



## Disk-Integrated Rainbow Signal from Earth?

| Cloud Phase  | Global cover (ISCCP) | Global cover (POLDER) | Total Reflectance (Tinetti et al. 2006) | Polarized Reflectance (Goloub et al. 1994) |
|--------------|----------------------|-----------------------|---|--|
| liquid cloud | 33.6%                | 47.3%                 | 35%                                     | 7%   |
| ice cloud    | 34.0%                | 20.3%                 | 14%                                     | 0%   |
| clear sky    | 32.4%                | 32.4%                 | 6%                                      | 0%   |

From combination of reflectances, weighted according to fraction of global cover, polarization of rainbow peak is:

$P = 15.5\%$  (POLDER cloud phase fractions)

$P = 12.7\%$  (ISCCP cloud phase fractions)

$P = 20.0\%$  (totally cloud covered Earth)



NASA  
Astrobiology  
Institute

University of Washington  
Astrobiology Seminar Series

4/29/2008 - Jeremy Bailey

1  
00:00:04,870 --> 00:00:02,869  
well hello everybody and welcome again

2  
00:00:06,710 --> 00:00:04,880  
to the university of washington's spring

3  
00:00:08,310 --> 00:00:06,720  
astrobiology seminar series and a

4  
00:00:09,509 --> 00:00:08,320  
special welcome to our videocon

5  
00:00:11,990 --> 00:00:09,519  
participants

6  
00:00:14,789 --> 00:00:12,000  
our speaker today is dr jeremy bailey of

7  
00:00:17,189 --> 00:00:14,799  
macquarie university in australia

8  
00:00:19,830 --> 00:00:17,199  
jeremy received his ba in physics from

9  
00:00:22,070 --> 00:00:19,840  
oxford university in 1995

10  
00:00:24,150 --> 00:00:22,080  
and his phd in astronomy from sussex

11  
00:00:25,750 --> 00:00:24,160  
university in 1978.

12  
00:00:27,429 --> 00:00:25,760  
he spent a large fraction of his career

13  
00:00:29,429 --> 00:00:27,439

at the anglo-australian observatory in

14

00:00:31,509 --> 00:00:29,439

sydney which is where i first met jeremy

15

00:00:33,510 --> 00:00:31,519

while i was working working on my phd

16

00:00:35,590 --> 00:00:33,520

and i think jeremy was there for over

17

00:00:38,709 --> 00:00:35,600

over 20 years

18

00:00:40,549 --> 00:00:38,719

but more recently from 2001 to 2007

19

00:00:41,590 --> 00:00:40,559

jeremy served as the associate director

20

00:00:43,990 --> 00:00:41,600

for the australian center for

21

00:00:46,389 --> 00:00:44,000

astrobiology and also as an associate

22

00:00:48,389 --> 00:00:46,399

professor of astrobiology from 2005 to

23

00:00:50,790 --> 00:00:48,399

2007.

24

00:00:52,630 --> 00:00:50,800

he is also in his spare time a member of

25

00:00:54,790 --> 00:00:52,640

the anglo-australian planet search team

26  
00:00:56,869 --> 00:00:54,800  
which has discovered 29 of the currently

27  
00:00:59,430 --> 00:00:56,879  
known exoplanets using radial velocity

28  
00:01:00,950 --> 00:00:59,440  
technique jeremy's interest in astronomy

29  
00:01:04,310 --> 00:01:00,960  
have been very broad ranging from

30  
00:01:06,149 --> 00:01:04,320  
cataclysmic variable stars through uh

31  
00:01:08,550 --> 00:01:06,159  
induction i guess of uh molecular

32  
00:01:10,710 --> 00:01:08,560  
homochirality in star-forming regions to

33  
00:01:13,350 --> 00:01:10,720  
most recently terrestrial planets in our

34  
00:01:15,109 --> 00:01:13,360  
own solar system and extrasolar planets

35  
00:01:16,870 --> 00:01:15,119  
however jeremy's diverse research has

36  
00:01:18,630 --> 00:01:16,880  
always been linked by his strong

37  
00:01:21,429 --> 00:01:18,640  
interest in the development and use of

38  
00:01:22,789 --> 00:01:21,439

both infrared and polarimetric

39

00:01:24,710 --> 00:01:22,799

instrumentation

40

00:01:26,870 --> 00:01:24,720

so today jeremy will enlighten us on how

41

00:01:30,390 --> 00:01:26,880

to use polarization techniques to detect

42

00:01:37,429 --> 00:01:30,400

and characterize extrasolar planets

43

00:01:42,870 --> 00:01:41,109

so the basic idea of using polarization

44

00:01:45,109 --> 00:01:42,880

with extracellular planets

45

00:01:47,830 --> 00:01:45,119

is that sunlight is essentially

46

00:01:50,389 --> 00:01:47,840

unpolarized that we know that it's

47

00:01:52,149 --> 00:01:50,399

unpolarized to a very high level

48

00:01:54,149 --> 00:01:52,159

the polarization of the sun has been

49

00:01:55,510 --> 00:01:54,159

measured to

50

00:01:57,190 --> 00:01:55,520

be less than around one part in a

51

00:01:59,030 --> 00:01:57,200  
million

52

00:02:00,630 --> 00:01:59,040  
but when that light scatters

53

00:02:01,990 --> 00:02:00,640  
off a planet

54

00:02:03,429 --> 00:02:02,000  
such as the earth

55

00:02:04,630 --> 00:02:03,439  
um it's polarized by a number of

56

00:02:07,030 --> 00:02:04,640  
processes

57

00:02:08,710 --> 00:02:07,040  
so scattering off off molecules radius

58

00:02:10,150 --> 00:02:08,720  
scattering produces very high

59

00:02:12,949 --> 00:02:10,160  
polarizations

60

00:02:14,470 --> 00:02:12,959  
that peak at a 90 degree scattering

61

00:02:17,350 --> 00:02:14,480  
angle

62

00:02:20,070 --> 00:02:17,360  
scattering off particles such as cloud

63

00:02:22,710 --> 00:02:20,080

droplets aerosols in the atmosphere also

64

00:02:24,550 --> 00:02:22,720

produces polarization somewhat lower

65

00:02:27,110 --> 00:02:24,560

levels

66

00:02:30,150 --> 00:02:27,120

20 or less

67

00:02:33,270 --> 00:02:30,160

and the variation of this polarization

68

00:02:35,990 --> 00:02:34,630

what we call phase angle which is the

69

00:02:37,430 --> 00:02:36,000

angle between the sunlight and the

70

00:02:39,990 --> 00:02:37,440

direction it comes off

71

00:02:44,710 --> 00:02:40,000

provides some information on the size

72

00:02:48,630 --> 00:02:46,470

so there's a number of ways that

73

00:02:51,030 --> 00:02:48,640

polarization can be applied in the study

74

00:02:52,150 --> 00:02:51,040

of exoplanets and

75

00:02:54,229 --> 00:02:52,160

i'm only going to talk about some of

76  
00:02:55,110 --> 00:02:54,239  
them here the ones that are highlighted

77  
00:02:56,229 --> 00:02:55,120  
here

78  
00:02:58,070 --> 00:02:56,239  
um

79  
00:02:59,750 --> 00:02:58,080  
polarization can be used as a

80  
00:03:02,949 --> 00:02:59,760  
differential technique

81  
00:03:04,790 --> 00:03:02,959  
to to help to pick out the

82  
00:03:06,790 --> 00:03:04,800  
planet from the

83  
00:03:08,550 --> 00:03:06,800  
echonois that you get around a star and

84  
00:03:10,710 --> 00:03:08,560  
this applies to

85  
00:03:12,550 --> 00:03:10,720  
techniques that are being developed for

86  
00:03:14,229 --> 00:03:12,560  
looking for extra solar planets with

87  
00:03:17,589 --> 00:03:14,239  
large ground-based telescopes where

88  
00:03:19,110 --> 00:03:17,599

they're using adaptive optics systems to

89

00:03:21,270 --> 00:03:19,120

sharpen up the light from the star and

90

00:03:22,630 --> 00:03:21,280

make it easy out the planet

91

00:03:24,229 --> 00:03:22,640

but you still get

92

00:03:25,830 --> 00:03:24,239

adaptive optic systems are not perfect

93

00:03:26,949 --> 00:03:25,840

so they still leave a halo of light

94

00:03:28,949 --> 00:03:26,959

around the star and you're trying to

95

00:03:30,550 --> 00:03:28,959

pick the planet out of that halo and

96

00:03:32,710 --> 00:03:30,560

polarization is one

97

00:03:34,390 --> 00:03:32,720

differential technique that that you can

98

00:03:35,990 --> 00:03:34,400

use to do that because the light of the

99

00:03:38,070 --> 00:03:36,000

planet should be polarized whereas the

100

00:03:39,910 --> 00:03:38,080

starlight won't be and so many of these

101  
00:03:43,190 --> 00:03:39,920  
instruments are incorporating

102  
00:03:45,910 --> 00:03:43,200  
polarization systems

103  
00:03:47,830 --> 00:03:45,920  
um you can also use polarization to try

104  
00:03:50,630 --> 00:03:47,840  
to detect the the scattered light from

105  
00:03:52,550 --> 00:03:50,640  
from unresolved planets and

106  
00:03:54,229 --> 00:03:52,560  
thinking here are hot jupiter type

107  
00:03:55,190 --> 00:03:54,239  
systems these are the planets that are

108  
00:03:56,229 --> 00:03:55,200  
being

109  
00:03:57,350 --> 00:03:56,239  
found

110  
00:03:58,869 --> 00:03:57,360  
in um

111  
00:04:00,309 --> 00:03:58,879  
doppler and transit planets such as

112  
00:04:01,910 --> 00:04:00,319  
whether where you have a giant planet

113  
00:04:04,070 --> 00:04:01,920

very close to its star orbiting in a

114

00:04:05,990 --> 00:04:04,080

period of a few days

115

00:04:08,630 --> 00:04:06,000

and at the moment we have no hope of

116

00:04:10,309 --> 00:04:08,640

actually being able to resolve the

117

00:04:11,509 --> 00:04:10,319

planet from the star with it with any

118

00:04:13,110 --> 00:04:11,519

reasonable technique all we can do is

119

00:04:15,509 --> 00:04:13,120

look at the combined light of the planet

120

00:04:17,509 --> 00:04:15,519

from the star but it might be possible

121

00:04:18,710 --> 00:04:17,519

to use polarization to pick out the

122

00:04:20,310 --> 00:04:18,720

fraction of light that's coming from the

123

00:04:21,749 --> 00:04:20,320

planet and

124

00:04:25,110 --> 00:04:21,759

if i have time i'll say a bit more about

125

00:04:27,030 --> 00:04:25,120

that at the the end of this talk

126

00:04:29,270 --> 00:04:27,040

the main part of the talk is going to be

127

00:04:31,270 --> 00:04:29,280

about looking using polarization to

128

00:04:34,790 --> 00:04:31,280

characterize the atmospheres

129

00:04:36,550 --> 00:04:34,800

particularly of terrestrial type planets

130

00:04:38,150 --> 00:04:36,560

and we can use polarization in a number

131

00:04:41,110 --> 00:04:38,160

of ways it can help to distinguish

132

00:04:42,950 --> 00:04:41,120

between clear and cloudy atmospheres it

133

00:04:44,310 --> 00:04:42,960

can help us to measure the atmospheric

134

00:04:46,230 --> 00:04:44,320

pressure

135

00:04:49,270 --> 00:04:46,240

it can help us to determine the

136

00:04:50,469 --> 00:04:49,280

composition and size of cloud particles

137

00:04:52,550 --> 00:04:50,479

and one of the things we're particularly

138

00:04:54,310 --> 00:04:52,560

interested in is looking for liquid

139

00:04:56,150 --> 00:04:54,320

water and there are ways of using

140

00:04:58,070 --> 00:04:56,160

polarization to look for liquid water

141

00:05:00,390 --> 00:04:58,080

both in the liquid water droplets in

142

00:05:01,990 --> 00:05:00,400

clouds and liquid water on the surface

143

00:05:04,550 --> 00:05:02,000

of a planet

144

00:05:06,950 --> 00:05:04,560

and all these things are hard to do with

145

00:05:09,110 --> 00:05:06,960

spectroscopy

146

00:05:10,150 --> 00:05:09,120

polarimetry provides so perimetry

147

00:05:11,510 --> 00:05:10,160

provides information that's very

148

00:05:13,110 --> 00:05:11,520

complementary to what you get out of

149

00:05:14,870 --> 00:05:13,120

spectroscopy

150

00:05:18,070 --> 00:05:14,880

it's also in fact possible these

151

00:05:20,790 --> 00:05:18,080

polarization itself as a biosignature

152

00:05:22,550 --> 00:05:20,800

you can in principle detect circular

153

00:05:25,670 --> 00:05:22,560

polarization effects

154

00:05:26,870 --> 00:05:25,680

due to light scattering off chiral

155

00:05:27,749 --> 00:05:26,880

molecules

156

00:05:34,150 --> 00:05:27,759

in

157

00:05:35,749 --> 00:05:34,160

cyanobacteria where you have um

158

00:05:37,830 --> 00:05:35,759

chlorophyll there there will be a

159

00:05:41,270 --> 00:05:37,840

circular polarization signature of that

160

00:05:42,870 --> 00:05:41,280

light that's a result of the uh

161

00:05:45,110 --> 00:05:42,880

preference for one-handedness the

162

00:05:47,350 --> 00:05:45,120

chirality of the molecules and for

163

00:05:48,950 --> 00:05:47,360

example bill sparks based telescope

164

00:05:50,629 --> 00:05:48,960

science attitude is looking at such

165

00:05:52,710 --> 00:05:50,639

effects but they're very small and

166

00:05:57,189 --> 00:05:52,720

they're way beyond what we can think of

167

00:06:01,990 --> 00:06:00,870

okay so the current status of extrasolar

168

00:06:04,629 --> 00:06:02,000

planets

169

00:06:06,629 --> 00:06:04,639

so we now have 287

170

00:06:09,189 --> 00:06:06,639

extrasolar planets known according to

171

00:06:10,309 --> 00:06:09,199

the extracellular planets encyclopedia

172

00:06:12,150 --> 00:06:10,319

um

173

00:06:14,629 --> 00:06:12,160

most of these have been detected by the

174

00:06:17,350 --> 00:06:14,639

doppler method it's looking at the um

175

00:06:19,590 --> 00:06:17,360

varying radial velocity of the star as

176

00:06:21,590 --> 00:06:19,600

the as as the planet moves around it and

177

00:06:22,629 --> 00:06:21,600

causes a wobble of the motion of the

178

00:06:23,510 --> 00:06:22,639

star

179

00:06:29,110 --> 00:06:23,520

um

180

00:06:30,550 --> 00:06:29,120

increased very recently is detection by

181

00:06:32,870 --> 00:06:30,560

by the transit method where we see the

182

00:06:33,670 --> 00:06:32,880

planet passing in front of the star and

183

00:06:35,189 --> 00:06:33,680

that's

184

00:06:36,309 --> 00:06:35,199

those transit plants are very useful

185

00:06:38,710 --> 00:06:36,319

because they get

186

00:06:40,150 --> 00:06:38,720

we can actually use the transit to get

187

00:06:42,550 --> 00:06:40,160

information on the atmosphere of the

188

00:06:47,110 --> 00:06:45,029

um we now have six planets detected by

189

00:06:48,469 --> 00:06:47,120

the micro lensing method and this is

190

00:06:50,950 --> 00:06:48,479

where we see the

191

00:06:52,309 --> 00:06:50,960

the planet passing in front the star in

192

00:06:54,629 --> 00:06:52,319

the planet passing in front of a more

193

00:06:56,629 --> 00:06:54,639

distant star and causing gravitational

194

00:06:58,390 --> 00:06:56,639

lensing of the

195

00:07:00,070 --> 00:06:58,400

star

196

00:07:01,990 --> 00:07:00,080

and you can get a characteristic curve

197

00:07:04,469 --> 00:07:02,000

which allows you to deduce the presence

198

00:07:06,070 --> 00:07:04,479

of a planet

199

00:07:07,830 --> 00:07:06,080

and then there's there's five detected

200

00:07:10,629 --> 00:07:07,840

by direct imaging methods these are

201  
00:07:13,270 --> 00:07:10,639  
mostly planets around around very young

202  
00:07:16,070 --> 00:07:13,280  
stars the planet is still young and

203  
00:07:21,589 --> 00:07:16,080  
still producing uh light through its own

204  
00:07:24,629 --> 00:07:22,629  
so

205  
00:07:26,150 --> 00:07:24,639  
most of these current detections are are

206  
00:07:27,589 --> 00:07:26,160  
giant planets

207  
00:07:31,350 --> 00:07:27,599  
the

208  
00:07:33,909 --> 00:07:31,360  
masses of hundreds of earth masses or

209  
00:07:35,510 --> 00:07:33,919  
more comparable to jupiter and saturn in

210  
00:07:37,510 --> 00:07:35,520  
our red solar system

211  
00:07:39,670 --> 00:07:37,520  
uh there's a few lower mass planets

212  
00:07:41,909 --> 00:07:39,680  
found the lowest so far founder down to

213  
00:07:43,430 --> 00:07:41,919

about five earth masses

214

00:07:45,189 --> 00:07:43,440

and these these planets are sometimes

215

00:07:46,870 --> 00:07:45,199

called called super earth they could be

216

00:07:51,670 --> 00:07:46,880

they could be large terrestrial planets

217

00:07:56,150 --> 00:07:53,990

almost all the current detections are

218

00:07:58,150 --> 00:07:56,160

indirect detections we are not seeing

219

00:08:00,150 --> 00:07:58,160

the planet itself we're deducing the

220

00:08:02,710 --> 00:08:00,160

presence of the planet from its effect

221

00:08:06,309 --> 00:08:02,720

on the star

222

00:08:08,150 --> 00:08:06,319

there's there's a few direct detections

223

00:08:10,710 --> 00:08:08,160

and and they're all by means of the

224

00:08:13,510 --> 00:08:10,720

thermal emission and so the spitzer

225

00:08:14,390 --> 00:08:13,520

space telescope has been used to detect

226

00:08:19,029 --> 00:08:14,400

the

227

00:08:21,909 --> 00:08:19,039

transiting planets

228

00:08:23,189 --> 00:08:21,919

and there's also these near-infrared

229

00:08:24,309 --> 00:08:23,199

um

230

00:08:25,830 --> 00:08:24,319

imaging

231

00:08:27,110 --> 00:08:25,840

observations of planets around young

232

00:08:29,189 --> 00:08:27,120

stars again we're seeing the thermal

233

00:08:31,350 --> 00:08:29,199

emission but no extracellular planet has

234

00:08:35,269 --> 00:08:31,360

yet been seen by the light reflected

235

00:08:39,350 --> 00:08:37,350

and of cour and we have yet to find

236

00:08:40,310 --> 00:08:39,360

anything else like earth orbiting

237

00:08:41,829 --> 00:08:40,320

another star we don't have the

238

00:08:44,949 --> 00:08:41,839

sensitivity in most of these methods to

239

00:08:48,470 --> 00:08:44,959

detect a planet of earth mass although

240

00:08:50,790 --> 00:08:48,480

that should become possible soon with um

241

00:08:52,550 --> 00:08:50,800

space missions such as kepler which will

242

00:08:57,350 --> 00:08:52,560

be capable of detecting earth-like

243

00:09:01,910 --> 00:08:58,630

nevertheless there's a number of

244

00:09:06,070 --> 00:09:04,790

missions to directly detect terrestrial

245

00:09:08,070 --> 00:09:06,080

planets

246

00:09:10,150 --> 00:09:08,080

this is very hard because a terrestrial

247

00:09:11,750 --> 00:09:10,160

planet is an extremely faint object it's

248

00:09:13,910 --> 00:09:11,760

probably fainter than anything

249

00:09:15,430 --> 00:09:13,920

astronomers have get measured and it's

250

00:09:17,110 --> 00:09:15,440

sitting next to a planet which is 10

251  
00:09:18,710 --> 00:09:17,120  
billion times brighter

252  
00:09:20,949 --> 00:09:18,720  
so these are pretty challenging

253  
00:09:22,470 --> 00:09:20,959  
observations but a number of methods

254  
00:09:24,870 --> 00:09:22,480  
have been proposed

255  
00:09:27,030 --> 00:09:24,880  
so these two

256  
00:09:28,470 --> 00:09:27,040  
instruments this is terrestrial planet

257  
00:09:29,670 --> 00:09:28,480  
finder imager

258  
00:09:31,430 --> 00:09:29,680  
interferometer

259  
00:09:33,430 --> 00:09:31,440  
and this is this is darwin which is a

260  
00:09:34,949 --> 00:09:33,440  
similar proposal from the european space

261  
00:09:37,030 --> 00:09:34,959  
agency

262  
00:09:39,030 --> 00:09:37,040  
these involve a number of infrared

263  
00:09:41,670 --> 00:09:39,040

telescopes um

264

00:09:43,590 --> 00:09:41,680

flying in formation and combining their

265

00:09:46,070 --> 00:09:43,600

light and they can use um

266

00:09:48,150 --> 00:09:46,080

interferometric methods to to get rid of

267

00:09:50,949 --> 00:09:48,160

the light of the star and reveal the

268

00:09:53,110 --> 00:09:50,959

planet that thermal infrared wavelengths

269

00:09:55,509 --> 00:09:53,120

and then an alternative approaches is

270

00:09:57,269 --> 00:09:55,519

what's called tpfc terrestrial planet

271

00:09:58,790 --> 00:09:57,279

finder corrodograph

272

00:10:00,870 --> 00:09:58,800

and this is a large

273

00:10:02,949 --> 00:10:00,880

optical telescope but working at visible

274

00:10:05,350 --> 00:10:02,959

wavelengths and using a technique called

275

00:10:07,269 --> 00:10:05,360

a coronagraph an optical system to get

276

00:10:09,990 --> 00:10:07,279

rid of the light of the star and again

277

00:10:12,150 --> 00:10:10,000

reveal the planet at visible wavelengths

278

00:10:13,750 --> 00:10:12,160

um it's actually tpssc and similar

279

00:10:15,350 --> 00:10:13,760

instruments that are most interesting

280

00:10:17,990 --> 00:10:15,360

for what i'm going to talk about here

281

00:10:20,150 --> 00:10:18,000

because it's only ttsc that is looking

282

00:10:21,430 --> 00:10:20,160

at like reflected starlight reflected

283

00:10:24,150 --> 00:10:21,440

off the star and that's where we get the

284

00:10:25,670 --> 00:10:24,160

polarization effects

285

00:10:28,069 --> 00:10:25,680

so all of these missions are aimed to

286

00:10:30,150 --> 00:10:28,079

detect and characterize

287

00:10:32,710 --> 00:10:30,160

extracellular terrestrial planets

288

00:10:36,870 --> 00:10:32,720

and the the primary tool for planetary

289

00:10:38,550 --> 00:10:36,880

characterization has usually been um

290

00:10:40,389 --> 00:10:38,560

as usually being spectroscopy in most of

291

00:10:41,750 --> 00:10:40,399

these proposals

292

00:10:43,350 --> 00:10:41,760

and what i want to point out here is

293

00:10:44,710 --> 00:10:43,360

that spectroscopy doesn't tell us

294

00:10:47,350 --> 00:10:44,720

anything everything we would like to

295

00:10:49,110 --> 00:10:47,360

know about these planets

296

00:10:50,069 --> 00:10:49,120

what it basically does is allows us to

297

00:10:53,269 --> 00:10:50,079

detect

298

00:10:54,790 --> 00:10:53,279

um some but not all of the gases that

299

00:10:56,790 --> 00:10:54,800

are pleasant present in a planetary

300

00:10:58,470 --> 00:10:56,800

atmosphere

301  
00:11:01,110 --> 00:10:58,480  
and i want to explain here what we can

302  
00:11:02,790 --> 00:11:01,120  
do by including polarization in such a

303  
00:11:04,150 --> 00:11:02,800  
mission

304  
00:11:07,350 --> 00:11:04,160  
and that can give us additional

305  
00:11:12,710 --> 00:11:09,910  
so these are some models of what the

306  
00:11:15,030 --> 00:11:12,720  
spectrum of a terrestrial planet might

307  
00:11:17,430 --> 00:11:15,040  
look like um

308  
00:11:20,710 --> 00:11:17,440  
observed with one of these missions

309  
00:11:22,949 --> 00:11:20,720  
so this is actually the infrared region

310  
00:11:24,710 --> 00:11:22,959  
up here showing showing what tpci or

311  
00:11:28,550 --> 00:11:24,720  
darwin would see and that shows

312  
00:11:30,230 --> 00:11:28,560  
absorptions due to co2 and ozone

313  
00:11:32,310 --> 00:11:30,240

and water

314

00:11:34,630 --> 00:11:32,320

and in the visible region of the region

315

00:11:36,550 --> 00:11:34,640

that tpfc would look at you can see

316

00:11:39,110 --> 00:11:36,560

again see absorption is due to oxygen

317

00:11:41,269 --> 00:11:39,120

and ozone so oxygen and ozone are

318

00:11:42,710 --> 00:11:41,279

biosignatures because they're produced

319

00:11:46,069 --> 00:11:42,720

in the atmosphere of the planet by

320

00:11:49,269 --> 00:11:47,990

we can also see water vapor in this

321

00:11:49,990 --> 00:11:49,279

region

322

00:11:56,870 --> 00:11:50,000

and

323

00:12:01,670 --> 00:11:58,710

but there's a number of things we'd like

324

00:12:03,509 --> 00:12:01,680

to do that spectroscopy can't do for us

325

00:12:04,949 --> 00:12:03,519

uh one thing it can't do is detect

326

00:12:09,670 --> 00:12:04,959

liquid water

327

00:12:12,069 --> 00:12:09,680

characteristic of a habitable planet

328

00:12:14,069 --> 00:12:12,079

and and the uh

329

00:12:16,230 --> 00:12:14,079

the mantra in astrobiology in the solar

330

00:12:18,389 --> 00:12:16,240

system has been follow the water um the

331

00:12:21,190 --> 00:12:18,399

water water is the

332

00:12:22,710 --> 00:12:21,200

one fundamental characteristic required

333

00:12:25,509 --> 00:12:22,720

for life

334

00:12:26,550 --> 00:12:25,519

and so um you want to look for liquid

335

00:12:28,310 --> 00:12:26,560

water

336

00:12:30,710 --> 00:12:28,320

to protect planets that are promising

337

00:12:33,269 --> 00:12:30,720

for life

338

00:12:34,629 --> 00:12:33,279

we can't do that with spectroscopy

339

00:12:37,509 --> 00:12:34,639

another thing we can't do very well is

340

00:12:39,430 --> 00:12:37,519

detect the presence of clouds

341

00:12:42,629 --> 00:12:39,440

and all planetary atmospheres in the

342

00:12:44,550 --> 00:12:42,639

solar system have clouds of of some sort

343

00:12:45,990 --> 00:12:44,560

and that means we can't really see tell

344

00:12:47,990 --> 00:12:46,000

if the light we're looking at is coming

345

00:12:49,590 --> 00:12:48,000

off a planet's surface or coming off the

346

00:12:52,310 --> 00:12:49,600

cloud tops and so anything we measure

347

00:12:53,590 --> 00:12:52,320

about the planet um we don't really know

348

00:12:55,269 --> 00:12:53,600

if it's telling us anything useful about

349

00:12:57,190 --> 00:12:55,279

the planet surface so for example if we

350

00:12:58,870 --> 00:12:57,200

look at a planet like venus

351

00:13:00,389 --> 00:12:58,880

the conditions of the cloud tops are

352

00:13:04,230 --> 00:13:00,399

very different from those at the surface

353

00:13:08,069 --> 00:13:05,990

another thing we can't easily get at is

354

00:13:10,389 --> 00:13:08,079

the atmospheric pressure and that's

355

00:13:11,590 --> 00:13:10,399

because we only detect some of the gases

356

00:13:13,350 --> 00:13:11,600

in the atmosphere

357

00:13:15,750 --> 00:13:13,360

some important gases

358

00:13:17,509 --> 00:13:15,760

in particular nitrogen and hydrogen

359

00:13:18,870 --> 00:13:17,519

which are the main components of the

360

00:13:20,710 --> 00:13:18,880

atmospheres of

361

00:13:22,870 --> 00:13:20,720

of hydrogen hydrogen in the case of the

362

00:13:25,030 --> 00:13:22,880

giant planets nitrogen in the case of

363

00:13:27,030 --> 00:13:25,040

earth and titan for example don't have

364

00:13:28,949 --> 00:13:27,040

any spectral features at the tpf

365

00:13:30,790 --> 00:13:28,959

wavelengths so if we're not seeing all

366

00:13:31,910 --> 00:13:30,800

the gases we can't get an idea of what

367

00:13:33,990 --> 00:13:31,920

the total

368

00:13:36,150 --> 00:13:34,000

atmospheric pressure is and that means

369

00:13:38,230 --> 00:13:36,160

we can't even measure the

370

00:13:40,710 --> 00:13:38,240

concentration of the observable gases

371

00:13:42,069 --> 00:13:40,720

properly because they're affected by the

372

00:13:43,910 --> 00:13:42,079

amount of pressure broadening by these

373

00:13:46,150 --> 00:13:43,920

gases we can't see

374

00:13:47,910 --> 00:13:46,160

so for example the co2 absorption

375

00:13:49,590 --> 00:13:47,920

features in the earth and mars

376

00:13:50,550 --> 00:13:49,600

atmosphere are actually roughly the same

377

00:13:52,710 --> 00:13:50,560

strength

378

00:13:54,629 --> 00:13:52,720

even though mars actually has a much

379

00:13:55,430 --> 00:13:54,639

bigger column of co2

380

00:13:57,030 --> 00:13:55,440

but

381

00:13:58,470 --> 00:13:57,040

in the earth case there's lots more

382

00:14:00,310 --> 00:13:58,480

pressure broadening due to nitrogen

383

00:14:02,790 --> 00:14:00,320

which brings the lines up to the same

384

00:14:04,550 --> 00:14:02,800

relative strength

385

00:14:06,389 --> 00:14:04,560

and polarization can help us to do all

386

00:14:07,990 --> 00:14:06,399

of these things

387

00:14:10,310 --> 00:14:08,000

and what the measurement we want to make

388

00:14:15,269 --> 00:14:10,320

is polarization as a function of phase

389

00:14:19,350 --> 00:14:17,670

so the features we're going to use

390

00:14:21,269 --> 00:14:19,360

to get information

391

00:14:22,790 --> 00:14:21,279

out of planetary atmospheres are

392

00:14:25,350 --> 00:14:22,800

the three that are illustrated here

393

00:14:26,629 --> 00:14:25,360

they're all very familiar phenomena on

394

00:14:29,269 --> 00:14:26,639

earth

395

00:14:32,310 --> 00:14:29,279

so so rainbows which are due to

396

00:14:33,430 --> 00:14:32,320

scattering off liquid water droplets

397

00:14:35,189 --> 00:14:33,440

um

398

00:14:37,750 --> 00:14:35,199

glint off

399

00:14:39,350 --> 00:14:37,760

of light reflected off of a water

400

00:14:41,350 --> 00:14:39,360

surface which is a possible technique

401  
00:14:43,189 --> 00:14:41,360  
for looking for oceans

402  
00:14:45,269 --> 00:14:43,199  
and rayleigh scattering which is simply

403  
00:14:49,350 --> 00:14:45,279  
light scattering off molecules it's what

404  
00:14:53,829 --> 00:14:51,590  
all of these phenomena if you looked at

405  
00:14:55,750 --> 00:14:53,839  
them through a polaroid sunglasses or

406  
00:14:59,990 --> 00:14:55,760  
any polarizing filter you will see that

407  
00:15:05,110 --> 00:15:02,310  
and that's how we can use detect them

408  
00:15:06,150 --> 00:15:05,120  
polarimetrically

409  
00:15:08,069 --> 00:15:06,160  
so

410  
00:15:09,509 --> 00:15:08,079  
i'll start by talking about rainbows

411  
00:15:12,470 --> 00:15:09,519  
rainbows are

412  
00:15:15,509 --> 00:15:12,480  
caused by light scattering off

413  
00:15:17,269 --> 00:15:15,519

spherical water droplets

414

00:15:19,430 --> 00:15:17,279

and what we have is is the light passing

415

00:15:21,509 --> 00:15:19,440

into the water droplet reflecting off

416

00:15:25,030 --> 00:15:21,519

the inside of the water droplet and then

417

00:15:27,590 --> 00:15:25,040

coming out at a different angle

418

00:15:30,150 --> 00:15:27,600

and the light actually scatters through

419

00:15:32,150 --> 00:15:30,160

different angles depending on

420

00:15:34,150 --> 00:15:32,160

depending on where it's coming into the

421

00:15:35,750 --> 00:15:34,160

droplet so this impact parameter which

422

00:15:37,110 --> 00:15:35,760

measures the distance from the center of

423

00:15:38,069 --> 00:15:37,120

the droplet

424

00:15:40,790 --> 00:15:38,079

um

425

00:15:42,389 --> 00:15:40,800

but if you plot those angles

426

00:15:44,470 --> 00:15:42,399

as a function of impact parameter you

427

00:15:46,470 --> 00:15:44,480

find that there's a there's a minimum

428

00:15:50,550 --> 00:15:46,480

scattering angle where the

429

00:15:55,269 --> 00:15:52,629

where these curves turn round and there

430

00:15:58,710 --> 00:15:55,279

you get a pile up of light coming out

431

00:16:01,269 --> 00:15:58,720

coming out of these particular angles

432

00:16:02,389 --> 00:16:01,279

um i better explain these terms phase

433

00:16:03,749 --> 00:16:02,399

angle and scattering angle because i'm

434

00:16:06,629 --> 00:16:03,759

going to use them a lot

435

00:16:08,790 --> 00:16:06,639

so we have light coming in from the sun

436

00:16:11,350 --> 00:16:08,800

reflecting off

437

00:16:13,030 --> 00:16:11,360

or scattering off a particle

438

00:16:14,870 --> 00:16:13,040

and the phase angle is just this this

439

00:16:16,629 --> 00:16:14,880

angle measured from the

440

00:16:17,910 --> 00:16:16,639

direction the sunlight is coming from

441

00:16:20,470 --> 00:16:17,920

and the scattering angle is the

442

00:16:21,670 --> 00:16:20,480

complement of that 180 degrees minus the

443

00:16:23,670 --> 00:16:21,680

phase angle

444

00:16:25,749 --> 00:16:23,680

and it's observers always use phase

445

00:16:27,430 --> 00:16:25,759

angle and scattering theorists always

446

00:16:29,829 --> 00:16:27,440

use scattering angles so i'm afraid i'm

447

00:16:31,350 --> 00:16:29,839

going to have a mixture of the two but

448

00:16:32,710 --> 00:16:31,360

but they mean

449

00:16:35,269 --> 00:16:32,720

they're measuring essentially the same

450

00:16:37,670 --> 00:16:35,279

thing and for rainbow scattering from

451

00:16:40,230 --> 00:16:37,680

water droplets the scattering angle is

452

00:16:46,470 --> 00:16:40,240

about 140 degrees the phase angle is

453

00:16:50,389 --> 00:16:48,550

so this is what rainbows look like and

454

00:16:53,110 --> 00:16:50,399

i've exaggerated the contrast a little

455

00:16:55,350 --> 00:16:53,120

on this picture to show up the effects

456

00:16:58,069 --> 00:16:55,360

so the you get the circular rainbow

457

00:17:02,470 --> 00:16:58,079

that's that's the 40 degree

458

00:17:07,669 --> 00:17:06,069

you get the coloured primary rainbow

459

00:17:09,350 --> 00:17:07,679

and the region inside this rainbow is

460

00:17:10,710 --> 00:17:09,360

not dark there's light scattering at all

461

00:17:13,270 --> 00:17:10,720

these angles

462

00:17:15,110 --> 00:17:13,280

as well as the actual rainbow angles but

463

00:17:16,949 --> 00:17:15,120

we only actually see the colors of this

464

00:17:19,270 --> 00:17:16,959

this turnaround point at the minimum

465

00:17:21,029 --> 00:17:19,280

scattering angle the light can reach

466

00:17:22,710 --> 00:17:21,039

whereas this region here is actually

467

00:17:25,029 --> 00:17:22,720

dark there's no light scattering off the

468

00:17:26,549 --> 00:17:25,039

water droplets into this region and then

469

00:17:27,909 --> 00:17:26,559

outside the

470

00:17:29,669 --> 00:17:27,919

primary rainbow you get a secondary

471

00:17:31,830 --> 00:17:29,679

rainbow and you get another bright

472

00:17:36,310 --> 00:17:31,840

region here and that's that's light that

473

00:17:36,320 --> 00:17:41,669

it's a cardstock then yes that's right

474

00:17:47,029 --> 00:17:43,590

so rainbows rainbows are very highly

475

00:17:49,430 --> 00:17:47,039

polarized um if you photograph through

476  
00:17:50,630 --> 00:17:49,440  
polarizing filters and through the

477  
00:17:53,669 --> 00:17:50,640  
um

478  
00:17:54,870 --> 00:17:53,679  
so the polarization is in this direction

479  
00:17:56,630 --> 00:17:54,880  
um

480  
00:17:58,390 --> 00:17:56,640  
and in this direction you the rainbow

481  
00:17:59,750 --> 00:17:58,400  
just disappears it's essentially there's

482  
00:18:01,270 --> 00:17:59,760  
essentially nothing come through the

483  
00:18:02,950 --> 00:18:01,280  
level of polarization of the rainbow is

484  
00:18:07,669 --> 00:18:02,960  
actually about 96

485  
00:18:11,430 --> 00:18:09,830  
now the the rainbows we're actually

486  
00:18:13,270 --> 00:18:11,440  
interested in for for looking at

487  
00:18:14,950 --> 00:18:13,280  
exoplanets and not the

488  
00:18:17,270 --> 00:18:14,960

familiar colored rainbows that we see

489

00:18:18,950 --> 00:18:17,280

which are rainbows coming off

490

00:18:22,630 --> 00:18:18,960

off it's actually raindrops large water

491

00:18:24,870 --> 00:18:22,640

droplets a millimeter or bigger in size

492

00:18:26,830 --> 00:18:24,880

but you also get the rainbow phenomenon

493

00:18:28,549 --> 00:18:26,840

persisting for much smaller

494

00:18:29,669 --> 00:18:28,559

droplets and

495

00:18:31,350 --> 00:18:29,679

in particular what we're interested in

496

00:18:32,870 --> 00:18:31,360

is cloud droplets

497

00:18:35,110 --> 00:18:32,880

because when we look at a planet from

498

00:18:36,150 --> 00:18:35,120

from outside um we're generally not

499

00:18:37,590 --> 00:18:36,160

going to see the raindrops because

500

00:18:38,789 --> 00:18:37,600

they're underneath the clouds but we do

501  
00:18:40,390 --> 00:18:38,799  
see the cloud

502  
00:18:41,750 --> 00:18:40,400  
the clouds themselves and the clouds of

503  
00:18:43,430 --> 00:18:41,760  
water droplets but they're just smaller

504  
00:18:46,789 --> 00:18:43,440  
water droplets

505  
00:18:49,510 --> 00:18:46,799  
typically about 10 microns in size

506  
00:18:51,590 --> 00:18:49,520  
so with what happens with small droplets

507  
00:18:53,590 --> 00:18:51,600  
is you still get a rainbow but

508  
00:18:55,990 --> 00:18:53,600  
diffraction effects broaden out the

509  
00:18:58,070 --> 00:18:56,000  
scattering peak of the rainbow so if you

510  
00:18:59,750 --> 00:18:58,080  
if you could see one of these

511  
00:19:01,669 --> 00:18:59,760  
sometimes called a fault bow or cloud

512  
00:19:03,350 --> 00:19:01,679  
bow it's not actually colored because

513  
00:19:06,230 --> 00:19:03,360

the smearing of the light essentially

514

00:19:09,590 --> 00:19:06,240

smears out all the colors

515

00:19:11,430 --> 00:19:09,600

but they remain highly polarized

516

00:19:12,789 --> 00:19:11,440

and so if you look at a planet

517

00:19:14,310 --> 00:19:12,799

with clouds

518

00:19:16,549 --> 00:19:14,320

from a distance

519

00:19:18,470 --> 00:19:16,559

there should be a peak in polarized

520

00:19:23,029 --> 00:19:18,480

light at this rainbow scattering angle

521

00:19:29,190 --> 00:19:25,990

um to study these small particle

522

00:19:30,150 --> 00:19:29,200

rainbows you can't really use the uh the

523

00:19:31,669 --> 00:19:30,160

ray

524

00:19:33,029 --> 00:19:31,679

optics approximation that i showed

525

00:19:35,510 --> 00:19:33,039

earlier

526

00:19:36,390 --> 00:19:35,520

we use methods

527

00:19:39,590 --> 00:19:36,400

um

528

00:19:40,470 --> 00:19:39,600

such as the lorenz me scattering theory

529

00:19:42,789 --> 00:19:40,480

and

530

00:19:45,110 --> 00:19:42,799

which models are scattering from small

531

00:19:47,350 --> 00:19:45,120

spherical particles and there's a

532

00:19:49,110 --> 00:19:47,360

associated

533

00:19:52,230 --> 00:19:49,120

t matrix theory which we can use for

534

00:19:54,630 --> 00:19:52,240

non-spherical particles

535

00:19:55,669 --> 00:19:54,640

so from these we can calculate

536

00:19:58,710 --> 00:19:55,679

the

537

00:20:00,470 --> 00:19:58,720

which contains

538

00:20:02,150 --> 00:20:00,480

one component of this is the phase

539

00:20:03,510 --> 00:20:02,160

function which is simply the the

540

00:20:06,710 --> 00:20:03,520

fraction of light that gets scattered

541

00:20:07,510 --> 00:20:06,720

into each possible phase angle

542

00:20:09,029 --> 00:20:07,520

and

543

00:20:10,710 --> 00:20:09,039

there's another component which

544

00:20:13,350 --> 00:20:10,720

describes the same thing tendency for

545

00:20:15,590 --> 00:20:13,360

linearly polarized light so how much

546

00:20:17,669 --> 00:20:15,600

the nearly polarized light is scattered

547

00:20:18,549 --> 00:20:17,679

at any one angle

548

00:20:20,150 --> 00:20:18,559

and the

549

00:20:22,230 --> 00:20:20,160

ratio of those is the degree of linear

550

00:20:23,029 --> 00:20:22,240

polarization

551  
00:20:25,830 --> 00:20:23,039  
so

552  
00:20:29,830 --> 00:20:25,840  
i for example use fortran codes from

553  
00:20:31,669 --> 00:20:29,840  
machenco to to calculate these

554  
00:20:33,909 --> 00:20:31,679  
i'll show a few plots as to what these

555  
00:20:37,430 --> 00:20:33,919  
look like

556  
00:20:39,190 --> 00:20:37,440  
so this is so this is just the

557  
00:20:40,870 --> 00:20:39,200  
the the phase function amount of

558  
00:20:43,270 --> 00:20:40,880  
scattered light as a function of

559  
00:20:44,950 --> 00:20:43,280  
scattering angle and you can see it's

560  
00:20:47,750 --> 00:20:44,960  
actually the same features that i showed

561  
00:20:50,470 --> 00:20:47,760  
in the photograph of the rainbow before

562  
00:20:52,870 --> 00:20:50,480  
so here's the primary rainbow

563  
00:20:54,789 --> 00:20:52,880

there's light inside the primary rainbow

564

00:20:57,510 --> 00:20:54,799

there's this dark region and then the

565

00:20:59,190 --> 00:20:57,520

secondary rainbow

566

00:21:00,789 --> 00:20:59,200

and if you actually have particles of

567

00:21:02,549 --> 00:21:00,799

almost the same size you get these

568

00:21:05,029 --> 00:21:02,559

things called supernumerary bows which

569

00:21:07,990 --> 00:21:05,039

appear inside the primary rainbow they

570

00:21:09,990 --> 00:21:08,000

tend to smear out somewhat if you have

571

00:21:11,510 --> 00:21:10,000

particles of a broad distribution in

572

00:21:13,350 --> 00:21:11,520

particle size but you can still

573

00:21:17,510 --> 00:21:13,360

sometimes see this supernumerary rainbow

574

00:21:21,669 --> 00:21:19,350

so this plot just shows the the effects

575

00:21:23,590 --> 00:21:21,679

of particle size on the rainbow so as

576

00:21:25,750 --> 00:21:23,600

the particles get smaller i've started

577

00:21:27,510 --> 00:21:25,760

at 100 microns here

578

00:21:29,270 --> 00:21:27,520

what happens is the width of the rainbow

579

00:21:30,870 --> 00:21:29,280

peak

580

00:21:33,669 --> 00:21:30,880

broadens out

581

00:21:36,549 --> 00:21:33,679

and eventually it starts to shift to

582

00:21:38,390 --> 00:21:36,559

um larger scattering angles

583

00:21:40,149 --> 00:21:38,400

so this is the the phase function the

584

00:21:42,390 --> 00:21:40,159

total intensity of the light and this is

585

00:21:44,230 --> 00:21:42,400

the the polarized intensity

586

00:21:46,310 --> 00:21:44,240

and they're on the same scale so if the

587

00:21:47,590 --> 00:21:46,320

polarized intensity is the same height

588

00:21:49,990 --> 00:21:47,600

as the

589

00:21:52,549 --> 00:21:50,000

uh phase function plot then that's

590

00:21:53,909 --> 00:21:52,559

essentially highly polarized light

591

00:21:56,470 --> 00:21:53,919

and one of the things you can see is

592

00:21:57,350 --> 00:21:56,480

that as you get down to small particles

593

00:22:00,470 --> 00:21:57,360

um

594

00:22:02,870 --> 00:22:00,480

you you start to see this feature at

595

00:22:04,870 --> 00:22:02,880

around 180 degrees scattering angle

596

00:22:06,710 --> 00:22:04,880

which that's actually a related optical

597

00:22:10,549 --> 00:22:06,720

phenomenon called the glory

598

00:22:14,870 --> 00:22:12,789

which occurs at this angle and as you

599

00:22:16,470 --> 00:22:14,880

get to small particles the rainbow and

600

00:22:18,470 --> 00:22:16,480

the glory sort of more or less join

601  
00:22:19,990 --> 00:22:18,480  
together and there's light at all

602  
00:22:21,990 --> 00:22:20,000  
wavelengths

603  
00:22:25,190 --> 00:22:22,000  
at all angles between between the

604  
00:22:26,950 --> 00:22:25,200  
rainbow peak and 180 degrees

605  
00:22:29,510 --> 00:22:26,960  
but if you look at polarization you

606  
00:22:31,510 --> 00:22:29,520  
still get a well-defined rainbow peak

607  
00:22:34,390 --> 00:22:31,520  
going down to quite small

608  
00:22:35,750 --> 00:22:34,400  
um particle sizes it broadens and shifts

609  
00:22:38,070 --> 00:22:35,760  
but there's still a fairly well defined

610  
00:22:40,470 --> 00:22:38,080  
peak in this small particle sizes

611  
00:22:43,110 --> 00:22:40,480  
typical cloud particle sizes range from

612  
00:22:44,789 --> 00:22:43,120  
about three to 30 microns so

613  
00:22:46,549 --> 00:22:44,799

the uh um

614

00:22:48,390 --> 00:22:46,559

average size that the global mean is

615

00:22:51,029 --> 00:22:48,400

actually about 11.4 microns so it's

616

00:22:52,710 --> 00:22:51,039

close to this 10 micro plot here so this

617

00:22:57,669 --> 00:22:52,720

is the sort of rainbow peak you would

618

00:23:02,390 --> 00:22:59,590

now where that

619

00:23:04,070 --> 00:23:02,400

the angle at which you see that rainbow

620

00:23:07,990 --> 00:23:04,080

depends on the refractive index of the

621

00:23:09,990 --> 00:23:08,000

liquid so um

622

00:23:12,549 --> 00:23:10,000

i've shown here the the rainbows

623

00:23:14,870 --> 00:23:12,559

calculated for three different liquids

624

00:23:16,149 --> 00:23:14,880

that we know occur in clouds within the

625

00:23:19,110 --> 00:23:16,159

solar system

626

00:23:20,470 --> 00:23:19,120

so water at the top this is sulfuric

627

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

acid which is what we get in the venous

628

00:23:23,430 --> 00:23:21,520

clouds

629

00:23:26,149 --> 00:23:23,440

and this is methane

630

00:23:27,909 --> 00:23:26,159

which we get in clouds in titan

631

00:23:29,590 --> 00:23:27,919

and you can see that you could

632

00:23:31,830 --> 00:23:29,600

you could clearly distinguish these

633

00:23:37,830 --> 00:23:31,840

liquids from the the shifting angle at

634

00:23:42,630 --> 00:23:40,390

um this is these plots show the effects

635

00:23:44,230 --> 00:23:42,640

of particle shape on the rainbow so you

636

00:23:45,990 --> 00:23:44,240

get nice rainbows with spherical

637

00:23:47,590 --> 00:23:46,000

particles but

638

00:23:49,350 --> 00:23:47,600

as soon as you the particle shape

639

00:23:52,149 --> 00:23:49,360

deviates from the sphere so these are

640

00:23:55,750 --> 00:23:52,159

spheroids with different axis ratios

641

00:23:58,390 --> 00:23:55,760

the rainbow peak rapidly disappears

642

00:23:59,990 --> 00:23:58,400

and these are these are some

643

00:24:03,510 --> 00:24:00,000

different shapes overlapping prolates

644

00:24:04,950 --> 00:24:03,520

varieties and cylindrical particles

645

00:24:06,789 --> 00:24:04,960

so so rainbows are very a very

646

00:24:09,669 --> 00:24:06,799

distinctive indicator

647

00:24:11,430 --> 00:24:09,679

of spherical droplets and spherical in

648

00:24:12,950 --> 00:24:11,440

practice in most practical conditions

649

00:24:14,549 --> 00:24:12,960

means you must be looking at a liquid

650

00:24:15,990 --> 00:24:14,559

because a liquid naturally forms a

651  
00:24:19,029 --> 00:24:16,000  
spherical shape because of surface

652  
00:24:21,830 --> 00:24:20,390  
and then the other thing you need for to

653  
00:24:23,990 --> 00:24:21,840  
get a rainbow is it has to be a

654  
00:24:26,789 --> 00:24:24,000  
transparent liquid so this is the

655  
00:24:29,110 --> 00:24:26,799  
effect of putting some absorption in the

656  
00:24:32,149 --> 00:24:29,120  
into the particle and that that also

657  
00:24:33,750 --> 00:24:32,159  
causes the rainbow to disappear and that

658  
00:24:35,990 --> 00:24:33,760  
means that if you actually looked at the

659  
00:24:38,070 --> 00:24:36,000  
spectrum of this rainbow scattered light

660  
00:24:40,549 --> 00:24:38,080  
you could see absorption features due to

661  
00:24:41,750 --> 00:24:40,559  
the liquid that caused to cause the

662  
00:24:42,630 --> 00:24:41,760  
rainbow

663  
00:24:44,149 --> 00:24:42,640

um

664

00:24:46,310 --> 00:24:44,159

the best place to look for that for a

665

00:24:47,669 --> 00:24:46,320

water rainbow would be at about 1.95

666

00:24:49,909 --> 00:24:47,679

microwaves

667

00:24:51,190 --> 00:24:49,919

outside the wavelength range of any of

668

00:24:55,430 --> 00:24:51,200

the tpf

669

00:24:58,149 --> 00:24:56,710

so to summarize the properties of

670

00:25:00,470 --> 00:24:58,159

rainbows they generate it by scattering

671

00:25:02,630 --> 00:25:00,480

from spherical particles any small

672

00:25:04,470 --> 00:25:02,640

departure from sphericity inhibits

673

00:25:06,149 --> 00:25:04,480

rainbow production

674

00:25:10,310 --> 00:25:06,159

they're present for sizes down about one

675

00:25:14,070 --> 00:25:10,320

micron which which covers all the clouds

676

00:25:15,830 --> 00:25:14,080

particles that we know about

677

00:25:17,430 --> 00:25:15,840

highly polarized and for small particles

678

00:25:20,710 --> 00:25:17,440

they're better defined in polarized

679

00:25:22,149 --> 00:25:20,720

light than in total intensity

680

00:25:23,830 --> 00:25:22,159

the the peak scattering angle is a

681

00:25:25,590 --> 00:25:23,840

measure of the refractive index and

682

00:25:28,149 --> 00:25:25,600

could help to tell us the the nature of

683

00:25:29,669 --> 00:25:28,159

the liquid responsible for the rainbow

684

00:25:32,870 --> 00:25:29,679

and any absorption in the particle

685

00:25:35,110 --> 00:25:32,880

inhibits rainbow production

686

00:25:36,710 --> 00:25:35,120

and that means that rainbows are a very

687

00:25:41,750 --> 00:25:36,720

strong indicator of the presence of

688

00:25:45,830 --> 00:25:44,149

so um in natural conditions the only way

689

00:25:48,070 --> 00:25:45,840

we're going to get a spherical particle

690

00:25:48,950 --> 00:25:48,080

is is due to

691

00:25:50,470 --> 00:25:48,960

um

692

00:25:52,070 --> 00:25:50,480

surface tension which

693

00:25:54,070 --> 00:25:52,080

causes a liquid to form spherical

694

00:25:56,470 --> 00:25:54,080

droplets

695

00:25:58,230 --> 00:25:56,480

and the solid particles are very

696

00:26:00,789 --> 00:25:58,240

unlikely to produce rainbows in in

697

00:26:02,710 --> 00:26:00,799

natural conditions or all the solid

698

00:26:04,390 --> 00:26:02,720

particle aerosols that we know about in

699

00:26:05,510 --> 00:26:04,400

in the earth and other planets

700

00:26:07,750 --> 00:26:05,520

atmospheres

701  
00:26:08,549 --> 00:26:07,760  
would have conditions that would prevent

702  
00:26:10,149 --> 00:26:08,559  
the

703  
00:26:11,669 --> 00:26:10,159  
formation of a rainbow due to

704  
00:26:14,310 --> 00:26:11,679  
non-sphericity

705  
00:26:18,950 --> 00:26:14,320  
small size or absorption and in most

706  
00:26:22,870 --> 00:26:20,950  
okay now the models i've i've shown you

707  
00:26:25,029 --> 00:26:22,880  
so far are single scattering models so

708  
00:26:26,710 --> 00:26:25,039  
they just look at what light scattered

709  
00:26:28,630 --> 00:26:26,720  
once offer

710  
00:26:31,110 --> 00:26:28,640  
water droplet would do what we're

711  
00:26:32,870 --> 00:26:31,120  
looking at in a realistic atmosphere is

712  
00:26:35,190 --> 00:26:32,880  
is a multiple scattering situation so

713  
00:26:38,230 --> 00:26:35,200

light can scatter many times off various

714

00:26:41,430 --> 00:26:38,240

particles before it finds its way out

715

00:26:43,350 --> 00:26:41,440

um it turns out though that the

716

00:26:45,590 --> 00:26:43,360

effect of multiple scattering is mostly

717

00:26:47,830 --> 00:26:45,600

to remove polarization

718

00:26:49,350 --> 00:26:47,840

so the polarized light you see from an

719

00:26:51,029 --> 00:26:49,360

atmosphere is mostly going to be due to

720

00:26:53,269 --> 00:26:51,039

light that's that has actually single

721

00:26:55,510 --> 00:26:53,279

scattered that's only scattered once off

722

00:26:58,070 --> 00:26:55,520

um droplets at the top of the clouds

723

00:27:00,149 --> 00:26:58,080

and there will be diluting light coming

724

00:27:01,990 --> 00:27:00,159

from multiple scattering cases

725

00:27:03,350 --> 00:27:02,000

which is which can be

726

00:27:04,950 --> 00:27:03,360

considered

727

00:27:07,350 --> 00:27:04,960

to reverse approximation be unpolarized

728

00:27:08,950 --> 00:27:07,360

and so it just dilutes the polarization

729

00:27:11,269 --> 00:27:08,960

so it actually means that the single

730

00:27:13,590 --> 00:27:11,279

scattering curves are pretty much what

731

00:27:15,110 --> 00:27:13,600

you would actually expect to see in the

732

00:27:17,269 --> 00:27:15,120

polarized light from an atmosphere

733

00:27:18,950 --> 00:27:17,279

except that the degree of polarization

734

00:27:21,190 --> 00:27:18,960

will be reduced because

735

00:27:23,430 --> 00:27:21,200

there's this diluting

736

00:27:24,630 --> 00:27:23,440

unpolarized radiation and you can see

737

00:27:27,430 --> 00:27:24,640

this this is an actual multiple

738

00:27:28,470 --> 00:27:27,440

scattering model of rainbows off water

739

00:27:30,310 --> 00:27:28,480

clouds

740

00:27:32,870 --> 00:27:30,320

and the shape is pretty much the same as

741

00:27:34,630 --> 00:27:32,880

the single scattering

742

00:27:38,310 --> 00:27:34,640

polarization that i showed in one of the

743

00:27:42,470 --> 00:27:40,870

um you can also see that in the multiple

744

00:27:44,870 --> 00:27:42,480

scattering case

745

00:27:46,870 --> 00:27:44,880

the the rainbow shows up very clearly in

746

00:27:50,549 --> 00:27:46,880

polarized light

747

00:27:53,669 --> 00:27:50,559

but is a relatively weak feature in the

748

00:27:55,269 --> 00:27:53,679

total intensity of the light

749

00:28:00,310 --> 00:27:55,279

so polarization is really the way to

750

00:28:03,350 --> 00:28:01,830

now just to show that this actually

751  
00:28:06,389 --> 00:28:03,360  
works that you can look at a planet from

752  
00:28:08,389 --> 00:28:06,399  
space and see rainbows um these are some

753  
00:28:10,230 --> 00:28:08,399  
observations from an instrument called

754  
00:28:11,990 --> 00:28:10,240  
polder

755  
00:28:13,909 --> 00:28:12,000  
which is polarization and directionality

756  
00:28:15,750 --> 00:28:13,919  
of earth reflectances this is a

757  
00:28:17,750 --> 00:28:15,760  
french-build instrument that's the first

758  
00:28:19,190 --> 00:28:17,760  
version flew on a japanese satellite

759  
00:28:20,549 --> 00:28:19,200  
called adios

760  
00:28:22,470 --> 00:28:20,559  
and there's a second version now

761  
00:28:23,750 --> 00:28:22,480  
operating on a micro satellite called

762  
00:28:24,950 --> 00:28:23,760  
parasol

763  
00:28:26,870 --> 00:28:24,960

and this is an instrument that looks

764

00:28:29,190 --> 00:28:26,880

down at clouds from earth orbit it's

765

00:28:31,830 --> 00:28:29,200

about 800 kilometers

766

00:28:34,950 --> 00:28:31,840

altitude and it looks at this phase

767

00:28:37,830 --> 00:28:34,960

curve of reflection from clouds

768

00:28:39,510 --> 00:28:37,840

and the basic aim of polder of the at

769

00:28:41,350 --> 00:28:39,520

least the polarization part of polar is

770

00:28:43,430 --> 00:28:41,360

to distinguish between liquid water

771

00:28:44,470 --> 00:28:43,440

clouds and ice clouds and it does this

772

00:28:46,310 --> 00:28:44,480

very clearly

773

00:28:48,630 --> 00:28:46,320

so red is a

774

00:28:49,750 --> 00:28:48,640

liquid water cloud and it produces a

775

00:28:51,430 --> 00:28:49,760

nice

776

00:28:53,590 --> 00:28:51,440

polarized rainbow curve just like the

777

00:28:55,430 --> 00:28:53,600

ones i've shown you and the blue is

778

00:28:56,710 --> 00:28:55,440

scattering off ice clouds and it's

779

00:28:58,389 --> 00:28:56,720

completely different

780

00:28:59,590 --> 00:28:58,399

there is still some polarization but the

781

00:29:04,549 --> 00:28:59,600

curve is completely different and

782

00:29:09,350 --> 00:29:06,389

so that shows you can really see these

783

00:29:11,430 --> 00:29:09,360

things looking at the earth from space

784

00:29:14,549 --> 00:29:11,440

and then the other good example is that

785

00:29:17,029 --> 00:29:14,559

they've been seen from the planet venus

786

00:29:19,269 --> 00:29:17,039

um polarization from of light from venus

787

00:29:21,350 --> 00:29:19,279

was first detected by by bernard leo

788

00:29:22,870 --> 00:29:21,360

back in the 1920s

789

00:29:24,470 --> 00:29:22,880

but for a long time it wasn't fully

790

00:29:27,350 --> 00:29:24,480

explained

791

00:29:29,750 --> 00:29:27,360

and the the explanation was largely due

792

00:29:32,149 --> 00:29:29,760

to the work of james hansen

793

00:29:34,389 --> 00:29:32,159

this is the james hansen who went on to

794

00:29:35,909 --> 00:29:34,399

be director of the goddard institute for

795

00:29:37,669 --> 00:29:35,919

space studies and the

796

00:29:39,830 --> 00:29:37,679

leading advocate for action on climate

797

00:29:41,830 --> 00:29:39,840

change climate modeler and so on he

798

00:29:43,510 --> 00:29:41,840

started by working on venus

799

00:29:45,430 --> 00:29:43,520

and he came up with the explanation for

800

00:29:47,590 --> 00:29:45,440

the polarization

801  
00:29:49,909 --> 00:29:47,600  
in the venous atmosphere

802  
00:29:51,430 --> 00:29:49,919  
and this is the polarization phase curve

803  
00:29:54,789 --> 00:29:51,440  
of venus

804  
00:29:56,470 --> 00:29:54,799  
observations here and hansen's model

805  
00:29:58,630 --> 00:29:56,480  
and what we see is a primary rainbow

806  
00:30:00,470 --> 00:29:58,640  
here this this peak which is actually

807  
00:30:01,590 --> 00:30:00,480  
for venus is about 20 degrees phase

808  
00:30:03,909 --> 00:30:01,600  
angle

809  
00:30:06,789 --> 00:30:03,919  
is is just the same rainbow scattering

810  
00:30:09,590 --> 00:30:06,799  
effect water droplets but it's shifted

811  
00:30:12,630 --> 00:30:09,600  
from 40 degrees where we see a

812  
00:30:14,549 --> 00:30:12,640  
water rainbow down to about 20 degrees

813  
00:30:16,950 --> 00:30:14,559

and that's because the the liquid in

814

00:30:18,710 --> 00:30:16,960

this case is sulfuric acid it has a much

815

00:30:20,310 --> 00:30:18,720

higher refractive index

816

00:30:22,710 --> 00:30:20,320

but also because the particles are very

817

00:30:24,789 --> 00:30:22,720

small the small particle also causes a

818

00:30:29,190 --> 00:30:24,799

shift in the rainbow position

819

00:30:30,789 --> 00:30:29,200

so from this polarization phase curve um

820

00:30:33,350 --> 00:30:30,799

it was possible to work out how

821

00:30:36,549 --> 00:30:33,360

particles were spherical droplets

822

00:30:39,750 --> 00:30:36,559

radius of 1.05 microns

823

00:30:41,830 --> 00:30:39,760

and the refractive index was

824

00:30:44,389 --> 00:30:41,840

was measured to be 1.44

825

00:30:46,549 --> 00:30:44,399

with considerable accuracy and the only

826

00:30:49,190 --> 00:30:46,559

possible

827

00:30:50,950 --> 00:30:49,200

liquid consistent with that is uh is

828

00:30:53,590 --> 00:30:50,960

it's actually concentrated sulfuric acid

829

00:30:55,990 --> 00:30:53,600

so 75 h<sub>2</sub>so<sub>4</sub>

830

00:30:57,510 --> 00:30:56,000

25 water

831

00:30:59,110 --> 00:30:57,520

so this shows that looking at the total

832

00:31:02,230 --> 00:30:59,120

light of a planet we can see a rainbow

833

00:31:08,470 --> 00:31:02,240

signal which tells us about the

834

00:31:13,430 --> 00:31:10,789

now i've tried to work out what the

835

00:31:14,950 --> 00:31:13,440

the total rainbow signal from the earth

836

00:31:17,029 --> 00:31:14,960

should be if we were looking at the

837

00:31:20,070 --> 00:31:17,039

integrated light of the earth

838

00:31:22,870 --> 00:31:20,080

and i'm using for this i'm using

839

00:31:24,950 --> 00:31:22,880

i'm basically modeling it as a combined

840

00:31:27,190 --> 00:31:24,960

from three components

841

00:31:28,870 --> 00:31:27,200

um clear sky

842

00:31:30,549 --> 00:31:28,880

regions where we won't see any rainbow

843

00:31:32,470 --> 00:31:30,559

signal

844

00:31:34,950 --> 00:31:32,480

liquid cloud regions that will show a

845

00:31:37,029 --> 00:31:34,960

rainbow signal an ice cloud which won't

846

00:31:39,509 --> 00:31:37,039

show a rainbow signal

847

00:31:41,990 --> 00:31:39,519

and i'm i'm using a couple of different

848

00:31:45,669 --> 00:31:42,000

models of what the typical global cover

849

00:31:47,590 --> 00:31:45,679

of these three components is

850

00:31:50,470 --> 00:31:47,600

total reflectance

851  
00:31:51,350 --> 00:31:50,480  
from the work of tinnetti

852  
00:31:52,789 --> 00:31:51,360  
and

853  
00:31:55,029 --> 00:31:52,799  
the polarized reflectance from the

854  
00:31:56,470 --> 00:31:55,039  
rainbow according to the multiple

855  
00:31:57,590 --> 00:31:56,480  
scattering models i've shown earlier

856  
00:31:59,509 --> 00:31:57,600  
golovkin

857  
00:32:02,230 --> 00:31:59,519  
and if you combine all this together you

858  
00:32:05,350 --> 00:32:02,240  
get a global signal of

859  
00:32:06,950 --> 00:32:05,360  
something between 12.7 and 15.5 and

860  
00:32:08,310 --> 00:32:06,960  
percent for the two different cloud

861  
00:32:10,710 --> 00:32:08,320  
models

862  
00:32:12,470 --> 00:32:10,720  
if the earth was totally cloud-covered

863  
00:32:14,549 --> 00:32:12,480

out you get a 20

864

00:32:16,710 --> 00:32:14,559

signal so these are these are reasonably

865

00:32:17,669 --> 00:32:16,720

large polarizations that should be

866

00:32:21,990 --> 00:32:17,679

possible

867

00:32:26,149 --> 00:32:24,389

okay now rainbows tell us about liquid

868

00:32:27,590 --> 00:32:26,159

water but but liquid water in the

869

00:32:29,029 --> 00:32:27,600

atmosphere what we really want to know

870

00:32:30,310 --> 00:32:29,039

about is if there's liquid water on the

871

00:32:32,470 --> 00:32:30,320

surface because that's really the

872

00:32:34,549 --> 00:32:32,480

defining characteristic

873

00:32:35,830 --> 00:32:34,559

of a habitable planet

874

00:32:38,070 --> 00:32:35,840

there is a way of doing this using

875

00:32:39,430 --> 00:32:38,080

polarization and that's using what's

876  
00:32:41,430 --> 00:32:39,440  
called glint so

877  
00:32:42,630 --> 00:32:41,440  
so simply

878  
00:32:45,029 --> 00:32:42,640  
sunlight

879  
00:32:49,350 --> 00:32:45,039  
glinting off water and

880  
00:32:52,630 --> 00:32:51,669  
under under most conditions but you do

881  
00:32:55,669 --> 00:32:52,640  
get this

882  
00:32:57,669 --> 00:32:55,679  
glint of water which occurs

883  
00:33:00,549 --> 00:32:57,679  
at for light that's actually reflected

884  
00:33:01,750 --> 00:33:00,559  
at the specular reflection angle so

885  
00:33:03,350 --> 00:33:01,760  
angle of incidence and angle of

886  
00:33:04,710 --> 00:33:03,360  
reflection the same

887  
00:33:07,830 --> 00:33:04,720  
so these are these are some actual

888  
00:33:09,590 --> 00:33:07,840

photos of blind spots off water

889

00:33:10,950 --> 00:33:09,600

um through two different polarizing

890

00:33:12,870 --> 00:33:10,960

filters

891

00:33:14,389 --> 00:33:12,880

and you can see there's a there's a big

892

00:33:15,990 --> 00:33:14,399

difference this light is highly

893

00:33:17,509 --> 00:33:16,000

polarized not quite as high as the

894

00:33:21,190 --> 00:33:17,519

rainbows but um

895

00:33:25,590 --> 00:33:23,750

and you can also see the pattern of the

896

00:33:27,750 --> 00:33:25,600

glint depends on or what the wind's

897

00:33:29,990 --> 00:33:27,760

doing to the surface of the water

898

00:33:32,950 --> 00:33:30,000

this changed

899

00:33:35,430 --> 00:33:32,960

between these two cases in in

900

00:33:37,029 --> 00:33:35,440

a minute or so

901  
00:33:38,870 --> 00:33:37,039  
now you could this is a

902  
00:33:41,830 --> 00:33:38,880  
photo of the earth from space and you

903  
00:33:43,750 --> 00:33:41,840  
can see the blitz spot there um

904  
00:33:45,750 --> 00:33:43,760  
it's clearly visible

905  
00:33:47,190 --> 00:33:45,760  
but you could also see that it's not

906  
00:33:49,190 --> 00:33:47,200  
going to be easy to observe this in the

907  
00:33:50,950 --> 00:33:49,200  
total light of the planet because

908  
00:33:52,630 --> 00:33:50,960  
there's a lot of other light coming from

909  
00:33:54,870 --> 00:33:52,640  
clouds

910  
00:34:03,590 --> 00:33:54,880  
around there which is going to dilute

911  
00:34:09,109 --> 00:34:07,909  
these are some models of the glint

912  
00:34:11,030 --> 00:34:09,119  
effects

913  
00:34:13,750 --> 00:34:11,040

from a recent paper by

914

00:34:15,349 --> 00:34:13,760

williams and gaydos

915

00:34:17,589 --> 00:34:15,359

and these show the

916

00:34:20,470 --> 00:34:17,599

polarization

917

00:34:21,589 --> 00:34:20,480

here and the total intensity as a

918

00:34:24,710 --> 00:34:21,599

function of

919

00:34:29,909 --> 00:34:25,750

and

920

00:34:31,990 --> 00:34:29,919

this so this top model is a model for a

921

00:34:34,869 --> 00:34:32,000

for a completely ocean covered earth

922

00:34:37,030 --> 00:34:34,879

with no clouds and that's

923

00:34:39,270 --> 00:34:37,040

um that's a favorable case for seeing

924

00:34:40,629 --> 00:34:39,280

glint because the oceans themselves are

925

00:34:43,669 --> 00:34:40,639

largely dark

926  
00:34:44,550 --> 00:34:43,679  
and the glitz spot bright

927  
00:34:49,430 --> 00:34:44,560  
so

928  
00:34:53,030 --> 00:34:51,589  
here it's going up to about 70

929  
00:34:55,109 --> 00:34:53,040  
polarization

930  
00:35:01,750 --> 00:34:55,119  
and

931  
00:35:02,710 --> 00:35:01,760  
simply because

932  
00:35:04,390 --> 00:35:02,720  
your

933  
00:35:06,390 --> 00:35:04,400  
the total light of the planet is is

934  
00:35:08,550 --> 00:35:06,400  
reduced relative to the glenn's blood

935  
00:35:10,230 --> 00:35:08,560  
spot is a larger proportion of the light

936  
00:35:11,109 --> 00:35:10,240  
coming from the planet

937  
00:35:15,910 --> 00:35:11,119  
this is

938  
00:35:17,589 --> 00:35:15,920

has been added so it's got continents as

939

00:35:19,270 --> 00:35:17,599

well as the ocean and the continents are

940

00:35:20,870 --> 00:35:19,280

brighter than the ocean

941

00:35:24,870 --> 00:35:20,880

so you get a much smaller

942

00:35:28,829 --> 00:35:24,880

glint polarization now about 30

943

00:35:32,150 --> 00:35:28,839

and it's shifted over to smaller smaller

944

00:35:33,750 --> 00:35:32,160

angles um more or more extreme present

945

00:35:34,630 --> 00:35:33,760

phases

946

00:35:36,630 --> 00:35:34,640

and

947

00:35:38,390 --> 00:35:36,640

what hasn't been modeled here is what

948

00:35:39,589 --> 00:35:38,400

happens if you add clouds

949

00:35:41,190 --> 00:35:39,599

and that's the real problem because

950

00:35:43,270 --> 00:35:41,200

clouds are brighter than both oceans and

951  
00:35:44,710 --> 00:35:43,280  
continents so if you put clouds into the

952  
00:35:47,349 --> 00:35:44,720  
model this this peak is going to get

953  
00:35:50,230 --> 00:35:47,359  
smaller and it's going to shift further

954  
00:35:50,240 --> 00:35:54,310  
more to more extreme present phases

955  
00:35:57,910 --> 00:35:55,990  
so glint is

956  
00:36:00,150 --> 00:35:57,920  
certainly potentially a way of detecting

957  
00:36:02,550 --> 00:36:00,160  
oceans but i think it's actually quite

958  
00:36:04,150 --> 00:36:02,560  
hard to do in practice at least for for

959  
00:36:05,990 --> 00:36:04,160  
a realistic planet like the earth where

960  
00:36:07,750 --> 00:36:06,000  
you've got the blind spot competing with

961  
00:36:08,630 --> 00:36:07,760  
reflection from clouds

962  
00:36:13,030 --> 00:36:08,640  
and

963  
00:36:16,870 --> 00:36:14,870

um the other feature that produces

964

00:36:18,390 --> 00:36:16,880

polarization in these atmospheres is

965

00:36:20,310 --> 00:36:18,400

radius scattering

966

00:36:23,349 --> 00:36:20,320

and radial scattering is just scattering

967

00:36:24,950 --> 00:36:23,359

off molecules in in the atmosphere so so

968

00:36:26,950 --> 00:36:24,960

just a clear atmosphere without any

969

00:36:28,550 --> 00:36:26,960

clouds will produce polarization due to

970

00:36:30,710 --> 00:36:28,560

rainy scattering

971

00:36:33,990 --> 00:36:30,720

and rayleigh scattering is

972

00:36:36,470 --> 00:36:34,000

is blue it's what makes the sky blue

973

00:36:38,790 --> 00:36:36,480

in the case of the earth so it's so it's

974

00:36:40,790 --> 00:36:38,800

it's the best at short wavelengths

975

00:36:43,190 --> 00:36:40,800

and it's also seen best at phase angles

976  
00:36:44,630 --> 00:36:43,200  
of about 90 degrees

977  
00:36:46,550 --> 00:36:44,640  
now you can see rayleigh scattering

978  
00:36:49,030 --> 00:36:46,560  
without polarization

979  
00:36:51,910 --> 00:36:49,040  
so if you have a spectrum of the earth

980  
00:36:53,750 --> 00:36:51,920  
this rise at the blue end

981  
00:36:55,109 --> 00:36:53,760  
is due to radius scattering

982  
00:36:56,870 --> 00:36:55,119  
if you have enough of it you may be able

983  
00:36:58,230 --> 00:36:56,880  
to pick out rayleigh scattering on that

984  
00:36:59,270 --> 00:36:58,240  
basis

985  
00:37:00,950 --> 00:36:59,280  
but

986  
00:37:02,069 --> 00:37:00,960  
um you can do it a lot better and more

987  
00:37:04,069 --> 00:37:02,079  
convincingly if you measure the

988  
00:37:05,750 --> 00:37:04,079

polarization

989

00:37:08,630 --> 00:37:05,760

this stuff this really scattered light

990

00:37:09,990 --> 00:37:08,640

is highly polarized so radio scattering

991

00:37:14,470 --> 00:37:10,000

is a very

992

00:37:16,390 --> 00:37:14,480

signature of rayleigh scattering and

993

00:37:18,390 --> 00:37:16,400

this is the the venus

994

00:37:20,150 --> 00:37:18,400

phase curve that i showed earlier here's

995

00:37:23,910 --> 00:37:20,160

the rainbow but the bit we're interested

996

00:37:25,670 --> 00:37:23,920

in now is this peak at 90 degree phase

997

00:37:27,030 --> 00:37:25,680

angle which is rainy scattering

998

00:37:29,430 --> 00:37:27,040

polarization

999

00:37:30,310 --> 00:37:29,440

and you wouldn't be able to pick out

1000

00:37:32,630 --> 00:37:30,320

um

1001  
00:37:34,069 --> 00:37:32,640  
a spectral rise to the blue in the case

1002  
00:37:35,670 --> 00:37:34,079  
of venus because there is much less

1003  
00:37:37,190 --> 00:37:35,680  
rainy scattering going on in the case of

1004  
00:37:38,950 --> 00:37:37,200  
the earth and in fact there are

1005  
00:37:40,950 --> 00:37:38,960  
absorbers in

1006  
00:37:42,230 --> 00:37:40,960  
the venus atmosphere which absorb at the

1007  
00:37:43,990 --> 00:37:42,240  
in the ultraviolet which would actually

1008  
00:37:44,950 --> 00:37:44,000  
bring the spectrum down so competing

1009  
00:37:47,030 --> 00:37:44,960  
with that

1010  
00:37:48,870 --> 00:37:47,040  
but in the polarization curve you can

1011  
00:37:51,349 --> 00:37:48,880  
clearly see the signature of radius

1012  
00:37:52,870 --> 00:37:51,359  
scattering and what you can measure from

1013  
00:37:53,910 --> 00:37:52,880

that is the

1014

00:37:56,150 --> 00:37:53,920

um

1015

00:37:58,069 --> 00:37:56,160

is an estimate of the total atmospheric

1016

00:37:59,670 --> 00:37:58,079

pressure and that's because because

1017

00:38:01,190 --> 00:37:59,680

unlike unlike spectroscopy we're only

1018

00:38:03,030 --> 00:38:01,200

seeing some of the gases all the gases

1019

00:38:04,710 --> 00:38:03,040

in the atmosphere contribute to radius

1020

00:38:06,710 --> 00:38:04,720

scattering so the amount of radio

1021

00:38:08,069 --> 00:38:06,720

scattering

1022

00:38:09,589 --> 00:38:08,079

allows you to tell the atmospheric

1023

00:38:11,750 --> 00:38:09,599

pressure of course in the case like

1024

00:38:13,510 --> 00:38:11,760

venus is the pressure cloud tops that

1025

00:38:22,230 --> 00:38:13,520

you're measuring you can't obviously see

1026

00:38:28,470 --> 00:38:25,589

so a combination of these um these three

1027

00:38:30,310 --> 00:38:28,480

effects the the glint the rainbows

1028

00:38:32,390 --> 00:38:30,320

and the rayleigh scattering can tell us

1029

00:38:35,670 --> 00:38:32,400

quite a lot about the atmosphere of the

1030

00:38:37,430 --> 00:38:35,680

terrestrial planet and even surface

1031

00:38:39,910 --> 00:38:37,440

so what what you would actually need to

1032

00:38:42,230 --> 00:38:39,920

do to observe this is use an instrument

1033

00:38:45,190 --> 00:38:42,240

like like tpfc

1034

00:38:46,470 --> 00:38:45,200

to observe the planet but to get any

1035

00:38:47,910 --> 00:38:46,480

useful information

1036

00:38:49,589 --> 00:38:47,920

from polarization you really need to be

1037

00:38:52,870 --> 00:38:49,599

able to follow the planet for a

1038

00:38:54,470 --> 00:38:52,880

significant part of its face cycle

1039

00:38:56,230 --> 00:38:54,480

so you can't just observe it when it's

1040

00:38:57,829 --> 00:38:56,240

at its greatest distance from the star

1041

00:38:59,510 --> 00:38:57,839

which is what you might otherwise think

1042

00:39:01,990 --> 00:38:59,520

of doing you need to be able to follow

1043

00:39:04,310 --> 00:39:02,000

it through a range of phases so if you

1044

00:39:06,390 --> 00:39:04,320

want to get the rainbow you need to be

1045

00:39:08,710 --> 00:39:06,400

able to look at this 40 degree phase

1046

00:39:09,910 --> 00:39:08,720

angle here if you want to see the glitch

1047

00:39:13,190 --> 00:39:09,920

you're going to be able to need to look

1048

00:39:16,069 --> 00:39:13,200

at phase phases over here

1049

00:39:19,589 --> 00:39:17,829

and you can't always do this because you

1050

00:39:22,550 --> 00:39:19,599

may just just not be lucky if the orbit

1051

00:39:24,550 --> 00:39:22,560

is face on you don't get any range of

1052

00:39:26,550 --> 00:39:24,560

phase angles and it just goes around the

1053

00:39:28,390 --> 00:39:26,560

star and it's always at 90 degrees phase

1054

00:39:29,349 --> 00:39:28,400

angle

1055

00:39:30,790 --> 00:39:29,359

but

1056

00:39:32,069 --> 00:39:30,800

um

1057

00:39:33,670 --> 00:39:32,079

but

1058

00:39:35,510 --> 00:39:33,680

for

1059

00:39:36,310 --> 00:39:35,520

most cases you should be able to reach

1060

00:39:39,270 --> 00:39:36,320

the

1061

00:39:41,109 --> 00:39:39,280

40 degree phase angle

1062

00:39:43,349 --> 00:39:41,119

that requires that the inclination of

1063

00:39:46,230 --> 00:39:43,359

the planet must be less than 50 degrees

1064

00:39:47,910 --> 00:39:46,240

and if they're randomly oriented

1065

00:39:50,470 --> 00:39:47,920

then about 64

1066

00:39:53,109 --> 00:39:50,480

of systems should be within that range

1067

00:39:59,349 --> 00:39:53,119

so it should be feasible for a large

1068

00:40:02,230 --> 00:40:01,190

but the as the planet is going around

1069

00:40:04,630 --> 00:40:02,240

the star it's also changing in

1070

00:40:05,349 --> 00:40:04,640

brightness quite a lot and

1071

00:40:09,430 --> 00:40:05,359

this

1072

00:40:12,870 --> 00:40:09,440

light curve of venus as a function of

1073

00:40:18,710 --> 00:40:14,230

so

1074

00:40:21,109 --> 00:40:18,720

phase it's fully eliminated

1075

00:40:23,109 --> 00:40:21,119

down here is present phases

1076  
00:40:24,790 --> 00:40:23,119  
and you can this helps to see why why

1077  
00:40:26,950 --> 00:40:24,800  
glimp observations are so difficult

1078  
00:40:28,390 --> 00:40:26,960  
because not that you would see in the

1079  
00:40:30,230 --> 00:40:28,400  
case of venus but other planets are

1080  
00:40:31,990 --> 00:40:30,240  
going to do similar things

1081  
00:40:34,470 --> 00:40:32,000  
observing the glint means observing down

1082  
00:40:36,710 --> 00:40:34,480  
here where the planet is only about 10

1083  
00:40:38,310 --> 00:40:36,720  
of its maximum brightness

1084  
00:40:40,470 --> 00:40:38,320  
the rayleigh scattering is a bit better

1085  
00:40:42,230 --> 00:40:40,480  
that's up here about 30

1086  
00:40:43,750 --> 00:40:42,240  
maximum brightness and also where the

1087  
00:40:46,230 --> 00:40:43,760  
planet is furthest from its star so

1088  
00:40:47,990 --> 00:40:46,240

that's an optimum time to observe

1089

00:40:49,750 --> 00:40:48,000

and the primary rainbow is up where the

1090

00:40:50,870 --> 00:40:49,760

planet is really bright although it is

1091

00:41:00,790 --> 00:40:50,880

starting to get

1092

00:41:06,069 --> 00:41:02,870

so this is just a picture of the the

1093

00:41:07,829 --> 00:41:06,079

optical system of of tpsc which is the

1094

00:41:16,710 --> 00:41:07,839

sort of instrument we would want to use

1095

00:41:19,270 --> 00:41:17,750

and

1096

00:41:21,510 --> 00:41:19,280

what i'm going to do here is just a

1097

00:41:23,190 --> 00:41:21,520

quick comparison of of what's involved

1098

00:41:25,109 --> 00:41:23,200

in doing polarimetric observations

1099

00:41:26,710 --> 00:41:25,119

compared with spectroscopic observations

1100

00:41:29,270 --> 00:41:26,720

which is the way people have normally

1101  
00:41:30,550 --> 00:41:29,280  
been thought of characterizing planets

1102  
00:41:32,069 --> 00:41:30,560  
and

1103  
00:41:33,270 --> 00:41:32,079  
what i've estimated here is that you

1104  
00:41:35,430 --> 00:41:33,280  
would need

1105  
00:41:37,109 --> 00:41:35,440  
to detect for example the rainbow signal

1106  
00:41:40,230 --> 00:41:37,119  
on the radius scattering signal you'd

1107  
00:41:41,430 --> 00:41:40,240  
need to measure maybe six

1108  
00:41:42,790 --> 00:41:41,440  
phase angles

1109  
00:41:44,630 --> 00:41:42,800  
and you'd need to measure measure the

1110  
00:41:46,230 --> 00:41:44,640  
polarization of each one to an accuracy

1111  
00:41:47,670 --> 00:41:46,240  
of about two percent completely

1112  
00:41:49,670 --> 00:41:47,680  
sufficient to

1113  
00:41:51,190 --> 00:41:49,680

comfortably see these effects

1114

00:41:54,790 --> 00:41:51,200

and you can calculate that that needs

1115

00:41:58,470 --> 00:41:56,470

and if you look at what's required for

1116

00:41:59,510 --> 00:41:58,480

spectroscopic observations

1117

00:42:01,349 --> 00:41:59,520

um

1118

00:42:02,390 --> 00:42:01,359

capable of detecting the spectral

1119

00:42:05,510 --> 00:42:02,400

features

1120

00:42:08,630 --> 00:42:05,520

similar calculation gives around 18 000

1121

00:42:10,470 --> 00:42:08,640

photons so so doing this is is no more

1122

00:42:12,630 --> 00:42:10,480

difficult than doing the spectroscopic

1123

00:42:13,829 --> 00:42:12,640

observation that doesn't mean it's easy

1124

00:42:15,109 --> 00:42:13,839

both of these are really difficult

1125

00:42:17,270 --> 00:42:15,119

things to do

1126

00:42:19,109 --> 00:42:17,280

but but the

1127

00:42:20,790 --> 00:42:19,119

but an important point is that you don't

1128

00:42:23,750 --> 00:42:20,800

have to do one or the other you can do

1129

00:42:25,829 --> 00:42:23,760

both of these at the same time

1130

00:42:27,990 --> 00:42:25,839

because you can use an instrument that

1131

00:42:28,829 --> 00:42:28,000

is that is measuring both polarization

1132

00:42:31,510 --> 00:42:28,839

and

1133

00:42:33,990 --> 00:42:31,520

spectroscopy um so there's it's not

1134

00:42:35,430 --> 00:42:34,000

really um increasing the the time you

1135

00:42:37,270 --> 00:42:35,440

need to characterize these planets

1136

00:42:38,630 --> 00:42:37,280

although it doesn't mean you need to

1137

00:42:40,630 --> 00:42:38,640

think of it think a bit more about how

1138

00:42:42,069 --> 00:42:40,640

you plan the observations you can do

1139

00:42:45,990 --> 00:42:42,079

both of these in principle with the same

1140

00:42:51,670 --> 00:42:49,510

and in fact the the designs for for tpfc

1141

00:42:54,390 --> 00:42:51,680

already include splitting the light into

1142

00:42:57,030 --> 00:42:54,400

two different polarization channels um i

1143

00:42:59,430 --> 00:42:57,040

believe this is this is done um

1144

00:43:01,510 --> 00:42:59,440

in order to allow the coronagraphic

1145

00:43:03,829 --> 00:43:01,520

systems to work optimally but it

1146

00:43:05,270 --> 00:43:03,839

essentially means that it's already got

1147

00:43:07,030 --> 00:43:05,280

built into it the

1148

00:43:14,230 --> 00:43:07,040

um the main instrumental requirement for

1149

00:43:18,069 --> 00:43:16,069

okay so um

1150

00:43:20,309 --> 00:43:18,079

how do we

1151

00:43:22,390 --> 00:43:20,319

follow up this work um

1152

00:43:23,589 --> 00:43:22,400

we would like to get better observations

1153

00:43:25,109 --> 00:43:23,599

of what

1154

00:43:26,550 --> 00:43:25,119

polarization phase curve the earth

1155

00:43:27,910 --> 00:43:26,560

actually produces

1156

00:43:29,349 --> 00:43:27,920

and there's a couple of ways you can do

1157

00:43:31,109 --> 00:43:29,359

this

1158

00:43:33,349 --> 00:43:31,119

you can observe the the lunar earth

1159

00:43:34,790 --> 00:43:33,359

shine this is this is earth light

1160

00:43:36,790 --> 00:43:34,800

scattered off the

1161

00:43:39,430 --> 00:43:36,800

dark side of the moon and this

1162

00:43:41,030 --> 00:43:39,440

technique's been used

1163

00:43:43,670 --> 00:43:41,040

by a number of groups to look at the

1164

00:43:45,190 --> 00:43:43,680

spectrum of the earth from space but in

1165

00:43:46,790 --> 00:43:45,200

principle you can look at polarization

1166

00:43:49,510 --> 00:43:46,800

of the earth in this way and in fact

1167

00:43:51,349 --> 00:43:49,520

audran dolphus did this back in the 50s

1168

00:43:53,589 --> 00:43:51,359

he measures the polarization of this

1169

00:43:56,230 --> 00:43:53,599

earth shine and he detected the rayleigh

1170

00:43:58,230 --> 00:43:56,240

scattering signal from the earth

1171

00:43:59,589 --> 00:43:58,240

the reflection of the moon complicates

1172

00:44:01,589 --> 00:43:59,599

things because that introduces

1173

00:44:03,190 --> 00:44:01,599

polarization effects of its own

1174

00:44:05,349 --> 00:44:03,200

um

1175

00:44:08,710 --> 00:44:05,359

it actually reduces the polarization to

1176

00:44:09,589 --> 00:44:08,720

about a third of the original amount

1177

00:44:12,069 --> 00:44:09,599

and

1178

00:44:13,910 --> 00:44:12,079

polarization observations are

1179

00:44:15,430 --> 00:44:13,920

now being attempted of the earthshine

1180

00:44:16,790 --> 00:44:15,440

particularly

1181

00:44:18,230 --> 00:44:16,800

at the

1182

00:44:20,630 --> 00:44:18,240

um

1183

00:44:23,510 --> 00:44:20,640

in the canary islands the iac is looking

1184

00:44:25,510 --> 00:44:23,520

at this the other way you can do it is

1185

00:44:26,790 --> 00:44:25,520

to observe the earth from space

1186

00:44:27,750 --> 00:44:26,800

and there's been

1187

00:44:29,910 --> 00:44:27,760

um

1188

00:44:31,829 --> 00:44:29,920

suggestions for simple space missions

1189

00:44:33,829 --> 00:44:31,839

that do this um

1190

00:44:36,630 --> 00:44:33,839

a couple of these were discussed at the

1191

00:44:38,950 --> 00:44:36,640

the recent pep cyclone meeting by nick

1192

00:44:40,710 --> 00:44:38,960

wolfe and maggie turnbull so one idea

1193

00:44:41,990 --> 00:44:40,720

was to have have something that would

1194

00:44:43,589 --> 00:44:42,000

actually operate from the surface of the

1195

00:44:45,910 --> 00:44:43,599

moon that the astronauts would take with

1196

00:44:49,910 --> 00:44:45,920

them and point at the earth

1197

00:44:51,510 --> 00:44:49,920

or you can have a spacecraft in

1198

00:44:58,630 --> 00:44:51,520

in space near the moon looking back at

1199

00:45:02,150 --> 00:45:00,069

and then the other thing i'm looking at

1200

00:45:05,109 --> 00:45:02,160

is is improved modeling of the

1201

00:45:06,710 --> 00:45:05,119

polarization effects um

1202

00:45:08,870 --> 00:45:06,720

most of the models i described early

1203

00:45:10,790 --> 00:45:08,880

were earlier were only using single

1204

00:45:12,230 --> 00:45:10,800

scattering models

1205

00:45:14,230 --> 00:45:12,240

but i have a

1206

00:45:15,510 --> 00:45:14,240

radio transfer model for plant free

1207

00:45:17,109 --> 00:45:15,520

atmospheres that i use to produce

1208

00:45:19,190 --> 00:45:17,119

planetary spectra

1209

00:45:21,990 --> 00:45:19,200

i've used successfully for more than the

1210

00:45:23,670 --> 00:45:22,000

spectra of earth mars venus and titan

1211

00:45:25,910 --> 00:45:23,680

shown here

1212

00:45:27,589 --> 00:45:25,920

and i'm planning to incorporate

1213

00:45:29,510 --> 00:45:27,599

polarization into this so that i have a

1214

00:45:31,829 --> 00:45:29,520

model capable of predicting uh

1215

00:45:32,950 --> 00:45:31,839

polarization of a planet at any

1216

00:45:35,349 --> 00:45:32,960

wavelength

1217

00:45:37,910 --> 00:45:35,359

and this will enable accurate estimates

1218

00:45:39,270 --> 00:45:37,920

of the rainbow and glint effects for a

1219

00:45:46,630 --> 00:45:39,280

range of different possible

1220

00:45:50,390 --> 00:45:47,589

so

1221

00:45:52,790 --> 00:45:50,400

um polarization could provide important

1222

00:45:53,829 --> 00:45:52,800

information about a planet's atmosphere

1223

00:45:56,550 --> 00:45:53,839

the presence

1224

00:45:58,470 --> 00:45:56,560

or absence of clouds cloud composition

1225

00:46:00,150 --> 00:45:58,480

the atmospheric pressure

1226

00:46:02,069 --> 00:46:00,160

and and even the presence of surface

1227

00:46:04,630 --> 00:46:02,079

oceans although this i think is

1228

00:46:06,630 --> 00:46:04,640

currently is difficult with a mission on

1229

00:46:08,470 --> 00:46:06,640

the scale of tpf

1230

00:46:10,790 --> 00:46:08,480

probably needs an even bigger telescope

1231

00:46:12,309 --> 00:46:10,800

than that

1232

00:46:14,470 --> 00:46:12,319

polarimetric and spectroscopic

1233

00:46:15,910 --> 00:46:14,480

techniques are complementary for

1234

00:46:17,510 --> 00:46:15,920

planetary characterization they give

1235

00:46:19,190 --> 00:46:17,520

very different information about the

1236

00:46:21,109 --> 00:46:19,200

planet

1237

00:46:23,510 --> 00:46:21,119

and the observations should be feasible

1238

00:46:24,950 --> 00:46:23,520

with emission like tpfcr

1239

00:46:27,750 --> 00:46:24,960

in similar integration times to

1240

00:46:30,710 --> 00:46:27,760

spectroscopic observations

1241

00:46:33,190 --> 00:46:30,720

so the recommendations are that when

1242

00:46:34,390 --> 00:46:33,200

the tpfcr mission or something similar is

1243

00:46:35,670 --> 00:46:34,400

continued

1244

00:46:37,670 --> 00:46:35,680

because the uh

1245

00:46:40,630 --> 00:46:37,680

that mission is uh is effectively on

1246

00:46:43,589 --> 00:46:40,640

hold it's not not funded at the moment

1247

00:46:45,430 --> 00:46:43,599

it must include polarimetry capabilities

1248

00:46:46,470 --> 00:46:45,440

in the instrument design and observing

1249

00:46:48,550 --> 00:46:46,480

plan

1250

00:46:52,630 --> 00:46:48,560

and polarization needs to be included in

1251

00:46:54,390 --> 00:46:52,640

models for extrasolar planet

1252

00:46:56,470 --> 00:46:54,400

atmospheres

1253

00:46:58,390 --> 00:46:56,480

such as those that the vpl team is

1254

00:47:00,390 --> 00:46:58,400

working on

1255

00:47:01,910 --> 00:47:00,400

now do i have a bit of time to

1256

00:47:03,670 --> 00:47:01,920

just say a bit about the hot jupiter

1257

00:47:04,470 --> 00:47:03,680

work okay

1258

00:47:05,190 --> 00:47:04,480

yep

1259

00:47:09,829 --> 00:47:05,200

so

1260

00:47:11,829 --> 00:47:09,839

we may be able to do way in the future

1261

00:47:13,750 --> 00:47:11,839

with missions like tpf

1262

00:47:14,950 --> 00:47:13,760

but there is actually um one type of

1263

00:47:16,630 --> 00:47:14,960

planet that we might be able to detect

1264

00:47:18,950 --> 00:47:16,640

polarization from now and that's that's

1265

00:47:20,950 --> 00:47:18,960

these hot jupiter type systems

1266

00:47:24,790 --> 00:47:20,960

where you have a planet orbiting very

1267

00:47:26,790 --> 00:47:24,800

close to the star a giant planet

1268

00:47:28,230 --> 00:47:26,800

um

1269

00:47:29,510 --> 00:47:28,240

and these are

1270

00:47:31,270 --> 00:47:29,520

these these are likely to be the

1271

00:47:32,309 --> 00:47:31,280

brightest planets in scattered light

1272

00:47:33,589 --> 00:47:32,319

because they're big planets and they're

1273

00:47:35,750 --> 00:47:33,599

very close to the stars so they're

1274

00:47:37,750 --> 00:47:35,760

receiving a lot of light from the star

1275

00:47:40,069 --> 00:47:37,760

and the idea is that

1276  
00:47:41,589 --> 00:47:40,079  
looking at the combined light the star

1277  
00:47:43,670 --> 00:47:41,599  
and planet

1278  
00:47:45,670 --> 00:47:43,680  
light from the star is unpolarized the

1279  
00:47:46,950 --> 00:47:45,680  
planet's light might be polarized at a

1280  
00:47:49,190 --> 00:47:46,960  
few percent

1281  
00:47:51,510 --> 00:47:49,200  
10 percent or so

1282  
00:47:53,589 --> 00:47:51,520  
but it's but it's only one ten thousand

1283  
00:47:55,270 --> 00:47:53,599  
the total light of the system

1284  
00:47:56,870 --> 00:47:55,280  
if you look at the combined light and

1285  
00:47:57,990 --> 00:47:56,880  
can measure the polarization accurately

1286  
00:47:59,990 --> 00:47:58,000  
enough should be able to see a

1287  
00:48:02,150 --> 00:48:00,000  
polarization

1288  
00:48:03,910 --> 00:48:02,160

at a fractional level of something like

1289

00:48:06,550 --> 00:48:03,920

ten to the minus five or less probably a

1290

00:48:08,550 --> 00:48:06,560

few times ten to minus six

1291

00:48:11,430 --> 00:48:08,560

and this this was actually modeled by uh

1292

00:48:12,950 --> 00:48:11,440

sega whitney and sassaloth in 2000 and

1293

00:48:15,589 --> 00:48:12,960

they produced the sort of polarization

1294

00:48:17,750 --> 00:48:15,599

curves you might expect to see from a

1295

00:48:19,589 --> 00:48:17,760

for one of these planetary systems

1296

00:48:20,870 --> 00:48:19,599

and they concluded that the polarization

1297

00:48:23,270 --> 00:48:20,880

signatures are well under the current

1298

00:48:25,510 --> 00:48:23,280

limits of detectability which are a few

1299

00:48:27,510 --> 00:48:25,520

times 10 to the minus 4 in fractional

1300

00:48:29,270 --> 00:48:27,520

polarization

1301

00:48:30,710 --> 00:48:29,280

and that was probably true for

1302

00:48:32,950 --> 00:48:30,720

astronomical polarimeters that were

1303

00:48:35,190 --> 00:48:32,960

available at the time

1304

00:48:37,829 --> 00:48:35,200

but um we knew that it's possible to do

1305

00:48:39,910 --> 00:48:37,839

polarization much better than that

1306

00:48:40,950 --> 00:48:39,920

in particular from the work of james

1307

00:48:42,630 --> 00:48:40,960

kemp

1308

00:48:44,790 --> 00:48:42,640

who'd developed

1309

00:48:47,109 --> 00:48:44,800

polarometric techniques using a device

1310

00:48:48,309 --> 00:48:47,119

called a photoelastic modulator and he'd

1311

00:48:49,270 --> 00:48:48,319

actually measured the polarization of

1312

00:48:53,510 --> 00:48:49,280

the sun

1313

00:48:56,950 --> 00:48:54,710

so um

1314

00:48:58,950 --> 00:48:56,960

together with the the group at

1315

00:49:00,950 --> 00:48:58,960

university of hartfordshire uh jim huff

1316

00:49:02,470 --> 00:49:00,960

and phil lucas

1317

00:49:04,870 --> 00:49:02,480

we came up with a design for a

1318

00:49:06,390 --> 00:49:04,880

polarimeter that could measure stellar

1319

00:49:08,549 --> 00:49:06,400

polarizations

1320

00:49:10,549 --> 00:49:08,559

to an accuracy of about one part in a

1321

00:49:13,030 --> 00:49:10,559

million and this is using these things

1322

00:49:15,829 --> 00:49:13,040

called photoelastic modulators which are

1323

00:49:17,589 --> 00:49:15,839

polarization modulators where you have a

1324

00:49:19,750 --> 00:49:17,599

um

1325

00:49:21,349 --> 00:49:19,760

a piece of optical material and you make

1326

00:49:24,710 --> 00:49:21,359

it oscillate as it's its natural

1327

00:49:26,390 --> 00:49:24,720

frequency by piezo transducers

1328

00:49:28,309 --> 00:49:26,400

attached to it and it produces

1329

00:49:33,430 --> 00:49:28,319

polarization modulations at high

1330

00:49:35,670 --> 00:49:33,440

frequencies um 20 kilohertz in our case

1331

00:49:37,670 --> 00:49:35,680

and these devices have been used

1332

00:49:39,190 --> 00:49:37,680

for both in astronomy and in

1333

00:49:41,990 --> 00:49:39,200

laboratory conditions for doing

1334

00:49:44,230 --> 00:49:42,000

polarization with very high accuracy

1335

00:49:45,750 --> 00:49:44,240

so this is the

1336

00:49:47,829 --> 00:49:45,760

schematic of the

1337

00:49:49,430 --> 00:49:47,839

device we built it as photoelastic

1338

00:49:51,990 --> 00:49:49,440

modulators

1339

00:49:54,390 --> 00:49:52,000

a walliston prism which splits the light

1340

00:49:56,150 --> 00:49:54,400

into two polarization beams

1341

00:49:58,630 --> 00:49:56,160

and the detectors are

1342

00:50:00,390 --> 00:49:58,640

avalanche photodiodes

1343

00:50:02,470 --> 00:50:00,400

which we chose because they

1344

00:50:04,390 --> 00:50:02,480

they're linear up to very high photon

1345

00:50:06,549 --> 00:50:04,400

rates and to do polarization to this

1346

00:50:08,390 --> 00:50:06,559

accuracy to to measure ten to the minus

1347

00:50:09,990 --> 00:50:08,400

six polarization effects basically the

1348

00:50:12,870 --> 00:50:10,000

ten to the twelve photons so you need to

1349

00:50:13,990 --> 00:50:12,880

work at very high photon levels

1350

00:50:15,190 --> 00:50:14,000

and so

1351

00:50:17,270 --> 00:50:15,200

so this is the instrument it's just an

1352

00:50:22,309 --> 00:50:17,280

aperture polarimeter just measures the

1353

00:50:27,349 --> 00:50:23,190

and

1354

00:50:29,349 --> 00:50:27,359

said it was sitting on the back of the

1355

00:50:36,630 --> 00:50:29,359

willie herschel telescope

1356

00:50:39,990 --> 00:50:38,470

and this is the the sort of results that

1357

00:50:41,670 --> 00:50:40,000

come out of it this is this is looking

1358

00:50:44,069 --> 00:50:41,680

at the

1359

00:50:46,390 --> 00:50:44,079

what we call the the second stage

1360

00:50:48,549 --> 00:50:46,400

chopping signal so we actually we

1361

00:50:50,630 --> 00:50:48,559

modulate the

1362

00:50:53,109 --> 00:50:50,640

light using the rapidly using the

1363

00:50:55,349 --> 00:50:53,119

photoelastic modulator but then we also

1364

00:50:56,790 --> 00:50:55,359

rotate um optical elements within the

1365

00:50:59,829 --> 00:50:56,800

system to reverse the sign of that

1366

00:51:01,190 --> 00:50:59,839

modulation um every um

1367

00:51:02,950 --> 00:51:01,200

every uh

1368

00:51:05,349 --> 00:51:02,960

couple of minutes or so

1369

00:51:07,910 --> 00:51:05,359

so this

1370

00:51:10,470 --> 00:51:07,920

square wave pattern is the uh

1371

00:51:11,430 --> 00:51:10,480

the polarized signal we're seeing from

1372

00:51:13,270 --> 00:51:11,440

the

1373

00:51:17,510 --> 00:51:13,280

two

1374

00:51:18,870 --> 00:51:17,520

avalanche photodiodes

1375

00:51:23,030 --> 00:51:18,880

and that

1376

00:51:24,470 --> 00:51:23,040

polarization of

1377

00:51:26,230 --> 00:51:24,480

i can't read that from here but it's

1378

00:51:27,349 --> 00:51:26,240

something like ten to the minus four

1379

00:51:28,630 --> 00:51:27,359

it's a

1380

00:51:29,829 --> 00:51:28,640

it's what would have been about the

1381

00:51:31,510 --> 00:51:29,839

limit of what you could measure with

1382

00:51:33,750 --> 00:51:31,520

previous astronomical instruments and it

1383

00:51:37,109 --> 00:51:33,760

gives a huge signal without system

1384

00:51:39,910 --> 00:51:37,119

and then these are smaller polarizations

1385

00:51:42,069 --> 00:51:39,920

between 20 times 10 to the minus 6

1386

00:51:44,069 --> 00:51:42,079

and 12 times 10 to the minus 6 that show

1387

00:51:46,470 --> 00:51:44,079

we can fairly easily see

1388

00:51:48,870 --> 00:51:46,480

polarizations at this 10 to the minus 6

1389

00:51:53,750 --> 00:51:50,470

we also have to remove telescope

1390

00:51:55,910 --> 00:51:53,760

polarization which we do by

1391

00:51:57,670 --> 00:51:55,920

using the fact that it's an an altamis

1392

00:51:58,950 --> 00:51:57,680

telescope and we can see

1393

00:52:05,270 --> 00:51:58,960

the

1394

00:52:07,829 --> 00:52:05,280

different hour angles

1395

00:52:09,510 --> 00:52:07,839

so we've observed a number of stars

1396

00:52:13,430 --> 00:52:09,520

this is

1397

00:52:15,670 --> 00:52:13,440

data of bright stars

1398

00:52:18,069 --> 00:52:15,680

nearby bright stars so most of the stars

1399

00:52:19,270 --> 00:52:18,079

and the size of the the disc here is is

1400

00:52:20,710 --> 00:52:19,280

a measure of the

1401  
00:52:24,150 --> 00:52:20,720  
polarization

1402  
00:52:25,990 --> 00:52:24,160  
so these big ones here are about 200

1403  
00:52:27,990 --> 00:52:26,000  
times 10 to the minus six so everything

1404  
00:52:29,349 --> 00:52:28,000  
in units at ten to the minus six

1405  
00:52:31,510 --> 00:52:29,359  
so these are

1406  
00:52:33,990 --> 00:52:31,520  
what we're seeing up here is is a region

1407  
00:52:35,750 --> 00:52:34,000  
where we're getting far enough um out to

1408  
00:52:37,829 --> 00:52:35,760  
see interstellar polarization effects to

1409  
00:52:38,630 --> 00:52:37,839  
see interstellar dust

1410  
00:52:40,309 --> 00:52:38,640  
but

1411  
00:52:42,230 --> 00:52:40,319  
um most of these other stars have very

1412  
00:52:44,390 --> 00:52:42,240  
low polarizations

1413  
00:52:45,670 --> 00:52:44,400

except for a couple of cases which we

1414

00:52:47,750 --> 00:52:45,680

think have

1415

00:52:49,589 --> 00:52:47,760

um intrinsic polarization regulus is

1416

00:52:52,069 --> 00:52:49,599

actually a rapidly rotating flattened

1417

00:52:53,670 --> 00:52:52,079

star and vega has a dust disc around it

1418

00:52:55,589 --> 00:52:53,680

so they're both cases that are probably

1419

00:52:58,549 --> 00:52:55,599

producing polarization

1420

00:53:00,390 --> 00:52:58,559

where does the sun come in there

1421

00:53:01,589 --> 00:53:00,400

the sun well it's not on the diagram but

1422

00:53:02,790 --> 00:53:01,599

it would be uh

1423

00:53:05,190 --> 00:53:02,800

it would be it's less than ten to the

1424

00:53:08,150 --> 00:53:05,200

minus six so the the smallest dots on

1425

00:53:12,710 --> 00:53:11,109

um okay well there's

1426

00:53:14,309 --> 00:53:12,720

the basic result so far is that we've

1427

00:53:16,309 --> 00:53:14,319

looked at one of these subject systems

1428

00:53:17,990 --> 00:53:16,319

and we've we've failed to detect the

1429

00:53:19,190 --> 00:53:18,000

polarization signature that was

1430

00:53:21,109 --> 00:53:19,200

predicted

1431

00:53:23,510 --> 00:53:21,119

but we probably chose star which was not

1432

00:53:25,109 --> 00:53:23,520

the best one for a number of reasons

1433

00:53:28,870 --> 00:53:25,119

so we're continuing observations of

1434

00:53:32,950 --> 00:53:30,790

and

1435

00:53:36,230 --> 00:53:32,960

we have found various other interesting

1436

00:53:41,510 --> 00:53:38,150

we've

1437

00:53:42,790 --> 00:53:41,520

nearby stars have very low polarization

1438

00:53:46,230 --> 00:53:42,800

which is helpful for detecting the

1439

00:53:49,270 --> 00:53:47,030

um

1440

00:53:51,750 --> 00:53:49,280

we don't yet see the expected

1441

00:53:54,230 --> 00:53:51,760

polarization signature of a hot jupiter

1442

00:53:56,150 --> 00:53:54,240

planet but we may be able to

1443

00:53:57,829 --> 00:53:56,160

do so by looking at other systems we've

1444

00:53:59,109 --> 00:53:57,839

also discovered interesting things about

1445

00:54:00,790 --> 00:53:59,119

polarization effects in the earth's

1446

00:54:02,630 --> 00:54:00,800

atmosphere um

1447

00:54:04,470 --> 00:54:02,640

at the la palma site frequently gets to

1448

00:54:06,230 --> 00:54:04,480

horror and dust blowing over and we've

1449

00:54:07,589 --> 00:54:06,240

found that that's a horrendous produces

1450

00:54:09,030 --> 00:54:07,599

lots of polarization or lots of

1451  
00:54:10,549 --> 00:54:09,040  
polarization of the levels we're looking

1452  
00:54:12,390 --> 00:54:10,559  
at which is actually tells us

1453  
00:54:13,829 --> 00:54:12,400  
interesting things about

1454  
00:54:15,109 --> 00:54:13,839  
what how does particles behave in the

1455  
00:54:19,589 --> 00:54:15,119  
earth's atmosphere because it implies

1456  
00:54:29,349 --> 00:54:20,549  
okay

1457  
00:54:33,670 --> 00:54:31,430  
uh it seems like you could use the

1458  
00:54:36,069 --> 00:54:33,680  
requirement of having the correct

1459  
00:54:39,030 --> 00:54:36,079  
phase angle to actually calculate the

1460  
00:54:41,829 --> 00:54:39,040  
angle of inclination um

1461  
00:54:44,230 --> 00:54:41,839  
is that something worthwhile have you

1462  
00:54:45,829 --> 00:54:44,240  
thought about that

1463  
00:54:49,349 --> 00:54:45,839

um which are you talking about the hot

1464

00:54:51,109 --> 00:54:49,359

jupiters or the oh sorry the the planet

1465

00:54:53,109 --> 00:54:51,119

um

1466

00:54:55,829 --> 00:54:53,119

well yeah for example the phase the

1467

00:54:57,589 --> 00:54:55,839

required phasing of blind

1468

00:54:59,430 --> 00:54:57,599

you could maybe use to figure out the

1469

00:55:01,349 --> 00:54:59,440

inclination between the

1470

00:55:02,870 --> 00:55:01,359

planet's orbit and the

1471

00:55:04,470 --> 00:55:02,880

star which

1472

00:55:06,549 --> 00:55:04,480

i don't know if the glint tells you that

1473

00:55:08,630 --> 00:55:06,559

but polarization angles in general will

1474

00:55:10,069 --> 00:55:08,640

do that because

1475

00:55:12,390 --> 00:55:10,079

the polarization

1476

00:55:15,190 --> 00:55:12,400

tells you the

1477

00:55:16,790 --> 00:55:15,200

the vector to the star effectively

1478

00:55:18,150 --> 00:55:16,800

polarization is always orthogonal to the

1479

00:55:19,430 --> 00:55:18,160

stars vectors so if you can see how that

1480

00:55:22,710 --> 00:55:19,440

rotates around the object you can get

1481

00:55:26,630 --> 00:55:24,870

i'm curious if you if the glint can

1482

00:55:28,309 --> 00:55:26,640

allow you to distinguish between uh

1483

00:55:29,829 --> 00:55:28,319

water ice or some other liquid if

1484

00:55:31,190 --> 00:55:29,839

there's characteristics

1485

00:55:32,870 --> 00:55:31,200

it'll tell you what uh but it's actually

1486

00:55:34,470 --> 00:55:32,880

collecting

1487

00:55:37,510 --> 00:55:34,480

i don't think you can easily tell that

1488

00:55:39,190 --> 00:55:37,520

all you can tell is that you've got a

1489

00:55:41,190 --> 00:55:39,200

reflecting surface and i think you

1490

00:55:43,109 --> 00:55:41,200

probably have to figure out from other

1491

00:55:45,109 --> 00:55:43,119

um properties of the atmosphere what

1492

00:55:46,230 --> 00:55:45,119

that is likely to be so i guess other

1493

00:55:54,390 --> 00:55:46,240

other information on the atmosphere

1494

00:55:58,789 --> 00:55:55,990

how long did you look at it so you can

1495

00:55:59,910 --> 00:55:58,799

just describe the observations and

1496

00:56:03,589 --> 00:55:59,920

how

1497

00:56:05,510 --> 00:56:03,599

predictions and so forth

1498

00:56:08,150 --> 00:56:05,520

well well this is this is what we're

1499

00:56:09,670 --> 00:56:08,160

seeing for tomato okay so we got a

1500

00:56:11,750 --> 00:56:09,680

reasonable coverage of the phase

1501

00:56:12,549 --> 00:56:11,760

although there's a few gaps

1502

00:56:14,870 --> 00:56:12,559

um

1503

00:56:16,950 --> 00:56:14,880

and we did seem to see some polarization

1504

00:56:18,950 --> 00:56:16,960

but the curve is completely wrong for

1505

00:56:20,870 --> 00:56:18,960

what we would expect

1506

00:56:22,309 --> 00:56:20,880

if it was a it was a clear atmosphere

1507

00:56:24,390 --> 00:56:22,319

for example we'd expect peak

1508

00:56:27,349 --> 00:56:24,400

polarization to be around 90 degrees

1509

00:56:28,829 --> 00:56:27,359

which is probably where we're seeing

1510

00:56:30,870 --> 00:56:28,839

low

1511

00:56:32,710 --> 00:56:30,880

polarizations we seem to be seeing high

1512

00:56:35,349 --> 00:56:32,720

polarizations here where we wouldn't

1513

00:56:37,270 --> 00:56:35,359

expect to see to see much polarization

1514

00:56:39,430 --> 00:56:37,280

so we don't really know what's going on

1515

00:56:41,589 --> 00:56:39,440

but what we suspect is that what we're

1516

00:56:43,030 --> 00:56:41,599

seeing is probably not due to the planet

1517

00:56:44,309 --> 00:56:43,040

it's probably due to what's going on on

1518

00:56:45,910 --> 00:56:44,319

the staff

1519

00:56:47,910 --> 00:56:45,920

because that that's consistent with

1520

00:56:50,069 --> 00:56:47,920

what's come out of the

1521

00:56:51,589 --> 00:56:50,079

the the canadian most satellite has been

1522

00:56:53,910 --> 00:56:51,599

observing this thing as well looking for

1523

00:56:55,349 --> 00:56:53,920

the for the light curve

1524

00:56:56,789 --> 00:56:55,359

that you'd expect from scaling off the

1525

00:56:58,390 --> 00:56:56,799

planet and they don't see anything like

1526  
00:56:59,589 --> 00:56:58,400  
that but they do see bigger effects

1527  
00:57:00,870 --> 00:56:59,599  
which they think are coming from the

1528  
00:57:04,309 --> 00:57:00,880  
star

1529  
00:57:05,670 --> 00:57:04,319  
active

1530  
00:57:08,230 --> 00:57:05,680  
which means there there might be some

1531  
00:57:10,150 --> 00:57:08,240  
polarization coming from magnetic zeeman

1532  
00:57:11,349 --> 00:57:10,160  
effects and so that might be confusing

1533  
00:57:13,990 --> 00:57:11,359  
us

1534  
00:57:18,470 --> 00:57:14,000  
but is each of these data points

1535  
00:57:20,630 --> 00:57:18,480  
just looking once or did you have many

1536  
00:57:23,109 --> 00:57:20,640  
many times

1537  
00:57:25,270 --> 00:57:23,119  
we followed it over well several cycles

1538  
00:57:27,670 --> 00:57:25,280

but but with incomplete coverage on all

1539

00:57:29,349 --> 00:57:27,680

of them because we listen

1540

00:57:31,829 --> 00:57:29,359

well you missed you missed the daytime

1541

00:57:34,230 --> 00:57:31,839

party anyway it's the periods only

1542

00:57:36,470 --> 00:57:34,240

three point something days

1543

00:57:48,789 --> 00:57:36,480

and we generally missed some bits due to

1544

00:57:48,799 --> 00:57:52,829

each data point is plotted there though

1545

00:57:57,190 --> 00:57:55,589

yes what

1546

00:57:59,270 --> 00:57:57,200

excuse me

1547

00:58:00,470 --> 00:57:59,280

those uh

1548

00:58:01,750 --> 00:58:00,480

sorry

1549

00:58:04,230 --> 00:58:01,760

the uh

1550

00:58:05,430 --> 00:58:04,240

the tpf integration times you were

1551  
00:58:07,510 --> 00:58:05,440  
talking about there i think are around

1552  
00:58:09,270 --> 00:58:07,520  
the order of a week or two so i was

1553  
00:58:12,230 --> 00:58:09,280  
wondering to get eighteen thousand or

1554  
00:58:13,589 --> 00:58:12,240  
whatever you need yeah but it's gonna be

1555  
00:58:14,870 --> 00:58:13,599  
for something like

1556  
00:58:17,750 --> 00:58:14,880  
earth

1557  
00:58:20,150 --> 00:58:17,760  
which has both these water and cloud

1558  
00:58:22,390 --> 00:58:20,160  
systems and it's gonna be but also land

1559  
00:58:24,309 --> 00:58:22,400  
how much is the the rotation

1560  
00:58:25,510 --> 00:58:24,319  
of the planet in that

1561  
00:58:27,270 --> 00:58:25,520  
ten days

1562  
00:58:30,630 --> 00:58:27,280  
if you will gonna smear out some of

1563  
00:58:34,390 --> 00:58:32,390

um

1564

00:58:35,589 --> 00:58:34,400

it's it's obviously gonna have some

1565

00:58:36,390 --> 00:58:35,599

effect

1566

00:58:37,510 --> 00:58:36,400

um

1567

00:58:39,349 --> 00:58:37,520

yeah i mean

1568

00:58:41,030 --> 00:58:39,359

well the not just the rotation but the

1569

00:58:42,630 --> 00:58:41,040

fact that the cloud cover is

1570

00:58:44,789 --> 00:58:42,640

edging all the time

1571

00:58:46,789 --> 00:58:44,799

um

1572

00:58:48,309 --> 00:58:46,799

i think it's

1573

00:58:49,270 --> 00:58:48,319

i think these are these are on the whole

1574

00:58:50,789 --> 00:58:49,280

big enough

1575

00:58:52,230 --> 00:58:50,799

certainly the rainbows and the rainy

1576

00:58:54,150 --> 00:58:52,240

scattering effects are big enough that

1577

00:58:56,390 --> 00:58:54,160

they should show up i'm not sure about

1578

00:58:57,670 --> 00:58:56,400

blind i mean obviously the blood spot

1579

00:59:00,870 --> 00:58:57,680

can disappear completely if a cloud

1580

00:59:03,190 --> 00:59:02,230

yes

1581

00:59:05,430 --> 00:59:03,200

so

1582

00:59:07,750 --> 00:59:05,440

but um um

1583

00:59:09,349 --> 00:59:07,760

i mean enric poller has been looking for

1584

00:59:11,109 --> 00:59:09,359

to see if you can see the rotation of

1585

00:59:13,670 --> 00:59:11,119

the earth in the

1586

00:59:15,510 --> 00:59:13,680

um earthshite data and i think he's

1587

00:59:17,190 --> 00:59:15,520

found it quite difficult to pick it out

1588

00:59:21,270 --> 00:59:17,200

so rotation effect doesn't seem to be

1589

00:59:24,470 --> 00:59:22,950

so i was talking to bill sparks at the

1590

00:59:27,430 --> 00:59:24,480

apps icon

1591

00:59:29,829 --> 00:59:27,440

and it was in looking at

1592

00:59:33,270 --> 00:59:29,839

being able to detect various color that

1593

00:59:35,030 --> 00:59:33,280

might be involved in photosynthesis

1594

00:59:37,589 --> 00:59:35,040

and not just

1595

00:59:38,870 --> 00:59:37,599

you know green plants but perhaps

1596

00:59:40,789 --> 00:59:38,880

red plants

1597

00:59:43,510 --> 00:59:40,799

and

1598

00:59:45,030 --> 00:59:43,520

is there a possibility of using

1599

00:59:47,670 --> 00:59:45,040

polarization that

1600

00:59:49,270 --> 00:59:47,680

not necessarily look at color from

1601  
00:59:52,950 --> 00:59:49,280  
photosynthesis

1602  
00:59:54,870 --> 00:59:52,960  
color that might be associated with

1603  
00:59:57,190 --> 00:59:54,880  
a chemical signal

1604  
00:59:59,910 --> 00:59:57,200  
organic or inorganic signal for example

1605  
01:00:01,910 --> 00:59:59,920  
the dark coloration on the leads of

1606  
01:00:04,630 --> 01:00:01,920  
europa for example could that be

1607  
01:00:06,950 --> 01:00:04,640  
detected with polarization and could we

1608  
01:00:13,670 --> 01:00:06,960  
actually find a way to delineate what

1609  
01:00:18,150 --> 01:00:16,630  
well i mean the reason the reason

1610  
01:00:20,390 --> 01:00:18,160  
bill sparks is able to detect

1611  
01:00:21,829 --> 01:00:20,400  
polarization signatures is is because

1612  
01:00:27,829 --> 01:00:21,839  
these are

1613  
01:00:29,589 --> 01:00:27,839

so so things like chlorophylls

1614

01:00:31,510 --> 01:00:29,599

do produce a circular polarization

1615

01:00:33,910 --> 01:00:31,520

signature

1616

01:00:36,630 --> 01:00:35,109

organic

1617

01:00:39,829 --> 01:00:36,640

in principle any

1618

01:00:43,349 --> 01:00:39,839

any organic molecule will do that but

1619

01:00:45,349 --> 01:00:43,359

in most molecules the circular dichroism

1620

01:00:48,309 --> 01:00:45,359

effects are more in the uv so you might

1621

01:00:50,150 --> 01:00:48,319

have to go far into the uv to to see to

1622

01:00:51,910 --> 01:00:50,160

see strong effects

1623

01:00:52,870 --> 01:00:51,920

but all of these are very small signals

1624

01:00:54,710 --> 01:00:52,880

i mean

1625

01:00:55,829 --> 01:00:54,720

the effects bill is seeing is sort of

1626  
01:00:57,910 --> 01:00:55,839  
0.2

1627  
01:00:59,670 --> 01:00:57,920  
polarization at best

1628  
01:01:01,510 --> 01:00:59,680  
so we're looking for something sort of

1629  
01:01:03,190 --> 01:01:01,520  
100 times down on the

1630  
01:01:05,030 --> 01:01:03,200  
sort of atmospheric polarizations i'm

1631  
01:01:06,309 --> 01:01:05,040  
talking about here

1632  
01:01:11,910 --> 01:01:06,319  
so

1633  
01:01:13,990 --> 01:01:11,920  
be feasible

1634  
01:01:16,069 --> 01:01:14,000  
is there a future for

1635  
01:01:19,589 --> 01:01:16,079  
making this technique

1636  
01:01:21,990 --> 01:01:19,599  
more sensitive than it is right now

1637  
01:01:25,430 --> 01:01:22,000  
is there a mechanism to make it 100

1638  
01:01:26,870 --> 01:01:25,440

times more sensitive

1639

01:01:28,390 --> 01:01:26,880

well if we're talking about exoplanets

1640

01:01:29,829 --> 01:01:28,400

the way you make it 100 times more

1641

01:01:33,190 --> 01:01:29,839

sensitive is make your telescope 100

1642

01:01:36,230 --> 01:01:34,710

if you talk about looking for things in

1643

01:01:37,510 --> 01:01:36,240

the solar system

1644

01:01:39,750 --> 01:01:37,520

then we

1645

01:01:41,670 --> 01:01:39,760

i guess we ought to be able to

1646

01:01:43,589 --> 01:01:41,680

push circular polarization measurements

1647

01:01:44,390 --> 01:01:43,599

down to these sort of ten to the minus

1648

01:01:46,549 --> 01:01:44,400

six

1649

01:01:47,829 --> 01:01:46,559

levels we're achieving with with

1650

01:01:49,829 --> 01:01:47,839

planetfall

1651

01:01:51,670 --> 01:01:49,839

principle which is

1652

01:01:53,670 --> 01:01:51,680

which is better than anybody's actually

1653

01:01:58,309 --> 01:01:53,680

used in a solar system observations so

1654

01:02:03,829 --> 01:02:00,150

how much you you showed the plots that

1655

01:02:05,750 --> 01:02:03,839

show basically the the peak migrating at

1656

01:02:06,950 --> 01:02:05,760

a single wavelength if i if i understood

1657

01:02:08,309 --> 01:02:06,960

correctly with the different

1658

01:02:09,990 --> 01:02:08,319

compositions how much additional

1659

01:02:11,990 --> 01:02:10,000

diagnostic information you get by

1660

01:02:14,470 --> 01:02:12,000

looking at the migration of a peak

1661

01:02:16,870 --> 01:02:14,480

so it's definitely the rainbow peak yeah

1662

01:02:17,829 --> 01:02:16,880

essentially the radial peak yeah

1663

01:02:20,390 --> 01:02:17,839

if you're looking at different

1664

01:02:22,150 --> 01:02:20,400

wavelengths and can you does it buy you

1665

01:02:23,829 --> 01:02:22,160

a whole lot more diagnostics yes yes it

1666

01:02:25,750 --> 01:02:23,839

does help a bit because you get not just

1667

01:02:27,829 --> 01:02:25,760

the refractive index of one wavelength

1668

01:02:29,030 --> 01:02:27,839

but you get part of the refractive index

1669

01:02:30,870 --> 01:02:29,040

curve

1670

01:02:33,430 --> 01:02:30,880

as a function of wavelengths and james

1671

01:02:35,030 --> 01:02:33,440

hudson actually used that in the venus

1672

01:02:36,390 --> 01:02:35,040

rainbow measurements that was part of

1673

01:02:39,910 --> 01:02:36,400

the information that tight tightened

1674

01:02:43,670 --> 01:02:41,510

um so if you want to

1675

01:02:45,109 --> 01:02:43,680

verify this for the earth the

1676

01:02:47,990 --> 01:02:45,119

polarization

1677

01:02:49,430 --> 01:02:48,000

why can't you use a

1678

01:02:51,109 --> 01:02:49,440

satellite that stays pretty close to the

1679

01:02:52,470 --> 01:02:51,119

earth why do you have to get so far away

1680

01:02:54,470 --> 01:02:52,480

couldn't you just kind of stare at the

1681

01:02:57,190 --> 01:02:54,480

ground at different angles and

1682

01:02:59,190 --> 01:02:57,200

get all the information you need

1683

01:03:00,870 --> 01:02:59,200

well effectively we have we have that

1684

01:03:04,150 --> 01:03:00,880

sort of information from polder so we

1685

01:03:07,589 --> 01:03:06,069

we know these polarization

1686

01:03:09,510 --> 01:03:07,599

effects are there

1687

01:03:10,470 --> 01:03:09,520

um in principle yeah i guess you could

1688

01:03:12,230 --> 01:03:10,480

try and

1689

01:03:13,750 --> 01:03:12,240

use a whole lot of satellite data and

1690

01:03:14,870 --> 01:03:13,760

combine it together to get some idea of

1691

01:03:17,109 --> 01:03:14,880

what the

1692

01:03:18,470 --> 01:03:17,119

total earth signal would look like

1693

01:03:20,309 --> 01:03:18,480

but you don't usually get quite the same

1694

01:03:22,390 --> 01:03:20,319

thing because for example the satellites

1695

01:03:23,829 --> 01:03:22,400

usually look straight down

1696

01:03:24,710 --> 01:03:23,839

whereas when

1697

01:03:27,029 --> 01:03:24,720

if you're actually looking at the

1698

01:03:28,789 --> 01:03:27,039

integrated

1699

01:03:29,910 --> 01:03:28,799

view of the earth from a distance you're

1700

01:03:30,870 --> 01:03:29,920

looking straight down in the center of

1701

01:03:32,789 --> 01:03:30,880

the planet and you're looking at

1702

01:03:34,470 --> 01:03:32,799

different angles as you go go to near

1703

01:03:35,670 --> 01:03:34,480

the limb

1704

01:03:37,670 --> 01:03:35,680

but there certainly may be some

1705

01:03:39,109 --> 01:03:37,680

potential for using existing sunlight

1706

01:03:40,710 --> 01:03:39,119

data to get some of this information i

1707

01:03:42,630 --> 01:03:40,720

mean if you just convince them to not

1708

01:03:45,750 --> 01:03:42,640

look straight down convince them to like

1709

01:03:49,589 --> 01:03:45,760

look look at the edge look towards the