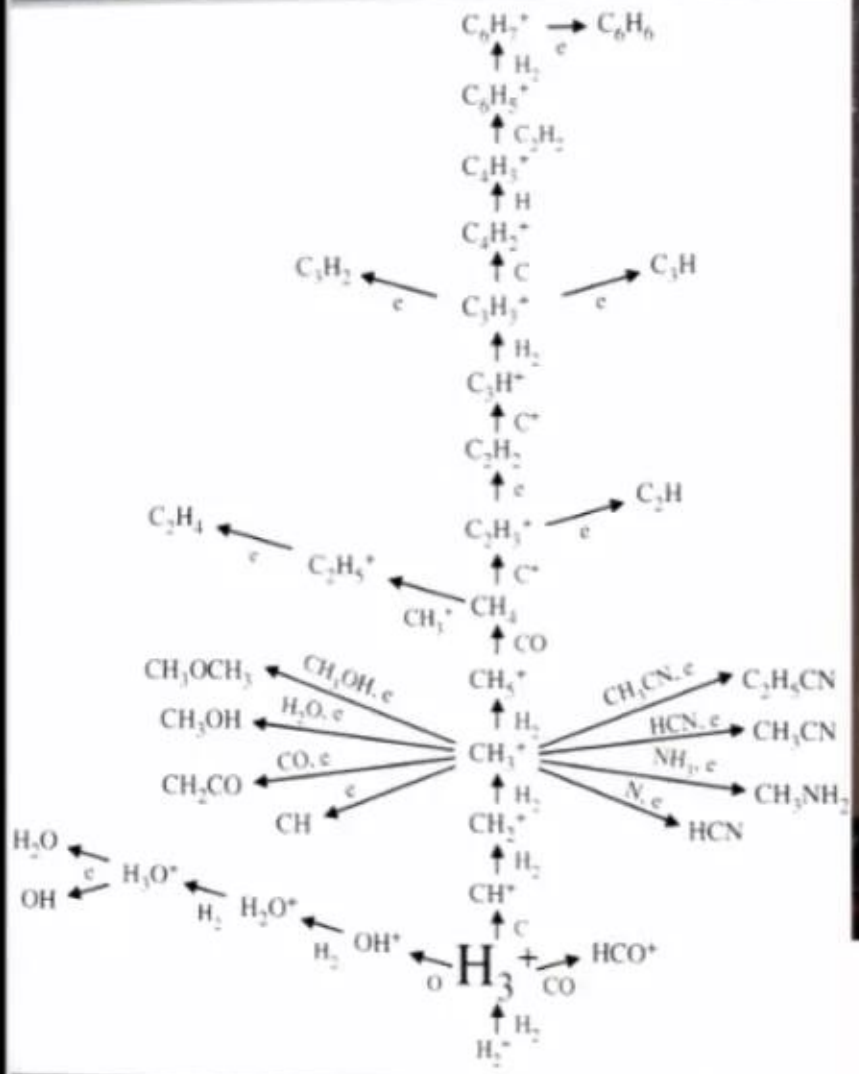
THE ISM IS A STRANGE PLACE



Phil. Trans. R. Soc. A (2006) 364, 2953–2963

Caltech

1
00:00:10,299 --> 00:00:08,170
good so yeah this is going to be a

2
00:00:11,529 --> 00:00:10,309
pretty big talk because we're going to

3
00:00:14,140 --> 00:00:11,539
try to cover everything from

4
00:00:16,299 --> 00:00:14,150
astrochemistry to emerging worlds in 12

5
00:00:17,890 --> 00:00:16,309
minutes so normally when I think of

6
00:00:19,599 --> 00:00:17,900
these two topics the sort of common

7
00:00:23,099 --> 00:00:19,609
theme is astronomy these are things we

8
00:00:30,609 --> 00:00:23,109
study with astronomy or astrophysics and

9
00:00:32,499 --> 00:00:30,619
now we wait yes all right so if you

10
00:00:34,770 --> 00:00:32,509
think about the circle of life a lot of

11
00:00:36,700 --> 00:00:34,780
biologists geologists and here but for

12
00:00:39,240 --> 00:00:36,710
astronomers the circle of life is

13
00:00:42,400 --> 00:00:39,250

something very different stars explode

14
00:00:44,710 --> 00:00:42,410
materials blasted out into the is M it

15
00:00:47,170 --> 00:00:44,720
then Cole messes again into gas clouds

16
00:00:49,660 --> 00:00:47,180
these clouds start to collapse you form

17
00:00:51,820 --> 00:00:49,670
a protostar and a disk around it this

18
00:00:54,460 --> 00:00:51,830
disk starts the segregate out you form

19
00:00:57,190 --> 00:00:54,470
distinct bodies comets meteors and

20
00:00:59,470 --> 00:00:57,200
obviously planets you deliver material

21
00:01:01,330 --> 00:00:59,480
to the planets and then you start to

22
00:01:03,640 --> 00:01:01,340
form habit of habitable worlds and

23
00:01:07,090 --> 00:01:03,650
eventually you get to life but this is a

24
00:01:08,770 --> 00:01:07,100
very big and complex topic so we're

25
00:01:11,320 --> 00:01:08,780
going to go through some of these stages

26
00:01:13,810 --> 00:01:11,330
one by one so the first one is the

27
00:01:16,600 --> 00:01:13,820
astronomers periodic table so this is

28
00:01:19,420 --> 00:01:16,610
scaled by the abundance so the bigger

29
00:01:21,610 --> 00:01:19,430
the square the more abundant it is so if

30
00:01:23,469 --> 00:01:21,620
you're an astronomer most of your world

31
00:01:25,540 --> 00:01:23,479
is hydrogen almost all of the universe

32
00:01:28,840 --> 00:01:25,550
is hydrogen there is a decent amount of

33
00:01:31,719 --> 00:01:28,850
helium and then the metals oxygen carbon

34
00:01:34,120 --> 00:01:31,729
nitrogen silicon iron make up a tiny

35
00:01:35,560 --> 00:01:34,130
fraction and then everything else so the

36
00:01:37,450 --> 00:01:35,570
interesting things like phosphorus that

37
00:01:40,330 --> 00:01:37,460
are required for life is this tiny

38
00:01:42,070 --> 00:01:40,340

square down here at the bottom oxygen

39
00:01:44,440 --> 00:01:42,080
and carbon or a factor of 10,000 down

40
00:01:47,680 --> 00:01:44,450
from hydrogen the metals are even

41
00:01:49,359 --> 00:01:47,690
further down and the dust and ice the

42
00:01:52,450 --> 00:01:49,369
solid parts of the universe are only

43
00:01:53,770 --> 00:01:52,460
about 1% of the observable mass so this

44
00:01:56,170 --> 00:01:53,780
is very different than what we're used

45
00:01:58,480 --> 00:01:56,180
to and it's actually a very strange

46
00:02:02,710 --> 00:01:58,490
place so most of the universe the

47
00:02:04,120 --> 00:02:02,720
diffuse is M is atomic so most of most

48
00:02:06,609 --> 00:02:04,130
of the matter is just hydrogen atoms

49
00:02:08,109 --> 00:02:06,619
that all of your carbon is ionized and

50
00:02:10,839 --> 00:02:08,119
there's a decent amount of electrons as

51
00:02:13,660 --> 00:02:10,849
you go to more dense and dense regions

52
00:02:15,010 --> 00:02:13,670
where the gas starts to shield itself

53
00:02:17,500 --> 00:02:15,020
and there's less dissociation you

54
00:02:19,270 --> 00:02:17,510
actually start to get neutral carbon and

55
00:02:22,510 --> 00:02:19,280
eventually you transition into

56
00:02:24,790 --> 00:02:22,520
to hetero diatomics actual molecules but

57
00:02:29,410 --> 00:02:24,800
it takes quite a while and this is

58
00:02:31,870 --> 00:02:29,420
actually most of the is M so the way the

59
00:02:33,850 --> 00:02:31,880
dust and gas sort of follows is it

60
00:02:36,400 --> 00:02:33,860
starts by coal messing into a dense

61
00:02:40,449 --> 00:02:36,410
cloud and then it'll start to collapse

62
00:02:42,520 --> 00:02:40,459
so this is about 10,000 au across so an

63
00:02:46,210 --> 00:02:42,530

au is the distance from the earth to the

64
00:02:48,820 --> 00:02:46,220
Sun so its enormous I this this is our

65
00:02:51,610 --> 00:02:48,830
start whoops this is our start point

66
00:02:54,220 --> 00:02:51,620
right here after about ten thousand to a

67
00:02:55,810 --> 00:02:54,230
hundred thousand years the gas starts to

68
00:02:58,000 --> 00:02:55,820
collapse you get a star forming in the

69
00:02:59,740 --> 00:02:58,010
center and you get an envelope around it

70
00:03:03,130 --> 00:02:59,750
that slowly starts to fall in and you

71
00:03:05,620 --> 00:03:03,140
get a disc in the center with a star so

72
00:03:07,420 --> 00:03:05,630
this takes a few thousand years and it

73
00:03:09,040 --> 00:03:07,430
starts to collapse down to only a few

74
00:03:11,320 --> 00:03:09,050
hundred au so starting to look like a

75
00:03:13,840 --> 00:03:11,330
solar system then we move on to the

76
00:03:16,449 --> 00:03:13,850
protoplanet dirt a protoplanetary disc

77
00:03:18,070 --> 00:03:16,459
phase this will take several hundred

78
00:03:19,990 --> 00:03:18,080
thousand to a few million years to

79
00:03:22,059 --> 00:03:20,000
complete and now we're actually on solar

80
00:03:24,580 --> 00:03:22,069
system scale so this is when the gas

81
00:03:27,670 --> 00:03:24,590
collapses down into a flat disk around

82
00:03:29,979 --> 00:03:27,680
the star it then it starts to segregate

83
00:03:32,860 --> 00:03:29,989
into planets and eventually we end up

84
00:03:34,780 --> 00:03:32,870
with a solar system this takes somewhere

85
00:03:37,780 --> 00:03:34,790
in the neighborhood of fifty million

86
00:03:40,780 --> 00:03:37,790
years to complete so astrochemistry

87
00:03:42,280 --> 00:03:40,790
mostly takes place in big gas clouds so

88
00:03:44,560 --> 00:03:42,290

once things are ejected from the star

89
00:03:46,180 --> 00:03:44,570
they're mostly atomized or solid pieces

90
00:03:48,640 --> 00:03:46,190
of dust and we have to build everything

91
00:03:51,729 --> 00:03:48,650
back up to the big complicated molecules

92
00:03:53,949 --> 00:03:51,739
we see in meteorites and comets today so

93
00:03:56,050 --> 00:03:53,959
the mass is something like ten thousand

94
00:03:57,759 --> 00:03:56,060
to a million solar masses its enormous

95
00:04:00,789 --> 00:03:57,769
and most of the mass doesn't end up in

96
00:04:03,970 --> 00:04:00,799
the solar system is just it's remnant

97
00:04:06,520 --> 00:04:03,980
dust it's a few hundred parsecs across

98
00:04:08,380 --> 00:04:06,530
the density is tiny it's only a hundred

99
00:04:11,050 --> 00:04:08,390
molecules per cubic centimeter and it's

100
00:04:12,430 --> 00:04:11,060
lonely ramps up to maybe a million for

101
00:04:14,860 --> 00:04:12,440
reference the air we're breathing right

102
00:04:17,860 --> 00:04:14,870
now is 10 to the 19 molecules per cubic

103
00:04:19,990 --> 00:04:17,870
centimeter so it's we cannot make a

104
00:04:22,659 --> 00:04:20,000
vacuum here on earth that is as good as

105
00:04:24,730 --> 00:04:22,669
anything in space it's incredibly

106
00:04:26,950 --> 00:04:24,740
diffuse and the temperature starts at

107
00:04:30,089 --> 00:04:26,960
about 10 Kelvin and slowly ramps up as

108
00:04:32,380 --> 00:04:30,099
the star turns on so astrochemistry is

109
00:04:33,170 --> 00:04:32,390
sort of an interplay between three

110
00:04:35,779 --> 00:04:33,180
things my

111
00:04:38,840 --> 00:04:35,789
pretoria astrophysics where we take

112
00:04:43,040 --> 00:04:38,850
spectra measure things we need either

113
00:04:45,200 --> 00:04:43,050

spectra or kinetics for understanding

114
00:04:47,840 --> 00:04:45,210
what we see ask your chemical modeling

115
00:04:49,820 --> 00:04:47,850
where we basically create models of how

116
00:04:52,790 --> 00:04:49,830
chemistry is going to occur in the is M

117
00:04:55,670 --> 00:04:52,800
this lets us understand the observations

118
00:04:57,860 --> 00:04:55,680
we see and feeds back to giving us new

119
00:04:59,360 --> 00:04:57,870
species to look for and you know

120
00:05:01,279 --> 00:04:59,370
reaction intermediates things that could

121
00:05:03,469 --> 00:05:01,289
lead to more interesting things like the

122
00:05:05,300 --> 00:05:03,479
building blocks of life and then

123
00:05:07,760 --> 00:05:05,310
observational astronomy is where we do

124
00:05:08,510 --> 00:05:07,770
our version of lab work this is where

125
00:05:11,890 --> 00:05:08,520
we're actually going to go out and

126
00:05:14,360 --> 00:05:11,900
observe things will I get abundances

127
00:05:15,890 --> 00:05:14,370
distributions temperatures of molecules

128
00:05:18,320 --> 00:05:15,900
understand what they are where they're

129
00:05:21,080 --> 00:05:18,330
going and get some ideas of how they

130
00:05:23,779 --> 00:05:21,090
formed and this all sort of feeds back

131
00:05:25,850 --> 00:05:23,789
together and slowly we start to build up

132
00:05:29,089 --> 00:05:25,860
an understanding of the chemistry that's

133
00:05:32,180 --> 00:05:29,099
happening so the chemistry that happens

134
00:05:35,120 --> 00:05:32,190
is actually not like anything you'll see

135
00:05:38,540 --> 00:05:35,130
on earth things like H 3 plus h three o

136
00:05:40,370 --> 00:05:38,550
plus c 2 h 5 plus most of the gas phase

137
00:05:42,140 --> 00:05:40,380
chemistry happens through ions that you

138
00:05:45,170 --> 00:05:42,150

could never that are extremely difficult

139
00:05:46,879 --> 00:05:45,180
to make in a lab and we do all of our

140
00:05:51,529 --> 00:05:46,889
work detecting them almost exclusively

141
00:05:54,140 --> 00:05:51,539
with radio astronomy so so far we have

142
00:05:56,870 --> 00:05:54,150
identified 180 molecules give or take in

143
00:06:00,110 --> 00:05:56,880
space see most of them are one or two

144
00:06:02,450 --> 00:06:00,120
three four Adam almost all the big

145
00:06:04,279 --> 00:06:02,460
molecules that we've detected have been

146
00:06:07,870 --> 00:06:04,289
through radio astronomy with the

147
00:06:11,390 --> 00:06:07,880
exception of c60 and c70 buckyballs and

148
00:06:12,950 --> 00:06:11,400
so the interesting thing here is one as

149
00:06:15,740 --> 00:06:12,960
they get bigger they get much more

150
00:06:16,939 --> 00:06:15,750
difficult to detect you see the two and

151
00:06:19,129 --> 00:06:16,949
three Adam ones are actually pretty easy

152
00:06:21,050 --> 00:06:19,139
but as you get past six things start to

153
00:06:22,550 --> 00:06:21,060
get very difficult and the other really

154
00:06:24,379 --> 00:06:22,560
interesting that's come I think this

155
00:06:26,330 --> 00:06:24,389
come out of astrochemistry in the last

156
00:06:28,189 --> 00:06:26,340
couple years is that anything more

157
00:06:30,740 --> 00:06:28,199
complicated than about methanol anything

158
00:06:33,620 --> 00:06:30,750
six atoms are above generally has to be

159
00:06:35,240 --> 00:06:33,630
made on a grain surface reactions in the

160
00:06:37,879 --> 00:06:35,250
gas phase can make a certain set of

161
00:06:39,710 --> 00:06:37,889
molecules but the big molecules are

162
00:06:42,379 --> 00:06:39,720
extremely difficult to make unless

163
00:06:43,850 --> 00:06:42,389

you're on a nice so the way this

164
00:06:45,740 --> 00:06:43,860
generally works is you have little

165
00:06:46,940 --> 00:06:45,750
silica dust grains that are floating

166
00:06:48,980 --> 00:06:46,950
around they condense it

167
00:06:51,770 --> 00:06:48,990
few layers of ice and then you can think

168
00:06:53,870 --> 00:06:51,780
you would create one molecule another I

169
00:06:55,190 --> 00:06:53,880
absorbs onto the surface they roam

170
00:06:56,810 --> 00:06:55,200
around and find each other and make

171
00:06:58,970 --> 00:06:56,820
molecules and this is the way we start

172
00:07:00,650 --> 00:06:58,980
to build up all of the big molecules so

173
00:07:02,990 --> 00:07:00,660
the amino acids purines pyrimidines

174
00:07:05,090 --> 00:07:03,000
things that you see in like the

175
00:07:08,360 --> 00:07:05,100
Murchison meteorite all have to be made

176
00:07:10,460 --> 00:07:08,370
through this process after that we move

177
00:07:12,650 --> 00:07:10,470
on to the protoplanetary disc phase all

178
00:07:15,680 --> 00:07:12,660
of the material that was made in the ice

179
00:07:18,950 --> 00:07:15,690
and dust I secreted into a flats or

180
00:07:20,720 --> 00:07:18,960
flared plane around a protostar so this

181
00:07:22,310 --> 00:07:20,730
is sort of a couple cartoons of what

182
00:07:24,860 --> 00:07:22,320
that ends up looking like so you have a

183
00:07:26,900 --> 00:07:24,870
central star as it turns on it blasts

184
00:07:29,600 --> 00:07:26,910
all the material around the star away so

185
00:07:31,220 --> 00:07:29,610
there's a big gap and the materials are

186
00:07:34,310 --> 00:07:31,230
created through magnetic accretion there

187
00:07:38,090 --> 00:07:34,320
as you move out you get thick layers of

188
00:07:40,040 --> 00:07:38,100

dust and so you get a series of

189
00:07:42,200 --> 00:07:40,050
complicated processes so you have

190
00:07:44,210 --> 00:07:42,210
vertical and horizontal mixing that

191
00:07:46,640 --> 00:07:44,220
takes matter from the top of the disk

192
00:07:48,710 --> 00:07:46,650
down and back up and then horizontally

193
00:07:51,230 --> 00:07:48,720
towards the edge or back towards the

194
00:07:53,540 --> 00:07:51,240
center of the disk the edges of the disk

195
00:07:54,830 --> 00:07:53,550
are extremely warm as is the front of

196
00:07:56,990 --> 00:07:54,840
the disk but as you move to the center

197
00:07:59,150 --> 00:07:57,000
it cools down this is where all your ice

198
00:08:02,240 --> 00:07:59,160
and dust are going to be and this is

199
00:08:04,550 --> 00:08:02,250
where small bits of dust will start to

200
00:08:06,200 --> 00:08:04,560
stick together and form bigger and

201
00:08:08,960 --> 00:08:06,210
bigger pieces that eventually become

202
00:08:11,750 --> 00:08:08,970
planets so understanding this is

203
00:08:13,070 --> 00:08:11,760
extremely complicated and this actually

204
00:08:15,590 --> 00:08:13,080
ends up determining a lot of your

205
00:08:17,120 --> 00:08:15,600
inventory for the planets meteorites

206
00:08:19,640 --> 00:08:17,130
comets that you're going to see in a

207
00:08:21,560 --> 00:08:19,650
planetary system and one of the big keys

208
00:08:23,090 --> 00:08:21,570
here is where the snow lines forms as

209
00:08:25,790 --> 00:08:23,100
you move further and further out water

210
00:08:27,440 --> 00:08:25,800
freezes out first then co2 then

211
00:08:30,710 --> 00:08:27,450
eventually CO and then eventually you

212
00:08:33,440 --> 00:08:30,720
start to drift into interstellar space

213
00:08:35,089 --> 00:08:33,450

and so where each one of these forms is

214
00:08:37,100 --> 00:08:35,099
going to determine a lot of the

215
00:08:39,890 --> 00:08:37,110
condensable matter that's available to

216
00:08:41,839 --> 00:08:39,900
be put into a planetary body so it has a

217
00:08:43,700 --> 00:08:41,849
huge effect on the solar systems that

218
00:08:45,830 --> 00:08:43,710
will come out of it and has a huge

219
00:08:47,990 --> 00:08:45,840
amount the gradients you see are varied

220
00:08:49,580 --> 00:08:48,000
to turn out very much determined by the

221
00:08:52,760 --> 00:08:49,590
star in the center and the total mass

222
00:08:54,260 --> 00:08:52,770
that goes into this so one of the really

223
00:08:56,750 --> 00:08:54,270
cool results that's come out very

224
00:08:58,940 --> 00:08:56,760
recently this is the atacama large

225
00:09:00,710 --> 00:08:58,950
millimeter array has finally imaged a

226
00:09:02,990 --> 00:09:00,720
protoplanetary disc this is sort of

227
00:09:04,309 --> 00:09:03,000
brand new science that's being done this

228
00:09:06,319 --> 00:09:04,319
is actually believe it or not the first

229
00:09:08,269 --> 00:09:06,329
time we've ever really observed a disk

230
00:09:10,220 --> 00:09:08,279
that has gaps in it so we've always

231
00:09:12,710 --> 00:09:10,230
known that in somewhere in the

232
00:09:14,240 --> 00:09:12,720
transition between a disk to a planetary

233
00:09:16,879 --> 00:09:14,250
system you have to form gaps small

234
00:09:18,590 --> 00:09:16,889
bodies start to form you get less

235
00:09:20,030 --> 00:09:18,600
emission and eventually they have to

236
00:09:21,259 --> 00:09:20,040
become planets but we've never seen it

237
00:09:23,749 --> 00:09:21,269
before so this was actually really

238
00:09:25,970 --> 00:09:23,759

amazing and so the really cool thing is

239
00:09:28,879 --> 00:09:25,980
if you look at where there is less dust

240
00:09:31,040 --> 00:09:28,889
so red is more dust emission the dark

241
00:09:32,929 --> 00:09:31,050
spots are where it's not that we've lost

242
00:09:35,269 --> 00:09:32,939
the dust it's that the dust is stuck

243
00:09:36,860 --> 00:09:35,279
together so now the surface area that

244
00:09:39,350 --> 00:09:36,870
can be emitting is much smaller and

245
00:09:41,869 --> 00:09:39,360
you're starting to form icy bodies and

246
00:09:43,910 --> 00:09:41,879
if you plot these these rings where

247
00:09:46,639 --> 00:09:43,920
we've lost emission they match up

248
00:09:50,980 --> 00:09:46,649
perfectly with the ice fronts for water

249
00:09:53,960 --> 00:09:50,990
ammonia and larger hydrated minerals so

250
00:09:55,460 --> 00:09:53,970
all of the chemistry that's happening

251
00:09:58,550 --> 00:09:55,470
and the physics of the discs are

252
00:10:00,139 --> 00:09:58,560
basically readily observable here and

253
00:10:04,189 --> 00:10:00,149
you can start to see how this affects

254
00:10:07,009 --> 00:10:04,199
the entire solar system and so from here

255
00:10:08,960 --> 00:10:07,019
what's going to happen is it's a very

256
00:10:11,660 --> 00:10:08,970
complicated process but now we have a

257
00:10:15,290 --> 00:10:11,670
solar system that's evolved from large

258
00:10:18,230 --> 00:10:15,300
large cloud of pre planetary material

259
00:10:19,970 --> 00:10:18,240
all of this is driven by chemistry that

260
00:10:22,009 --> 00:10:19,980
happened in the cloud almost all of the

261
00:10:23,780 --> 00:10:22,019
condensable material is formed in the

262
00:10:25,910 --> 00:10:23,790
cloud as it heats up and as it collapses

263
00:10:28,309 --> 00:10:25,920

and so what's going to happen is now you

264
00:10:31,840 --> 00:10:28,319
formed a planetary disc all the

265
00:10:34,400 --> 00:10:31,850
planetary bodies that existed I've now

266
00:10:36,439 --> 00:10:34,410
condensed and now you in enter the

267
00:10:38,540 --> 00:10:36,449
debris disk in heavy bombardment period

268
00:10:40,850 --> 00:10:38,550
so now you have planets and now we start

269
00:10:43,249 --> 00:10:40,860
delivering organic material to them from

270
00:10:45,079 --> 00:10:43,259
the disk that was formed and this is

271
00:10:47,840 --> 00:10:45,089
going to provide the feedstock for the

272
00:10:50,329 --> 00:10:47,850
planetary system so this is how things

273
00:10:52,069 --> 00:10:50,339
like Earth get their water and their

274
00:10:54,170 --> 00:10:52,079
organic material this is where Murchison

275
00:10:59,030 --> 00:10:54,180
comes from and this will be the starting

276
00:11:15,540 --> 00:10:59,040
point for evolving life on a planet all

277
00:11:22,090 --> 00:11:19,150
some people talk about the lack of

278
00:11:25,840 --> 00:11:22,100
source of energies to for reformation of

279
00:11:30,309 --> 00:11:25,850
some molecules based on temperature but

280
00:11:34,300 --> 00:11:30,319
as you mentioned dark but they make good

281
00:11:36,460 --> 00:11:34,310
form in sterile conditions and then

282
00:11:39,759 --> 00:11:36,470
trash transfer to somewhere else or

283
00:11:43,030 --> 00:11:39,769
there are cosmic rays which which effect

284
00:11:45,850 --> 00:11:43,040
is dominant because based on papers and

285
00:11:49,590 --> 00:11:45,860
preliminary papers is just there talking

286
00:11:52,449 --> 00:11:49,600
about temperatures and they're trying to

287
00:11:54,009 --> 00:11:52,459
model the same conditions based on

288
00:11:56,290 --> 00:11:54,019

temperature but as you said there are a

289
00:11:59,139 --> 00:11:56,300
lot of sorts of energies and then they

290
00:12:01,030 --> 00:11:59,149
they can get energy from there yeah so I

291
00:12:04,749 --> 00:12:01,040
this is a lot of stuff i glossed over

292
00:12:06,730 --> 00:12:04,759
but I just even in a disc so you have UV

293
00:12:08,019 --> 00:12:06,740
and x-ray photons doing a lot of work on

294
00:12:11,710 --> 00:12:08,029
the edge of the disc but you also have

295
00:12:12,970 --> 00:12:11,720
cosmic rays that so for those of you who

296
00:12:14,860 --> 00:12:12,980
don't know cosmic rays are just

297
00:12:17,290 --> 00:12:14,870
high-energy particles they can be

298
00:12:20,559 --> 00:12:17,300
electrons or protons things like that so

299
00:12:21,939 --> 00:12:20,569
they cosmic rays are always present we

300
00:12:23,530 --> 00:12:21,949
know they have to be doing some of the

301
00:12:24,790 --> 00:12:23,540
chemistry but it really depends on where

302
00:12:27,460 --> 00:12:24,800
you're talking about if you're talking

303
00:12:29,079 --> 00:12:27,470
about in a dense cold core when the star

304
00:12:31,240 --> 00:12:29,089
hasn't turned on than cosmic rays or a

305
00:12:33,490 --> 00:12:31,250
dominant source of energy for the system

306
00:12:35,650 --> 00:12:33,500
as the star turns on if you're close to

307
00:12:36,579 --> 00:12:35,660
the star obviously temperature gradients

308
00:12:39,250 --> 00:12:36,589
are going to drive a lot of the

309
00:12:40,480 --> 00:12:39,260
chemistry UV photons so it really

310
00:12:42,519 --> 00:12:40,490
depends on where you're talking about

311
00:12:44,980 --> 00:12:42,529
but all of those are very valid sources

312
00:12:47,379 --> 00:12:44,990
of energy it's just the dominant source

313
00:12:50,139 --> 00:12:47,389

changes depending because we're going

314
00:12:52,660 --> 00:12:50,149
from several you know tens of thousands

315
00:12:54,660 --> 00:12:52,670
of solar masses down to a few hundred to

316
00:12:57,639 --> 00:12:54,670
make a planetary system most of this

317
00:13:00,100 --> 00:12:57,649
it's huge orders of magnitude scale

318
00:13:02,530 --> 00:13:00,110
process so it really depends on where

319
00:13:04,540 --> 00:13:02,540
you are so you always can get energy for

320
00:13:07,090 --> 00:13:04,550
the reaction yes yeah there's always

321
00:13:09,939 --> 00:13:07,100
there there's always some source whether

322
00:13:12,550 --> 00:13:09,949
it's enough to drive in a cold region or

323
00:13:14,590 --> 00:13:12,560
in a dense cold cloud you generally

324
00:13:16,809 --> 00:13:14,600
don't have a ton you of the outside is

325
00:13:17,950 --> 00:13:16,819
externally irradiated by UV photons but

326
00:13:19,960 --> 00:13:17,960
cosmic rays

327
00:13:22,020 --> 00:13:19,970
have taken really low cross sections

328
00:13:24,310 --> 00:13:22,030
they'll penetrate very far into a cloud

329
00:13:26,050 --> 00:13:24,320
so there's always some source but it

330
00:13:38,680 --> 00:13:26,060
changes very much depending on where you

331
00:13:41,380 --> 00:13:38,690
are okay thanks awesome a great warm-up

332
00:13:42,580 --> 00:13:41,390
talk Brandon that was great you said

333
00:13:44,640 --> 00:13:42,590
that we can't make a vacuum on earth

334
00:13:46,840 --> 00:13:44,650
that is anything like that of space

335
00:13:48,160 --> 00:13:46,850
could you throw some numbers at that

336
00:13:50,440 --> 00:13:48,170
like I'm trying to wrap my mind around

337
00:13:53,440 --> 00:13:50,450
what a vacuum would be in like the

338
00:13:54,970 --> 00:13:53,450

dispersal of molecules versus the vacuum

339
00:13:57,340 --> 00:13:54,980
of space and the vacuum of space

340
00:14:00,220 --> 00:13:57,350
especially if you're talking the really

341
00:14:03,190 --> 00:14:00,230
diffuse is M is like 10 molecules per

342
00:14:05,440 --> 00:14:03,200
cubic centimeter I trying to think we

343
00:14:08,940 --> 00:14:05,450
are at what one atmosphere right now and

344
00:14:11,380 --> 00:14:08,950
that's 10 to the 19 we can get down to a

345
00:14:13,510 --> 00:14:11,390
few hundreds of thousands millions of

346
00:14:15,910 --> 00:14:13,520
that but we're still orders a magnitude

347
00:14:17,530 --> 00:14:15,920
away it's actually really difficult to

348
00:14:18,880 --> 00:14:17,540
pump all the hydrogen and helium out

349
00:14:20,080 --> 00:14:18,890
because they just keep coming back

350
00:14:21,910 --> 00:14:20,090
they're tiny and they're really

351
00:14:25,920 --> 00:14:21,920
difficult to get out of the system so

352
00:14:29,410 --> 00:14:25,930
they're really yeah well at the mean

353
00:14:31,090 --> 00:14:29,420
many orders of magnitude it's just it's

354
00:14:32,740 --> 00:14:31,100
impossible with so much crap around

355
00:14:34,840 --> 00:14:32,750
everything finds its way back and

356
00:14:36,580 --> 00:14:34,850
eventually it's really tough well that

357
00:14:43,030 --> 00:14:36,590
was fantastic that was my big mind

358
00:14:45,160 --> 00:14:43,040
opening moment of the day okay oh hi

359
00:14:48,240 --> 00:14:45,170
Brenda nam OU the end of the talk you

360
00:14:51,130 --> 00:14:48,250
mentioned how protoplanetary disks are

361
00:14:54,490 --> 00:14:51,140
responsible for the chemistry of life on

362
00:14:57,040 --> 00:14:54,500
Earth d well the disks are the discs are

363
00:14:59,140 --> 00:14:57,050

remnants of the original molecular cloud

364
00:15:01,720 --> 00:14:59,150
so the inventory there is at least

365
00:15:04,570 --> 00:15:01,730
partially driven by what happened in the

366
00:15:06,130 --> 00:15:04,580
cloud as it collapsed and me this is a

367
00:15:08,170 --> 00:15:06,140
dynamic process so there's a lot that

368
00:15:10,270 --> 00:15:08,180
goes on even in the protoplanetary disk

369
00:15:12,550 --> 00:15:10,280
phase yeah okay but you mentioned that

370
00:15:15,130 --> 00:15:12,560
that is responsible for what we see on

371
00:15:17,410 --> 00:15:15,140
the chemistry or not well it's a

372
00:15:19,990 --> 00:15:17,420
feedstock it's your starting point okay

373
00:15:22,840 --> 00:15:20,000
so let's see if I have this tucked

374
00:15:26,920 --> 00:15:22,850
somewhere away yeah so if you look at

375
00:15:28,990 --> 00:15:26,930
the dth ratio the protostar is the dth

376
00:15:31,150 --> 00:15:29,000
ratio is the sort of interstellar 10 to

377
00:15:31,439 --> 00:15:31,160
the minus 5 earth is up here attending

378
00:15:44,909 --> 00:15:31,449
the

379
00:15:47,970 --> 00:15:44,919
science paper by also please I just like

380
00:15:50,220 --> 00:15:47,980
water is one of the big things you need

381
00:15:53,099 --> 00:15:50,230
to well at least we think make life on

382
00:15:54,239 --> 00:15:53,109
Earth and that has to come from likely

383
00:15:56,489 --> 00:15:54,249
has to come from the outer solar system

384
00:15:58,799 --> 00:15:56,499
and during the heavy bombardment period

385
00:16:01,379 --> 00:15:58,809
at least partially or and you also said

386
00:16:04,519 --> 00:16:01,389
just before that that you are now able

387
00:16:07,919 --> 00:16:04,529
to see protoplanetary disks

388
00:16:11,099 --> 00:16:07,929

protoplanetary disks in this detail so

389
00:16:15,150 --> 00:16:11,109
can you get to the chemistry of these

390
00:16:16,710 --> 00:16:15,160
disks and perhaps in touch that's yeah

391
00:16:20,280 --> 00:16:16,720
that's so there'll be some talks about

392
00:16:22,829 --> 00:16:20,290
this today but this is this is pushing

393
00:16:25,259 --> 00:16:22,839
the world's best interferometer to its

394
00:16:27,119 --> 00:16:25,269
absolute limit so this is a continuum

395
00:16:28,829 --> 00:16:27,129
image so basically they're just bending

396
00:16:31,409 --> 00:16:28,839
every channel together you have to

397
00:16:35,009 --> 00:16:31,419
actually resolve the spectra to see

398
00:16:36,659 --> 00:16:35,019
molecular lines and so to make images of

399
00:16:38,999 --> 00:16:36,669
a protoplanetary disk where you can

400
00:16:40,499 --> 00:16:39,009
actually sort of image say CEO or

401
00:16:43,349 --> 00:16:40,509
methanol or something like that is going

402
00:16:44,970 --> 00:16:43,359
to be really tricky okay the next couple

403
00:16:47,400 --> 00:16:44,980
decades will be really exciting for that

404
00:16:49,109 --> 00:16:47,410
but yeah it's sort of right on the edge

405
00:16:51,269 --> 00:16:49,119
of what we're going to be able to do see

406
00:16:55,919 --> 00:16:51,279
probably not at this resolution though

407
00:16:57,659 --> 00:16:55,929
right thanks all right I think we need