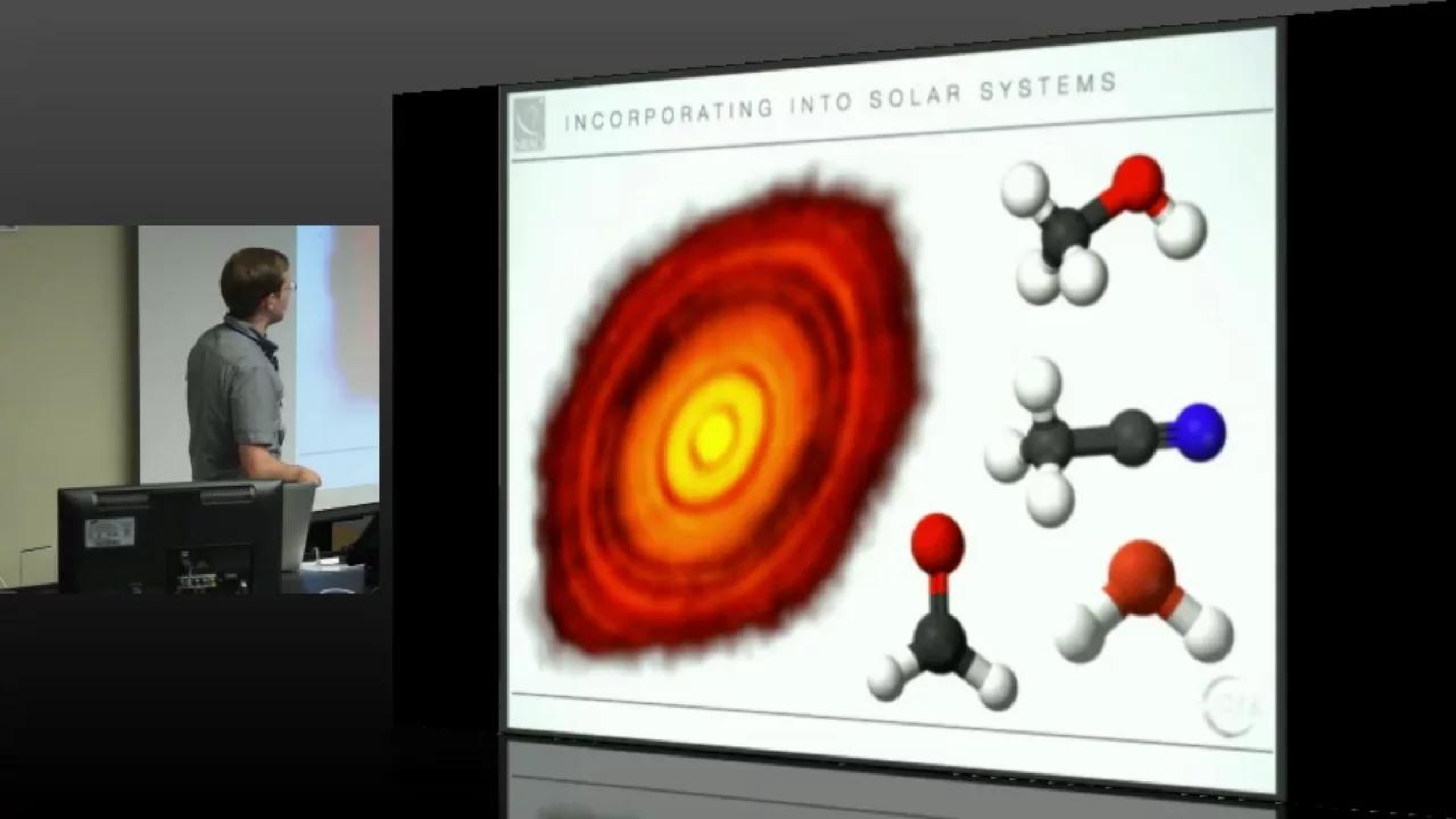
INCORPORATING INTO SOLAR SYSTEMS

1
00:00:09,230 --> 00:00:08,120
so hi I'm Brett McGuire I'm going to be

2
00:00:13,970 --> 00:00:09,240
the session chair this morning for

3
00:00:15,410 --> 00:00:13,980
astrochemistry and for exoplanets so

4
00:00:16,880 --> 00:00:15,420
since I thought we'd probably be

5
00:00:21,140 --> 00:00:16,890
starting a little bit late I put

6
00:00:22,550 --> 00:00:21,150
together a kind of short warm-up talk

7
00:00:25,009 --> 00:00:22,560
here and it's just going to touch on a

8
00:00:26,960 --> 00:00:25,019
few different topics in astrochemistry

9
00:00:29,000 --> 00:00:26,970
and in exoplanets it's not meant to be

10
00:00:30,140 --> 00:00:29,010
comprehensive you're going to get the

11
00:00:32,420 --> 00:00:30,150
details and the people that are giving

12
00:00:34,340 --> 00:00:32,430
the talks today and it may not actually

13
00:00:36,229 --> 00:00:34,350

talk about everything that are going to

14
00:00:38,600 --> 00:00:36,239
be in the talks today it's just supposed

15
00:00:41,420 --> 00:00:38,610
to get you thinking about the topic that

16
00:00:42,799 --> 00:00:41,430
we're going to be discussing I don't

17
00:00:45,049 --> 00:00:42,809
really plan to stop for questions at the

18
00:00:46,639 --> 00:00:45,059
end but that doesn't mean that you

19
00:00:48,200 --> 00:00:46,649
shouldn't stop to either ask questions

20
00:00:50,510 --> 00:00:48,210
or more importantly give commentary

21
00:00:52,189 --> 00:00:50,520
along the way if there's any experts in

22
00:00:55,970 --> 00:00:52,199
the room that want to add something to a

23
00:00:58,670 --> 00:00:55,980
particular topic that would be fine so

24
00:01:00,830 --> 00:00:58,680
just getting started here in the

25
00:01:03,080 --> 00:01:00,840
beginning there was hydrogen and helium

26
00:01:06,200 --> 00:01:03,090
from the big bang and a smattering of a

27
00:01:08,840 --> 00:01:06,210
few other less interesting things like

28
00:01:10,850 --> 00:01:08,850
boron and lithium that hydrogen helium

29
00:01:13,580 --> 00:01:10,860
formed into the first stars and then

30
00:01:16,910 --> 00:01:13,590
these stars eventually spat out more

31
00:01:20,090 --> 00:01:16,920
complicated things so here's a periodic

32
00:01:21,320 --> 00:01:20,100
table I got off of Wikipedia that tells

33
00:01:22,880 --> 00:01:21,330
you it's actually really nicely

34
00:01:25,280 --> 00:01:22,890
color-coded right the different things

35
00:01:27,469 --> 00:01:25,290
that came out of the Big Bang things

36
00:01:29,780 --> 00:01:27,479
that are produced in large stars or have

37
00:01:31,399 --> 00:01:29,790
to be made in supernovae and then of

38
00:01:35,090 --> 00:01:31,409

course the the fun things down here that

39
00:01:36,830 --> 00:01:35,100
we make in labs so we really had to go

40
00:01:38,090 --> 00:01:36,840
through a first generation of processing

41
00:01:41,380 --> 00:01:38,100
and stars to get anything more

42
00:01:44,539 --> 00:01:41,390
complicated than hydrogen and helium

43
00:01:46,580 --> 00:01:44,549
eventually we started looking for things

44
00:01:50,420 --> 00:01:46,590
even more complicated than that up until

45
00:01:55,160 --> 00:01:50,430
the 1930s so I guess this reference here

46
00:01:57,980 --> 00:01:55,170
is 1937 the prevailing wisdom was that

47
00:02:01,670 --> 00:01:57,990
there was nothing other than atoms and

48
00:02:03,260 --> 00:02:01,680
their ions in space because it was just

49
00:02:05,149 --> 00:02:03,270
going to be too harsh there's too much

50
00:02:06,889 --> 00:02:05,159
UV radiation there's too much high

51
00:02:10,279 --> 00:02:06,899
energy stuff coming out of these stars

52
00:02:11,960 --> 00:02:10,289
for molecules to exist and people that

53
00:02:13,590 --> 00:02:11,970
we're looking for molecules were kind of

54
00:02:17,400 --> 00:02:13,600
shunned to the edges

55
00:02:19,410 --> 00:02:17,410
of of the field so there were some folks

56
00:02:21,420 --> 00:02:19,420
that said screw you we're going to look

57
00:02:24,080 --> 00:02:21,430
for them anyways so this is a spectrum

58
00:02:28,500 --> 00:02:24,090
taken with them out wilson observatory I

59
00:02:34,320 --> 00:02:28,510
there of CH the first molecule detected

60
00:02:36,150 --> 00:02:34,330
in space so the spectrums from 1941 1937

61
00:02:37,290 --> 00:02:36,160
was when the assignments were made but

62
00:02:39,810 --> 00:02:37,300
there weren't any pretty spectra in the

63
00:02:44,250 --> 00:02:39,820

papers so I couldn't show you those and

64
00:02:45,990 --> 00:02:44,260
then so this timeline there over the the

65
00:02:48,630 --> 00:02:46,000
next few years they picked up a few more

66
00:02:51,600 --> 00:02:48,640
some very simple ones cnc h plus and OH

67
00:02:55,380 --> 00:02:51,610
h and then astrochemistry as a field was

68
00:02:58,080 --> 00:02:55,390
really born here between 1963 and 1980

69
00:03:01,620 --> 00:02:58,090
this is when radio astronomy came to the

70
00:03:03,600 --> 00:03:01,630
forefront all of these small molecules

71
00:03:06,030 --> 00:03:03,610
here were being detected primarily in

72
00:03:09,300 --> 00:03:06,040
electronic transitions using visible and

73
00:03:10,950 --> 00:03:09,310
infrared telescopes it's kind of a

74
00:03:12,030 --> 00:03:10,960
challenging way to find molecules

75
00:03:13,860 --> 00:03:12,040
because you have to have a background

76
00:03:15,720 --> 00:03:13,870
light source to absorb against so you

77
00:03:17,310 --> 00:03:15,730
have to have molecules between you and

78
00:03:19,620 --> 00:03:17,320
the star and you have to know what that

79
00:03:21,420 --> 00:03:19,630
star spectrum looks like so that you can

80
00:03:23,490 --> 00:03:21,430
register what those dips in the spectra

81
00:03:25,110 --> 00:03:23,500
are with radio telescopes you can look

82
00:03:27,420 --> 00:03:25,120
for the emission for molecules that are

83
00:03:29,940 --> 00:03:27,430
rotating and tumbling over in space and

84
00:03:31,770 --> 00:03:29,950
I have a very unique spectra a unique

85
00:03:33,570 --> 00:03:31,780
spectra not a very unique spectra so

86
00:03:35,130 --> 00:03:33,580
there were 59 more molecules detected in

87
00:03:37,170 --> 00:03:35,140
this space and then since then we've

88
00:03:39,660 --> 00:03:37,180

we've gotten I put this slide together

89
00:03:42,420 --> 00:03:39,670
two years ago so 110 so now we're up to

90
00:03:45,180 --> 00:03:42,430
this number should be like 120 or 130

91
00:03:48,990 --> 00:03:45,190
where we're nearing the 200 mark for

92
00:03:51,240 --> 00:03:49,000
molecules detected in space so what is

93
00:03:53,160 --> 00:03:51,250
astrochemistry then well I call it the

94
00:03:56,070 --> 00:03:53,170
study of molecules in space where they

95
00:03:59,160 --> 00:03:56,080
are how they got there and what they are

96
00:04:01,050 --> 00:03:59,170
doing all right so chemistry does occur

97
00:04:02,820 --> 00:04:01,060
in space it's very different from the

98
00:04:05,250 --> 00:04:02,830
chemistry that occurs here on earth

99
00:04:08,370 --> 00:04:05,260
because you're in a vacuum you're at low

100
00:04:10,410 --> 00:04:08,380
temperatures most of the time and the

101
00:04:12,510 --> 00:04:10,420
time between collisions for molecules is

102
00:04:15,000 --> 00:04:12,520
very small so you can get exciting

103
00:04:17,520 --> 00:04:15,010
energetic exotic species that don't last

104
00:04:19,770 --> 00:04:17,530
for any amount of time on earth that

105
00:04:20,849 --> 00:04:19,780
have very long lifetimes in space so

106
00:04:24,420 --> 00:04:20,859
they can hang out and do interesting

107
00:04:26,500 --> 00:04:24,430
things so how do you build up some

108
00:04:30,490 --> 00:04:26,510
molecular complexity in the is M

109
00:04:32,500 --> 00:04:30,500
for a while I on molecule chemistry will

110
00:04:34,330 --> 00:04:32,510
dominate and what that means is that you

111
00:04:37,150 --> 00:04:34,340
have one neutral molecule and one eye on

112
00:04:38,770 --> 00:04:37,160
right space is a very good vacuum so

113
00:04:41,170 --> 00:04:38,780

it's very hard for molecules to find

114
00:04:43,300 --> 00:04:41,180
each other to react if you have one

115
00:04:44,950 --> 00:04:43,310
that's charged that can induce just a

116
00:04:46,900 --> 00:04:44,960
little bit of a dipole and the other

117
00:04:48,490 --> 00:04:46,910
molecule and pull an attractive force

118
00:04:51,070 --> 00:04:48,500
together so that they're more likely to

119
00:04:53,230 --> 00:04:51,080
find each other and react all right i am

120
00:04:55,030 --> 00:04:53,240
molecule reactions also have the benefit

121
00:04:56,920 --> 00:04:55,040
of being largely exothermic and

122
00:04:58,750 --> 00:04:56,930
kinetically favorable so they go fast

123
00:05:00,550 --> 00:04:58,760
and they release energy they don't take

124
00:05:03,520 --> 00:05:00,560
energy input so it's very good for the

125
00:05:06,280 --> 00:05:03,530
cold vacuum regions of space so you can

126
00:05:08,050 --> 00:05:06,290
see here you start with H 3 plus alright

127
00:05:10,000 --> 00:05:08,060
and then you can just start using H 3

128
00:05:12,280 --> 00:05:10,010
plus to transfer charge all the way up

129
00:05:15,070 --> 00:05:12,290
the line now this can build up

130
00:05:18,130 --> 00:05:15,080
long-chain hydrocarbons up to about h c

131
00:05:20,140 --> 00:05:18,140
9n all right so that's just a long

132
00:05:22,750 --> 00:05:20,150
linear chain molecules and it can do

133
00:05:25,120 --> 00:05:22,760
some organic chemistry you can get up to

134
00:05:26,830 --> 00:05:25,130
about methanol efficiently in the gas

135
00:05:28,930 --> 00:05:26,840
phase but at that point these ion

136
00:05:31,330 --> 00:05:28,940
molecule reactions drop off and you

137
00:05:33,850 --> 00:05:31,340
really can't make anything more complex

138
00:05:37,300 --> 00:05:33,860

than that what you have to do then is

139
00:05:38,770 --> 00:05:37,310
turn to these ice surfaces all right so

140
00:05:40,420 --> 00:05:38,780
you take a dust screen you freeze out

141
00:05:42,430 --> 00:05:40,430
molecules onto the surface and now

142
00:05:44,830 --> 00:05:42,440
you've concentrated all of your rare

143
00:05:46,720 --> 00:05:44,840
reactants into one place and you have a

144
00:05:48,220 --> 00:05:46,730
third body that grain surface to take

145
00:05:51,370 --> 00:05:48,230
away some of the energy so you can start

146
00:05:53,590 --> 00:05:51,380
piecing together more complex things you

147
00:05:55,210 --> 00:05:53,600
take methanol you bring a cosmic ray in

148
00:05:57,610 --> 00:05:55,220
you break it up into a methyl under an o

149
00:05:59,320 --> 00:05:57,620
H and now you just start clicking blocks

150
00:06:01,630 --> 00:05:59,330
together like legos to build up more

151
00:06:03,550 --> 00:06:01,640
complicated structures and then these

152
00:06:08,290 --> 00:06:03,560
Isis can be desorbed into the gas phase

153
00:06:09,550 --> 00:06:08,300
and detected that way so astrochemistry

154
00:06:10,930 --> 00:06:09,560
you're going to hear about some

155
00:06:12,730 --> 00:06:10,940
different talks today from the different

156
00:06:13,960 --> 00:06:12,740
disciplines is laboratory astrophysics

157
00:06:15,550 --> 00:06:13,970
these are the people that measure the

158
00:06:17,080 --> 00:06:15,560
spectra of molecules in the lab measure

159
00:06:19,450 --> 00:06:17,090
how they react with one another the

160
00:06:20,950 --> 00:06:19,460
rates and the thermodynamics there's the

161
00:06:22,600 --> 00:06:20,960
observational astronomers that go out

162
00:06:24,700 --> 00:06:22,610
and look for the molecules tell us which

163
00:06:27,910 --> 00:06:24,710

ones are there how many are there how

164
00:06:28,900 --> 00:06:27,920
excited are they and then astro chemical

165
00:06:30,370 --> 00:06:28,910
modelers that try to take the

166
00:06:32,500 --> 00:06:30,380
information from both of these groups

167
00:06:34,330 --> 00:06:32,510
pieced them together and say well you

168
00:06:35,770 --> 00:06:34,340
have this soup of molecules what can you

169
00:06:36,650 --> 00:06:35,780
make next what does this tell us about

170
00:06:39,740 --> 00:06:36,660
the chemistry

171
00:06:41,590 --> 00:06:39,750
in the region so we're also going to

172
00:06:44,540 --> 00:06:41,600
talk about exoplanets today and

173
00:06:45,770 --> 00:06:44,550
molecules have been found in the

174
00:06:48,590 --> 00:06:45,780
birthplace of exoplanets these

175
00:06:50,300 --> 00:06:48,600
protoplanetary disks this is HL tau an

176
00:06:52,520 --> 00:06:50,310
image from oma that came out last year

177
00:06:54,230 --> 00:06:52,530
the most complex molecules seemed to

178
00:06:56,870 --> 00:06:54,240
date there is methanol just came out in

179
00:06:58,700 --> 00:06:56,880
a paper a couple months ago methyl

180
00:06:59,990 --> 00:06:58,710
cyanide was out earlier than that and

181
00:07:03,350 --> 00:07:00,000
we've also seen things like formaldehyde

182
00:07:04,670 --> 00:07:03,360
and water can't see anything more

183
00:07:05,690 --> 00:07:04,680
complicated in that yet just because

184
00:07:07,790 --> 00:07:05,700
there's not a lot of those molecules

185
00:07:10,160 --> 00:07:07,800
there they're very faint and hard to

186
00:07:13,220 --> 00:07:10,170
detect but the molecules still play an

187
00:07:16,160 --> 00:07:13,230
important role in these disks there was

188
00:07:18,170 --> 00:07:16,170

a paper out just about a month ago or so

189
00:07:20,090 --> 00:07:18,180
showing that if you take the small

190
00:07:22,360 --> 00:07:20,100
little dust grains that are coated in

191
00:07:24,800 --> 00:07:22,370
ice you can actually start

192
00:07:27,380 --> 00:07:24,810
conglomerating them together not as a

193
00:07:29,540 --> 00:07:27,390
large icy chunk like a comet but

194
00:07:31,190 --> 00:07:29,550
sintered like a sintered glass crucible

195
00:07:33,440 --> 00:07:31,200
so that they have little connecting

196
00:07:35,210 --> 00:07:33,450
bridges of Isis between them and this

197
00:07:38,060 --> 00:07:35,220
allows them to aggregate into larger and

198
00:07:39,740 --> 00:07:38,070
larger structures now this hasn't been

199
00:07:41,840 --> 00:07:39,750
proven yet this is a you know a

200
00:07:43,730 --> 00:07:41,850
theoretical paper modeling paper that

201
00:07:45,290 --> 00:07:43,740
came out but it's a very good theory for

202
00:07:49,610 --> 00:07:45,300
how you can overcome the barrier between

203
00:07:51,650 --> 00:07:49,620
small icy dust grains and rocks

204
00:07:56,150 --> 00:07:51,660
planetesimals that will chunk together

205
00:08:00,260 --> 00:07:56,160
to make these exoplanets so speaking of

206
00:08:02,510 --> 00:08:00,270
exoplanets this was as of two days ago

207
00:08:05,600 --> 00:08:02,520
when I went and got this pot from the

208
00:08:07,220 --> 00:08:05,610
exoplanet database Kepler one of the

209
00:08:08,900 --> 00:08:07,230
main observatories that's been

210
00:08:11,180 --> 00:08:08,910
contributing to the detection of

211
00:08:14,030 --> 00:08:11,190
exoplanets there are thousands of them

212
00:08:15,350 --> 00:08:14,040
here this is a plot of orbital period so

213
00:08:17,450 --> 00:08:15,360

how long it takes them to orbit their

214
00:08:20,000 --> 00:08:17,460
star and the mass of the planet and then

215
00:08:22,430 --> 00:08:20,010
this I just picked the size of the dot

216
00:08:24,440 --> 00:08:22,440
to give the size relative to the radius

217
00:08:26,690 --> 00:08:24,450
of the actual planet alright so we have

218
00:08:28,430 --> 00:08:26,700
a lot of these relatively large planets

219
00:08:31,010 --> 00:08:28,440
over here that are on Jupiter mass but

220
00:08:33,260 --> 00:08:31,020
we're starting to fill in the smaller

221
00:08:36,740 --> 00:08:33,270
mass more earth-like more earth-like

222
00:08:38,180 --> 00:08:36,750
radius planets just give a brief

223
00:08:41,000 --> 00:08:38,190
overview of a couple of different ways

224
00:08:42,620 --> 00:08:41,010
that these can be detected you know we

225
00:08:44,750 --> 00:08:42,630
can hope to do some direct imaging but

226
00:08:46,970 --> 00:08:44,760
it's kind of really really hard planets

227
00:08:48,920 --> 00:08:46,980
are not bright they're hard to see

228
00:08:49,759 --> 00:08:48,930
they're far away and they tend to be

229
00:08:52,819 --> 00:08:49,769
embedded in

230
00:08:56,479 --> 00:08:52,829
dust from that forming disk and it's

231
00:08:59,329 --> 00:08:56,489
really hard to see through a dusty dusty

232
00:09:02,210 --> 00:08:59,339
gas disk to look at these planets

233
00:09:04,489 --> 00:09:02,220
directly so we can play some tricks the

234
00:09:06,439 --> 00:09:04,499
one that is used as we'll see in a

235
00:09:08,419 --> 00:09:06,449
second another slide most commonly is

236
00:09:10,879 --> 00:09:08,429
this transit photometry so you just put

237
00:09:12,829 --> 00:09:10,889
the planet in front of a star and look

238
00:09:14,650 --> 00:09:12,839

for the dip as that planet blocks some

239
00:09:16,939 --> 00:09:14,660
of the light this is what Kepler does

240
00:09:19,129 --> 00:09:16,949
and it's really good at detecting

241
00:09:21,289 --> 00:09:19,139
planets that are relatively large or

242
00:09:23,660 --> 00:09:21,299
that are small but they have a small

243
00:09:25,340 --> 00:09:23,670
star so you can see the dip it that

244
00:09:27,079 --> 00:09:25,350
comes along with them the only downside

245
00:09:28,519 --> 00:09:27,089
to this is that if you have a planet

246
00:09:30,350 --> 00:09:28,529
that takes three years to orbit your

247
00:09:32,179 --> 00:09:30,360
star you only get one dip every three

248
00:09:33,859 --> 00:09:32,189
years so you have to get lucky and be

249
00:09:35,269 --> 00:09:33,869
observing it at that point and then if

250
00:09:37,249 --> 00:09:35,279
you want reproducibility you have to

251
00:09:40,189 --> 00:09:37,259
wait another three years this is really

252
00:09:41,539 --> 00:09:40,199
good for short period planets but it's a

253
00:09:44,090 --> 00:09:41,549
little harder for the longer ones but

254
00:09:46,699 --> 00:09:44,100
we're starting to see them and the last

255
00:09:49,009 --> 00:09:46,709
one that I'll mention is radial velocity

256
00:09:52,579 --> 00:09:49,019
measurements so this is where you take a

257
00:09:55,460 --> 00:09:52,589
star here that you're looking at and as

258
00:09:56,509 --> 00:09:55,470
it as it moves relative to the earth the

259
00:09:58,579 --> 00:09:56,519
light that we see from it is going to be

260
00:10:01,009 --> 00:09:58,589
Doppler shifted all right red and blue

261
00:10:02,840 --> 00:10:01,019
but it has a planet perturbing that

262
00:10:04,730 --> 00:10:02,850
movement a little bit that's going to

263
00:10:06,340 --> 00:10:04,740

perturb that Doppler shift that we see

264
00:10:09,919 --> 00:10:06,350
and you can pull out a planet's

265
00:10:12,439 --> 00:10:09,929
perturbation of its own host star by

266
00:10:16,249 --> 00:10:12,449
looking at changes in the Doppler shift

267
00:10:19,460 --> 00:10:16,259
and here's I think my last slide because

268
00:10:20,749 --> 00:10:19,470
I am right on time to be done just a

269
00:10:23,470 --> 00:10:20,759
graph of the different ways that these

270
00:10:25,759 --> 00:10:23,480
planets have been detected over the last

271
00:10:28,850 --> 00:10:25,769
decade and a half two decades there

272
00:10:30,289 --> 00:10:28,860
you'll see that this huge bump in the

273
00:10:31,819 --> 00:10:30,299
number that we've detected from transit

274
00:10:33,340 --> 00:10:31,829
photometry that's do pretty much

275
00:10:35,749 --> 00:10:33,350
exclusively to the Kepler telescope

276
00:10:38,539 --> 00:10:35,759
which has been out hunting planets for a

277
00:10:40,669 --> 00:10:38,549
very long time now close second well

278
00:10:41,840 --> 00:10:40,679
distant second I don't know is the

279
00:10:43,189 --> 00:10:41,850
radial velocity and then there's a

280
00:10:45,109 --> 00:10:43,199
little bit here for direct imaging and

281
00:10:47,869 --> 00:10:45,119
there's a few other I don't want to say

282
00:10:49,129 --> 00:10:47,879
niche but niche detection methods which

283
00:10:53,989 --> 00:10:49,139
maybe we'll hear about today and maybe

284
00:10:56,949 --> 00:10:53,999
we won't oh very last thing exoplanet

285
00:11:00,559 --> 00:10:56,959
atmospheres if you are doing transit

286
00:11:01,970 --> 00:11:00,569
photometry you are actually capable if

287
00:11:03,049 --> 00:11:01,980
you're lucky of getting an absorption

288
00:11:04,639 --> 00:11:03,059

spectrum of that

289
00:11:07,819 --> 00:11:04,649
planetary atmosphere as it passes in

290
00:11:09,919 --> 00:11:07,829
front of the star so here's one the red

291
00:11:12,889 --> 00:11:09,929
is a model black are the data points

292
00:11:15,649 --> 00:11:12,899
showing the absorption of CO CO 2 water

293
00:11:17,439 --> 00:11:15,659
in the intern exoplanet atmosphere as it

294
00:11:20,929 --> 00:11:17,449
transited in front of its host star

295
00:11:24,759 --> 00:11:20,939
presumably over many many many averages

296
00:11:26,929 --> 00:11:24,769
of that data I think that is it yes