



1
00:00:10,520 --> 00:00:09,170
so I'm going to go back to the

2
00:00:12,410 --> 00:00:10,530
astrochemistry session because I'm an

3
00:00:14,359 --> 00:00:12,420
asteroid chemists and talk about the

4
00:00:15,709 --> 00:00:14,369
detection of an interstellar molecule so

5
00:00:18,800 --> 00:00:15,719
as you remember a lot of the motivation

6
00:00:22,670 --> 00:00:18,810
for those first few talks was the

7
00:00:25,250 --> 00:00:22,680
detection of new molecules in space so

8
00:00:26,750 --> 00:00:25,260
carbo diam adore carbodiimide however

9
00:00:29,779 --> 00:00:26,760
you want to pronounce it this molecule

10
00:00:32,119 --> 00:00:29,789
right here hnc NH and I promised it

11
00:00:34,970 --> 00:00:32,129
would be relevant to this section and

12
00:00:38,000 --> 00:00:34,980
here's why there was a paper very

13
00:00:41,720 --> 00:00:38,010

recently that said if you want to make a

14

00:00:43,370 --> 00:00:41,730

Dineen which is in RNA and DNA is the

15

00:00:44,960 --> 00:00:43,380

connection you can start with this

16

00:00:46,580 --> 00:00:44,970

molecule here which I've called almost

17

00:00:50,479 --> 00:00:46,590

adenine because I have no idea how to

18

00:00:53,180 --> 00:00:50,489

pronounce the name ah and this

19

00:00:55,340 --> 00:00:53,190

conversion happens barrier lessly in the

20

00:00:57,920 --> 00:00:55,350

gas phase in space according to theory

21

00:00:59,720 --> 00:00:57,930

now that's pretty shocking because as we

22

00:01:01,910 --> 00:00:59,730

said almost all of the complex molecules

23

00:01:04,459 --> 00:01:01,920

have to be formed in these Isis normally

24

00:01:06,350 --> 00:01:04,469

this can happen in the gas phase and if

25

00:01:09,440 --> 00:01:06,360

you look at the subunits of almost a

26
00:01:14,480 --> 00:01:09,450
Dineen here you've got this backbone c3

27
00:01:17,499 --> 00:01:14,490
NH but on either whoo on either side and

28
00:01:20,959 --> 00:01:17,509
it may advance automatic there we go r2

29
00:01:23,179 --> 00:01:20,969
carbodiimide molecules and actually as

30
00:01:27,230 --> 00:01:23,189
it turns out the theorists say you don't

31
00:01:29,359 --> 00:01:27,240
even need Isis to make almost adenine

32
00:01:31,730 --> 00:01:29,369
all you need is to carbon I am accused

33
00:01:32,719 --> 00:01:31,740
in this backbone and all three don't

34
00:01:34,789 --> 00:01:32,729
even have to be together at the same

35
00:01:38,059 --> 00:01:34,799
time you can piece this together one by

36
00:01:40,099 --> 00:01:38,069
one barrier lessly in the gas phase I'm

37
00:01:41,599 --> 00:01:40,109
not sure I believe them some laboratory

38
00:01:43,580 --> 00:01:41,609

work needs been done but in any case

39

00:01:46,429 --> 00:01:43,590

it's intriguing because this backbone

40

00:01:48,889 --> 00:01:46,439

has been detected for years so if we can

41

00:01:51,080 --> 00:01:48,899

detect this one now we have a potential

42

00:01:53,330 --> 00:01:51,090

route for the synthesis of a nucleobase

43

00:01:57,949 --> 00:01:53,340

in the gas phase in space which i think

44

00:02:00,620 --> 00:01:57,959

is pretty cool so moving on to how we

45

00:02:02,359 --> 00:02:00,630

might detect a molecule in space just a

46

00:02:04,789 --> 00:02:02,369

brief overview there's two main methods

47

00:02:06,529 --> 00:02:04,799

one is to use infrared spectroscopy so

48

00:02:10,760 --> 00:02:06,539

using something like the Keck telescope

49

00:02:13,730 --> 00:02:10,770

here and this is optical light so we use

50

00:02:17,120 --> 00:02:13,740

mirrors and cameras and this is looking

51
00:02:18,740 --> 00:02:17,130
at vibrations of molecules all right the

52
00:02:19,309 --> 00:02:18,750
other option which is what I'm going to

53
00:02:20,989 --> 00:02:19,319
talk about

54
00:02:22,929 --> 00:02:20,999
the way most molecules are detected is

55
00:02:25,910 --> 00:02:22,939
rotational spectroscopy so that's

56
00:02:27,440 --> 00:02:25,920
predominantly done in the radio or the

57
00:02:29,780 --> 00:02:27,450
microwave or sub millimeter so that's

58
00:02:33,259 --> 00:02:29,790
using electronics so use oscillators

59
00:02:35,750 --> 00:02:33,269
generate frequencies of light on that

60
00:02:37,849 --> 00:02:35,760
time scale and you use radio telescopes

61
00:02:39,770 --> 00:02:37,859
this is one from the now-defunct

62
00:02:43,069 --> 00:02:39,780
combined array for research and

63
00:02:45,879 --> 00:02:43,079

millimeter wave astronomy to detect

64

00:02:49,250 --> 00:02:45,889

rotational transitions of the molecules

65

00:02:51,020 --> 00:02:49,260

so how does that work well if you want

66

00:02:52,250 --> 00:02:51,030

to detect a molecule in space first you

67

00:02:54,319 --> 00:02:52,260

have to understand what you're looking

68

00:02:55,909 --> 00:02:54,329

for so you go into the lab say for

69

00:02:57,349 --> 00:02:55,919

carbon monoxide here one of the most

70

00:02:59,839 --> 00:02:57,359

prevalent molecules in space and you

71

00:03:03,110 --> 00:02:59,849

take the spectrum this infrared spectra

72

00:03:05,149 --> 00:03:03,120

carbon dioxide collected in the lab you

73

00:03:07,250 --> 00:03:05,159

go to your telescope you collect the

74

00:03:10,099 --> 00:03:07,260

spectrum of the exact same frequency

75

00:03:12,589 --> 00:03:10,109

region in space and then you compare all

76

00:03:13,970 --> 00:03:12,599

right and so if you're a Praetorian

77

00:03:15,349 --> 00:03:13,980

spectrum in your infrared spectrum of

78

00:03:17,959 --> 00:03:15,359

the space match up then you've detected

79

00:03:21,199 --> 00:03:17,969

the molecule now there are a couple

80

00:03:23,030 --> 00:03:21,209

constraints to this if I have this

81

00:03:25,789 --> 00:03:23,040

laboratory spectrum I have this large

82

00:03:27,289 --> 00:03:25,799

peak that was measured there and say I

83

00:03:29,420 --> 00:03:27,299

went out in space and I measured it in

84

00:03:31,520 --> 00:03:29,430

that peak was missing that's a little

85

00:03:33,289 --> 00:03:31,530

concerning you can't just turn Peaks on

86

00:03:34,999 --> 00:03:33,299

and off these are frequencies that are

87

00:03:37,460 --> 00:03:35,009

intrinsic to the molecule so if you're

88

00:03:39,080 --> 00:03:37,470

missing something that quantum mechanics

89

00:03:41,809 --> 00:03:39,090

and your experiment says should be there

90

00:03:43,249 --> 00:03:41,819

then something is going on and you don't

91

00:03:45,080 --> 00:03:43,259

actually have a detection of this

92

00:03:47,059 --> 00:03:45,090

molecule it's an incidental transition

93

00:03:49,280 --> 00:03:47,069

from something else right this is not

94

00:03:50,839 --> 00:03:49,290

just isolated CO and there you see those

95

00:03:53,119 --> 00:03:50,849

Peaks from other molecules there that

96

00:03:54,170 --> 00:03:53,129

could be interfering so that's that's

97

00:03:55,670 --> 00:03:54,180

the most important thing to remember

98

00:03:57,199 --> 00:03:55,680

going forwards you have to have every

99

00:03:58,699 --> 00:03:57,209

line that you measure in the lab of a

100

00:04:02,030 --> 00:03:58,709

preacher full intensity show up in your

101

00:04:06,170 --> 00:04:02,040

spectrum from space so here's

102

00:04:08,149 --> 00:04:06,180

carbodiimide carbodiimide it's actually

103

00:04:09,530 --> 00:04:08,159

a tautomer of cyanamid here this

104

00:04:13,459 --> 00:04:09,540

molecule is detected in the interstellar

105

00:04:14,869 --> 00:04:13,469

medium in 1975 so you might say well why

106

00:04:17,770 --> 00:04:14,879

didn't people just go look for carbon

107

00:04:20,390 --> 00:04:17,780

diamont and the problem is that this

108

00:04:22,009 --> 00:04:20,400

tautomer is for kcals per mole higher

109

00:04:24,080 --> 00:04:22,019

and energy which doesn't sound much to a

110

00:04:27,860 --> 00:04:24,090

chemist but in space where the

111

00:04:29,659 --> 00:04:27,870

temperatures are cold it's not actually

112

00:04:31,760 --> 00:04:29,669

much of it so at room temperature here

113

00:04:32,430 --> 00:04:31,770

about 1% of a bottle would be covered i

114

00:04:33,720 --> 00:04:32,440

omit but in

115

00:04:38,460 --> 00:04:33,730

space where we're looking at

116

00:04:40,920 --> 00:04:38,470

temperatures of a much smaller so 10k or

117

00:04:43,860 --> 00:04:40,930

50k that that drops to a tenth of a

118

00:04:45,810 --> 00:04:43,870

percent or 100th of a percent but about

119

00:04:49,200 --> 00:04:45,820

ten years ago some folks said well if

120

00:04:51,450 --> 00:04:49,210

you put cyanamid in water ice and as we

121

00:04:52,560 --> 00:04:51,460

heard from Brandon water ices the most

122

00:04:54,120 --> 00:04:52,570

predominant ice in the interstellar

123

00:04:55,860 --> 00:04:54,130

medium you can actually get an

124

00:04:58,620 --> 00:04:55,870

enhancement of this carbon diamond

125

00:05:01,710 --> 00:04:58,630

something like four percent or thirteen

126
00:05:03,810 --> 00:05:01,720
percent of the cyanamid abundance all of

127
00:05:07,500 --> 00:05:03,820
a sudden that's actually a detectable

128
00:05:11,910 --> 00:05:07,510
abundance using radio astronomy so we

129
00:05:14,430 --> 00:05:11,920
went and took a look we looked in the

130
00:05:16,920 --> 00:05:14,440
center of our galaxy in a region called

131
00:05:18,480 --> 00:05:16,930
Sagittarius b2n this is where almost all

132
00:05:21,720 --> 00:05:18,490
of the new molecular detection to date

133
00:05:23,880 --> 00:05:21,730
have been made so it's an incredibly

134
00:05:26,520 --> 00:05:23,890
chemically rich source and we actually

135
00:05:28,220 --> 00:05:26,530
already had radio Spectre taken towards

136
00:05:30,930 --> 00:05:28,230
that source so this is part of the

137
00:05:33,930 --> 00:05:30,940
prebiotic interstellar molecular survey

138
00:05:36,420 --> 00:05:33,940

and we just took a broad frequency scan

139

00:05:38,810 --> 00:05:36,430

from about 300 megahertz up to 50

140

00:05:41,220 --> 00:05:38,820

gigahertz covered everything at once and

141

00:05:43,050 --> 00:05:41,230

we can say well where do the laboratory

142

00:05:45,360 --> 00:05:43,060

data say that carbon diamond should be

143

00:05:46,920 --> 00:05:45,370

found and here's the red line so we

144

00:05:48,330 --> 00:05:46,930

don't have coverage here at 16 gigahertz

145

00:05:50,190 --> 00:05:48,340

unfortunately but everywhere else

146

00:05:52,140 --> 00:05:50,200

including these down here at four

147

00:05:53,900 --> 00:05:52,150

there's a little black dot there we have

148

00:05:56,130 --> 00:05:53,910

some spectra so we can go and compare

149

00:05:58,890 --> 00:05:56,140

this is a cartoon of what we would

150

00:06:02,730 --> 00:05:58,900

expect to see the most intense lines up

151
00:06:03,900 --> 00:06:02,740
at 45 as we go up in frequency so we

152
00:06:07,110 --> 00:06:03,910
step through and see what our

153
00:06:09,510 --> 00:06:07,120
observational spectra show us so 4

154
00:06:11,670 --> 00:06:09,520
gigahertz we have two lines just like we

155
00:06:14,159 --> 00:06:11,680
would expect to see 16 gigahertz we

156
00:06:15,900 --> 00:06:14,169
don't have coverage for 25 gigahertz we

157
00:06:17,850 --> 00:06:15,910
have a line here this is another

158
00:06:20,610 --> 00:06:17,860
interfering transition of methanol so

159
00:06:22,470 --> 00:06:20,620
that's hiding our line there and at

160
00:06:24,090 --> 00:06:22,480
forty five gigahertz we have a line

161
00:06:26,790 --> 00:06:24,100
right there and this one we don't have

162
00:06:28,170 --> 00:06:26,800
coverage for but at 36 gigahertz

163
00:06:29,970 --> 00:06:28,180

remember that was going to be the second

164

00:06:31,770 --> 00:06:29,980

most intense transition set of

165

00:06:34,980 --> 00:06:31,780

transitions in the line there's

166

00:06:38,010 --> 00:06:34,990

absolutely nothing here it's just dead

167

00:06:39,450 --> 00:06:38,020

noise in the middle so just like not

168

00:06:41,219 --> 00:06:39,460

having one of those transitions

169

00:06:42,960 --> 00:06:41,229

recovered monoxide now we have a problem

170

00:06:46,260 --> 00:06:42,970

slab data say it should be there and the

171

00:06:48,690 --> 00:06:46,270

observational data don't see it there

172

00:06:50,910 --> 00:06:48,700

these are really strong and that one's

173

00:06:52,920 --> 00:06:50,920

pretty big and this one's not negligible

174

00:06:54,210 --> 00:06:52,930

so we were wondering exactly what was

175

00:06:55,800 --> 00:06:54,220

going on here and whether or not

176
00:06:59,070 --> 00:06:55,810
something was happening that we weren't

177
00:07:01,040 --> 00:06:59,080
quite understanding and and to give you

178
00:07:03,870 --> 00:07:01,050
an answer for that we have to go do a

179
00:07:07,050 --> 00:07:03,880
that's what we expected a brief review

180
00:07:08,970 --> 00:07:07,060
of laser theory or in this case maser

181
00:07:11,220 --> 00:07:08,980
the microwave equivalent of a laser ah

182
00:07:14,310 --> 00:07:11,230
so if you can imagine a four level

183
00:07:16,140 --> 00:07:14,320
energy system for your molecule with

184
00:07:18,780 --> 00:07:16,150
fast transitions between three of them

185
00:07:20,520 --> 00:07:18,790
and at a very slow transition here you

186
00:07:22,020 --> 00:07:20,530
just put some molecules in here like

187
00:07:24,360 --> 00:07:22,030
marbles and let them flow around the

188
00:07:26,610 --> 00:07:24,370

system as I'd like to do absorbing and

189

00:07:28,140 --> 00:07:26,620

emitting energy those go really fast and

190

00:07:30,510 --> 00:07:28,150

eventually you just build up a large

191

00:07:33,690 --> 00:07:30,520

population up here in III that's waiting

192

00:07:36,180 --> 00:07:33,700

to undergo this very slow transition now

193

00:07:37,980 --> 00:07:36,190

when one of them goes it stimulates all

194

00:07:39,360 --> 00:07:37,990

of them to go at the same time and so

195

00:07:41,550 --> 00:07:39,370

you get a coherent emission of radiation

196

00:07:43,650 --> 00:07:41,560

much more intense than you would expect

197

00:07:46,770 --> 00:07:43,660

otherwise from just one molecule going

198

00:07:49,440 --> 00:07:46,780

at a time so a laser pointer works and

199

00:07:52,710 --> 00:07:49,450

that's the way that the transitions that

200

00:07:54,240 --> 00:07:52,720

we're going to look at now might work so

201
00:07:55,950 --> 00:07:54,250
if we go and look at the energy level

202
00:07:58,680 --> 00:07:55,960
diagram for carbodiimide it's more

203
00:08:00,930 --> 00:07:58,690
complicated but we can step through it

204
00:08:03,330 --> 00:08:00,940
the same way so these are the two energy

205
00:08:07,140 --> 00:08:03,340
levels involved in the 4 gigahertz

206
00:08:09,180 --> 00:08:07,150
transitions and there's fast transitions

207
00:08:11,220 --> 00:08:09,190
out of the ground state as fast

208
00:08:13,320 --> 00:08:11,230
transitions into the excited state and

209
00:08:15,420 --> 00:08:13,330
there's a slow transition between them

210
00:08:17,240 --> 00:08:15,430
so you can see it's very simple here to

211
00:08:19,470 --> 00:08:17,250
build up a population inversion up

212
00:08:21,840 --> 00:08:19,480
piling up in this upper excited state

213
00:08:25,020 --> 00:08:21,850

and then undergoing amazing transition

214

00:08:26,840 --> 00:08:25,030

here amplifying the the intensity of

215

00:08:29,790 --> 00:08:26,850

that transition in our observed spectra

216

00:08:33,300 --> 00:08:29,800

this holds for the 25 gigahertz and the

217

00:08:35,070 --> 00:08:33,310

45 gigahertz lines as well if you go to

218

00:08:37,530 --> 00:08:35,080

the 36 gigahertz lines which we don't

219

00:08:40,230 --> 00:08:37,540

see again here's the transitions

220

00:08:42,120 --> 00:08:40,240

involved we have fast transitions into

221

00:08:43,490 --> 00:08:42,130

the upper state fast transitions out of

222

00:08:46,020 --> 00:08:43,500

the ground state and a slow transition

223

00:08:48,270 --> 00:08:46,030

between them so that's initially

224

00:08:49,650 --> 00:08:48,280

concerning it should be amazing to but

225

00:08:51,480 --> 00:08:49,660

because the energy level structure is

226

00:08:53,460 --> 00:08:51,490

slightly different there's also a fast

227

00:08:55,890 --> 00:08:53,470

transition out of this upper state down

228

00:08:57,600 --> 00:08:55,900

to another lower one so that means you

229

00:08:59,010 --> 00:08:57,610

can't build up any population up here

230

00:09:00,040 --> 00:08:59,020

because while it's waiting the undergo

231

00:09:01,930 --> 00:09:00,050

this it says screw that

232

00:09:04,780 --> 00:09:01,940

I'm going to go down here instead and it

233

00:09:07,120 --> 00:09:04,790

just piles down really fast so we won't

234

00:09:08,949 --> 00:09:07,130

see any enhancement in amazing emission

235

00:09:11,860 --> 00:09:08,959

there so that line shouldn't be any

236

00:09:13,900 --> 00:09:11,870

brighter than it would normally be so if

237

00:09:16,360 --> 00:09:13,910

you go back take a look at our spectra

238

00:09:18,910 --> 00:09:16,370

once again is the 4 gigahertz 25

239

00:09:21,430 --> 00:09:18,920

gigahertz 36 and 45 I haven't shown the

240

00:09:23,680 --> 00:09:21,440

other corresponding ones down here these

241

00:09:27,160 --> 00:09:23,690

four are these three can undergo amazing

242

00:09:29,079 --> 00:09:27,170

so you see the lines there that's the

243

00:09:31,090 --> 00:09:29,089

one that can't undergo amazing so we

244

00:09:34,210 --> 00:09:31,100

don't see any line there now what this

245

00:09:35,800 --> 00:09:34,220

means is that this population if it

246

00:09:39,069 --> 00:09:35,810

weren't amazing wouldn't be detectable

247

00:09:41,170 --> 00:09:39,079

at all right is everything was happening

248

00:09:42,670 --> 00:09:41,180

normally this would be the second

249

00:09:44,710 --> 00:09:42,680

brightest transition in the spectrum

250

00:09:48,069 --> 00:09:44,720

that means that we wouldn't see these at

251

00:09:50,019 --> 00:09:48,079

all ah this is very little carbon

252

00:09:52,120 --> 00:09:50,029

diamond out there it's not very much of

253

00:09:53,710 --> 00:09:52,130

it but we were able to detect it because

254

00:09:55,540 --> 00:09:53,720

it's undergoing these amazing

255

00:09:57,430 --> 00:09:55,550

transitions and this way we can get

256

00:09:59,319 --> 00:09:57,440

around the rule of having to see every

257

00:10:00,970 --> 00:09:59,329

transition as measured in the lab by

258

00:10:03,160 --> 00:10:00,980

explaining with physics why some of them

259

00:10:06,370 --> 00:10:03,170

are brighter than others in this

260

00:10:09,250 --> 00:10:06,380

specific environment so we published

261

00:10:10,510 --> 00:10:09,260

this a few years ago and hopefully

262

00:10:12,760 --> 00:10:10,520

somebody will figure out a way to make

263

00:10:15,100 --> 00:10:12,770

nucleobase out of it in the lab now that

264

00:10:17,350 --> 00:10:15,110

we have it there um so I think I've

265

00:10:24,850 --> 00:10:17,360

occupied almost enough of our time ah

266

00:10:31,060 --> 00:10:24,860

thank you we can take a question before

267

00:10:35,769 --> 00:10:31,070

we transition thank you super chair so

268

00:10:38,440 --> 00:10:35,779

that was amazing so how come you don't

269

00:10:41,590 --> 00:10:38,450

get these in the lab to get the amazing

270

00:10:42,910 --> 00:10:41,600

transition yeah you can but you have to

271

00:10:45,819 --> 00:10:42,920

be careful about the way that you

272

00:10:47,290 --> 00:10:45,829

excited um so to get the population to

273

00:10:49,389 --> 00:10:47,300

that upper state the way it works in

274

00:10:51,579 --> 00:10:49,399

space is that at least in this

275

00:10:54,340 --> 00:10:51,589

environment we're not certain either you

276

00:10:55,600 --> 00:10:54,350

RAM molecules into one another and use

277

00:10:58,720 --> 00:10:55,610

the energy from that collision to

278

00:11:01,300 --> 00:10:58,730

populate the upper state or you pump

279

00:11:02,650 --> 00:11:01,310

higher energy states with radiation from

280

00:11:04,780 --> 00:11:02,660

further in the electromagnetic spectrum

281

00:11:07,780 --> 00:11:04,790

far infrared radiation unfortunately

282

00:11:10,449 --> 00:11:07,790

this region has both as a possibility so

283

00:11:12,170 --> 00:11:10,459

we have observations in now actually to

284

00:11:13,970 --> 00:11:12,180

untangle which one's happening

285

00:11:15,079 --> 00:11:13,980

so you could do it in the lab you just

286

00:11:23,060 --> 00:11:15,089

have to make sure to provide one of

287

00:11:26,690 --> 00:11:23,070

those conditions so you said their gas

288

00:11:31,340 --> 00:11:26,700

phase reactions with this but you also

289

00:11:34,100 --> 00:11:31,350

said that it is primarily on ice so so

290

00:11:37,040 --> 00:11:34,110

what happens is that carbon diamond will

291

00:11:38,990 --> 00:11:37,050

form from cyanamid in the ice and then

292

00:11:40,850 --> 00:11:39,000

get liberated into the gas phase once

293

00:11:42,829 --> 00:11:40,860

it's in the gas phase it can't get over

294

00:11:59,210 --> 00:11:42,839

the barrier to go back to cyanamid so

295

00:12:01,070 --> 00:11:59,220

it's trapped okay all right I has this

296

00:12:03,110 --> 00:12:01,080

actually been found in a comet or

297

00:12:06,260 --> 00:12:03,120

meteorite yet actually I don't know no

298

00:12:08,990 --> 00:12:06,270

it hasn't and what's the barrier for

299

00:12:12,740 --> 00:12:09,000

inversion back and forth it's several

300

00:12:14,600 --> 00:12:12,750

hundred wave numbers in the gas phase

301

00:12:18,800 --> 00:12:14,610

once you put it in that and the ice the

302

00:12:25,880 --> 00:12:18,810

barrier drops to zero is there another

303

00:12:28,220 --> 00:12:25,890

one real quick how can people say the

304

00:12:30,800 --> 00:12:28,230

reaction is barrier diseases just by

305

00:12:32,570 --> 00:12:30,810

computational calculation yeah all the

306

00:12:37,400 --> 00:12:32,580

all of the theories of ours is