Exploring Titan's Atmospheric Chemistry and Dynamical State with ALMA

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1
00:00:03,270 --> 00:00:02,790
hello everyone my name is alexander

2
00:00:06,470 --> 00:00:03,280
thielen

3
00:00:08,390 --> 00:00:06,480
i'm an astrobiology npp postdoc at

4
00:00:10,150 --> 00:00:08,400
assets goddard space flight center

5
00:00:11,669 --> 00:00:10,160
and thank you for joining me today at

6
00:00:13,589 --> 00:00:11,679
april icon where i'll be talking about

7
00:00:15,190 --> 00:00:13,599
the exploration of titan's atmospheric

8
00:00:18,470 --> 00:00:15,200
chemistry and dynamical state

9
00:00:20,070 --> 00:00:18,480
with alma titan herbert is a substantial

10
00:00:21,590 --> 00:00:20,080
atmosphere which is primarily composed

11
00:00:23,029 --> 00:00:21,600
of molecular nitrogen

12
00:00:24,950 --> 00:00:23,039
there's also a small percentage of

13
00:00:26,550 --> 00:00:24,960

methane molecular hydrogen and all of

14
00:00:27,269 --> 00:00:26,560
these species are dissociated and

15
00:00:30,310 --> 00:00:27,279
recombined

16
00:00:31,429 --> 00:00:30,320
into a wealth of organic compounds today

17
00:00:33,190 --> 00:00:31,439
we'll be talking about mostly

18
00:00:34,470 --> 00:00:33,200
hydrocarbon and nitrile species but

19
00:00:36,709 --> 00:00:34,480
there are also some oxygen burying

20
00:00:38,869 --> 00:00:36,719
species such as carbon monoxide and a

21
00:00:40,630 --> 00:00:38,879
wealth of yet to be identified

22
00:00:41,910 --> 00:00:40,640
heavy ionospheric species in the upper

23
00:00:43,830 --> 00:00:41,920
atmosphere

24
00:00:45,110 --> 00:00:43,840
over on the right we have a temperature

25
00:00:48,549 --> 00:00:45,120
profile of

26
00:00:49,910 --> 00:00:48,559
the earth and these are remarkably

27
00:00:51,270 --> 00:00:49,920
similar in shape although titan's

28
00:00:54,069 --> 00:00:51,280
profile is much more extended

29
00:00:55,270 --> 00:00:54,079
and much colder the study of titan and

30
00:00:56,069 --> 00:00:55,280
the sub millimeter which we'll be

31
00:00:59,510 --> 00:00:56,079
discussing today

32
00:01:01,750 --> 00:00:59,520
between about a 1070 kilometers

33
00:01:03,750 --> 00:01:01,760
is comparable to previous observations

34
00:01:04,229 --> 00:01:03,760
by the cassini spacecraft and those from

35
00:01:07,429 --> 00:01:04,239
the ground

36
00:01:08,950 --> 00:01:07,439
in the uv and in the infrared the

37
00:01:10,390 --> 00:01:08,960
combination of all of these studies

38
00:01:11,030 --> 00:01:10,400

allows us to characterize titan's

39
00:01:13,270 --> 00:01:11,040
atmosphere

40
00:01:14,550 --> 00:01:13,280
chemically and dynamically and allows us

41
00:01:17,109 --> 00:01:14,560
to answer some questions

42
00:01:19,030 --> 00:01:17,119
such as how extensive is the atmospheric

43
00:01:20,710 --> 00:01:19,040
chemistry and the molecular inventory

44
00:01:22,390 --> 00:01:20,720
of titan and how are these trace

45
00:01:23,590 --> 00:01:22,400
constituents distributed spatially and

46
00:01:25,910 --> 00:01:23,600
temporally

47
00:01:27,990 --> 00:01:25,920
for interest to astrobiology we also

48
00:01:29,749 --> 00:01:28,000
wonder how are these species able to

49
00:01:31,749 --> 00:01:29,759
interact with the surface and possibly

50
00:01:33,350 --> 00:01:31,759
tighten the subsurface ocean

51
00:01:35,190 --> 00:01:33,360
to try to answer some of these questions

52
00:01:37,030 --> 00:01:35,200
we use the atacama large millimeters

53
00:01:38,870 --> 00:01:37,040
submillimeter array or alma which is

54
00:01:41,429 --> 00:01:38,880
located high in the chilean desert

55
00:01:43,670 --> 00:01:41,439
close to 5000 meters in altitude almost

56
00:01:46,069 --> 00:01:43,680
comprised of 66 antenna dishes

57
00:01:47,030 --> 00:01:46,079
in multiple different arrays and these

58
00:01:49,749 --> 00:01:47,040
are movable

59
00:01:51,830 --> 00:01:49,759
which allows for baselines between 150

60
00:01:54,389 --> 00:01:51,840
meters and 16 kilometers

61
00:01:55,190 --> 00:01:54,399
this enables fairly high spatial

62
00:01:58,069 --> 00:01:55,200
resolution

63
00:01:59,749 --> 00:01:58,079

at these long wavelengths and you can

64
00:02:02,469 --> 00:01:59,759
see that titan is a fairly

65
00:02:03,429 --> 00:02:02,479
bright and compact continuum source at

66
00:02:05,749 --> 00:02:03,439
these frequencies

67
00:02:07,109 --> 00:02:05,759
and as such alma used titan for a number

68
00:02:09,669 --> 00:02:07,119
of different flux calibration

69
00:02:11,190 --> 00:02:09,679
observations since its inception in 2011

70
00:02:12,470 --> 00:02:11,200
all the way until 2017

71
00:02:14,550 --> 00:02:12,480
so there's a wealth of titan

72
00:02:17,830 --> 00:02:14,560
observations that are available on the

73
00:02:20,150 --> 00:02:17,840
alma science archive for us to use

74
00:02:21,350 --> 00:02:20,160
when looking through the alma flux

75
00:02:23,030 --> 00:02:21,360
calibration archive

76
00:02:25,510 --> 00:02:23,040
of titan observations we quickly found

77
00:02:26,229 --> 00:02:25,520
that alma has a variety of capabilities

78
00:02:27,830 --> 00:02:26,239
that are

79
00:02:29,589 --> 00:02:27,840
suitable for planetary atmosphere

80
00:02:32,229 --> 00:02:29,599
studies in addition to those of

81
00:02:34,630 --> 00:02:32,239
astrophysical and extra galactic sources

82
00:02:36,790 --> 00:02:34,640
this includes the coverage of numerous

83
00:02:37,990 --> 00:02:36,800
molecular species which may appear in

84
00:02:40,390 --> 00:02:38,000
planetary atmospheres

85
00:02:41,270 --> 00:02:40,400
for chemistry and isotopic ratio studies

86
00:02:43,509 --> 00:02:41,280
the high

87
00:02:44,790 --> 00:02:43,519
spectral resolution of alma heterodyne

88
00:02:46,630 --> 00:02:44,800

spectra allow for

89
00:02:48,470 --> 00:02:46,640
wind speed measurements through doppler

90
00:02:50,390 --> 00:02:48,480
shift and also to resolve

91
00:02:51,990 --> 00:02:50,400
atmospheric emission lines which allow

92
00:02:55,430 --> 00:02:52,000
you to measure the temperature

93
00:02:57,350 --> 00:02:55,440
the abundance of gas with altitude

94
00:02:58,869 --> 00:02:57,360
the spatial resolution as mentioned

95
00:03:01,350 --> 00:02:58,879
before allows us to map

96
00:03:03,350 --> 00:03:01,360
these things instantaneously to look at

97
00:03:05,350 --> 00:03:03,360
abundance or brightness temperature maps

98
00:03:06,710 --> 00:03:05,360
and the sensitivity of the array as a

99
00:03:08,309 --> 00:03:06,720
whole allows for

100
00:03:09,910 --> 00:03:08,319
new molecular detections in the

101
00:03:12,070 --> 00:03:09,920
atmosphere of titan and other solar

102
00:03:14,710 --> 00:03:12,080
system targets

103
00:03:16,149 --> 00:03:14,720
here's a representative spectrum of

104
00:03:18,149 --> 00:03:16,159
titan which is actually obtained from

105
00:03:19,430 --> 00:03:18,159
flux calibration observations so roughly

106
00:03:22,070 --> 00:03:19,440
two and a half minutes

107
00:03:23,190 --> 00:03:22,080
on source during 2014 but even in this

108
00:03:25,190 --> 00:03:23,200
short integration

109
00:03:27,110 --> 00:03:25,200
we can see the richness of these

110
00:03:29,110 --> 00:03:27,120
submillimeter spectra

111
00:03:30,630 --> 00:03:29,120
over on the left we have a band of

112
00:03:31,990 --> 00:03:30,640
acetonitrile we have these two

113
00:03:34,309 --> 00:03:32,000

relatively strong lines

114
00:03:35,270 --> 00:03:34,319
of hydrogen cyanide isotopes the carbon

115
00:03:38,070 --> 00:03:35,280
and nitrogen

116
00:03:38,630 --> 00:03:38,080
isotopes and then we even have some low

117
00:03:40,390 --> 00:03:38,640
signal

118
00:03:41,670 --> 00:03:40,400
acrylonitrile or ethyl cyanide

119
00:03:43,270 --> 00:03:41,680
transitions here

120
00:03:44,710 --> 00:03:43,280
so analyzing these spectra in a number

121
00:03:46,309 --> 00:03:44,720
of different ways will

122
00:03:48,630 --> 00:03:46,319
allow us to complete some of the

123
00:03:51,350 --> 00:03:48,640
projects that i'll describe

124
00:03:51,830 --> 00:03:51,360
here after and even just integrating

125
00:03:54,869 --> 00:03:51,840
over

126
00:03:55,750 --> 00:03:54,879
these spectral lines you can obtain

127
00:03:57,830 --> 00:03:55,760
these nice

128
00:03:59,110 --> 00:03:57,840
emission maps which will show you a

129
00:04:01,350 --> 00:03:59,120
snapshot view

130
00:04:02,309 --> 00:04:01,360
of the distribution of a given molecular

131
00:04:04,309 --> 00:04:02,319
species

132
00:04:05,350 --> 00:04:04,319
at a certain time when the observation

133
00:04:07,910 --> 00:04:05,360
was taken so

134
00:04:09,670 --> 00:04:07,920
on the top row we have hc3n or

135
00:04:12,229 --> 00:04:09,680
cyanoacetylene which we can see

136
00:04:14,470 --> 00:04:12,239
very rapidly transitions from the north

137
00:04:17,270 --> 00:04:14,480
pole to the south pole during

138
00:04:18,229 --> 00:04:17,280

2012 to 2015 and this is because of the

139
00:04:20,310 --> 00:04:18,239
relatively

140
00:04:21,670 --> 00:04:20,320
short photochemical lifetime of this

141
00:04:24,390 --> 00:04:21,680
species whereas

142
00:04:25,510 --> 00:04:24,400
in contrast the bottom row we can see

143
00:04:27,110 --> 00:04:25,520
ch3cn

144
00:04:29,990 --> 00:04:27,120
or pseudonitrile which we showed

145
00:04:32,870 --> 00:04:30,000
previously which stays at the north pole

146
00:04:34,230 --> 00:04:32,880
much longer than saturn acetylene

147
00:04:35,270 --> 00:04:34,240
because of its long photochemical

148
00:04:38,150 --> 00:04:35,280
lifetime which

149
00:04:40,390 --> 00:04:38,160
makes it a good tracer of the dynamics

150
00:04:42,310 --> 00:04:40,400
of titan's atmosphere

151
00:04:44,310 --> 00:04:42,320
there's a few ways that we can assess

152
00:04:46,390 --> 00:04:44,320
titan's dynamical state using

153
00:04:48,150 --> 00:04:46,400
alma observations the first is through

154
00:04:51,030 --> 00:04:48,160
the retrieval of temperature

155
00:04:51,830 --> 00:04:51,040
from carbon monoxide from roughly the

156
00:04:53,909 --> 00:04:51,840
tropopause

157
00:04:55,270 --> 00:04:53,919
around 60 kilometers to the lower

158
00:04:58,070 --> 00:04:55,280
mesosphere above

159
00:04:59,670 --> 00:04:58,080
500 kilometers and this is because co is

160
00:05:01,430 --> 00:04:59,680
well mixed in the atmosphere titan at

161
00:05:04,230 --> 00:05:01,440
roughly 50 parts per million

162
00:05:05,110 --> 00:05:04,240
so here is a composition of different

163
00:05:07,430 --> 00:05:05,120

radio transfer

164
00:05:08,870 --> 00:05:07,440
retrieval results of titan's temperature

165
00:05:10,150 --> 00:05:08,880
at different latitudes which i've made

166
00:05:13,909 --> 00:05:10,160
into a temperature map

167
00:05:14,950 --> 00:05:13,919
during 2017 in titan's northern summer

168
00:05:16,870 --> 00:05:14,960
solstice

169
00:05:19,270 --> 00:05:16,880
so we can see a large warming that

170
00:05:21,909 --> 00:05:19,280
occurs at the

171
00:05:22,790 --> 00:05:21,919
subsolar latitudes around 26 north but

172
00:05:24,469 --> 00:05:22,800
there's also

173
00:05:25,990 --> 00:05:24,479
warming that's occurring in the

174
00:05:28,710 --> 00:05:26,000
stratopause

175
00:05:29,909 --> 00:05:28,720
at the north polar region and the mid

176
00:05:32,390 --> 00:05:29,919
southern latitudes

177
00:05:34,230 --> 00:05:32,400
and this is indicative of titan's global

178
00:05:37,110 --> 00:05:34,240
pole the pole circulation cell

179
00:05:38,070 --> 00:05:37,120
which is currently lofting air from the

180
00:05:41,189 --> 00:05:38,080
northern or

181
00:05:44,070 --> 00:05:41,199
summer pole down into the southern

182
00:05:45,510 --> 00:05:44,080
winter pole we can measure titan's

183
00:05:47,510 --> 00:05:45,520
atmospheric temperature further up in

184
00:05:48,310 --> 00:05:47,520
the atmosphere using emission lines of

185
00:05:50,469 --> 00:05:48,320
hcn

186
00:05:51,990 --> 00:05:50,479
as you can see over here on the left

187
00:05:55,749 --> 00:05:52,000
these really broad features

188
00:05:58,790 --> 00:05:55,759

allow us to sound temperatures into the

189
00:05:59,590 --> 00:05:58,800
800 and 900 kilometer range and in

190
00:06:02,469 --> 00:05:59,600
particular

191
00:06:04,390 --> 00:06:02,479
this absorption core in the hdm spectra

192
00:06:05,749 --> 00:06:04,400
allows us to infer the mesopause

193
00:06:05,990 --> 00:06:05,759
temperature of titan which hasn't really

194
00:06:08,629 --> 00:06:06,000
been

195
00:06:09,350 --> 00:06:08,639
studied in depth with latitude or with

196
00:06:11,350 --> 00:06:09,360
time

197
00:06:12,790 --> 00:06:11,360
before these analyses so this is a

198
00:06:13,749 --> 00:06:12,800
preliminary result but we're seeing

199
00:06:16,070 --> 00:06:13,759
already from

200
00:06:16,790 --> 00:06:16,080
observations that the mesopause likely

201
00:06:18,870 --> 00:06:16,800
varies

202
00:06:20,790 --> 00:06:18,880
significantly in both its altitude and

203
00:06:23,909 --> 00:06:20,800
its temperature measurement

204
00:06:25,830 --> 00:06:23,919
so this is you know largely due to wave

205
00:06:27,350 --> 00:06:25,840
motion and changes in the atmospheric

206
00:06:29,029 --> 00:06:27,360
composition which can have effects on

207
00:06:30,870 --> 00:06:29,039
the radiative energy budget

208
00:06:33,350 --> 00:06:30,880
of titan's atmosphere we've previously

209
00:06:36,309 --> 00:06:33,360
seen that this portion of the atmosphere

210
00:06:39,590 --> 00:06:36,319
is really variable with time from

211
00:06:43,270 --> 00:06:41,430
alma's high spectral resolution

212
00:06:45,510 --> 00:06:43,280
capabilities allow us to

213
00:06:46,790 --> 00:06:45,520

observe doppler shifts in emission lines

214
00:06:50,469 --> 00:06:46,800
of rotational spectra

215
00:06:52,469 --> 00:06:50,479
which we can directly map to wind

216
00:06:54,710 --> 00:06:52,479
speed magnitudes in the atmosphere of

217
00:06:57,189 --> 00:06:54,720
titan depending on what chemical species

218
00:06:59,510 --> 00:06:57,199
you're observing you can look between

219
00:07:00,790 --> 00:06:59,520
300 and 1000 kilometers in the

220
00:07:01,350 --> 00:07:00,800
atmosphere depending on where the

221
00:07:04,390 --> 00:07:01,360
species

222
00:07:06,790 --> 00:07:04,400
line core is sensitive to emission so

223
00:07:07,870 --> 00:07:06,800
in martin coroner's paper from last year

224
00:07:12,230 --> 00:07:07,880
we were looking at

225
00:07:15,189 --> 00:07:12,240
ch3cn hc3n and hnc

226
00:07:15,830 --> 00:07:15,199
wind maps from 2017 and comparing those

227
00:07:18,870 --> 00:07:15,840
to

228
00:07:21,749 --> 00:07:18,880
the published ones in 2016 from luciano

229
00:07:23,350 --> 00:07:21,759
where they found a thermospheric jet in

230
00:07:24,230 --> 00:07:23,360
titan's upper atmosphere around the

231
00:07:26,469 --> 00:07:24,240
equator

232
00:07:28,070 --> 00:07:26,479
our wind speed measurements showed a

233
00:07:31,830 --> 00:07:28,080
dramatic decrease

234
00:07:34,070 --> 00:07:31,840
over this nine-month period of about 47

235
00:07:35,749 --> 00:07:34,080
which is due to a dynamical instability

236
00:07:36,950 --> 00:07:35,759
or variable wave activity

237
00:07:39,990 --> 00:07:36,960
between the middle and the upper

238
00:07:41,589 --> 00:07:40,000

atmosphere of titan which is really cool

239
00:07:43,029 --> 00:07:41,599
now moving on to some chemistry and

240
00:07:44,950 --> 00:07:43,039
composition studies which

241
00:07:46,550 --> 00:07:44,960
are possible from these alma

242
00:07:48,150 --> 00:07:46,560
observations we can take the

243
00:07:49,830 --> 00:07:48,160
temperatures that we retrieved earlier

244
00:07:51,670 --> 00:07:49,840
from co and acn

245
00:07:53,430 --> 00:07:51,680
and use them to do radio transfer

246
00:07:56,230 --> 00:07:53,440
analysis in multiple occasions on

247
00:07:58,309 --> 00:07:56,240
titan's disk to make these abundance

248
00:07:59,110 --> 00:07:58,319
maps with latitude and altitude or

249
00:08:01,589 --> 00:07:59,120
pressure

250
00:08:02,629 --> 00:08:01,599
so on the left we have a map of

251
00:08:04,950 --> 00:08:02,639
cytoacetylene

252
00:08:05,830 --> 00:08:04,960
with altitude and on the right we have a

253
00:08:08,550 --> 00:08:05,840
pseudo nitrile

254
00:08:09,110 --> 00:08:08,560
and again similar to the maps that i

255
00:08:11,830 --> 00:08:09,120
showed

256
00:08:12,869 --> 00:08:11,840
a few slides ago both of these molecules

257
00:08:15,430 --> 00:08:12,879
have an abundance

258
00:08:17,430 --> 00:08:15,440
enhancement towards the pole and in

259
00:08:19,189 --> 00:08:17,440
particular the enhancement of the south

260
00:08:21,990 --> 00:08:19,199
pole compared to the equator

261
00:08:23,350 --> 00:08:22,000
for these species varies by an order of

262
00:08:26,550 --> 00:08:23,360
magnitude which is

263
00:08:28,550 --> 00:08:26,560

really interesting and the global

264
00:08:29,909 --> 00:08:28,560
circulation of titan's pole the pole

265
00:08:32,149 --> 00:08:29,919
cell is also evident

266
00:08:33,190 --> 00:08:32,159
here in the enhancement above the south

267
00:08:36,149 --> 00:08:33,200
pole and

268
00:08:38,310 --> 00:08:36,159
the relative dearth of each of these

269
00:08:41,990 --> 00:08:38,320
molecular species towards the equator or

270
00:08:46,630 --> 00:08:45,030
and maybe more exciting is the detection

271
00:08:48,310 --> 00:08:46,640
of a new molecular species

272
00:08:49,990 --> 00:08:48,320
in titan's atmosphere which has a lot of

273
00:08:53,190 --> 00:08:50,000
applications for both

274
00:08:54,630 --> 00:08:53,200
its overall chemistry feedback into its

275
00:08:56,710 --> 00:08:54,640
atmospheric dynamics and for

276
00:08:59,350 --> 00:08:56,720
perspectives on astrobiology

277
00:09:00,910 --> 00:08:59,360
previous detections from our group early

278
00:09:03,829 --> 00:09:00,920
on included

279
00:09:06,470 --> 00:09:03,839
c2h5cn or just ethyl cyanide on the top

280
00:09:07,990 --> 00:09:06,480
and c2h3cn which is vinyl side on the

281
00:09:11,030 --> 00:09:08,000
bottom which had a lot of interest

282
00:09:13,190 --> 00:09:11,040
from the astrobiology community and

283
00:09:14,630 --> 00:09:13,200
last year we made two new molecular

284
00:09:17,310 --> 00:09:14,640
detections in the atmosphere of titan

285
00:09:18,870 --> 00:09:17,320
using dedicated alma observations from

286
00:09:20,710 --> 00:09:18,880
2016-2019

287
00:09:22,790 --> 00:09:20,720
on the top i'm showing the detection of

288
00:09:26,070 --> 00:09:22,800

methyl cyanoacetylene in this

289
00:09:29,350 --> 00:09:26,080
purple spectrum inset from our 2019 data

290
00:09:32,630 --> 00:09:29,360
and this molecule ch3c3n is

291
00:09:34,870 --> 00:09:32,640
the largest nitrogen bearing species

292
00:09:36,070 --> 00:09:34,880
that we've found thus far also has a

293
00:09:39,389 --> 00:09:36,080
really long name

294
00:09:41,509 --> 00:09:39,399
and in contrast to this molecule is

295
00:09:43,350 --> 00:09:41,519
cyclopropanilidine which also has a long

296
00:09:46,150 --> 00:09:43,360
name and is the smallest

297
00:09:47,990 --> 00:09:46,160
cyclic molecule that we found thus far

298
00:09:49,829 --> 00:09:48,000
in any solar system object

299
00:09:51,990 --> 00:09:49,839
both of these molecules have column

300
00:09:53,829 --> 00:09:52,000
density measurements which are

301
00:09:56,310 --> 00:09:53,839
far below everything else that we've

302
00:09:59,190 --> 00:09:56,320
found thus far in titan's atmosphere

303
00:10:00,870 --> 00:09:59,200
so alma really is one of the best tools

304
00:10:04,150 --> 00:10:00,880
that we have in the moment to push

305
00:10:05,990 --> 00:10:04,160
the molecular inventory and the you know

306
00:10:08,870 --> 00:10:06,000
photochemical products of titan's

307
00:10:10,790 --> 00:10:08,880
atmosphere even further

308
00:10:12,310 --> 00:10:10,800
finally alma allows us to observe many

309
00:10:13,829 --> 00:10:12,320
different isotopic species in the

310
00:10:17,030 --> 00:10:13,839
atmosphere of titan on the top

311
00:10:19,110 --> 00:10:17,040
row we have ch3d as well as isotopes of

312
00:10:22,710 --> 00:10:19,120
hcn and on the bottom right we have

313
00:10:25,110 --> 00:10:22,720

co and ch3 cn isotopes

314
00:10:26,389 --> 00:10:25,120
shown and their respective values are

315
00:10:28,949 --> 00:10:26,399
printed below

316
00:10:31,030 --> 00:10:28,959
the investigation of isotope ratios

317
00:10:32,949 --> 00:10:31,040
gives us insights into the formation and

318
00:10:36,069 --> 00:10:32,959
evolution of the atmosphere of titan

319
00:10:38,150 --> 00:10:36,079
and nitrogen and carbon ratios give us

320
00:10:40,710 --> 00:10:38,160
some insights into the selective

321
00:10:42,069 --> 00:10:40,720
isotopic fractionation that happens in

322
00:10:44,069 --> 00:10:42,079
the upper atmosphere

323
00:10:46,150 --> 00:10:44,079
the dh ratio of titan is interesting

324
00:10:48,310 --> 00:10:46,160
because it's an order of magnitude

325
00:10:49,269 --> 00:10:48,320
higher than that of saturn or jupiter is

326
00:10:51,829 --> 00:10:49,279
much more in line

327
00:10:53,350 --> 00:10:51,839
with the oceans on earth similarly the

328
00:10:57,030 --> 00:10:53,360
oxygen ratios on titan are pretty

329
00:10:59,910 --> 00:10:58,949
so in summary this was a collection of

330
00:11:00,710 --> 00:10:59,920
different projects that we've been

331
00:11:03,509 --> 00:11:00,720
working on

332
00:11:04,230 --> 00:11:03,519
and nasa are using alma to observe titan

333
00:11:06,150 --> 00:11:04,240
and also

334
00:11:08,150 --> 00:11:06,160
now to observe other planetary

335
00:11:08,790 --> 00:11:08,160
atmospheres but alma is a really great

336
00:11:10,550 --> 00:11:08,800
tool

337
00:11:12,310 --> 00:11:10,560
to look at the spatial and temporal

338
00:11:12,949 --> 00:11:12,320

variations in the temperature the

339
00:11:15,350 --> 00:11:12,959
abundance

340
00:11:17,509 --> 00:11:15,360
and the wind speeds of different plants

341
00:11:19,509 --> 00:11:17,519
and its high sensitivity allows for

342
00:11:21,829 --> 00:11:19,519
the detection of new complex molecular

343
00:11:23,829 --> 00:11:21,839
species and also isotopes

344
00:11:24,949 --> 00:11:23,839
these things together allow us to

345
00:11:27,269 --> 00:11:24,959
examine the

346
00:11:28,470 --> 00:11:27,279
chemical complexity and the evolution of

347
00:11:30,310 --> 00:11:28,480
planetary atmospheres

348
00:11:31,670 --> 00:11:30,320
and for titan in particular allows us to

349
00:11:32,630 --> 00:11:31,680
continue the legacy of the cassini

350
00:11:35,110 --> 00:11:32,640
huygens mission

351
00:11:36,230 --> 00:11:35,120
after its end in 2017 and observe

352
00:11:37,910 --> 00:11:36,240
seasonal changes

353
00:11:40,069 --> 00:11:37,920
in titan after its northern summer

354
00:11:41,990 --> 00:11:40,079
solstice these measurements will help us

355
00:11:45,030 --> 00:11:42,000
to constrain photochemical and dynamical

356
00:11:47,350 --> 00:11:45,040
models of titan's atmosphere and

357
00:11:49,190 --> 00:11:47,360
we'll hopefully get more observations

358
00:11:50,150 --> 00:11:49,200
that are dedicated observations of titan

359
00:11:51,430 --> 00:11:50,160
in the future