populations as their stars evolve

38

00:01:30,000 --> 00:01:28,060

secondly I think that planets with thick

39  
00:01:32,190 --> 00:01:30,010  
photochemical Hayes's may also be common

40  
00:01:33,840 --> 00:01:32,200  
in the exoplanet population in our own

41  
00:01:36,330 --> 00:01:33,850  
solar system of the four terrestrial

42  
00:01:39,180 --> 00:01:36,340  
worlds that have substantial atmospheres

43  
00:01:40,590 --> 00:01:39,190  
so Earth Mars Venus and Titan two of

44  
00:01:42,870 --> 00:01:40,600  
those worlds Venus and Titan have thick

45  
00:01:44,310 --> 00:01:42,880  
photochemical Hayes's and earth itself

46  
00:01:46,680 --> 00:01:44,320  
some authors think may have had a

47  
00:01:48,540 --> 00:01:46,690  
photochemical haze in its past so it's

48  
00:01:49,800 --> 00:01:48,550  
interesting to me to try to understand

49  
00:01:52,590 --> 00:01:49,810  
what we can learn about the surface

50  
00:01:55,530 --> 00:01:52,600  
environments of photochemical chemically

51  
00:01:58,290 --> 00:01:55,540  
hazy enshrouded worlds I think that has

52  
00:01:59,730 --> 00:01:58,300  
significant implications to future

53  
00:02:01,740 --> 00:01:59,740  
remote sensing and planetary

54  
00:02:05,820 --> 00:02:01,750  
characterization of extrasolar planets

55  
00:02:09,180 --> 00:02:05,830  
oh there's a movie but it's not playing

56  
00:02:12,210 --> 00:02:09,190  
oh well pretend the little volcano is

57  
00:02:14,819 --> 00:02:12,220  
going off an i oh they're so this is the

58  
00:02:16,410 --> 00:02:14,829  
innermost moon of Jupiter IO IO is the

59  
00:02:18,780 --> 00:02:16,420  
most volcanically active body in the

60  
00:02:19,540 --> 00:02:18,790  
solar system because it's on a slightly

61  
00:02:21,130 --> 00:02:19,550  
eccentric or

62  
00:02:23,200 --> 00:02:21,140  
a bit near Jupiter and Jupiter is

63  
00:02:24,610 --> 00:02:23,210

putting tidal energy into IO and melting

64

00:02:27,370 --> 00:02:24,620

its interior and so I Oh has these

65

00:02:29,380 --> 00:02:27,380

incredibly huge volcanoes like that one

66

00:02:31,540 --> 00:02:29,390

spewing off the limb of the planet a

67

00:02:33,040 --> 00:02:31,550

class of world's proposed by one of my

68

00:02:35,310 --> 00:02:33,050

collaborators at the University of

69

00:02:38,620 --> 00:02:35,320

Washington Rory Barnes has proposed that

70

00:02:40,180 --> 00:02:38,630

he thinks that you can get tidal Venus's

71

00:02:43,060 --> 00:02:40,190

which are worlds that have a high enough

72

00:02:44,620 --> 00:02:43,070

heat flux driven by tidal heating close

73

00:02:46,720 --> 00:02:44,630

to their star so these are worlds on

74

00:02:48,490 --> 00:02:46,730

slightly eccentric orbits or worlds that

75

00:02:50,500 --> 00:02:48,500

are in the process of Title II circular

76

00:02:52,480 --> 00:02:50,510

izing their orbits and if they have a

77

00:02:54,130 --> 00:02:52,490

high in a fleet heat flux about 300

78

00:02:55,660 --> 00:02:54,140

watts per square meter you can actually

79

00:02:57,190 --> 00:02:55,670

drive those planets into a runaway

80

00:02:59,770 --> 00:02:57,200

greenhouse and get what's called a tidal

81

00:03:02,410 --> 00:02:59,780

Venus Rory believes that the danger zone

82

00:03:04,420 --> 00:03:02,420

for getting tidal Venus's exists for

83

00:03:06,250 --> 00:03:04,430

star is less than about point one solar

84

00:03:07,870 --> 00:03:06,260

masses and that doesn't mean all of

85

00:03:09,550 --> 00:03:07,880

those stars necessarily have tidal

86

00:03:11,590 --> 00:03:09,560

Venus's it just means they could have

87

00:03:13,300 --> 00:03:11,600

tidal Venus's depending on the various

88

00:03:16,180 --> 00:03:13,310

properties the planets orbits and their

89

00:03:17,830 --> 00:03:16,190

masses and the really really important

90

00:03:19,650 --> 00:03:17,840

thing about tidal Venus's is that four

91

00:03:21,910 --> 00:03:19,660

stars less than point three solar masses

92

00:03:24,100 --> 00:03:21,920

tidal Venus's can exist within the

93

00:03:25,390 --> 00:03:24,110

habitable zones of stars so they may

94

00:03:26,979 --> 00:03:25,400

potentially confuse future

95

00:03:28,330 --> 00:03:26,989

characterization missions if we find

96

00:03:33,070 --> 00:03:28,340

these planets and don't understand what

97

00:03:34,600 --> 00:03:33,080

we're looking at what this is showing is

98

00:03:36,460 --> 00:03:34,610

um I don't want to spend too much time

99

00:03:38,470 --> 00:03:36,470

talking about this but this is showing

100

00:03:40,750 --> 00:03:38,480

the planet star separation angle for

101

00:03:43,170 --> 00:03:40,760

various earth-like hypothetical

102

00:03:45,970 --> 00:03:43,180

earth-like planets around the nearest

103

00:03:48,550 --> 00:03:45,980

stars in the nearest 20 or so parsecs in

104

00:03:50,440 --> 00:03:48,560

the higher part goes catalog so for the

105

00:03:52,360 --> 00:03:50,450

non astronomers just to remind you a

106

00:03:54,100 --> 00:03:52,370

dwarf so the hottest most massive type

107

00:03:55,600 --> 00:03:54,110

of stars that I've plotted here and then

108

00:03:57,820 --> 00:03:55,610

endures that I've plotted are the

109

00:03:59,560 --> 00:03:57,830

coolest least massive type of star so

110

00:04:00,940 --> 00:03:59,570

the planet star separation for endures

111

00:04:02,530 --> 00:04:00,950

in the Hannibal zone is going to be less

112

00:04:07,780 --> 00:04:02,540

than the planet star separation for a

113

00:04:10,150 --> 00:04:07,790

Dwarfs so these are the stars that are

114

00:04:11,920 --> 00:04:10,160

below the match / hold which could host

115

00:04:13,780 --> 00:04:11,930

a title Venus and again this doesn't

116

00:04:15,520 --> 00:04:13,790

mean these stars do have title Venus's

117

00:04:17,289 --> 00:04:15,530

even if they do have a planet in the

118

00:04:19,900 --> 00:04:17,299

habitable zone it just means that they

119

00:04:21,550 --> 00:04:19,910

possibly could the title Venus's could

120

00:04:22,750 --> 00:04:21,560

not be detected by the first generation

121

00:04:25,120 --> 00:04:22,760

of terrestrial planet finder 'he's

122

00:04:27,969 --> 00:04:25,130

that's what's these two lines are so

123

00:04:29,680 --> 00:04:27,979

those are the inner working angles of

124

00:04:31,990 --> 00:04:29,690

the terrestrial planet finder zaz they

125

00:04:33,040 --> 00:04:32,000

were proposed initially and so all of

126

00:04:34,600 --> 00:04:33,050

them are below that

127

00:04:36,460 --> 00:04:34,610

threshold but these planets could be

128

00:04:38,800 --> 00:04:36,470

detected if they exist through transit

129

00:04:40,360 --> 00:04:38,810

transmission spectroscopy about thirty

130

00:04:45,159 --> 00:04:40,370

percent of the nearby and dwarfs could

131

00:04:46,629 --> 00:04:45,169

host tidal Venus's okay so now my work

132

00:04:48,070 --> 00:04:46,639

is seeing through the pale yellow cloud

133

00:04:51,249 --> 00:04:48,080

so how do we actually characterize these

134

00:04:52,899 --> 00:04:51,259

worlds the way you do is you have to use

135

00:04:54,490 --> 00:04:52,909

what's called these nights I'd spectral

136

00:04:57,249 --> 00:04:54,500

windows they were discovered by Allen

137

00:04:59,140 --> 00:04:57,259

and Crawford in 1984 these special

138

00:05:01,570 --> 00:04:59,150

windows are you don't want to think of

139

00:05:03,730 --> 00:05:01,580

them as literal places on the planet

140

00:05:05,320 --> 00:05:03,740

where the clouds are thin and you're

141

00:05:08,290 --> 00:05:05,330

actually you know peering through holes

142

00:05:10,119 --> 00:05:08,300

in the clouds these are special windows

143

00:05:13,809 --> 00:05:10,129

so you want to think of it in wavelength

144

00:05:16,089 --> 00:05:13,819

space so they exist from about one to

145

00:05:18,730 --> 00:05:16,099

2.5 microns at least the ones that I'm

146

00:05:21,129 --> 00:05:18,740

interested in and their places in the

147

00:05:22,930 --> 00:05:21,139

spectrum of the planet where gases are

148

00:05:24,850 --> 00:05:22,940

not significantly absorbing the spectrum

149

00:05:26,409 --> 00:05:24,860

is relatively transparent so you can

150

00:05:27,999 --> 00:05:26,419

look in these wavelength regions and you

151  
00:05:30,490 --> 00:05:28,009  
can probe deep down into the atmosphere

152  
00:05:32,649 --> 00:05:30,500  
and in some cases for example the one

153  
00:05:34,869 --> 00:05:32,659  
micron window you can probe all the way

154  
00:05:36,309 --> 00:05:34,879  
down to the surface of the planet so

155  
00:05:38,559 --> 00:05:36,319  
that's great because this gives us

156  
00:05:40,120 --> 00:05:38,569  
information about the surface conditions

157  
00:05:42,790 --> 00:05:40,130  
of this completely photochemically

158  
00:05:44,469 --> 00:05:42,800  
enshrouded planet so what we did is we

159  
00:05:47,860 --> 00:05:44,479  
observe them in November and December of

160  
00:05:50,350 --> 00:05:47,870  
2010 using the APO 3.5 meter telescope

161  
00:05:52,600 --> 00:05:50,360  
the triple speck instrument which is a

162  
00:05:55,510 --> 00:05:52,610  
spectrometer with a range from 1 to 2.5

163  
00:05:58,330 --> 00:05:55,520

microns and a resolution of about 3,500

164

00:05:59,890 --> 00:05:58,340

these are night side windows because you

165

00:06:01,809 --> 00:05:59,900

can't observe them on the dayside of the

166

00:06:04,089 --> 00:06:01,819

planet unfortunately at least in the

167

00:06:05,439 --> 00:06:04,099

case of Venus because in this case what

168

00:06:07,990 --> 00:06:05,449

you're sampling through the windows is

169

00:06:09,969 --> 00:06:08,000

thermal emission which gets completely

170

00:06:11,439 --> 00:06:09,979

dwarfed and swamped by reflected

171

00:06:16,089 --> 00:06:11,449

sunlight if you try to observe them on

172

00:06:17,529 --> 00:06:16,099

the day side ok so just prove to you

173

00:06:19,959 --> 00:06:17,539

that you can see the surface of Venus

174

00:06:21,839 --> 00:06:19,969

from Earth what you do is you measure

175

00:06:23,769 --> 00:06:21,849

the one micron brightness in each pixel

176

00:06:26,110 --> 00:06:23,779

then you can build up a map of

177

00:06:29,260 --> 00:06:26,120

brightness variations and this little

178

00:06:30,909 --> 00:06:29,270

guy here that's Aphrodite Terra it's

179

00:06:32,290 --> 00:06:30,919

kind of hard to see but it's darker than

180

00:06:33,640 --> 00:06:32,300

the surrounding Plains and the reason

181

00:06:35,709 --> 00:06:33,650

why it's darker is because it's higher

182

00:06:37,480 --> 00:06:35,719

in elevation Aphrodite tara is a

183

00:06:39,610 --> 00:06:37,490

Highland Plateau about the size of South

184

00:06:42,760 --> 00:06:39,620

America and it's about four kilometers

185

00:06:44,529 --> 00:06:42,770

above the plains so the adiabatic lapse

186

00:06:45,930 --> 00:06:44,539

rate on Venus is about seven Kelvin per

187

00:06:47,730 --> 00:06:45,940

kilometer so this thing

188

00:06:52,890 --> 00:06:47,740

about 30 calvin cooler than the planes

189

00:06:54,900 --> 00:06:52,900

that's why it's darker if you were to

190

00:06:56,490 --> 00:06:54,910

sort of naively try to measure the

191

00:06:58,740 --> 00:06:56,500

brightness temperature of Venus by

192

00:07:00,540 --> 00:06:58,750

measuring the effective temperature of

193

00:07:02,910 --> 00:07:00,550

the cloud deck you would get a very cold

194

00:07:05,550 --> 00:07:02,920

temperature it's like 218 degrees Kelvin

195

00:07:07,140 --> 00:07:05,560

which is grossly mischaracterizing the

196

00:07:09,450 --> 00:07:07,150

surface environment of the planet so if

197

00:07:11,100 --> 00:07:09,460

you were to naively believe that you

198

00:07:12,780 --> 00:07:11,110

would completely misunderstand what's

199

00:07:14,580 --> 00:07:12,790

going on here the actual surface

200

00:07:16,200 --> 00:07:14,590

temperature of Venus is about seven

201  
00:07:18,180 --> 00:07:16,210  
hundred and thirty degrees Kelvin and

202  
00:07:20,370 --> 00:07:18,190  
using in particular the one micron

203  
00:07:22,860 --> 00:07:20,380  
window again which is about ninety six

204  
00:07:24,600 --> 00:07:22,870  
percent surface thermal emission you can

205  
00:07:26,130 --> 00:07:24,610  
measure the surface temperature through

206  
00:07:27,420 --> 00:07:26,140  
the through the thick atmosphere you

207  
00:07:28,620 --> 00:07:27,430  
don't need to descend a probe into the

208  
00:07:32,310 --> 00:07:28,630  
atmosphere you can actually do it

209  
00:07:34,530 --> 00:07:32,320  
remotely so again yeah that measures the

210  
00:07:36,690 --> 00:07:34,540  
surface and this entire wavelength range

211  
00:07:40,980 --> 00:07:36,700  
from 12 to 1 point 3 microns you can

212  
00:07:42,780 --> 00:07:40,990  
measure the lowest scale height okay so

213  
00:07:44,430 --> 00:07:42,790

the next thing I did is I used the

214

00:07:46,200 --> 00:07:44,440

spectra that we collected from Apache

215

00:07:48,180 --> 00:07:46,210

point observatory and combine those with

216

00:07:49,920 --> 00:07:48,190

radiative transfer models to try to get

217

00:07:51,600 --> 00:07:49,930

a handle on the cloud opacity over the

218

00:07:54,540 --> 00:07:51,610

planet and also to measure the abundance

219

00:07:56,100 --> 00:07:54,550

of minor atmospheric species so

220

00:07:58,170 --> 00:07:56,110

obviously the major atmospheric species

221

00:08:00,180 --> 00:07:58,180

for Venus is carbon dioxide but it has a

222

00:08:06,900 --> 00:08:00,190

lot of other gases that are present much

223

00:08:08,610 --> 00:08:06,910

less abundant levels so one thing I did

224

00:08:10,560 --> 00:08:08,620

was I measure the cloud opacity so these

225

00:08:12,270 --> 00:08:10,570

are a radiative transfer models where

226

00:08:15,150 --> 00:08:12,280

I'm changing the opacity of the lower

227

00:08:17,250 --> 00:08:15,160

cloud deck the relative heights of the

228

00:08:19,320 --> 00:08:17,260

spectral windows are very very sensitive

229

00:08:22,470 --> 00:08:19,330

to the opacity of the lower cloud deck

230

00:08:24,600 --> 00:08:22,480

you can see that as you go from let's

231

00:08:26,670 --> 00:08:24,610

see lower opacity clouds to hire opacity

232

00:08:28,320 --> 00:08:26,680

clouds the windows change heights

233

00:08:29,820 --> 00:08:28,330

absolutely but they also chain sites

234

00:08:33,480 --> 00:08:29,830

relative to each other so you can use

235

00:08:36,089 --> 00:08:33,490

that relative effect to quantify the

236

00:08:37,469 --> 00:08:36,099

cloud opacity which is what I did here

237

00:08:38,850 --> 00:08:37,479

so what you're looking at is this is

238

00:08:40,800 --> 00:08:38,860

just orient you we're looking at the

239

00:08:42,659 --> 00:08:40,810

night side of the planet each of these

240

00:08:44,280 --> 00:08:42,669

columns is a different nights that I

241

00:08:47,370 --> 00:08:44,290

observe the planet it looks like it got

242

00:08:49,829 --> 00:08:47,380

little cut off on here this one at the

243

00:08:51,480 --> 00:08:49,839

very end let's see so this is the first

244

00:08:53,490 --> 00:08:51,490

night this is actually the last night

245

00:08:55,500 --> 00:08:53,500

and the very last one is all the nights

246

00:08:57,440 --> 00:08:55,510

co added on top of each other just to

247

00:08:59,190 --> 00:08:57,450

look for long-term persisting patterns

248

00:09:01,500 --> 00:08:59,200

so the cloud

249

00:09:03,660 --> 00:09:01,510

measures the brightness of the clouds in

250

00:09:05,400 --> 00:09:03,670

the places where it's very bright or red

251  
00:09:06,780 --> 00:09:05,410  
is places where the clouds are thin and

252  
00:09:08,700 --> 00:09:06,790  
your sampling lower into the hotter

253  
00:09:10,110 --> 00:09:08,710  
atmosphere and then vice versa where

254  
00:09:11,460 --> 00:09:10,120  
it's dark or blue or you're sampling

255  
00:09:13,860 --> 00:09:11,470  
higher in the atmosphere where it's

256  
00:09:16,230 --> 00:09:13,870  
cooler I measured the cloud opacity

257  
00:09:18,150 --> 00:09:16,240  
using my radiative transfer models here

258  
00:09:19,770 --> 00:09:18,160  
and you can see that there is a

259  
00:09:22,110 --> 00:09:19,780  
correlation between places where the

260  
00:09:23,760 --> 00:09:22,120  
clouds are thinner and places where you

261  
00:09:25,740 --> 00:09:23,770  
again would expect from the cloud maps

262  
00:09:28,110 --> 00:09:25,750  
that it would be thinner so these this

263  
00:09:29,880 --> 00:09:28,120

row here is built up from the models and

264

00:09:31,650 --> 00:09:29,890

this one is from the data and there's a

265

00:09:35,760 --> 00:09:31,660

good correspondence between what I would

266

00:09:38,220 --> 00:09:35,770

expect it's really important to remove

267

00:09:40,080 --> 00:09:38,230

cloud opacity features that are

268

00:09:42,660 --> 00:09:40,090

wavelength dependent because those can

269

00:09:44,370 --> 00:09:42,670

contaminate your measurements of minor

270

00:09:46,170 --> 00:09:44,380

atmospheric species which was the next

271

00:09:48,420 --> 00:09:46,180

thing that I wanted to do so first I had

272

00:09:51,890 --> 00:09:48,430

to use these wavelength dependent cloud

273

00:09:54,360 --> 00:09:51,900

opacity maps to remove these features

274

00:09:55,800 --> 00:09:54,370

another really nice thing about the

275

00:09:57,690 --> 00:09:55,810

Venus spectral windows is that they're

276

00:09:58,770 --> 00:09:57,700

sensitive to different altitudes so when

277

00:10:00,420 --> 00:09:58,780

you're measuring the abundances of

278

00:10:02,400 --> 00:10:00,430

various species you can actually build

279

00:10:03,720 --> 00:10:02,410

up vertically resolve profiles depending

280

00:10:06,270 --> 00:10:03,730

on the window that you measure them in

281

00:10:08,790 --> 00:10:06,280

so in the 1.18 Mike on window your

282

00:10:10,770 --> 00:10:08,800

sensitive lowest in the atmosphere when

283

00:10:12,180 --> 00:10:10,780

you get up to the 2.5 microns window

284

00:10:16,530 --> 00:10:12,190

you're probing just below the lower

285

00:10:18,840 --> 00:10:16,540

cloud deck okay so I know there's a lot

286

00:10:20,430 --> 00:10:18,850

of green on this slide but these are my

287

00:10:22,170 --> 00:10:20,440

water maps so this is just measuring the

288

00:10:24,450 --> 00:10:22,180

water in each pixel across the surface

289

00:10:27,330 --> 00:10:24,460

of the planet Venus's atmosphere is

290

00:10:30,360 --> 00:10:27,340

extremely dry the water vapor abundance

291

00:10:33,510 --> 00:10:30,370

is about 30 parts per million that's a

292

00:10:34,800 --> 00:10:33,520

lot less than the earth has by a lot and

293

00:10:37,980 --> 00:10:34,810

you can see that you get these

294

00:10:40,980 --> 00:10:37,990

vertically so this is 40 to 16

295

00:10:42,720 --> 00:10:40,990

kilometers 16 to 30 30 to 45 kilometers

296

00:10:45,500 --> 00:10:42,730

you can build up what it looks like at

297

00:10:48,840 --> 00:10:45,510

different heights in the atmosphere and

298

00:10:50,520 --> 00:10:48,850

then drawing your attention to the sorry

299

00:10:52,590 --> 00:10:50,530

this should not have been there he's got

300

00:10:54,510 --> 00:10:52,600

all screwed up but um drawing your

301  
00:10:59,100 --> 00:10:54,520  
attention to the lower cloud opacity and

302  
00:11:01,350 --> 00:10:59,110  
the 2.3 micron water maps I did notice

303  
00:11:03,060 --> 00:11:01,360  
that there's some correlations this

304  
00:11:04,680 --> 00:11:03,070  
one's probably hard to see but there are

305  
00:11:06,420 --> 00:11:04,690  
some correlations where sometimes

306  
00:11:08,250 --> 00:11:06,430  
thicker cloud regions have less water

307  
00:11:10,860 --> 00:11:08,260  
and thinner cloud regions have more

308  
00:11:12,720 --> 00:11:10,870  
water this was an effect that has

309  
00:11:14,790 --> 00:11:12,730  
previously been reported by some of the

310  
00:11:16,439 --> 00:11:14,800  
this Express team members and what may

311  
00:11:17,910 --> 00:11:16,449  
be causing this is cloud subsidence

312  
00:11:20,579 --> 00:11:17,920  
where you have a cloud parcel in the

313  
00:11:22,290 --> 00:11:20,589

atmosphere that some atmospheric

314

00:11:25,800 --> 00:11:22,300

downdraft pulls it lower into the

315

00:11:27,480 --> 00:11:25,810

atmosphere then the h<sub>2</sub>so<sub>4</sub> droplets that

316

00:11:30,060 --> 00:11:27,490

make up the cloud disassociate into

317

00:11:32,280 --> 00:11:30,070

water vapor and so<sub>2</sub> so in some places

318

00:11:33,780 --> 00:11:32,290

where you have thinner clouds that may

319

00:11:35,610 --> 00:11:33,790

be places where the cloud subsidence is

320

00:11:37,290 --> 00:11:35,620

occurring and you may be getting thicker

321

00:11:43,439 --> 00:11:37,300

water from that because it's producing

322

00:11:45,180 --> 00:11:43,449

water vapor I also measured HCl hydrogen

323

00:11:47,550 --> 00:11:45,190

chloride which is abundant at about

324

00:11:50,100 --> 00:11:47,560

point five parts per million and co

325

00:11:51,960 --> 00:11:50,110

which has a really interesting spatial

326

00:11:53,699 --> 00:11:51,970

distribution that's previously been

327

00:11:56,069 --> 00:11:53,709

reported in the literature by cotton at

328

00:11:57,660 --> 00:11:56,079

all and what's probably going on here is

329

00:11:59,759 --> 00:11:57,670

co is being produced photochemically

330

00:12:02,460 --> 00:11:59,769

from co<sub>2</sub> higher in the atmosphere and

331

00:12:04,199 --> 00:12:02,470

then it down wells at the poles so you

332

00:12:05,939 --> 00:12:04,209

get this abundant more higher abundance

333

00:12:07,350 --> 00:12:05,949

at the poles and then by the time it

334

00:12:09,540 --> 00:12:07,360

gets to the equatorial region in these

335

00:12:12,240 --> 00:12:09,550

kind of circulating cells it's a lot

336

00:12:13,680 --> 00:12:12,250

more depleted because it um reacts with

337

00:12:18,120 --> 00:12:13,690

other species and becomes other species

338

00:12:20,100 --> 00:12:18,130

like OCS okay so take away points is the

339

00:12:21,960 --> 00:12:20,110

main point is that completely crap cloud

340

00:12:23,910 --> 00:12:21,970

enshrouded worlds and completely haze

341

00:12:25,860 --> 00:12:23,920

and shrouded world even if they're 100%

342

00:12:27,780 --> 00:12:25,870

enshrouded it's not the end of the day

343

00:12:29,040 --> 00:12:27,790

for trying to sense their surface

344

00:12:30,900 --> 00:12:29,050

environments and characterize what's

345

00:12:32,550 --> 00:12:30,910

going on in their surfaces so I think

346

00:12:34,079 --> 00:12:32,560

atmospheric windows are very important

347

00:12:35,759 --> 00:12:34,089

because I think hazy planets are

348

00:12:49,080 --> 00:12:35,769

probably important in the exoplanet

349

00:12:54,670 --> 00:12:51,820

so for your cloud opacity you you've

350

00:12:56,800 --> 00:12:54,680

been using water clouds there so the

351  
00:12:58,300 --> 00:12:56,810  
cloud of past me i have it i was gonna

352  
00:13:01,060 --> 00:12:58,310  
cuz there was a modern data as well

353  
00:13:05,380 --> 00:13:01,070  
right yeah let me where was my club

354  
00:13:07,630 --> 00:13:05,390  
sorry so the clouds are h2so4 droplets

355  
00:13:09,970 --> 00:13:07,640  
sulfuric acid droplets and i'm basing

356  
00:13:11,500 --> 00:13:09,980  
them off of this crisp 1986 model and I

357  
00:13:14,080 --> 00:13:11,510  
should have mentioned that these units

358  
00:13:16,240 --> 00:13:14,090  
are in units of the sort of default

359  
00:13:17,740 --> 00:13:16,250  
opacity in the Christmas 1986 model

360  
00:13:20,110 --> 00:13:17,750  
they're not sort of absolute units so

361  
00:13:23,350 --> 00:13:20,120  
this is 3 times a crisp cloud opacity

362  
00:13:26,890 --> 00:13:23,360  
and this is 0 point 05 so is the h2o

363  
00:13:29,470 --> 00:13:26,900

supply opacity data in that paper or

364

00:13:31,030 --> 00:13:29,480

ready get the opacity the Ambassador

365

00:13:41,680 --> 00:13:31,040

yeah i got it from Dave Chris he's one

366

00:13:43,930 --> 00:13:41,690

of my collaborators okay thanks what is

367

00:13:46,240 --> 00:13:43,940

the specific chemical role of the HCL

368

00:13:48,580 --> 00:13:46,250

that you measured the specific what

369

00:13:51,310 --> 00:13:48,590

chemical role of the HCL that you were

370

00:13:53,950 --> 00:13:51,320

looking at yeah so agency hell I'm

371

00:13:58,330 --> 00:13:53,960

trying to remember now et al has not

372

00:13:59,770 --> 00:13:58,340

changed in abundance over the last 40 or

373

00:14:01,600 --> 00:13:59,780

however many years that we've measured

374

00:14:03,520 --> 00:14:01,610

it so it's thought to be an equilibrium

375

00:14:05,110 --> 00:14:03,530

with the surface and I cannot remember

376

00:14:06,250 --> 00:14:05,120

how they think it's produced I don't

377

00:14:07,780 --> 00:14:06,260

think they think it's volcanic Lee

378

00:14:10,780 --> 00:14:07,790

produced like some of the species in the

379

00:14:14,380 --> 00:14:10,790

atmosphere yeah I know there is some

380

00:14:16,540 --> 00:14:14,390

cloud chemistry between chlorine that

381

00:14:22,460 --> 00:14:16,550

you get in the atmosphere in the HCL but

382

00:14:33,860 --> 00:14:30,980

I didn't understand this title Venus

383

00:14:36,350 --> 00:14:33,870

stuff I think so at i/o you have this

384

00:14:39,320 --> 00:14:36,360

Laplace resonance with Ganymede and

385

00:14:43,130 --> 00:14:39,330

Europa to not get into this tidal

386

00:14:46,070 --> 00:14:43,140

locking but how does it work at a vino

387

00:14:49,310 --> 00:14:46,080

surrounding a dumpster right so Rory

388

00:14:51,530 --> 00:14:49,320

would be the person to ask that but the

389

00:14:53,660 --> 00:14:51,540

way it works is you have to assume that

390

00:14:55,490 --> 00:14:53,670

the planets not in a circular orbit and

391

00:14:58,280 --> 00:14:55,500

you have to assume that the time that it

392

00:14:59,840 --> 00:14:58,290

takes to Title II circularize is shorter

393

00:15:01,430 --> 00:14:59,850

than the timescale for it to undergo

394

00:15:04,010 --> 00:15:01,440

this desiccating greenhouse and that's

395

00:15:05,600 --> 00:15:04,020

how you get a title Venus so somehow you

396

00:15:08,240 --> 00:15:05,610

have a planet that's either persisting

397

00:15:09,890 --> 00:15:08,250

in a sort of subtly elliptical orbit

398

00:15:11,720 --> 00:15:09,900

perhaps there's another planet in there

399

00:15:14,330 --> 00:15:11,730

just like around Jupiter that's keeping

400

00:15:15,740 --> 00:15:14,340

those moons in a elliptical orbit or you

401  
00:15:17,030 --> 00:15:15,750  
have a planet that's being tidally

402  
00:15:18,710 --> 00:15:17,040  
circularized so it starts in an

403  
00:15:21,080 --> 00:15:18,720  
elliptical orbit one it can be tidally

404  
00:15:23,240 --> 00:15:21,090  
heated and then it circular rises so if

405  
00:15:25,430 --> 00:15:23,250  
that occurs in the long enough time

406  
00:15:27,440 --> 00:15:25,440  
frame for it to undergo a desiccating

407  
00:15:29,540 --> 00:15:27,450  
greenhouse then you can trigger a title

408  
00:15:32,810 --> 00:15:29,550  
greenhouse so these are planets that are

409  
00:15:34,640 --> 00:15:32,820  
close in to low mass stars it's directly

410  
00:15:36,830 --> 00:15:34,650  
analogous to the Jupiter system and

411  
00:15:39,770 --> 00:15:36,840  
you're producing a lot more heat than

412  
00:15:41,870 --> 00:15:39,780  
you are on io io has like two watts per

413  
00:15:43,610 --> 00:15:41,880

square meter whereas for tidal Venus's

414

00:15:44,900 --> 00:15:43,620

you need 300 watts per square meter so

415

00:15:49,460 --> 00:15:44,910

there's there's quite a difference but