B.Photoevaporation by External Star Observed!

courtesy of J. Bally, HST image

HST 10 "proplyd" about 0.1 pc from massive star Θ^1C in Orion

1
00:00:05,710 --> 00:00:03,909
well good morning everybody everybody

2
00:00:10,230 --> 00:00:05,720
welcome to the

3
00:00:11,990 --> 00:00:10,240
2008 director seminar series uh i'm glad

4
00:00:15,190 --> 00:00:12,000
to have you all here

5
00:00:19,510 --> 00:00:15,200
we are inaugurating the use of the new

6
00:00:21,670 --> 00:00:19,520
nai central videocon room uh which is a

7
00:00:24,230 --> 00:00:21,680
really nice facility which marco bolt

8
00:00:26,470 --> 00:00:24,240
and shige abe had a lot to do with

9
00:00:28,790 --> 00:00:26,480
designing and operating so

10
00:00:33,430 --> 00:00:28,800
i hope you'll all have a chance to see

11
00:00:35,110 --> 00:00:33,440
it and we've got a great seminar series

12
00:00:37,270 --> 00:00:35,120
set up for this year

13
00:00:40,150 --> 00:00:37,280

i'll tell you about some of the future

14
00:00:41,990 --> 00:00:40,160
seminars after today's talk

15
00:00:43,590 --> 00:00:42,000
and right now i'd like to introduce

16
00:00:46,310 --> 00:00:43,600
today's speaker

17
00:00:48,310 --> 00:00:46,320
who is dave hollenbach from our ames

18
00:00:51,910 --> 00:00:48,320
research center team

19
00:00:53,910 --> 00:00:51,920
dave is a an expert on the formation of

20
00:00:55,189 --> 00:00:53,920
protoplanetary disks and stellar

21
00:00:58,869 --> 00:00:55,199
formation

22
00:01:01,750 --> 00:00:58,879
and the effects of protoplanetary disk

23
00:01:03,510 --> 00:01:01,760
processes on planetary formation and

24
00:01:06,230 --> 00:01:03,520
he's going to be talking with us

25
00:01:08,469 --> 00:01:06,240
about that today he has a bachelor's

26
00:01:11,030 --> 00:01:08,479
degree from hope college a phd in

27
00:01:13,910 --> 00:01:11,040
theoretical physics from cornell

28
00:01:16,310 --> 00:01:13,920
and was a postdoc at harvard before

29
00:01:18,310 --> 00:01:16,320
coming out here to ames he's been

30
00:01:21,749 --> 00:01:18,320
involved in a great many spacecraft

31
00:01:23,109 --> 00:01:21,759
missions including kao and swas and iso

32
00:01:25,190 --> 00:01:23,119
and certif

33
00:01:27,350 --> 00:01:25,200
and in particular he's a co-investigator

34
00:01:29,109 --> 00:01:27,360
on the certified legacy program

35
00:01:30,390 --> 00:01:29,119
formation and evolution of planetary

36
00:01:32,310 --> 00:01:30,400
systems

37
00:01:34,789 --> 00:01:32,320
and today he's going to be talking with

38
00:01:37,270 --> 00:01:34,799

us about the effect of protoplanetary

39
00:01:39,670 --> 00:01:37,280
disk dispersion on planet formation and

40
00:01:41,590 --> 00:01:39,680
i'll turn it over to dave

41
00:01:43,510 --> 00:01:41,600
thank you carl

42
00:01:45,590 --> 00:01:43,520
uh so this is my first video con and

43
00:01:47,830 --> 00:01:45,600
this will be interesting experience

44
00:01:49,389 --> 00:01:47,840
and i'm very happy to talk a bit about

45
00:01:52,069 --> 00:01:49,399
the sort of the first question that

46
00:01:53,749 --> 00:01:52,079
astrobiologists asked which is

47
00:01:55,590 --> 00:01:53,759
you know what stars are going to have

48
00:01:57,510 --> 00:01:55,600
habitable planets what types of stars

49
00:01:59,910 --> 00:01:57,520
and what are the conditions

50
00:02:02,069 --> 00:01:59,920
that make it favorable for habitable

51
00:02:04,230 --> 00:02:02,079
planets to form around stars and what

52
00:02:05,350 --> 00:02:04,240
places may there be unfavorable

53
00:02:06,550 --> 00:02:05,360
conditions

54
00:02:08,550 --> 00:02:06,560
now you can approach this in an

55
00:02:10,710 --> 00:02:08,560
observational way or a theoretical way i

56
00:02:12,630 --> 00:02:10,720
mean observationally jeff marcy and the

57
00:02:14,390 --> 00:02:12,640
planet hunters have been looking just to

58
00:02:15,430 --> 00:02:14,400
see which stars have planets and where

59
00:02:16,790 --> 00:02:15,440
they are

60
00:02:18,949 --> 00:02:16,800
but we'd like to understand it

61
00:02:20,869 --> 00:02:18,959
theoretically of why

62
00:02:22,470 --> 00:02:20,879
why plants form around certain stars and

63
00:02:24,390 --> 00:02:22,480

that's sort of the kind of work that i'm

64
00:02:27,190 --> 00:02:24,400
going to be describing today and as carl

65
00:02:30,869 --> 00:02:27,200
mentioned i'm part of the nasa ames

66
00:02:33,190 --> 00:02:30,879
astrology team dave demare the pi

67
00:02:35,190 --> 00:02:33,200
so just to start off since we're an

68
00:02:36,630 --> 00:02:35,200
interdisciplinary group i thought i'd

69
00:02:38,070 --> 00:02:36,640
start off by

70
00:02:40,309 --> 00:02:38,080
talking a little bit about just the

71
00:02:43,350 --> 00:02:40,319
basics of planet formation

72
00:02:45,670 --> 00:02:43,360
that we astronomers uh now sort of have

73
00:02:46,710 --> 00:02:45,680
evolved this this this picture of planet

74
00:02:49,110 --> 00:02:46,720
formation

75
00:02:51,589 --> 00:02:49,120
and i'll try not to use any uh jargon

76
00:02:53,990 --> 00:02:51,599
that non-astronomer will not understand

77
00:02:55,270 --> 00:02:54,000
but if you feel free to ask questions if

78
00:02:57,270 --> 00:02:55,280
i forget

79
00:02:59,110 --> 00:02:57,280
i'm going to try to use this laser

80
00:03:00,949 --> 00:02:59,120
pointer i hope you can all see this

81
00:03:03,190 --> 00:03:00,959
there's a little red dot

82
00:03:04,630 --> 00:03:03,200
to point to things so that if you're

83
00:03:06,149 --> 00:03:04,640
looking at my view graphs you'll see

84
00:03:08,470 --> 00:03:06,159
them

85
00:03:10,229 --> 00:03:08,480
so the picture is is that in the in the

86
00:03:13,030 --> 00:03:10,239
galaxy in the interstellar medium there

87
00:03:14,630 --> 00:03:13,040
are clouds of molecules and dust

88
00:03:17,190 --> 00:03:14,640

particles these dust particles are less

89
00:03:19,750 --> 00:03:17,200
than a micron in size and they typically

90
00:03:21,830 --> 00:03:19,760
are silicate material or carbonaceous

91
00:03:23,990 --> 00:03:21,840
material uh and

92
00:03:26,630 --> 00:03:24,000
uh but mostly it's uh it's made up of

93
00:03:28,630 --> 00:03:26,640
hydrogen gas these clouds uh and they

94
00:03:30,869 --> 00:03:28,640
become fairly dense and they

95
00:03:33,190 --> 00:03:30,879
they we they form what we call molecular

96
00:03:35,030 --> 00:03:33,200
cloud cores which are quite dense and

97
00:03:37,270 --> 00:03:35,040
their sizes are in the order of a tenth

98
00:03:39,509 --> 00:03:37,280
of a parsec which astronomers use

99
00:03:42,309 --> 00:03:39,519
parsecs for distance this is about on

100
00:03:44,229 --> 00:03:42,319
the order of a light year in size

101
00:03:46,869 --> 00:03:44,239
and this material then gravitationally

102
00:03:49,750 --> 00:03:46,879
collapses it has some angular momentum

103
00:03:52,390 --> 00:03:49,760
and it spins and so as it collapses it

104
00:03:54,309 --> 00:03:52,400
forms not just a star but it forms a

105
00:03:56,229 --> 00:03:54,319
disc and in fact it's the disc that

106
00:03:59,110 --> 00:03:56,239
probably feeds the material and makes

107
00:04:01,750 --> 00:03:59,120
the star grow as this collapse proceeds

108
00:04:04,149 --> 00:04:01,760
the materials kind of spirals into hits

109
00:04:05,910 --> 00:04:04,159
the disc and then accretes onto the star

110
00:04:07,910 --> 00:04:05,920
this process takes maybe a hundred

111
00:04:09,030 --> 00:04:07,920
thousand years a few hundred thousand

112
00:04:11,589 --> 00:04:09,040
years

113
00:04:13,830 --> 00:04:11,599

now an astronomical unit which i have a

114
00:04:15,990 --> 00:04:13,840
typo here that should be big a big u

115
00:04:17,349 --> 00:04:16,000
capital a capital u and that will be in

116
00:04:18,789 --> 00:04:17,359
the future view graphs you'll see that

117
00:04:20,390 --> 00:04:18,799
that's an astronomical unit one

118
00:04:21,110 --> 00:04:20,400
astronomical unit is the distance from

119
00:04:29,350 --> 00:04:21,120
the

120
00:04:31,030 --> 00:04:29,360
distance out to pluto

121
00:04:33,590 --> 00:04:31,040
so this gives you a sense of the scale

122
00:04:35,430 --> 00:04:33,600
of this disc around the star then in the

123
00:04:37,670 --> 00:04:35,440
disc you initially have these small

124
00:04:39,830 --> 00:04:37,680
interstellar dust particles and then the

125
00:04:41,830 --> 00:04:39,840
dust particles start to coagulate and

126
00:04:43,110 --> 00:04:41,840
settle to the mid plane due to the

127
00:04:44,950 --> 00:04:43,120
gravity of the star and there's a

128
00:04:47,350 --> 00:04:44,960
tendency to settle they're orbiting in a

129
00:04:48,870 --> 00:04:47,360
keplerian orbits around the star but

130
00:04:51,030 --> 00:04:48,880
they settle to the mid plane and they

131
00:04:53,590 --> 00:04:51,040
coagulate into bigger and bigger rocks

132
00:04:56,230 --> 00:04:53,600
and icy uh particles

133
00:04:58,950 --> 00:04:56,240
and eventually these things coagulate to

134
00:05:02,070 --> 00:04:58,960
form planets in time scales of order of

135
00:05:03,830 --> 00:05:02,080
10 million years now the gas giants like

136
00:05:05,670 --> 00:05:03,840
jupiter may take a little bit different

137
00:05:08,870 --> 00:05:05,680
time scales than planets like the earth

138
00:05:10,790 --> 00:05:08,880

i'll talk about that in the next slides

139
00:05:12,629 --> 00:05:10,800
the um so let's just look at a little

140
00:05:14,390 --> 00:05:12,639
bit at the formation of gas giant

141
00:05:16,469 --> 00:05:14,400
planets there's there's two basic

142
00:05:18,390 --> 00:05:16,479
theories of the formation of gas giant

143
00:05:20,629 --> 00:05:18,400
planets one is that they form a

144
00:05:22,550 --> 00:05:20,639
gravitational instability and the other

145
00:05:24,230 --> 00:05:22,560
is by something called core accretion

146
00:05:26,390 --> 00:05:24,240
i'm going to focus on this talk just on

147
00:05:29,029 --> 00:05:26,400
the core accretion idea

148
00:05:31,189 --> 00:05:29,039
of the formation of gas giant planets

149
00:05:33,670 --> 00:05:31,199
so in this scenario

150
00:05:35,830 --> 00:05:33,680
as i say you have a star with a disk

151
00:05:37,270 --> 00:05:35,840
around it the dust particles settle to

152
00:05:38,550 --> 00:05:37,280
the midplane there's some turbulence

153
00:05:40,310 --> 00:05:38,560
that sort of is

154
00:05:42,390 --> 00:05:40,320
pictured here by these little spirals

155
00:05:44,230 --> 00:05:42,400
they accumulate into planetesimals which

156
00:05:45,189 --> 00:05:44,240
are things that are maybe a kilometer in

157
00:05:46,390 --> 00:05:45,199
size

158
00:05:49,350 --> 00:05:46,400
big enough

159
00:05:50,870 --> 00:05:49,360
that they can now gravitationally focus

160
00:05:53,749 --> 00:05:50,880
particles into them they actually sort

161
00:05:55,749 --> 00:05:53,759
of suck material onto them and then once

162
00:05:57,990 --> 00:05:55,759
that happens you get a sort of a very

163
00:06:00,390 --> 00:05:58,000

rapid growth of these things

164
00:06:01,909 --> 00:06:00,400
that that can grow up to lunar size or

165
00:06:04,150 --> 00:06:01,919
mars size

166
00:06:05,510 --> 00:06:04,160
objects and then

167
00:06:07,510 --> 00:06:05,520
then there's a process where they

168
00:06:10,230 --> 00:06:07,520
collide you can eventually build up up

169
00:06:11,670 --> 00:06:10,240
to sort of 10 to 15 earth mass what we

170
00:06:15,270 --> 00:06:11,680
call cores

171
00:06:16,469 --> 00:06:15,280
uh and so it's just ice rock material 15

172
00:06:18,390 --> 00:06:16,479
earth masses

173
00:06:20,550 --> 00:06:18,400
then its gravity is strong enough that

174
00:06:22,790 --> 00:06:20,560
it can actually attract a hydrogen gas

175
00:06:25,029 --> 00:06:22,800
which is by far the most dominant mass

176
00:06:27,189 --> 00:06:25,039
component of the disc and the gas can

177
00:06:29,909 --> 00:06:27,199
now be gravitationally attracted to this

178
00:06:33,510 --> 00:06:29,919
core and it rapidly can build up things

179
00:06:35,430 --> 00:06:33,520
like jupiter gas rich giants jupiter has

180
00:06:39,029 --> 00:06:35,440
something like

181
00:06:41,749 --> 00:06:39,039
uh 300 earth masses of gas but only 15

182
00:06:43,830 --> 00:06:41,759
earth masses of this sort of rocky icy

183
00:06:45,990 --> 00:06:43,840
core to start with

184
00:06:48,070 --> 00:06:46,000
and that may take a few million years in

185
00:06:49,670 --> 00:06:48,080
fact in the early models of this it took

186
00:06:51,350 --> 00:06:49,680
10 million years and now we're beginning

187
00:06:53,189 --> 00:06:51,360
to realize that discs don't last that

188
00:06:54,710 --> 00:06:53,199

long and so there's been a kind of a

189
00:06:56,870 --> 00:06:54,720
work theoretical work that's being done

190
00:06:58,629 --> 00:06:56,880
to show that actually it can happen in

191
00:07:00,870 --> 00:06:58,639
maybe 3 million years or 200 years i

192
00:07:03,830 --> 00:07:00,880
mean they're pushing it but it does take

193
00:07:05,909 --> 00:07:03,840
some time for this all to happen um so

194
00:07:09,670 --> 00:07:05,919
that's how a gas giant forms like like

195
00:07:11,510 --> 00:07:09,680
jupiter uh the terrestrial planets uh

196
00:07:13,909 --> 00:07:11,520
sort of form in us in something that

197
00:07:15,670 --> 00:07:13,919
goes like step one and step two here

198
00:07:16,550 --> 00:07:15,680
except that you build up these lunar

199
00:07:19,189 --> 00:07:16,560
mass

200
00:07:20,790 --> 00:07:19,199
objects and at that point you only have

201
00:07:23,110 --> 00:07:20,800
sort of a few of them and they tend to

202
00:07:25,270 --> 00:07:23,120
be on eccentric orbits which cross each

203
00:07:27,350 --> 00:07:25,280
other and eventually they'll collide and

204
00:07:28,790 --> 00:07:27,360
merge to form larger and larger planets

205
00:07:30,710 --> 00:07:28,800
like the earth

206
00:07:33,270 --> 00:07:30,720
but that may take tens of millions of

207
00:07:35,430 --> 00:07:33,280
years uh so that that's a slower process

208
00:07:37,589 --> 00:07:35,440
but it doesn't really uh involve the gas

209
00:07:39,270 --> 00:07:37,599
directly it's just these rocks that get

210
00:07:41,110 --> 00:07:39,280
bigger and bigger and crash into each

211
00:07:42,830 --> 00:07:41,120
other and it takes uh somewhat longer

212
00:07:45,830 --> 00:07:42,840
time

213
00:07:48,950 --> 00:07:45,840

so one thing that the gas does affect

214
00:07:50,950 --> 00:07:48,960
though in in terrestrial planets is sort

215
00:07:52,710 --> 00:07:50,960
of how big they can grow and what kind

216
00:07:55,270 --> 00:07:52,720
of orbits they're on

217
00:07:56,790 --> 00:07:55,280
if you have a lot of gas i mean if you

218
00:07:58,629 --> 00:07:56,800
have very little gas

219
00:08:00,230 --> 00:07:58,639
then there's no interaction between

220
00:08:03,990 --> 00:08:00,240
gravitational interaction between the

221
00:08:06,070 --> 00:08:04,000
gas and these uh lunar size objects and

222
00:08:07,830 --> 00:08:06,080
so they do collide they have eccentric

223
00:08:09,270 --> 00:08:07,840
elliptical orbits that cross and they

224
00:08:11,189 --> 00:08:09,280
collide and they smash into each other

225
00:08:12,309 --> 00:08:11,199
in fact you know it was one of the last

226
00:08:14,070 --> 00:08:12,319
collisions that's supposed to have

227
00:08:16,629 --> 00:08:14,080
formed the earth moon system or a sort

228
00:08:19,670 --> 00:08:16,639
of a mars-sized object hit the earth and

229
00:08:21,510 --> 00:08:19,680
it ended up forming an earth moon system

230
00:08:23,589 --> 00:08:21,520
and in this case you can build up fairly

231
00:08:25,749 --> 00:08:23,599
massive terrestrial planets by massive i

232
00:08:27,909 --> 00:08:25,759
mean as massive as the earth or maybe

233
00:08:29,990 --> 00:08:27,919
even a few times as massive as the earth

234
00:08:31,749 --> 00:08:30,000
and they tend to be on elliptical or

235
00:08:33,430 --> 00:08:31,759
eccentric orbits

236
00:08:35,269 --> 00:08:33,440
on the other hand if you have gas

237
00:08:37,750 --> 00:08:35,279
present for tens of millions of years

238
00:08:40,389 --> 00:08:37,760

that this takes and you only need about

239
00:08:41,829 --> 00:08:40,399
a hundredth of a jupiter mass this mj is

240
00:08:43,509 --> 00:08:41,839
a jupiter mass

241
00:08:45,910 --> 00:08:43,519
then the gravitational interaction

242
00:08:48,870 --> 00:08:45,920
between the planet and the gas as sort

243
00:08:51,670 --> 00:08:48,880
of a tidal effect circularizes the orbit

244
00:08:54,070 --> 00:08:51,680
of these objects and so then you tend to

245
00:08:54,870 --> 00:08:54,080
end up with many small sort of lunar

246
00:08:57,670 --> 00:08:54,880
mass

247
00:08:59,750 --> 00:08:57,680
uh planets that are orbiting uh and and

248
00:09:01,269 --> 00:08:59,760
you don't build up as large a planet you

249
00:09:04,150 --> 00:09:01,279
sort of have a lot of

250
00:09:06,790 --> 00:09:04,160
moon size things that are orbiting

251
00:09:08,550 --> 00:09:06,800
so the presence of gas uh in this for

252
00:09:11,110 --> 00:09:08,560
tens of millions of years

253
00:09:13,670 --> 00:09:11,120
a small amount of gas is is can make a

254
00:09:17,190 --> 00:09:13,680
big difference in forming uh uh

255
00:09:20,870 --> 00:09:19,269
now as i say one approach to this is

256
00:09:22,389 --> 00:09:20,880
just to look at things observationally

257
00:09:24,550 --> 00:09:22,399
and this talk's going to talk about the

258
00:09:26,150 --> 00:09:24,560
theoretical underpinning of trying to

259
00:09:28,949 --> 00:09:26,160
explain these observations but here's

260
00:09:29,910 --> 00:09:28,959
what we know in brief observationally is

261
00:09:34,070 --> 00:09:29,920
that

262
00:09:36,949 --> 00:09:34,080
about a tenth of the met of the mass of

263
00:09:39,030 --> 00:09:36,959

the star that they're orbiting and

264
00:09:41,590 --> 00:09:39,040
in the if we look at very young stars

265
00:09:43,269 --> 00:09:41,600
about 50 to 100 percent of them

266
00:09:44,550 --> 00:09:43,279
initially do have discs so that

267
00:09:46,389 --> 00:09:44,560
apparently they collapse with enough

268
00:09:48,230 --> 00:09:46,399
angular momentum to form disks often

269
00:09:50,389 --> 00:09:48,240
this often happens

270
00:09:52,230 --> 00:09:50,399
now if we look at stars old that are

271
00:09:54,070 --> 00:09:52,240
older and older as we look at stars that

272
00:09:55,829 --> 00:09:54,080
are 2 million years 3 million 4 or 5

273
00:09:58,150 --> 00:09:55,839
million years old what we see is that

274
00:10:00,710 --> 00:09:58,160
the dust in them disappears

275
00:10:02,790 --> 00:10:00,720
this dust that initially is sort of

276
00:10:04,150 --> 00:10:02,800
small particles and it's very opaque

277
00:10:05,910 --> 00:10:04,160
because you've got a lot of surface area

278
00:10:07,590 --> 00:10:05,920
in these small particles

279
00:10:09,030 --> 00:10:07,600
and so it's like a big

280
00:10:10,949 --> 00:10:09,040
opaque cloud

281
00:10:12,710 --> 00:10:10,959
and they become optically thin meaning

282
00:10:14,150 --> 00:10:12,720
you can see right through the disk in a

283
00:10:15,910 --> 00:10:14,160
few million years

284
00:10:17,110 --> 00:10:15,920
the stellar photons can go right through

285
00:10:18,550 --> 00:10:17,120
the disk

286
00:10:19,910 --> 00:10:18,560
and that only happens in a few million

287
00:10:22,150 --> 00:10:19,920
years so something's happening to the

288
00:10:23,990 --> 00:10:22,160

dust very rapidly in the inner disc and

289
00:10:26,069 --> 00:10:24,000
similarly in the outer disc we can

290
00:10:29,269 --> 00:10:26,079
measure actually the sub-millimeter

291
00:10:31,350 --> 00:10:29,279
radiation that this cold dust emits

292
00:10:33,670 --> 00:10:31,360
out there and see that it's diminishing

293
00:10:36,150 --> 00:10:33,680
in mass as well and about the same time

294
00:10:37,990 --> 00:10:36,160
scale so the dust is going away and by

295
00:10:39,110 --> 00:10:38,000
that i mean particles smaller than a

296
00:10:41,509 --> 00:10:39,120
millimeter

297
00:10:43,750 --> 00:10:41,519
now it could be that one way that's

298
00:10:45,829 --> 00:10:43,760
going away is that it's forming planets

299
00:10:47,509 --> 00:10:45,839
and if you form a planet you become

300
00:10:49,430 --> 00:10:47,519
optically thin because even though the

301
00:10:51,190 --> 00:10:49,440
planet you can't see through there's all

302
00:10:53,829 --> 00:10:51,200
this space between the planets that's

303
00:10:56,389 --> 00:10:53,839
just completely transparent and the disc

304
00:10:57,670 --> 00:10:56,399
becomes thin

305
00:11:00,310 --> 00:10:57,680
but there are other ways to get rid of

306
00:11:02,069 --> 00:11:00,320
the dust too which i'll be describing

307
00:11:03,910 --> 00:11:02,079
now there are some cases where we see a

308
00:11:05,350 --> 00:11:03,920
hole in the center of that it's

309
00:11:07,030 --> 00:11:05,360
optically thin you can see right through

310
00:11:09,430 --> 00:11:07,040
the inner part of the disc but with an

311
00:11:10,790 --> 00:11:09,440
optically thick outer disc

312
00:11:12,949 --> 00:11:10,800
one of the things that we're beginning

313
00:11:14,870 --> 00:11:12,959

to see just observationally with these

314
00:11:16,870 --> 00:11:14,880
uh radial velocity measurements of

315
00:11:17,910 --> 00:11:16,880
planets around the uh

316
00:11:20,790 --> 00:11:17,920
stars

317
00:11:22,630 --> 00:11:20,800
is that this initial mass which is a

318
00:11:23,509 --> 00:11:22,640
tenth of the solar mass or the stellar

319
00:11:25,190 --> 00:11:23,519
mass

320
00:11:26,630 --> 00:11:25,200
doesn't all go into planets because you

321
00:11:28,150 --> 00:11:26,640
add up the mass of planets that we're

322
00:11:29,269 --> 00:11:28,160
detecting and they tend to be 10 to the

323
00:11:31,030 --> 00:11:29,279
minus three

324
00:11:33,350 --> 00:11:31,040
solar masses that's true in our solar

325
00:11:35,110 --> 00:11:33,360
system as well so most of this mass

326
00:11:36,949 --> 00:11:35,120
doesn't go into planets it gets

327
00:11:38,710 --> 00:11:36,959
dispersed somehow it either goes onto

328
00:11:40,630 --> 00:11:38,720
the star or it goes out back out to

329
00:11:42,550 --> 00:11:40,640
space

330
00:11:45,269 --> 00:11:42,560
now the radial velocity observation

331
00:11:47,110 --> 00:11:45,279
suggests uh that at least 10 percent of

332
00:11:49,269 --> 00:11:47,120
stars form planets they're just done the

333
00:11:50,790 --> 00:11:49,279
statistics on the ones they've looked at

334
00:11:52,470 --> 00:11:50,800
and of course they they don't quite know

335
00:11:54,310 --> 00:11:52,480
how to extrapolate to systems that they

336
00:11:56,630 --> 00:11:54,320
can't see but might have planets so it's

337
00:11:58,630 --> 00:11:56,640
at least 10 percent uh so it could be

338
00:12:00,710 --> 00:11:58,640

that every star that has a disc forms

339
00:12:03,269 --> 00:12:00,720
some sort of planetary system or it

340
00:12:05,910 --> 00:12:03,279
could be that maybe of the stars that

341
00:12:07,750 --> 00:12:05,920
initially had discs maybe 50 of them

342
00:12:10,069 --> 00:12:07,760
never formed planets or something like

343
00:12:12,629 --> 00:12:10,079
that and the other because they the this

344
00:12:14,389 --> 00:12:12,639
dispersed too rapidly person

345
00:12:17,509 --> 00:12:14,399
so we'll talk a little bit about things

346
00:12:19,190 --> 00:12:17,519
that compete with planet formation

347
00:12:21,670 --> 00:12:19,200
again to give you a little more detail

348
00:12:23,829 --> 00:12:21,680
on how uh planets form here is this

349
00:12:25,590 --> 00:12:23,839
early stage where the cloud is falling

350
00:12:27,350 --> 00:12:25,600
onto the disk and one of the things

351
00:12:30,069 --> 00:12:27,360
theoretically we think may happen is

352
00:12:32,069 --> 00:12:30,079
that the disk builds up mass most of the

353
00:12:34,790 --> 00:12:32,079
material from the molecular cloud falls

354
00:12:36,710 --> 00:12:34,800
onto the disk not directly onto the star

355
00:12:38,389 --> 00:12:36,720
and the disk may build up mass until it

356
00:12:41,110 --> 00:12:38,399
gets to be about a tenth of the mass of

357
00:12:43,670 --> 00:12:41,120
the central star and then it becomes

358
00:12:44,870 --> 00:12:43,680
gravitationally unstable and this then

359
00:12:46,870 --> 00:12:44,880
leads to

360
00:12:49,269 --> 00:12:46,880
spiral waves and things that happen in

361
00:12:50,710 --> 00:12:49,279
the disc that allow angular momentum to

362
00:12:52,470 --> 00:12:50,720
be spread

363
00:12:54,629 --> 00:12:52,480

and what that happens when that happens

364
00:12:56,949 --> 00:12:54,639
material spirals onto the star from the

365
00:12:59,190 --> 00:12:56,959
outside in and material starts accreting

366
00:13:01,110 --> 00:12:59,200
onto the star as rapidly as material

367
00:13:03,190 --> 00:13:01,120
falls onto the disc material is agreeing

368
00:13:05,430 --> 00:13:03,200
on the star and it also causes the

369
00:13:08,069 --> 00:13:05,440
spreading of the disc and in these early

370
00:13:09,990 --> 00:13:08,079
stages the info is so opaque that the

371
00:13:12,389 --> 00:13:10,000
effects of radiation from the star on

372
00:13:14,629 --> 00:13:12,399
the disc are nil because it's the the

373
00:13:17,110 --> 00:13:14,639
info is keeping that radiation from the

374
00:13:21,509 --> 00:13:19,509
if we now look at a later stage when the

375
00:13:23,829 --> 00:13:21,519
collapse has stopped which is after

376
00:13:25,750 --> 00:13:23,839
perhaps a few ten of the fifth years

377
00:13:28,150 --> 00:13:25,760
and there's no more not much material

378
00:13:29,829 --> 00:13:28,160
flowing onto the disc from the cloud

379
00:13:32,069 --> 00:13:29,839
then you get this situation which is

380
00:13:33,430 --> 00:13:32,079
more likely that the place where planets

381
00:13:35,430 --> 00:13:33,440
form i should have mentioned that in

382
00:13:37,190 --> 00:13:35,440
that early stage when you have this very

383
00:13:39,110 --> 00:13:37,200
vigorous accretion of material any

384
00:13:40,710 --> 00:13:39,120
planets that could form that rapidly

385
00:13:42,230 --> 00:13:40,720
would probably be swept right into the

386
00:13:43,670 --> 00:13:42,240
central star

387
00:13:45,430 --> 00:13:43,680
and and

388
00:13:47,269 --> 00:13:45,440

whereas it's these later stages where

389
00:13:49,350 --> 00:13:47,279
the disc mass gets less than a tenth of

390
00:13:51,829 --> 00:13:49,360
the mass of the star that the planets

391
00:13:53,670 --> 00:13:51,839
that form may survive and orbit you know

392
00:13:55,350 --> 00:13:53,680
for billions of years

393
00:13:57,269 --> 00:13:55,360
uh and in this stage

394
00:13:58,949 --> 00:13:57,279
you still have accretion onto the star

395
00:14:01,509 --> 00:13:58,959
but it's at a much lower rate and it's

396
00:14:05,269 --> 00:14:01,519
driven by turbulent viscosity

397
00:14:07,910 --> 00:14:05,279
and with this mri is something that's a

398
00:14:09,670 --> 00:14:07,920
magnetic rotational instability which is

399
00:14:11,350 --> 00:14:09,680
sometimes thought to drive this

400
00:14:13,750 --> 00:14:11,360
turbulence which then leads to this

401
00:14:15,990 --> 00:14:13,760
spread of angular momentum

402
00:14:17,990 --> 00:14:16,000
and that leads to accretion out of the

403
00:14:19,509 --> 00:14:18,000
disk of this and so the disk mass then

404
00:14:21,350 --> 00:14:19,519
starts to drop from the tenth of the

405
00:14:24,069 --> 00:14:21,360
massive star to lower and lower values

406
00:14:25,750 --> 00:14:24,079
as material accretes onto the star but

407
00:14:27,509 --> 00:14:25,760
at the same time what the reason the

408
00:14:29,110 --> 00:14:27,519
mass of the disk is is dropping is that

409
00:14:32,470 --> 00:14:29,120
there are evaporation or there are

410
00:14:34,629 --> 00:14:32,480
dispersal mechanisms that are going on

411
00:14:37,350 --> 00:14:34,639
and there are several that are important

412
00:14:39,269 --> 00:14:37,360
one is that the ultraviolet radiation

413
00:14:40,710 --> 00:14:39,279

and the x-rays from the central star

414
00:14:43,189 --> 00:14:40,720
shine on the surface of the disk and

415
00:14:45,269 --> 00:14:43,199
they heat the surface up and that drives

416
00:14:47,430 --> 00:14:45,279
photo evaporation of the outer parts of

417
00:14:49,750 --> 00:14:47,440
the disc the disc is thermally hot the

418
00:14:52,790 --> 00:14:49,760
thermal pressure drives it out to uh

419
00:14:54,150 --> 00:14:52,800
interstellar space and it evaporates

420
00:14:56,470 --> 00:14:54,160
the other thing that can happen is that

421
00:14:58,230 --> 00:14:56,480
the wind from the central star can hit

422
00:15:00,310 --> 00:14:58,240
the surface of the disc and just entrain

423
00:15:01,910 --> 00:15:00,320
material and just drive it out uh to the

424
00:15:04,470 --> 00:15:01,920
interstellar space and and and so

425
00:15:07,189 --> 00:15:04,480
material is entrained and driven out uh

426
00:15:08,949 --> 00:15:07,199
and and lost uh from the disc

427
00:15:11,430 --> 00:15:08,959
uh and i'll talk about another one which

428
00:15:14,310 --> 00:15:11,440
is a stellar encounters in just a minute

429
00:15:16,230 --> 00:15:14,320
but this this whole process of planets

430
00:15:18,790 --> 00:15:16,240
forming the material accreting onto the

431
00:15:20,389 --> 00:15:18,800
star and and dispersal mechanisms

432
00:15:22,470 --> 00:15:20,399
happening occurs over periods of

433
00:15:25,189 --> 00:15:22,480
millions of years and there's a very

434
00:15:27,590 --> 00:15:25,199
intense composition competition going on

435
00:15:29,829 --> 00:15:27,600
between the planets trying to form but

436
00:15:31,990 --> 00:15:29,839
this dispersal happening simultaneously

437
00:15:35,670 --> 00:15:32,000
trying to try in a way trying to stop

438
00:15:39,750 --> 00:15:38,150

so the effects of gas dispersal on the

439
00:15:42,310 --> 00:15:39,760
plant formation and by gas dispersal

440
00:15:43,990 --> 00:15:42,320
it's not only the gas but the gas when

441
00:15:46,389 --> 00:15:44,000
when the gas is dispersed it actually

442
00:15:47,750 --> 00:15:46,399
pulls with it the dust that is small

443
00:15:49,269 --> 00:15:47,760
everything less than a millimeter in

444
00:15:51,350 --> 00:15:49,279
size and dust particles kind of goes

445
00:15:53,590 --> 00:15:51,360
with the gas but the bigger stuff can

446
00:15:55,910 --> 00:15:53,600
stay behind because the gas just passes

447
00:15:57,990 --> 00:15:55,920
over it they're like cannon balls that

448
00:15:59,110 --> 00:15:58,000
don't get affected and still orbit the

449
00:16:00,470 --> 00:15:59,120
star

450
00:16:02,389 --> 00:16:00,480
so the first thing that can happen is

451
00:16:04,150 --> 00:16:02,399
that it can affect the formation of gas

452
00:16:06,069 --> 00:16:04,160
giant planets because if you get rid of

453
00:16:08,470 --> 00:16:06,079
the gas too quickly there's no gas for

454
00:16:10,870 --> 00:16:08,480
those cores to attract

455
00:16:12,949 --> 00:16:10,880
like to form jupiters

456
00:16:14,790 --> 00:16:12,959
but secondly the gas effects as i've

457
00:16:16,870 --> 00:16:14,800
mentioned the eccentricity and size of

458
00:16:18,629 --> 00:16:16,880
terrestrial planets and it also affects

459
00:16:21,110 --> 00:16:18,639
planet migration this

460
00:16:22,949 --> 00:16:21,120
the gas the planet pulls on the gas and

461
00:16:25,030 --> 00:16:22,959
the gas pulls on the planet and the net

462
00:16:26,629 --> 00:16:25,040
effect is a kind of a friction on the

463
00:16:28,949 --> 00:16:26,639

planets and so that can cause them to

464
00:16:31,269 --> 00:16:28,959
actually spiral into the star and they

465
00:16:33,269 --> 00:16:31,279
move around it's called planet migration

466
00:16:34,870 --> 00:16:33,279
and it affects the eccentricity of the

467
00:16:37,590 --> 00:16:34,880
planets as well how elliptical their

468
00:16:39,590 --> 00:16:37,600
orbits are

469
00:16:41,269 --> 00:16:39,600
in addition uh it turns out that

470
00:16:43,269 --> 00:16:41,279
different mass stars are going to

471
00:16:45,670 --> 00:16:43,279
evaporate or disperse their discs in

472
00:16:47,430 --> 00:16:45,680
different time scales and some of the

473
00:16:49,590 --> 00:16:47,440
more massive stars for example as i'll

474
00:16:51,030 --> 00:16:49,600
show you disperse them very rapidly and

475
00:16:53,509 --> 00:16:51,040
so there won't be time enough for

476
00:16:54,710 --> 00:16:53,519
planets to form around very high mass

477
00:16:57,189 --> 00:16:54,720
stars

478
00:16:59,189 --> 00:16:57,199
and finally because that some of these

479
00:17:01,110 --> 00:16:59,199
dispersal mechanisms are getting rid of

480
00:17:03,269 --> 00:17:01,120
the material in the outer parts of the

481
00:17:05,270 --> 00:17:03,279
disk where water and volatile rich

482
00:17:07,750 --> 00:17:05,280
objects form like comets

483
00:17:09,510 --> 00:17:07,760
it may affect the formation of these

484
00:17:13,909 --> 00:17:09,520
things that may be reservoirs for

485
00:17:16,309 --> 00:17:13,919
volatiles and water-rich materials

486
00:17:17,829 --> 00:17:16,319
so the outline of the talk is to

487
00:17:19,669 --> 00:17:17,839
look at these various dispersal

488
00:17:21,270 --> 00:17:19,679

mechanisms the viscous evolution that

489
00:17:23,110 --> 00:17:21,280
makes things spiral under the star

490
00:17:25,350 --> 00:17:23,120
stellar encounters we'll talk about

491
00:17:27,029 --> 00:17:25,360
stripping by winds and photo evaporation

492
00:17:29,750 --> 00:17:27,039
i'm going to show you that viscous

493
00:17:31,029 --> 00:17:29,760
evolution and photo evaporation probably

494
00:17:33,029 --> 00:17:31,039
dominate

495
00:17:34,470 --> 00:17:33,039
these dispersal mechanisms and then

496
00:17:35,990 --> 00:17:34,480
we'll put the two together the two

497
00:17:38,230 --> 00:17:36,000
important ones viscous evolution and

498
00:17:40,470 --> 00:17:38,240
photo evaporation and see what the

499
00:17:44,070 --> 00:17:40,480
evolution of the disc will be with those

500
00:17:47,990 --> 00:17:46,070
so the viscous spreading as i mentioned

501
00:17:50,310 --> 00:17:48,000
is this sort of friction because the

502
00:17:52,150 --> 00:17:50,320
inner gas is orbiting faster than the

503
00:17:54,470 --> 00:17:52,160
outer gas and if there's any kind of

504
00:17:56,470 --> 00:17:54,480
friction then the outer gas kind of rubs

505
00:17:58,390 --> 00:17:56,480
against the inner gas makes it slow down

506
00:18:00,789 --> 00:17:58,400
and then it spirals into the star and

507
00:18:03,669 --> 00:18:00,799
you get this spiraling in uh to the star

508
00:18:05,909 --> 00:18:03,679
where uh so the the secretion tends to

509
00:18:07,909 --> 00:18:05,919
spread the disc this small amount of

510
00:18:10,310 --> 00:18:07,919
material gets more angular momentum and

511
00:18:13,990 --> 00:18:10,320
goes out but most of it is being

512
00:18:16,630 --> 00:18:14,000
spiraling in onto the star

513
00:18:19,029 --> 00:18:16,640

and we do the calculations uh of this

514
00:18:21,669 --> 00:18:19,039
turbulent viscous evolution

515
00:18:23,750 --> 00:18:21,679
we use a a dimensionless parameter to

516
00:18:26,630 --> 00:18:23,760
sort of hide our uncertainties in

517
00:18:29,190 --> 00:18:26,640
processes called alpha and astronomers

518
00:18:31,909 --> 00:18:29,200
talk about alpha disc evolution alpha

519
00:18:33,430 --> 00:18:31,919
then measures how much of this viscosity

520
00:18:34,789 --> 00:18:33,440
is present in the disc

521
00:18:37,190 --> 00:18:34,799
uh and

522
00:18:39,270 --> 00:18:37,200
we kind of know what the value of alpha

523
00:18:40,950 --> 00:18:39,280
is just by observational constraints we

524
00:18:42,549 --> 00:18:40,960
see how fast discs are accreting on

525
00:18:44,150 --> 00:18:42,559
their stars and we can kind of back up

526
00:18:46,390 --> 00:18:44,160
and see how viscous it had to be in

527
00:18:48,070 --> 00:18:46,400
order for it to viscously evolve but we

528
00:18:50,950 --> 00:18:48,080
also have theoretical models of this

529
00:18:52,789 --> 00:18:50,960
magneto rotational instability which

530
00:18:54,950 --> 00:18:52,799
people have done very detailed numerical

531
00:18:57,270 --> 00:18:54,960
models of this evolution and and found

532
00:18:57,990 --> 00:18:57,280
that alpha's of this order as well

533
00:19:00,310 --> 00:18:58,000
uh

534
00:19:02,549 --> 00:19:00,320
and the way a viscous evolution works is

535
00:19:04,470 --> 00:19:02,559
that the time scales are much shorter in

536
00:19:06,870 --> 00:19:04,480
the inner parts of the disk i've plotted

537
00:19:08,950 --> 00:19:06,880
time scales versus how far out in the

538
00:19:11,510 --> 00:19:08,960

disk you are what radius out in the disk

539
00:19:13,990 --> 00:19:11,520
you are in astronomical units so one is

540
00:19:15,110 --> 00:19:14,000
the earth

541
00:19:17,590 --> 00:19:15,120
um

542
00:19:20,310 --> 00:19:17,600
so this time scale is defined as follows

543
00:19:22,630 --> 00:19:20,320
it's the surface density sigma of the

544
00:19:24,710 --> 00:19:22,640
disk at that radius divided by how

545
00:19:26,710 --> 00:19:24,720
rapidly that surface density is changing

546
00:19:29,669 --> 00:19:26,720
in time due to this

547
00:19:31,830 --> 00:19:29,679
spreading and this accretion inward

548
00:19:34,470 --> 00:19:31,840
so when i say that if you have alpha of

549
00:19:36,470 --> 00:19:34,480
10 to the minus 3 here at 1au

550
00:19:39,430 --> 00:19:36,480
you find that the time scale is about 10

551
00:19:41,350 --> 00:19:39,440
to the 5th years now that means what

552
00:19:44,630 --> 00:19:41,360
that really means is that that material

553
00:19:46,789 --> 00:19:44,640
at at one a u spirals into like a half

554
00:19:48,310 --> 00:19:46,799
of an au in that time scale of ten to

555
00:19:51,430 --> 00:19:48,320
the fifth years that's a time scale to

556
00:19:53,110 --> 00:19:51,440
move a significant distance inward

557
00:19:55,430 --> 00:19:53,120
but it doesn't mean that that material

558
00:19:57,350 --> 00:19:55,440
disappears at 1au in 10 to the 5th years

559
00:19:58,630 --> 00:19:57,360
because what happens if you viscously

560
00:20:01,110 --> 00:19:58,640
evolve this

561
00:20:04,310 --> 00:20:01,120
is that most of the mass is contained

562
00:20:06,549 --> 00:20:04,320
further out in the disk at say 100 au

563
00:20:08,390 --> 00:20:06,559

and this material where most of the mass

564
00:20:11,190 --> 00:20:08,400
is replenishes the material that's

565
00:20:12,789 --> 00:20:11,200
inside of it so as as this material

566
00:20:14,150 --> 00:20:12,799
rapidly goes in

567
00:20:15,909 --> 00:20:14,160
that's a small amount of mass that

568
00:20:17,430 --> 00:20:15,919
rapidly goes in you've got a lot of mass

569
00:20:20,070 --> 00:20:17,440
here which the time scales are longer

570
00:20:22,390 --> 00:20:20,080
but the mass flux inward is enough to

571
00:20:23,750 --> 00:20:22,400
replace it because you've got a big mass

572
00:20:25,270 --> 00:20:23,760
even though the time scales are longer

573
00:20:27,590 --> 00:20:25,280
the m-dot

574
00:20:29,909 --> 00:20:27,600
replaces it so what happens is that the

575
00:20:31,430 --> 00:20:29,919
discs viscously do last longer than 10

576
00:20:33,590 --> 00:20:31,440
of the fifth years at one of you because

577
00:20:36,390 --> 00:20:33,600
of the longer time scales for the

578
00:20:37,909 --> 00:20:36,400
material outward to go in it also means

579
00:20:39,590 --> 00:20:37,919
that what determines the lifetime of

580
00:20:42,070 --> 00:20:39,600
discs that are just viscously evolving

581
00:20:43,830 --> 00:20:42,080
is sort of the the the time scale out at

582
00:20:45,990 --> 00:20:43,840
the distance where most of the mass is

583
00:20:47,190 --> 00:20:46,000
which might be at 100 a year

584
00:20:48,950 --> 00:20:47,200
well i've kind of beaten that one to

585
00:20:51,510 --> 00:20:48,960
death um

586
00:20:53,190 --> 00:20:51,520
so let's look at so i'm gonna by the way

587
00:20:55,270 --> 00:20:53,200
uh you you see this you say well that's

588
00:20:56,789 --> 00:20:55,280

that's a nice graph but um

589
00:20:58,070 --> 00:20:56,799
i'm gonna show other graphs of all these

590
00:20:59,270 --> 00:20:58,080
different mechanisms which will have

591
00:21:00,870 --> 00:20:59,280
time scales and then we'll be able to

592
00:21:02,870 --> 00:21:00,880
compare them and see which ones are the

593
00:21:04,390 --> 00:21:02,880
most important so that remember sort of

594
00:21:06,710 --> 00:21:04,400
try to remember that one but we'll i'll

595
00:21:09,029 --> 00:21:06,720
show it to you again later

596
00:21:10,549 --> 00:21:09,039
so here's the other thing about stars

597
00:21:11,830 --> 00:21:10,559
forming is that they tend to form in

598
00:21:14,870 --> 00:21:11,840
clusters

599
00:21:16,710 --> 00:21:14,880
and so uh in fact we see some star

600
00:21:19,190 --> 00:21:16,720
clusters where there are a thousand or

601
00:21:21,909 --> 00:21:19,200
ten thousand stars within a light year

602
00:21:23,750 --> 00:21:21,919
of each other and that's i mean here at

603
00:21:25,830 --> 00:21:23,760
the sun right now we've our nearest star

604
00:21:27,669 --> 00:21:25,840
is a few light years from us so uh we're

605
00:21:29,270 --> 00:21:27,679
talking about much denser than the stars

606
00:21:30,549 --> 00:21:29,280
here and so if we were born in that

607
00:21:33,029 --> 00:21:30,559
system we would see a lot of bright

608
00:21:34,230 --> 00:21:33,039
stars out in the sky uh very bright

609
00:21:36,390 --> 00:21:34,240
stars

610
00:21:38,310 --> 00:21:36,400
um and they uh

611
00:21:39,270 --> 00:21:38,320
they tend to have these densities then

612
00:21:40,870 --> 00:21:39,280
of uh

613
00:21:42,710 --> 00:21:40,880

they can have densities up to 10 to the

614
00:21:45,590 --> 00:21:42,720
fourth per cubic parsec which is about

615
00:21:47,510 --> 00:21:45,600
per cubic light year more or less

616
00:21:49,270 --> 00:21:47,520
so you can calculate the close

617
00:21:50,470 --> 00:21:49,280
encounters that these stars will have

618
00:21:52,070 --> 00:21:50,480
with each other

619
00:21:54,630 --> 00:21:52,080
and when they make a close encounter the

620
00:21:56,310 --> 00:21:54,640
disc around one of the stars is going to

621
00:21:57,750 --> 00:21:56,320
can get truncated

622
00:21:59,750 --> 00:21:57,760
for example i show this picture here

623
00:22:00,950 --> 00:21:59,760
here's a star going by a star and disc

624
00:22:02,950 --> 00:22:00,960
system

625
00:22:05,110 --> 00:22:02,960
and what happens when you make an

626
00:22:07,510 --> 00:22:05,120
encounter is that you strip the material

627
00:22:10,230 --> 00:22:07,520
away to about one third of the distance

628
00:22:11,909 --> 00:22:10,240
of the closest approach of that star

629
00:22:13,909 --> 00:22:11,919
so if the disc is bigger than that it

630
00:22:16,310 --> 00:22:13,919
will just be stripped down to that size

631
00:22:18,230 --> 00:22:16,320
of about one-third the closest approach

632
00:22:20,710 --> 00:22:18,240
by that encounter

633
00:22:22,470 --> 00:22:20,720
so if you want to start stripping

634
00:22:25,190 --> 00:22:22,480
discs that are hundreds of au you need

635
00:22:39,110 --> 00:22:25,200
encounters that occur that close of 400

636
00:22:39,120 --> 00:22:41,750
which i'll available

637
00:22:45,190 --> 00:22:43,350
here's the time scales now this is in

638
00:22:47,430 --> 00:22:45,200

the one of the densest clusters that we

639
00:22:49,909 --> 00:22:47,440
know about a very dense cluster like the

640
00:22:51,909 --> 00:22:49,919
trapezium cluster in orion where we have

641
00:22:54,870 --> 00:22:51,919
this sort of 10 to the four stars per

642
00:22:56,710 --> 00:22:54,880
cubic light year and you see that if the

643
00:22:58,149 --> 00:22:56,720
discs are big the time scales are very

644
00:22:59,510 --> 00:22:58,159
short because

645
00:23:02,310 --> 00:22:59,520
you do have a lot of collisions that

646
00:23:03,990 --> 00:23:02,320
occur within a thousand au of a disc

647
00:23:05,590 --> 00:23:04,000
but if the disc gets small the time

648
00:23:07,669 --> 00:23:05,600
scales get very long because you have to

649
00:23:09,270 --> 00:23:07,679
get really close encounters in order to

650
00:23:15,029 --> 00:23:09,280
strip those discs smaller and to make

651
00:23:18,950 --> 00:23:17,190
now we'll move to another mechanism for

652
00:23:21,350 --> 00:23:18,960
dispersal which is stripping by stellar

653
00:23:24,149 --> 00:23:21,360
winds which historically was if you ask

654
00:23:25,830 --> 00:23:24,159
people what dispersed the solar nebula

655
00:23:27,510 --> 00:23:25,840
people would have said it was the wind

656
00:23:29,029 --> 00:23:27,520
from the start from the sun that

657
00:23:30,870 --> 00:23:29,039
eventually you know just blew away the

658
00:23:32,470 --> 00:23:30,880
gas that because we knew that not all

659
00:23:34,549 --> 00:23:32,480
the hydrogen went into jupiter we could

660
00:23:35,750 --> 00:23:34,559
tell from from looking at the metal

661
00:23:37,669 --> 00:23:35,760
content of jupiter that there was

662
00:23:39,190 --> 00:23:37,679
hydrogen missing and so we said well

663
00:23:41,029 --> 00:23:39,200

that hydrogen just got blown away by the

664
00:23:43,990 --> 00:23:41,039
stellar wind well that turns out

665
00:23:46,070 --> 00:23:44,000
probably not correct uh that

666
00:23:47,430 --> 00:23:46,080
we've done some more recent calculations

667
00:23:49,669 --> 00:23:47,440
of this

668
00:23:51,669 --> 00:23:49,679
stripping by stellar winds the situation

669
00:23:53,430 --> 00:23:51,679
is that you have a disc like this and

670
00:23:56,310 --> 00:23:53,440
you have a wind impacting it at a very

671
00:23:58,070 --> 00:23:56,320
glancing angle and it it impacts on the

672
00:23:59,909 --> 00:23:58,080
surface and it creates a sheer layer on

673
00:24:01,669 --> 00:23:59,919
the surface which material gets sort of

674
00:24:04,070 --> 00:24:01,679
entrained and driven out into the

675
00:24:06,390 --> 00:24:04,080
interstellar space and you can calculate

676
00:24:08,070 --> 00:24:06,400
the mass loss rate in the disk by

677
00:24:10,149 --> 00:24:08,080
basically taking the area and then

678
00:24:12,070 --> 00:24:10,159
multiplying by a flux

679
00:24:14,070 --> 00:24:12,080
this is the density of the gas times its

680
00:24:16,310 --> 00:24:14,080
sound speed times an efficiency factor

681
00:24:17,909 --> 00:24:16,320
sort of a flux of material from the disk

682
00:24:20,549 --> 00:24:17,919
going up into that mixing layer and then

683
00:24:21,909 --> 00:24:20,559
being carried out uh into interstellar

684
00:24:24,710 --> 00:24:21,919
space

685
00:24:26,549 --> 00:24:24,720
and in doing such a calculation we found

686
00:24:28,470 --> 00:24:26,559
our group has found that

687
00:24:31,350 --> 00:24:28,480
these are the time scales for around a

688
00:24:33,350 --> 00:24:31,360

one solar mass star with a typical wind

689
00:24:35,269 --> 00:24:33,360
that's about as strong as the early

690
00:24:36,789 --> 00:24:35,279
winds on the sun were

691
00:24:38,230 --> 00:24:36,799
and with a surface density that looks

692
00:24:41,590 --> 00:24:38,240
something like what we think the surface

693
00:24:43,990 --> 00:24:41,600
density of the sun looked like

694
00:24:45,750 --> 00:24:44,000
as a function of radius and we find that

695
00:24:47,909 --> 00:24:45,760
these time scales to get rid of the

696
00:24:49,990 --> 00:24:47,919
material at these different distances in

697
00:24:51,830 --> 00:24:50,000
the disk range from fairly short time

698
00:24:53,909 --> 00:24:51,840
scales on the inner part of the disk to

699
00:24:55,830 --> 00:24:53,919
fairly long time scales in the outer

700
00:24:57,029 --> 00:24:55,840
part of the disk and we will compare

701
00:24:59,669 --> 00:24:57,039
these time scales with the other

702
00:25:01,990 --> 00:24:59,679
mechanisms in a minute

703
00:25:03,990 --> 00:25:02,000
so now let's finally move to the final

704
00:25:05,990 --> 00:25:04,000
mechanism for dispersing these discs and

705
00:25:06,870 --> 00:25:06,000
that's photo evaporation which turns out

706
00:25:08,950 --> 00:25:06,880
to be

707
00:25:10,950 --> 00:25:08,960
the important one for the outer part of

708
00:25:12,070 --> 00:25:10,960
the disc

709
00:25:13,750 --> 00:25:12,080
so these are something that i've been

710
00:25:15,269 --> 00:25:13,760
working on for the last more than the

711
00:25:16,149 --> 00:25:15,279
last 10 years

712
00:25:16,950 --> 00:25:16,159
and they're

713
00:25:19,750 --> 00:25:16,960

pretty

714
00:25:22,310 --> 00:25:19,760
difficult models to get right

715
00:25:23,750 --> 00:25:22,320
it's it's a complicated process so

716
00:25:25,350 --> 00:25:23,760
let's just run through a few things

717
00:25:28,549 --> 00:25:25,360
elements that go into these computer

718
00:25:30,230 --> 00:25:28,559
codes our codes now take a week to run

719
00:25:33,269 --> 00:25:30,240
and the fastest machines we have a week

720
00:25:34,789 --> 00:25:33,279
to run one run of one particular disk at

721
00:25:36,630 --> 00:25:34,799
one instant of time

722
00:25:38,870 --> 00:25:36,640
and of course we try to evolve it with

723
00:25:40,310 --> 00:25:38,880
time it takes forever and so we're

724
00:25:42,789 --> 00:25:40,320
really running into some serious

725
00:25:45,350 --> 00:25:42,799
computational problems but so here's a

726
00:25:48,149 --> 00:25:45,360
situation you've got the central star

727
00:25:49,830 --> 00:25:48,159
irradiating this disc the disc gas

728
00:25:51,830 --> 00:25:49,840
temperature does not necessarily equal a

729
00:25:54,230 --> 00:25:51,840
dust temperature and i will show you

730
00:25:56,149 --> 00:25:54,240
some results from our code where that's

731
00:25:57,590 --> 00:25:56,159
we show that to be true in the mid plane

732
00:25:59,350 --> 00:25:57,600
it is true that the gas temperature

733
00:26:01,909 --> 00:25:59,360
equals the dust temperature but as you

734
00:26:03,190 --> 00:26:01,919
go up in the disk the gas

735
00:26:05,669 --> 00:26:03,200
because it has different heating and

736
00:26:07,750 --> 00:26:05,679
cooling mechanisms up high and can and

737
00:26:09,269 --> 00:26:07,760
can radiate to space and dust radiates

738
00:26:11,029 --> 00:26:09,279

the space even more efficiently the gas

739
00:26:12,390 --> 00:26:11,039
tends to get hotter than the dust up

740
00:26:15,909 --> 00:26:12,400
near the surface

741
00:26:18,149 --> 00:26:15,919
due to the heating by x-rays and uv

742
00:26:19,990 --> 00:26:18,159
what we have to do is a self-consistent

743
00:26:21,590 --> 00:26:20,000
solution in the disc of its chemistry

744
00:26:23,029 --> 00:26:21,600
because this chemistry determines its

745
00:26:24,789 --> 00:26:23,039
heating and cooling so we got to do the

746
00:26:26,230 --> 00:26:24,799
chemistry then we have to do the heating

747
00:26:28,549 --> 00:26:26,240
and cooling we have to do the radio

748
00:26:30,710 --> 00:26:28,559
transfer of how the photons escape from

749
00:26:32,549 --> 00:26:30,720
the disc because uh they tend to be

750
00:26:34,710 --> 00:26:32,559
optically thick and they self-absorb and

751
00:26:36,230 --> 00:26:34,720
they eventually sort of percolate out

752
00:26:38,870 --> 00:26:36,240
um

753
00:26:40,950 --> 00:26:38,880
and it's and then the vertical structure

754
00:26:42,149 --> 00:26:40,960
of the disc is determined by the gas

755
00:26:44,149 --> 00:26:42,159
temperature so you have to self

756
00:26:46,070 --> 00:26:44,159
consistently then if the gas is hotter

757
00:26:48,149 --> 00:26:46,080
it puffs up and if it's cooler it gets

758
00:26:50,070 --> 00:26:48,159
thinner uh you have to do everything

759
00:26:51,830 --> 00:26:50,080
simultaneously and then do the dynamics

760
00:26:54,230 --> 00:26:51,840
of the flow so we do make some

761
00:26:57,029 --> 00:26:54,240
approximations and already it's fairly

762
00:26:58,149 --> 00:26:57,039
complicated um

763
00:27:00,230 --> 00:26:58,159

so uh

764
00:27:01,830 --> 00:27:00,240
let me just i want to tell you one or

765
00:27:04,070 --> 00:27:01,840
two things about the physics of this

766
00:27:06,710 --> 00:27:04,080
photo evaporation just to get you sort

767
00:27:08,789 --> 00:27:06,720
of a better idea of what's going on

768
00:27:11,110 --> 00:27:08,799
so regardless of whether you've got uv

769
00:27:13,190 --> 00:27:11,120
photons from an external star shining on

770
00:27:15,830 --> 00:27:13,200
the disc here's a low mass star like the

771
00:27:18,310 --> 00:27:15,840
sun with a disc in this plane here

772
00:27:19,909 --> 00:27:18,320
that's what we're seeing an edge on

773
00:27:21,190 --> 00:27:19,919
you can either have external photons or

774
00:27:22,870 --> 00:27:21,200
you can have photons from the central

775
00:27:25,590 --> 00:27:22,880
star you get the same structure you get

776
00:27:28,310 --> 00:27:25,600
this inner part where you you this uv

777
00:27:30,310 --> 00:27:28,320
heating uh heats it up and it causes it

778
00:27:32,470 --> 00:27:30,320
to puff more and more as you go out in

779
00:27:33,990 --> 00:27:32,480
radius because gravity from the star is

780
00:27:35,909 --> 00:27:34,000
getting weaker and so it puffs up more

781
00:27:37,350 --> 00:27:35,919
and more the thermal pressure posted up

782
00:27:39,110 --> 00:27:37,360
eventually you get to the point where

783
00:27:41,430 --> 00:27:39,120
you have a flow out to the interstellar

784
00:27:43,990 --> 00:27:41,440
medium and that point turns out to be

785
00:27:46,390 --> 00:27:44,000
roughly where the thermal speed of the

786
00:27:48,470 --> 00:27:46,400
atoms is equal to the escape speed from

787
00:27:50,390 --> 00:27:48,480
this system the gravitational escape

788
00:27:52,789 --> 00:27:50,400

speed from the system

789
00:27:53,830 --> 00:27:52,799
now euv photons are those that ionize

790
00:27:56,149 --> 00:27:53,840
hydrogen

791
00:27:58,710 --> 00:27:56,159
and fuv photons are those that are not

792
00:28:00,789 --> 00:27:58,720
energetic enough to ionize hydrogen so

793
00:28:03,590 --> 00:28:00,799
it turns out that in terms of electron

794
00:28:06,870 --> 00:28:03,600
volts it takes 13.6 electron volts to

795
00:28:08,470 --> 00:28:06,880
ionize hydrogen atom so

796
00:28:10,630 --> 00:28:08,480
photons more energetic than that which

797
00:28:11,909 --> 00:28:10,640
are about 912 angstroms

798
00:28:15,909 --> 00:28:11,919
we'll

799
00:28:17,830 --> 00:28:15,919
will ionize the disc and these fue

800
00:28:19,350 --> 00:28:17,840
photons will not ionize it but they will

801
00:28:21,830 --> 00:28:19,360
heat it

802
00:28:24,230 --> 00:28:21,840
okay so there is this characteristic

803
00:28:25,590 --> 00:28:24,240
distance where you get the flow

804
00:28:28,310 --> 00:28:25,600
well first there's a characteristic

805
00:28:30,549 --> 00:28:28,320
distance let me say that rg that is

806
00:28:32,310 --> 00:28:30,559
defined as the place where the escape

807
00:28:33,750 --> 00:28:32,320
speed from the system which is given by

808
00:28:35,510 --> 00:28:33,760
this formula

809
00:28:37,669 --> 00:28:35,520
the mass of the star times gravitational

810
00:28:39,510 --> 00:28:37,679
constant over our g of the one half is

811
00:28:42,070 --> 00:28:39,520
equal to the thermal speed of the gas

812
00:28:44,630 --> 00:28:42,080
atom c

813
00:28:47,510 --> 00:28:44,640

that defines rg it turns out that if you

814
00:28:49,990 --> 00:28:47,520
actually do the details of the flow

815
00:28:52,389 --> 00:28:50,000
that you do get significant evaporation

816
00:28:54,950 --> 00:28:52,399
even inside rg down to about two-tenths

817
00:28:56,230 --> 00:28:54,960
of rg so the critical distance where you

818
00:28:58,310 --> 00:28:56,240
get the flow

819
00:29:01,830 --> 00:28:58,320
uh is defined by rg but it's more like

820
00:29:04,149 --> 00:29:01,840
two tenths of rg and so for euv photons

821
00:29:07,110 --> 00:29:04,159
which heat the surface gas up to ten

822
00:29:08,789 --> 00:29:07,120
thousand degrees uh by ionizing hydrogen

823
00:29:10,710 --> 00:29:08,799
uh atoms

824
00:29:12,710 --> 00:29:10,720
that that critical distance is a few

825
00:29:15,750 --> 00:29:12,720
astronomical units

826
00:29:17,909 --> 00:29:15,760
but if you're at the fuv photons they

827
00:29:19,750 --> 00:29:17,919
they only heat up to a thousand degrees

828
00:29:22,630 --> 00:29:19,760
and so they're most of their mass loss

829
00:29:24,630 --> 00:29:22,640
is occurring beyond 38

830
00:29:26,789 --> 00:29:24,640
and there's another big difference is in

831
00:29:28,710 --> 00:29:26,799
that the e photons because of the radius

832
00:29:31,510 --> 00:29:28,720
of transfer tend to focus their

833
00:29:33,190 --> 00:29:31,520
evaporation right at this uh this

834
00:29:35,750 --> 00:29:33,200
critical radius so that they tend to try

835
00:29:38,630 --> 00:29:35,760
to burn a hole in the disk at 2au

836
00:29:41,029 --> 00:29:38,640
but the fuv photons tend to evaporate

837
00:29:42,389 --> 00:29:41,039
from the outside of the disk in

838
00:29:43,590 --> 00:29:42,399

so they evaporate the outside that is

839
00:29:48,310 --> 00:29:43,600
first and then they sort of work their

840
00:29:51,110 --> 00:29:49,590
okay so

841
00:29:53,430 --> 00:29:51,120
let's look first then at the photo

842
00:29:55,590 --> 00:29:53,440
evaporation by an external star in other

843
00:29:57,430 --> 00:29:55,600
words you have a low mass star with a

844
00:29:59,190 --> 00:29:57,440
disc around it at low mass meaning uh

845
00:30:00,870 --> 00:29:59,200
like the sun sun is considered a low

846
00:30:04,070 --> 00:30:00,880
mass star

847
00:30:06,310 --> 00:30:04,080
is considered like 10 times the mass of

848
00:30:08,710 --> 00:30:06,320
the sun or 30 times the mass of the sun

849
00:30:10,630 --> 00:30:08,720
and they're not as they're they're rarer

850
00:30:12,230 --> 00:30:10,640
but they are incredibly luminous in

851
00:30:15,110 --> 00:30:12,240
ultraviolet maybe a hundred thousand

852
00:30:17,510 --> 00:30:15,120
times as luminous as the sun uh in just

853
00:30:18,549 --> 00:30:17,520
in volumetric luminosity

854
00:30:20,710 --> 00:30:18,559
anyway

855
00:30:22,070 --> 00:30:20,720
if stars form in clusters the masses

856
00:30:23,430 --> 00:30:22,080
stars tend to be at the center of the

857
00:30:25,190 --> 00:30:23,440
cluster you have all these low mass

858
00:30:27,350 --> 00:30:25,200
stars that are sort of orbiting around

859
00:30:29,510 --> 00:30:27,360
the center of the cluster maybe 100 or

860
00:30:31,430 --> 00:30:29,520
10 000 of these low mass stars and

861
00:30:32,950 --> 00:30:31,440
they're at distances typically of a

862
00:30:34,070 --> 00:30:32,960
tenth of a light year

863
00:30:35,830 --> 00:30:34,080

pretty close

864
00:30:37,830 --> 00:30:35,840
and this radiation from the star then

865
00:30:39,350 --> 00:30:37,840
heats up the surface this massive star

866
00:30:41,669 --> 00:30:39,360
heats up the surface of the disc and

867
00:30:44,070 --> 00:30:41,679
causes it to photo evaporate

868
00:30:46,789 --> 00:30:44,080
so here is a picture of a cluster uh

869
00:30:48,470 --> 00:30:46,799
this is in orion and uh it maybe is a

870
00:30:51,350 --> 00:30:48,480
little washed out i hope you can see it

871
00:30:53,750 --> 00:30:51,360
out there in television land uh

872
00:30:56,870 --> 00:30:53,760
this is the orion nebula so it's in the

873
00:30:58,070 --> 00:30:56,880
uh sort of sheath of uh of orion's where

874
00:30:59,830 --> 00:30:58,080
a sword is

875
00:31:02,310 --> 00:30:59,840
there's the trapezium stars four very

876
00:31:05,190 --> 00:31:02,320
bright stars that form a trapezium one

877
00:31:06,870 --> 00:31:05,200
of them theta 1c is the brightest it's

878
00:31:08,389 --> 00:31:06,880
about a 30 solar mass star it's very

879
00:31:10,470 --> 00:31:08,399
luminous and then you've got all these

880
00:31:12,070 --> 00:31:10,480
little dots are low mass stars that have

881
00:31:13,669 --> 00:31:12,080
formed in the last million years in this

882
00:31:15,669 --> 00:31:13,679
cluster of stars and they're being

883
00:31:16,950 --> 00:31:15,679
illuminated by this very massive

884
00:31:18,870 --> 00:31:16,960
luminous star

885
00:31:20,630 --> 00:31:18,880
at close range

886
00:31:21,350 --> 00:31:20,640
so here's a blown up picture of one of

887
00:31:24,310 --> 00:31:21,360
them

888
00:31:25,830 --> 00:31:24,320

this is hst-10 discovered by the hubble

889
00:31:27,830 --> 00:31:25,840
space well actually it wasn't discovered

890
00:31:29,110 --> 00:31:27,840
that uh the hubble really took the great

891
00:31:30,389 --> 00:31:29,120
pictures of it

892
00:31:33,110 --> 00:31:30,399
this is uh

893
00:31:34,389 --> 00:31:33,120
a hubble space telescope image of this

894
00:31:36,549 --> 00:31:34,399
one star

895
00:31:38,070 --> 00:31:36,559
the star the low mass star is not really

896
00:31:40,549 --> 00:31:38,080
seen in this picture it's right at the

897
00:31:42,389 --> 00:31:40,559
center of this little green ring uh and

898
00:31:44,310 --> 00:31:42,399
it's slightly obscured because the disc

899
00:31:45,909 --> 00:31:44,320
is sort of slightly edge on and you

900
00:31:47,750 --> 00:31:45,919
can't quite see the star you can

901
00:31:49,110 --> 00:31:47,760
actually see it in some images

902
00:31:51,830 --> 00:31:49,120
and then this is the disc and it's sort

903
00:31:53,990 --> 00:31:51,840
of glowing in green it's being heated up

904
00:31:55,509 --> 00:31:54,000
the neutral gas is being heated up to

905
00:31:58,310 --> 00:31:55,519
thousands of degrees and it's actually

906
00:31:59,430 --> 00:31:58,320
glowing in an atomic oxygen line that

907
00:32:01,909 --> 00:31:59,440
you see

908
00:32:03,990 --> 00:32:01,919
uh then there is neutral gas that's

909
00:32:05,830 --> 00:32:04,000
heated that's photo evaporating off of

910
00:32:07,430 --> 00:32:05,840
this disc

911
00:32:09,590 --> 00:32:07,440
and then by the time it gets out to

912
00:32:12,310 --> 00:32:09,600
where this bright region is it becomes

913
00:32:14,230 --> 00:32:12,320

ionized due to these euv photons that

914
00:32:16,389 --> 00:32:14,240
can ionize hydrogen that are being

915
00:32:18,470 --> 00:32:16,399
emitted by this very massive star which

916
00:32:21,269 --> 00:32:18,480
is up in this direction away from this

917
00:32:22,789 --> 00:32:21,279
very bright spot here it's up this way

918
00:32:24,950 --> 00:32:22,799
and so now those photons are then

919
00:32:26,789 --> 00:32:24,960
ionizing and when this gasket ionized it

920
00:32:29,750 --> 00:32:26,799
starts to glow and that's what's glowing

921
00:32:31,190 --> 00:32:29,760
uh is these this ionized gas it's

922
00:32:32,950 --> 00:32:31,200
actually hydrogen it's a line of

923
00:32:35,830 --> 00:32:32,960
hydrogen that's

924
00:32:37,750 --> 00:32:35,840
recombining actually uh but it forms

925
00:32:39,669 --> 00:32:37,760
this sort of reddish and bright bright

926
00:32:41,509 --> 00:32:39,679
glow

927
00:32:43,750 --> 00:32:41,519
so this is actually you're seeing a disc

928
00:32:46,230 --> 00:32:43,760
being photo evaporated here and you're

929
00:32:47,750 --> 00:32:46,240
seeing the neutral material moving out

930
00:32:50,710 --> 00:32:47,760
and then eventually getting ionized by

931
00:32:52,549 --> 00:32:50,720
the photo ionizing photons from theta 1

932
00:32:58,070 --> 00:32:52,559
c

933
00:33:00,149 --> 00:32:58,080
evaporated

934
00:33:03,350 --> 00:33:00,159
by these external stars

935
00:33:06,070 --> 00:33:03,360
so this is a plot that shows the plots

936
00:33:09,029 --> 00:33:06,080
the mass of the central star the masses

937
00:33:11,430 --> 00:33:09,039
are on the horizontal axis and then the

938
00:33:13,669 --> 00:33:11,440

mass loss rate on the vertical axis from

939
00:33:15,029 --> 00:33:13,679
from the low mass star that's near this

940
00:33:16,789 --> 00:33:15,039
massive star

941
00:33:18,870 --> 00:33:16,799
uh this is the mass loss rate and over

942
00:33:20,310 --> 00:33:18,880
here a kind of a depending on the mass

943
00:33:21,909 --> 00:33:20,320
of the disc this gives you an idea of

944
00:33:24,070 --> 00:33:21,919
what the time scale for the disc to

945
00:33:26,070 --> 00:33:24,080
evaporate is from ten to the fifth years

946
00:33:27,750 --> 00:33:26,080
to ten to seven years so the way you

947
00:33:29,350 --> 00:33:27,760
interpret this is that if you're a low

948
00:33:32,149 --> 00:33:29,360
mass star like the sun and you're in a

949
00:33:34,070 --> 00:33:32,159
cluster of maybe fifty stars

950
00:33:35,909 --> 00:33:34,080
and so your most massive star is maybe a

951
00:33:37,269 --> 00:33:35,919
four or five solar mass star which is

952
00:33:41,029 --> 00:33:37,279
down here

953
00:33:42,710 --> 00:33:41,039
then you will evaporate to 80 au

954
00:33:44,230 --> 00:33:42,720
you're evaporating from outside in in

955
00:33:45,590 --> 00:33:44,240
this case from an external star

956
00:33:46,389 --> 00:33:45,600
evaporating

957
00:33:50,310 --> 00:33:46,399
you

958
00:33:52,470 --> 00:33:50,320
years

959
00:33:54,389 --> 00:33:52,480
but if you're in a cluster of 2 000

960
00:33:56,310 --> 00:33:54,399
stars where your most massive star may

961
00:33:57,590 --> 00:33:56,320
be 20 or 30 solar masses like in the

962
00:33:59,110 --> 00:33:57,600
orion case

963
00:34:01,750 --> 00:33:59,120

then you evaporate

964
00:34:02,710 --> 00:34:01,760
down to a 20 au or 10 au in a million

965
00:34:04,630 --> 00:34:02,720
years

966
00:34:06,870 --> 00:34:04,640
you evaporate to a very long small

967
00:34:09,190 --> 00:34:06,880
radius and then the viscosity will take

968
00:34:10,950 --> 00:34:09,200
care of that inner part very rapidly as

969
00:34:15,270 --> 00:34:10,960
well so the whole disc will go away in

970
00:34:20,230 --> 00:34:17,829
so we can plot for the orion conditions

971
00:34:22,149 --> 00:34:20,240
which are fairly extreme 0.2 parsecs

972
00:34:24,069 --> 00:34:22,159
from a 30 solar mass star we can plot

973
00:34:25,990 --> 00:34:24,079
this time scale to evaporate due to the

974
00:34:28,230 --> 00:34:26,000
external star so there's two e's

975
00:34:30,389 --> 00:34:28,240
evaporation and external

976
00:34:32,950 --> 00:34:30,399
and this time scale looks like this the

977
00:34:34,869 --> 00:34:32,960
blue is by the evaporation caused by the

978
00:34:37,030 --> 00:34:34,879
hydrogen ionizing photons and the green

979
00:34:39,510 --> 00:34:37,040
is the evaporation caused by the

980
00:34:41,030 --> 00:34:39,520
fuv photons which can't ionize hydrogen

981
00:34:42,389 --> 00:34:41,040
and this is as a function of the radius

982
00:34:44,069 --> 00:34:42,399
of the disk so you see that there's very

983
00:34:45,270 --> 00:34:44,079
short time scales to evaporate the outer

984
00:34:47,109 --> 00:34:45,280
part of the disk

985
00:34:49,909 --> 00:34:47,119
so the disks rapidly evaporate and

986
00:34:52,069 --> 00:34:49,919
truncate inward and then eventually

987
00:34:53,190 --> 00:34:52,079
they get truncated to a point where

988
00:34:56,629 --> 00:34:53,200

viscous

989
00:35:00,390 --> 00:34:59,190
so for astrobiology the key question is

990
00:35:02,390 --> 00:35:00,400
then

991
00:35:04,550 --> 00:35:02,400
what fraction of solar mass fires like

992
00:35:06,470 --> 00:35:04,560
the sun spend a sufficient time close to

993
00:35:08,550 --> 00:35:06,480
a massive star in their early evolution

994
00:35:09,990 --> 00:35:08,560
that their disks are dispersed in less

995
00:35:11,510 --> 00:35:10,000
than a few million years which is sort

996
00:35:13,750 --> 00:35:11,520
of the time scale we think we need in

997
00:35:15,270 --> 00:35:13,760
order to form planets particularly giant

998
00:35:16,870 --> 00:35:15,280
gas giant planets

999
00:35:19,829 --> 00:35:16,880
and thereby affecting the plant

1000
00:35:22,470 --> 00:35:19,839
formation and the answer uh and fred

1001
00:35:25,109 --> 00:35:22,480
adams uh has been working on this with a

1002
00:35:27,910 --> 00:35:25,119
tusso and others and and and we've been

1003
00:35:29,589 --> 00:35:27,920
working on this too and

1004
00:35:31,430 --> 00:35:29,599
we're trying to get it somewhat more

1005
00:35:32,790 --> 00:35:31,440
accurately at present time but it's

1006
00:35:34,710 --> 00:35:32,800
somewhere between five and thirty

1007
00:35:37,030 --> 00:35:34,720
percent so it's not a huge fraction of

1008
00:35:38,550 --> 00:35:37,040
the stars in our galaxy that this exp

1009
00:35:39,750 --> 00:35:38,560
happens to maybe it's on the order of

1010
00:35:41,750 --> 00:35:39,760
ten percent

1011
00:35:43,109 --> 00:35:41,760
so that it is happening to some and so

1012
00:35:45,190 --> 00:35:43,119
there's going to be some systems where

1013
00:35:47,270 --> 00:35:45,200

they were near a massive star and they

1014
00:35:49,190 --> 00:35:47,280
just got they're just blown away and

1015
00:35:51,670 --> 00:35:49,200
it's really going to seriously affect

1016
00:35:53,190 --> 00:35:51,680
planet formation but it's probably not a

1017
00:35:55,109 --> 00:35:53,200
huge effect

1018
00:35:56,710 --> 00:35:55,119
and we see that i mean as i said jeff

1019
00:35:59,030 --> 00:35:56,720
marcy and his crew has seen that there's

1020
00:36:01,589 --> 00:35:59,040
a high percentage of stars that do seem

1021
00:36:03,910 --> 00:36:01,599
to have planets so this is corresponds

1022
00:36:05,510 --> 00:36:03,920
to what we're seeing

1023
00:36:07,589 --> 00:36:05,520
so finally we need to look at the photo

1024
00:36:09,430 --> 00:36:07,599
evaporation by the central star itself

1025
00:36:11,030 --> 00:36:09,440
not by some external star in a cluster

1026
00:36:13,349 --> 00:36:11,040
so this will happen to any star even

1027
00:36:15,109 --> 00:36:13,359
some isolated star that's borne off not

1028
00:36:17,109 --> 00:36:15,119
near a massive star

1029
00:36:20,150 --> 00:36:17,119
and so the same process occurs that

1030
00:36:23,430 --> 00:36:21,670
um and uh

1031
00:36:25,510 --> 00:36:23,440
so i'm going to show you a result from

1032
00:36:27,589 --> 00:36:25,520
one of these models that takes a week to

1033
00:36:30,230 --> 00:36:27,599
run and i'm only going to show you the

1034
00:36:31,750 --> 00:36:30,240
the solution that at nine astronomical

1035
00:36:34,069 --> 00:36:31,760
units from the star so what we're

1036
00:36:36,230 --> 00:36:34,079
looking here is that a vertical cut

1037
00:36:38,790 --> 00:36:36,240
in the disk from the mid plane which is

1038
00:36:41,510 --> 00:36:38,800

at zero here on the horizontal axis

1039
00:36:43,270 --> 00:36:41,520
up vertically z is as vertical height

1040
00:36:45,109 --> 00:36:43,280
above the mid plane and then we're

1041
00:36:48,310 --> 00:36:45,119
plotting both the temperature and the

1042
00:36:49,510 --> 00:36:48,320
density of gas and dust

1043
00:36:51,430 --> 00:36:49,520
so this is actually the density of the

1044
00:36:53,990 --> 00:36:51,440
gas here let's go with that first so at

1045
00:36:56,230 --> 00:36:54,000
the mid plane the density which is shown

1046
00:36:57,910 --> 00:36:56,240
over here the log of the density is

1047
00:36:59,990 --> 00:36:57,920
shown over here in particles per cubic

1048
00:37:01,829 --> 00:37:00,000
centimeter the density is 10 to the 12th

1049
00:37:02,790 --> 00:37:01,839
hydrogens per cubic centimeters quite

1050
00:37:04,230 --> 00:37:02,800
dense

1051
00:37:06,069 --> 00:37:04,240
and at the midplane you see that the

1052
00:37:07,190 --> 00:37:06,079
temperature of the gas and the dust are

1053
00:37:08,790 --> 00:37:07,200
both equal

1054
00:37:12,630 --> 00:37:08,800
and they're about i don't know 70

1055
00:37:13,670 --> 00:37:12,640
degrees or i can't read it 50 70 degrees

1056
00:37:15,349 --> 00:37:13,680
uh

1057
00:37:17,510 --> 00:37:15,359
then as you go up vertically you see

1058
00:37:18,870 --> 00:37:17,520
that the gas and dust the density is

1059
00:37:20,310 --> 00:37:18,880
dropping because you're kind of going up

1060
00:37:22,630 --> 00:37:20,320
in the disc getting up more in the

1061
00:37:24,710 --> 00:37:22,640
atmosphere of the disc density is

1062
00:37:26,950 --> 00:37:24,720
dropping rapidly the and the temperature

1063
00:37:29,030 --> 00:37:26,960

then starts to rise because the gas and

1064
00:37:30,870 --> 00:37:29,040
dust start to see the stellar photons

1065
00:37:32,390 --> 00:37:30,880
and that starts to warm them at the mid

1066
00:37:34,390 --> 00:37:32,400
plane they're just heated by the

1067
00:37:37,750 --> 00:37:34,400
infrared radiation field

1068
00:37:39,270 --> 00:37:37,760
of the dust of the disc itself

1069
00:37:41,910 --> 00:37:39,280
but then as they get up higher they

1070
00:37:43,109 --> 00:37:41,920
start to see the stellar photons

1071
00:37:44,550 --> 00:37:43,119
because they're up higher in the

1072
00:37:46,470 --> 00:37:44,560
atmosphere where they can start to see

1073
00:37:48,470 --> 00:37:46,480
the star and they start to heat up and

1074
00:37:50,230 --> 00:37:48,480
the dust then eventually as it sees the

1075
00:37:52,630 --> 00:37:50,240
stellar photons reaches an equilibrium

1076
00:37:54,710 --> 00:37:52,640
temperature of a couple hundred degrees

1077
00:37:56,150 --> 00:37:54,720
but the gas keeps getting hotter because

1078
00:37:58,710 --> 00:37:56,160
it's being heated by x-rays and

1079
00:38:00,630 --> 00:37:58,720
ultraviolet photons and this is a

1080
00:38:02,390 --> 00:38:00,640
situation of a gas of around a one solar

1081
00:38:04,630 --> 00:38:02,400
mass star where we put in some typical

1082
00:38:07,109 --> 00:38:04,640
values of what the x-ray luminosity of

1083
00:38:10,870 --> 00:38:07,119
these young solar mass stars are and the

1084
00:38:13,430 --> 00:38:10,880
uv fluxes from these young stars

1085
00:38:16,150 --> 00:38:13,440
this shows av of one is to the star

1086
00:38:18,069 --> 00:38:16,160
that's the av in astronomers lingo is

1087
00:38:19,990 --> 00:38:18,079
kind of this is where you start to get a

1088
00:38:21,349 --> 00:38:20,000

real clear view of the star up in the

1089
00:38:23,030 --> 00:38:21,359
disc

1090
00:38:24,630 --> 00:38:23,040
in the visible

1091
00:38:25,829 --> 00:38:24,640
and this is where the molecular hydrogen

1092
00:38:28,069 --> 00:38:25,839
turns atomic because it's

1093
00:38:30,550 --> 00:38:28,079
photodissociated by the uv photons from

1094
00:38:32,550 --> 00:38:30,560
the star this is where co

1095
00:38:35,270 --> 00:38:32,560
turns to ionized carbon because of the

1096
00:38:37,910 --> 00:38:35,280
uv dissociation of co and ionization of

1097
00:38:39,990 --> 00:38:37,920
carbon by the uv from the star

1098
00:38:41,829 --> 00:38:40,000
you can see that eventually the euv

1099
00:38:44,950 --> 00:38:41,839
photons which can ionize hydrogen heat

1100
00:38:47,109 --> 00:38:44,960
the gas up to 10 000 degrees here

1101
00:38:49,190 --> 00:38:47,119
in this case at 9 a.u this is where the

1102
00:38:51,190 --> 00:38:49,200
photo evaporated flow starts right at

1103
00:38:53,510 --> 00:38:51,200
the base of this ionized layer this is

1104
00:38:55,430 --> 00:38:53,520
where the flow starts coming off and you

1105
00:38:58,230 --> 00:38:55,440
start evaporating the disc further out

1106
00:39:00,150 --> 00:38:58,240
in the disc it's this neutral heated gas

1107
00:39:02,870 --> 00:39:00,160
by the fuv that actually where the flow

1108
00:39:06,069 --> 00:39:04,390
so that gives you an idea of these

1109
00:39:09,030 --> 00:39:06,079
models and how they do the chemistry and

1110
00:39:11,510 --> 00:39:09,040
the flow and the temperature of the gas

1111
00:39:14,550 --> 00:39:11,520
so if you do the central star you get

1112
00:39:16,230 --> 00:39:14,560
this is for a one solar mass star again

1113
00:39:18,310 --> 00:39:16,240

the central star this is the blue is

1114
00:39:20,710 --> 00:39:18,320
caused by the uv photons that can ionize

1115
00:39:22,870 --> 00:39:20,720
hydrogen and the green is by the fuv

1116
00:39:25,670 --> 00:39:22,880
photons there is this tendency to burn a

1117
00:39:28,069 --> 00:39:25,680
hole at one au that the euv photons have

1118
00:39:30,630 --> 00:39:28,079
the time scales get short your mass loss

1119
00:39:32,630 --> 00:39:30,640
is high there and then you out here the

1120
00:39:34,870 --> 00:39:32,640
fpv photons take over and they warm the

1121
00:39:37,270 --> 00:39:34,880
gas enough to get a pretty vigorous flow

1122
00:39:39,510 --> 00:39:37,280
going and particularly short time scales

1123
00:39:42,630 --> 00:39:39,520
at large radio so that would tend to

1124
00:39:43,510 --> 00:39:42,640
truncate these discs and it makes this

1125
00:39:45,430 --> 00:39:43,520
uh

1126
00:39:48,950 --> 00:39:45,440
very rapidly photo evaporate once they

1127
00:39:51,589 --> 00:39:48,960
get bigger than 100au

1128
00:39:53,510 --> 00:39:51,599
so let's uh see how we're doing okay

1129
00:39:55,430 --> 00:39:53,520
i'm now going to combine all these time

1130
00:39:57,349 --> 00:39:55,440
scales to give you an idea of what now

1131
00:39:59,190 --> 00:39:57,359
is the most important

1132
00:40:02,069 --> 00:39:59,200
and so we've got the

1133
00:40:05,030 --> 00:40:02,079
viscous time scale in red here plotted

1134
00:40:07,270 --> 00:40:05,040
as a function of the radius and the disk

1135
00:40:09,589 --> 00:40:07,280
these time scales to get rid of the gas

1136
00:40:12,230 --> 00:40:09,599
the wind time scales the evaporation by

1137
00:40:13,910 --> 00:40:12,240
the central star by an external star and

1138
00:40:16,150 --> 00:40:13,920

by stellar encounters first thing you

1139
00:40:17,190 --> 00:40:16,160
see stellar encounters are then rarely

1140
00:40:19,109 --> 00:40:17,200
important

1141
00:40:21,190 --> 00:40:19,119
uh maybe if the disks start off to be a

1142
00:40:22,550 --> 00:40:21,200
thousand au in size the the stellar

1143
00:40:24,870 --> 00:40:22,560
encounters will get to be important in

1144
00:40:26,710 --> 00:40:24,880
truncating a very big disc

1145
00:40:29,349 --> 00:40:26,720
in these clusters

1146
00:40:31,430 --> 00:40:29,359
but what you see is the wind maybe has a

1147
00:40:33,589 --> 00:40:31,440
little bit of importance at 10 a.u but

1148
00:40:35,430 --> 00:40:33,599
it tends to be overshadowed by viscous

1149
00:40:37,589 --> 00:40:35,440
evolution in the inner part and it's

1150
00:40:39,589 --> 00:40:37,599
certainly overshadowed by evaporation

1151
00:40:42,310 --> 00:40:39,599
photo evaporation in the outer parts

1152
00:40:44,390 --> 00:40:42,320
where these time scales get short

1153
00:40:46,470 --> 00:40:44,400
so this external star is a pretty

1154
00:40:48,470 --> 00:40:46,480
extreme case and even this extreme case

1155
00:40:50,790 --> 00:40:48,480
doesn't compete that much with the

1156
00:40:52,710 --> 00:40:50,800
central stars effect on the disc so i'm

1157
00:40:54,710 --> 00:40:52,720
just ignore the external part and we're

1158
00:40:56,150 --> 00:40:54,720
just going to now plot the three

1159
00:40:57,990 --> 00:40:56,160
important ones then that have the short

1160
00:40:59,750 --> 00:40:58,000
time scales you've got viscous secretion

1161
00:41:01,430 --> 00:40:59,760
in the inner part

1162
00:41:03,030 --> 00:41:01,440
the winds maybe a little bit here and

1163
00:41:04,390 --> 00:41:03,040

then you've got the evaporation by the

1164
00:41:07,349 --> 00:41:04,400
central star

1165
00:41:08,870 --> 00:41:07,359
in the outer part and as i said this

1166
00:41:10,390 --> 00:41:08,880
does not mean that the inner part of

1167
00:41:12,950 --> 00:41:10,400
those intent of the fifth year is due to

1168
00:41:14,710 --> 00:41:12,960
viscous evolution what happens is that

1169
00:41:18,230 --> 00:41:14,720
this part of the disc lasts for a few

1170
00:41:20,950 --> 00:41:18,240
million years out here at 10 to 30 au

1171
00:41:23,030 --> 00:41:20,960
and then that viscously is replacing

1172
00:41:25,990 --> 00:41:23,040
this material inwards that's creeping

1173
00:41:27,990 --> 00:41:26,000
fairly rapidly onto the star

1174
00:41:29,990 --> 00:41:28,000
so that's the conclusion of these

1175
00:41:31,030 --> 00:41:30,000
dispersal mechanisms and you can start

1176
00:41:32,550 --> 00:41:31,040
to see

1177
00:41:33,829 --> 00:41:32,560
why uh

1178
00:41:35,829 --> 00:41:33,839
this

1179
00:41:38,630 --> 00:41:35,839
lose a lot of their mass and not all the

1180
00:41:41,750 --> 00:41:38,640
mass goes into planets

1181
00:41:43,870 --> 00:41:41,760
so let's now combine the two important

1182
00:41:45,750 --> 00:41:43,880
ones the viscous evolution and

1183
00:41:47,349 --> 00:41:45,760
photoevaporation and see how it disc

1184
00:41:49,030 --> 00:41:47,359
evolves we're starting to do evolution

1185
00:41:51,349 --> 00:41:49,040
calculations now

1186
00:41:53,829 --> 00:41:51,359
to do these we've had to make severe

1187
00:41:56,069 --> 00:41:53,839
approximations as to calculating the gas

1188
00:41:58,390 --> 00:41:56,079

temperature if we try to fully do the

1189
00:41:59,910 --> 00:41:58,400
chemistry and the thermal balance along

1190
00:42:02,069 --> 00:41:59,920
with the evolution that would take years

1191
00:42:03,829 --> 00:42:02,079
on a computer so we have this very

1192
00:42:05,270 --> 00:42:03,839
simple at this point it's a very simple

1193
00:42:06,790 --> 00:42:05,280
approximation and we're working toward

1194
00:42:08,470 --> 00:42:06,800
getting more sophisticated ones because

1195
00:42:09,829 --> 00:42:08,480
it's very sensitive to the gas

1196
00:42:11,990 --> 00:42:09,839
temperature but i think this will give

1197
00:42:14,710 --> 00:42:12,000
you an idea of what happens i'm pretty

1198
00:42:16,390 --> 00:42:14,720
sure that this gives a basic idea

1199
00:42:18,069 --> 00:42:16,400
so what i'm plotting here is the surface

1200
00:42:19,670 --> 00:42:18,079
density of the discs if you look

1201
00:42:21,510 --> 00:42:19,680
vertically through the disks how many

1202
00:42:23,990 --> 00:42:21,520
grams per square centimeters are in a

1203
00:42:25,670 --> 00:42:24,000
disk as a function of radius

1204
00:42:27,270 --> 00:42:25,680
and i'm showing you the evolution from 1

1205
00:42:29,270 --> 00:42:27,280
million years to 10 million years we

1206
00:42:30,390 --> 00:42:29,280
started off i should have shown you the

1207
00:42:32,390 --> 00:42:30,400
start off point

1208
00:42:34,550 --> 00:42:32,400
it was a surface density that dropped is

1209
00:42:36,950 --> 00:42:34,560
one over radius out to 200 au and then

1210
00:42:38,950 --> 00:42:36,960
it was truncated at 200 au

1211
00:42:42,230 --> 00:42:38,960
astronomical units

1212
00:42:43,990 --> 00:42:42,240
so what happens is that the viscous

1213
00:42:46,710 --> 00:42:44,000

evolution tends to give you this one

1214
00:42:48,870 --> 00:42:46,720
over r distribution of surface density

1215
00:42:51,270 --> 00:42:48,880
and because the mass goes as the surface

1216
00:42:53,910 --> 00:42:51,280
density times the area which is radius

1217
00:42:56,230 --> 00:42:53,920
squared most of the mass is actually out

1218
00:42:57,510 --> 00:42:56,240
here at 100 au

1219
00:42:59,270 --> 00:42:57,520
even though the surface density is

1220
00:43:00,790 --> 00:42:59,280
higher inward

1221
00:43:02,630 --> 00:43:00,800
so what you see is that the surface

1222
00:43:04,470 --> 00:43:02,640
density maintains a kind of a one over r

1223
00:43:06,630 --> 00:43:04,480
squared distribution and with just

1224
00:43:08,710 --> 00:43:06,640
viscous evolution going on

1225
00:43:10,550 --> 00:43:08,720
the mass is dropping some it maybe drops

1226
00:43:12,790 --> 00:43:10,560
a factor of 10 in the disk because it's

1227
00:43:14,630 --> 00:43:12,800
accreting onto the central star

1228
00:43:16,230 --> 00:43:14,640
but it also spreads you can see this

1229
00:43:18,309 --> 00:43:16,240
spreading effect you're getting material

1230
00:43:21,109 --> 00:43:18,319
now out of 1000 of you or even 10 000 of

1231
00:43:23,190 --> 00:43:21,119
you it's just the disc is spreading

1232
00:43:24,870 --> 00:43:23,200
so we can follow that evolution even i'm

1233
00:43:27,030 --> 00:43:24,880
sorry so now let's add

1234
00:43:29,270 --> 00:43:27,040
euv

1235
00:43:31,589 --> 00:43:29,280
that photo evaporation we just turn on

1236
00:43:34,630 --> 00:43:31,599
the hydrogen ionizing photons from this

1237
00:43:36,309 --> 00:43:34,640
one solar mass star shining on this disc

1238
00:43:38,230 --> 00:43:36,319

well for the first 10 million years it's

1239
00:43:40,230 --> 00:43:38,240
absolutely nothing happens the euv is

1240
00:43:43,430 --> 00:43:40,240
too weak even this is a very generous

1241
00:43:45,910 --> 00:43:43,440
amount of euv for a a one solar mass

1242
00:43:47,670 --> 00:43:45,920
star uh early in its evolution and even

1243
00:43:49,589 --> 00:43:47,680
with this generous amount

1244
00:43:51,750 --> 00:43:49,599
it's identical to just viscously

1245
00:43:53,589 --> 00:43:51,760
evolving for 10 million years the euv is

1246
00:43:55,109 --> 00:43:53,599
trying to eat away at 1au but there's

1247
00:43:55,990 --> 00:43:55,119
just so much mass there it's not doing

1248
00:43:57,910 --> 00:43:56,000
much

1249
00:44:00,390 --> 00:43:57,920
so you have to wait for the

1250
00:44:02,309 --> 00:44:00,400
surface density to drop at 1au for

1251
00:44:04,630 --> 00:44:02,319
anything to happen and so you have to

1252
00:44:06,630 --> 00:44:04,640
wait for the viscous evolution to keep

1253
00:44:09,349 --> 00:44:06,640
spreading the disc of creating the disc

1254
00:44:11,910 --> 00:44:09,359
lowering the mass so we now evolved it

1255
00:44:13,829 --> 00:44:11,920
for 22 million years and so the surface

1256
00:44:15,750 --> 00:44:13,839
density now this is at 10 million years

1257
00:44:17,190 --> 00:44:15,760
now the solid one

1258
00:44:18,790 --> 00:44:17,200
as you get close to 20 million years the

1259
00:44:21,349 --> 00:44:18,800
surface density drops enough that now

1260
00:44:23,750 --> 00:44:21,359
the euv you see it eating at 1au you see

1261
00:44:25,910 --> 00:44:23,760
it eating this hole in the disc

1262
00:44:27,190 --> 00:44:25,920
and you can see this little kink right

1263
00:44:29,670 --> 00:44:27,200

here

1264
00:44:31,589 --> 00:44:29,680
as it starts to eat this hole at i guess

1265
00:44:33,670 --> 00:44:31,599
it's about 20 million years

1266
00:44:36,710 --> 00:44:33,680
and then in the next time step which is

1267
00:44:38,069 --> 00:44:36,720
just a little bit after that it produces

1268
00:44:39,829 --> 00:44:38,079
a gap

1269
00:44:41,430 --> 00:44:39,839
at 1au you can

1270
00:44:42,950 --> 00:44:41,440
we didn't quite catch it in this so you

1271
00:44:45,190 --> 00:44:42,960
can see a little bit of material still

1272
00:44:47,109 --> 00:44:45,200
inside of one of you but very rapidly

1273
00:44:49,270 --> 00:44:47,119
then the whole inner part viscously it

1274
00:44:51,349 --> 00:44:49,280
creaks onto the star it just spirals

1275
00:44:53,510 --> 00:44:51,359
into the star from 1au inward and you

1276
00:44:56,550 --> 00:44:53,520
get a big hole in the center and you get

1277
00:44:58,870 --> 00:44:56,560
this torus of material outside of 1au

1278
00:45:01,910 --> 00:44:58,880
which then the euv photons each from the

1279
00:45:03,670 --> 00:45:01,920
inside out and you can see this

1280
00:45:05,750 --> 00:45:03,680
here it is at one time step at the next

1281
00:45:07,510 --> 00:45:05,760
at the next it's eating it out but

1282
00:45:09,270 --> 00:45:07,520
viciously it's kind of the disc has

1283
00:45:11,510 --> 00:45:09,280
spread so you have this torus of

1284
00:45:12,630 --> 00:45:11,520
material out at 100 or 1000 au of dust

1285
00:45:14,710 --> 00:45:12,640
and gas

1286
00:45:16,710 --> 00:45:14,720
so if this were really what was going on

1287
00:45:18,550 --> 00:45:16,720
in plant formation we would have first

1288
00:45:20,630 --> 00:45:18,560

of all uranus and neptune

1289
00:45:22,950 --> 00:45:20,640
which don't have much gas would be gas

1290
00:45:24,630 --> 00:45:22,960
rich like jupiter and saturn if this is

1291
00:45:26,790 --> 00:45:24,640
what were happening we'd probably have

1292
00:45:28,870 --> 00:45:26,800
more kuiper belt objects more comets i

1293
00:45:31,109 --> 00:45:28,880
mean we might have more planets out at

1294
00:45:33,030 --> 00:45:31,119
hundreds of au but we can observe that

1295
00:45:35,430 --> 00:45:33,040
this is not what's happening the dust

1296
00:45:37,270 --> 00:45:35,440
and gas is not surviving this long out

1297
00:45:39,829 --> 00:45:37,280
here at 100 au

1298
00:45:42,550 --> 00:45:39,839
so it's not just viscous secretion and

1299
00:45:45,109 --> 00:45:42,560
euv photo evaporation that's occurring

1300
00:45:47,190 --> 00:45:45,119
so now we add fuv evaporation this is

1301
00:45:49,750 --> 00:45:47,200
without euv this is just the ones that

1302
00:45:51,829 --> 00:45:49,760
can't ionize hydrogen but they can heat

1303
00:45:54,309 --> 00:45:51,839
up the surface gas

1304
00:45:56,069 --> 00:45:54,319
particularly out quite far

1305
00:45:57,910 --> 00:45:56,079
and you can see that what happens is

1306
00:45:59,910 --> 00:45:57,920
that with a reasonable amount of this

1307
00:46:01,750 --> 00:45:59,920
fuv luminosity quite comparable to what

1308
00:46:02,710 --> 00:46:01,760
we observe in these low mass stars like

1309
00:46:05,109 --> 00:46:02,720
the sun

1310
00:46:07,990 --> 00:46:05,119
that with fuv and with the viscous

1311
00:46:10,550 --> 00:46:08,000
evolution what we have is that the

1312
00:46:12,790 --> 00:46:10,560
outside is being eaten away by this

1313
00:46:14,550 --> 00:46:12,800

evaporation you can see the time it's

1314
00:46:17,190 --> 00:46:14,560
truncating closer and closer in the

1315
00:46:19,109 --> 00:46:17,200
outside is being eaten by fpv viscous is

1316
00:46:21,990 --> 00:46:19,119
trying to push it out but as it pushes

1317
00:46:23,829 --> 00:46:22,000
it out it just gets evaporated away and

1318
00:46:26,150 --> 00:46:23,839
you can see that in a few million years

1319
00:46:29,270 --> 00:46:26,160
the the surface density goes down

1320
00:46:31,910 --> 00:46:29,280
and very rapidly you can also see that

1321
00:46:33,750 --> 00:46:31,920
there isn't much left i mean once this

1322
00:46:35,750 --> 00:46:33,760
combination of viscous evolution and

1323
00:46:37,510 --> 00:46:35,760
photo evaporation are taking place you

1324
00:46:39,910 --> 00:46:37,520
don't have 10 to the minus two jupiter

1325
00:46:41,670 --> 00:46:39,920
masses to circularize the orbits of

1326
00:46:44,230 --> 00:46:41,680
lunar mass things i mean it just goes

1327
00:46:46,309 --> 00:46:44,240
away fast very fast

1328
00:46:49,190 --> 00:46:46,319
all goes away

1329
00:46:51,829 --> 00:46:49,200
so now we combine euv and fuv and

1330
00:46:53,670 --> 00:46:51,839
viscous evolution and that even shortens

1331
00:46:55,910 --> 00:46:53,680
it a little bit more now it takes only

1332
00:46:58,150 --> 00:46:55,920
about 2.7 million years for it to come

1333
00:47:01,190 --> 00:46:58,160
basically completely go away and you can

1334
00:47:03,349 --> 00:47:01,200
see that the combination of the fuv and

1335
00:47:05,829 --> 00:47:03,359
the viscous evolution drives the surface

1336
00:47:07,510 --> 00:47:05,839
density down and then euv burns a hole

1337
00:47:09,990 --> 00:47:07,520
at one au you see this little gap i

1338
00:47:12,390 --> 00:47:10,000

should call it a gap first there's a gap

1339
00:47:14,550 --> 00:47:12,400
here and then in a time step to 2.7

1340
00:47:17,430 --> 00:47:14,560
million years all that material inside

1341
00:47:19,030 --> 00:47:17,440
the gap this material that's shown here

1342
00:47:21,670 --> 00:47:19,040
just all it creates onto the central

1343
00:47:23,990 --> 00:47:21,680
star and you get a torus that briefly

1344
00:47:25,190 --> 00:47:24,000
exists between 10 and 100 au but briefly

1345
00:47:27,270 --> 00:47:25,200
meaning 10 to the fifth years this

1346
00:47:28,309 --> 00:47:27,280
doesn't last long that you have a little

1347
00:47:30,230 --> 00:47:28,319
sort of a

1348
00:47:34,069 --> 00:47:30,240
inner hole with an outer disc but it

1349
00:47:38,710 --> 00:47:36,069
so it's maybe easier to see if i plot it

1350
00:47:40,230 --> 00:47:38,720
just as the disc mass versus uh

1351
00:47:41,109 --> 00:47:40,240
time

1352
00:47:43,430 --> 00:47:41,119
um

1353
00:47:45,829 --> 00:47:43,440
and so here i'm plotting the mass of the

1354
00:47:47,510 --> 00:47:45,839
disc as a in solar masses

1355
00:47:51,109 --> 00:47:47,520
which starts off at a tenth of a solar

1356
00:47:53,109 --> 00:47:51,119
mass around a one solar mass star uh and

1357
00:47:54,950 --> 00:47:53,119
this solid line or this line here is

1358
00:47:57,349 --> 00:47:54,960
just viscous evolution and you can see

1359
00:47:59,030 --> 00:47:57,359
that the disc does keep getting less and

1360
00:48:00,950 --> 00:47:59,040
less in mass as material accretes on the

1361
00:48:03,829 --> 00:48:00,960
star but it's spreading and it's just

1362
00:48:05,270 --> 00:48:03,839
lowering its mass to a factor of 10 over

1363
00:48:07,589 --> 00:48:05,280

you know tens of millions of years this

1364
00:48:09,270 --> 00:48:07,599
we do not observe and this this would be

1365
00:48:10,710 --> 00:48:09,280
an optically thick disc existing for

1366
00:48:11,430 --> 00:48:10,720
very long periods of time which we don't

1367
00:48:13,589 --> 00:48:11,440
see

1368
00:48:16,069 --> 00:48:13,599
so that doesn't happen if we turn on the

1369
00:48:17,829 --> 00:48:16,079
euv it it still lasts too long but then

1370
00:48:20,069 --> 00:48:17,839
if the combination of viscous evolution

1371
00:48:21,910 --> 00:48:20,079
and euv does all of a sudden rapidly get

1372
00:48:23,990 --> 00:48:21,920
rid of the rest of the mass

1373
00:48:25,670 --> 00:48:24,000
the euv eats this hole in the disc and

1374
00:48:27,910 --> 00:48:25,680
then it rapidly photo evaporates the

1375
00:48:29,430 --> 00:48:27,920
outside part of the disc which viscously

1376
00:48:33,349 --> 00:48:29,440
would have lasted a long time but with

1377
00:48:35,270 --> 00:48:33,359
ev being added lasts a short time

1378
00:48:37,349 --> 00:48:35,280
but then if you add the fuv from the

1379
00:48:39,109 --> 00:48:37,359
star the non-hydrogen ionizing photons

1380
00:48:41,670 --> 00:48:39,119
we get an evolution where the disc mass

1381
00:48:44,549 --> 00:48:41,680
very rapidly cuts off uh to very low

1382
00:48:46,630 --> 00:48:44,559
values at a few million years

1383
00:48:47,589 --> 00:48:46,640
and that's kind of what we see and so we

1384
00:48:50,069 --> 00:48:47,599
think that we're starting to

1385
00:48:51,510 --> 00:48:50,079
theoretically understand what we see uh

1386
00:48:53,349 --> 00:48:51,520
observationally and we started to

1387
00:48:56,549 --> 00:48:53,359
understand it's its effect then on

1388
00:48:58,549 --> 00:48:56,559

planet formation and habitable planets

1389
00:48:59,910 --> 00:48:58,559
so very recently over the weekend we've

1390
00:49:00,710 --> 00:48:59,920
been doing runs

1391
00:49:04,230 --> 00:49:00,720
and

1392
00:49:05,510 --> 00:49:04,240
crude

1393
00:49:06,870 --> 00:49:05,520
assumption about what the gas

1394
00:49:08,150 --> 00:49:06,880
temperature is

1395
00:49:09,750 --> 00:49:08,160
in these discs

1396
00:49:11,990 --> 00:49:09,760
because we can't do the detailed

1397
00:49:13,510 --> 00:49:12,000
calculation but we've done the evolution

1398
00:49:15,190 --> 00:49:13,520
of the mass of the disc like i just

1399
00:49:16,950 --> 00:49:15,200
showed you the case for the one solar

1400
00:49:19,190 --> 00:49:16,960
mass star but we've done it around a 30

1401
00:49:20,069 --> 00:49:19,200
solar mass star and a 0.5 solar mass

1402
00:49:21,829 --> 00:49:20,079
star

1403
00:49:23,670 --> 00:49:21,839
and you can see that in the 30 solar

1404
00:49:25,750 --> 00:49:23,680
mass star you start off with a bigger

1405
00:49:27,190 --> 00:49:25,760
mass disc because more massive stars

1406
00:49:29,430 --> 00:49:27,200
tend to start off with a more massive

1407
00:49:31,589 --> 00:49:29,440
disc but because they have so much uv

1408
00:49:33,190 --> 00:49:31,599
they rapidly in in a few ten to the

1409
00:49:34,390 --> 00:49:33,200
fifth years go away

1410
00:49:35,510 --> 00:49:34,400
and i think it's even gonna be a little

1411
00:49:37,510 --> 00:49:35,520
shorter than this probably gonna be more

1412
00:49:39,270 --> 00:49:37,520
like one times ten to the fifth years

1413
00:49:41,750 --> 00:49:39,280

but uh when we do the detailed

1414
00:49:43,190 --> 00:49:41,760
calculation but it's very rapid so these

1415
00:49:44,630 --> 00:49:43,200
of course these stars don't last very

1416
00:49:45,670 --> 00:49:44,640
long but the discs really don't last

1417
00:49:47,349 --> 00:49:45,680
very long

1418
00:49:49,349 --> 00:49:47,359
and it's very unlikely places for

1419
00:49:51,510 --> 00:49:49,359
planets to form

1420
00:49:53,270 --> 00:49:51,520
if you go to lower mass stars than the

1421
00:49:54,790 --> 00:49:53,280
sun the interesting thing is is first of

1422
00:49:55,589 --> 00:49:54,800
all they start off with a lower mass

1423
00:49:57,510 --> 00:49:55,599
disc

1424
00:49:59,910 --> 00:49:57,520
secondly because their gravity holds the

1425
00:50:01,829 --> 00:49:59,920
disc less strongly we tend to get photo

1426
00:50:03,190 --> 00:50:01,839
evaporation happening more rapidly and

1427
00:50:05,109 --> 00:50:03,200
so they

1428
00:50:07,589 --> 00:50:05,119
more rapidly disappear too and they

1429
00:50:09,750 --> 00:50:07,599
start off with less mass so if you are

1430
00:50:11,270 --> 00:50:09,760
thinking that what planets need is to

1431
00:50:12,870 --> 00:50:11,280
have a lot of gas and dust for the

1432
00:50:15,270 --> 00:50:12,880
longest period of time or for them to

1433
00:50:17,109 --> 00:50:15,280
have time to form the planets then it

1434
00:50:18,870 --> 00:50:17,119
turns out that a solar mass car is a

1435
00:50:20,790 --> 00:50:18,880
kind of a good place because you can see

1436
00:50:23,190 --> 00:50:20,800
that there's more mass in the disk and

1437
00:50:25,829 --> 00:50:23,200
it lasts longer

1438
00:50:27,510 --> 00:50:25,839

or this this just integrate the amount

1439
00:50:29,589 --> 00:50:27,520
of mass and how long it lasts the one

1440
00:50:31,829 --> 00:50:29,599
solar mass star is the best and we think

1441
00:50:33,109 --> 00:50:31,839
the cutoff where where we really start

1442
00:50:34,630 --> 00:50:33,119
getting rapid

1443
00:50:36,870 --> 00:50:34,640
dispersion of the disc is probably

1444
00:50:38,630 --> 00:50:36,880
around five solar masses but we need

1445
00:50:42,150 --> 00:50:38,640
detailed models of the of the

1446
00:50:44,150 --> 00:50:42,160
temperature to really pinpoint that

1447
00:50:45,950 --> 00:50:44,160
so i'm going to conclude by summarizing

1448
00:50:48,470 --> 00:50:45,960
and telling what i think are the

1449
00:50:50,790 --> 00:50:48,480
astrobiological conclusions of this sort

1450
00:50:52,630 --> 00:50:50,800
of theoretical description of how we

1451
00:50:53,829 --> 00:50:52,640
think plants form and what kind of

1452
00:50:55,430 --> 00:50:53,839
environments are going to be good and

1453
00:50:56,870 --> 00:50:55,440
what kind of stellar masses are good for

1454
00:50:58,870 --> 00:50:56,880
plant information

1455
00:51:00,710 --> 00:50:58,880
so the summary is that photoevaporation

1456
00:51:02,470 --> 00:51:00,720
is the dominant dispersal mechanism for

1457
00:51:04,150 --> 00:51:02,480
the outer part of the disc beyond a few

1458
00:51:06,230 --> 00:51:04,160
astronomical units

1459
00:51:07,829 --> 00:51:06,240
viscous spreading and accretion dis is

1460
00:51:08,870 --> 00:51:07,839
what disperses the inner part of the

1461
00:51:10,710 --> 00:51:08,880
disc

1462
00:51:13,270 --> 00:51:10,720
the winds and stellar encounters play

1463
00:51:15,589 --> 00:51:13,280

little role in dispersal

1464
00:51:18,309 --> 00:51:15,599
the photo evaporation by the euv from

1465
00:51:20,710 --> 00:51:18,319
the central star oops sorry

1466
00:51:22,549 --> 00:51:20,720
creates a gap at a few au and then an

1467
00:51:24,150 --> 00:51:22,559
inner hole and then it rapidly photo

1468
00:51:25,510 --> 00:51:24,160
evaporates the outer torus from the

1469
00:51:28,309 --> 00:51:25,520
inside out

1470
00:51:30,309 --> 00:51:28,319
whereas photo evaporation by fuv or by

1471
00:51:32,630 --> 00:51:30,319
external star photo evaporates from the

1472
00:51:34,309 --> 00:51:32,640
outside in and it has a sharp outer edge

1473
00:51:36,069 --> 00:51:34,319
and it just evaporates from the outside

1474
00:51:37,670 --> 00:51:36,079
in

1475
00:51:39,750 --> 00:51:37,680
now if you take this

1476
00:51:42,710 --> 00:51:39,760
photo evaporation by the central star or

1477
00:51:45,430 --> 00:51:42,720
by a nearby massive star

1478
00:51:47,589 --> 00:51:45,440
and what we find is that it evaporates

1479
00:51:48,470 --> 00:51:47,599
the main mass reservoir of the disk so

1480
00:51:50,470 --> 00:51:48,480
this

1481
00:51:52,069 --> 00:51:50,480
process in conjunction with viscous

1482
00:51:53,910 --> 00:51:52,079
evolution determines their lifestyle

1483
00:51:55,430 --> 00:51:53,920
it's not just viscous evolution that

1484
00:51:57,750 --> 00:51:55,440
determines it it's the combination of

1485
00:51:59,829 --> 00:51:57,760
the photoevaporation and viscous that

1486
00:52:01,190 --> 00:51:59,839
determines how these discs evolve

1487
00:52:03,670 --> 00:52:01,200
in their in their gas and dust and

1488
00:52:06,069 --> 00:52:03,680

therefore how planets form

1489
00:52:07,750 --> 00:52:06,079
so i've tried to draw some astrobiology

1490
00:52:10,790 --> 00:52:07,760
conclusions from this i mean there's

1491
00:52:12,790 --> 00:52:10,800
some clear ones first of all

1492
00:52:14,309 --> 00:52:12,800
there are stars born near massive stars

1493
00:52:16,390 --> 00:52:14,319
that are going to just completely blow

1494
00:52:17,829 --> 00:52:16,400
away their discs the massive stars are

1495
00:52:20,390 --> 00:52:17,839
going to evaporate these discs fast and

1496
00:52:22,790 --> 00:52:20,400
we probably see this happening in orion

1497
00:52:25,190 --> 00:52:22,800
and so but we think in estimating what

1498
00:52:27,349 --> 00:52:25,200
fraction of solar type stars that that

1499
00:52:29,990 --> 00:52:27,359
do this is probably on the order of 5 to

1500
00:52:31,589 --> 00:52:30,000
30 percent so it's not a huge fraction

1501
00:52:32,950 --> 00:52:31,599
but there is going to be some discs that

1502
00:52:35,109 --> 00:52:32,960
are going to be compromised the planet

1503
00:52:37,190 --> 00:52:35,119
formation compromised

1504
00:52:39,510 --> 00:52:37,200
stars more massive than about five solar

1505
00:52:40,790 --> 00:52:39,520
masses don't need an external star to do

1506
00:52:42,069 --> 00:52:40,800
damage they're going to damage

1507
00:52:43,510 --> 00:52:42,079
themselves they're going to

1508
00:52:45,109 --> 00:52:43,520
self-destruct

1509
00:52:46,710 --> 00:52:45,119
and they'll lose their discs in less

1510
00:52:48,549 --> 00:52:46,720
than a million years and make it

1511
00:52:52,069 --> 00:52:48,559
difficult for for planets to form

1512
00:52:53,829 --> 00:52:52,079
particularly gas giant planets

1513
00:52:56,470 --> 00:52:53,839

and then the photo evaporation by the

1514
00:52:58,549 --> 00:52:56,480
central star may lead to a peak in the

1515
00:53:02,150 --> 00:52:58,559
disk mass in lifetime first or disks

1516
00:53:04,470 --> 00:53:02,160
around roughly one silver mass stars

1517
00:53:07,510 --> 00:53:04,480
that this may be the best place

1518
00:53:09,430 --> 00:53:07,520
for for uh for habitable planets to form

1519
00:53:11,030 --> 00:53:09,440
because the discs have the most time to

1520
00:53:12,950 --> 00:53:11,040
form the planets

1521
00:53:15,990 --> 00:53:12,960
and the and we've seen that in these

1522
00:53:18,309 --> 00:53:16,000
models that we rarely we never uh have

1523
00:53:22,230 --> 00:53:18,319
seen that we could keep 10 to the minus

1524
00:53:23,990 --> 00:53:22,240
two jupiter masses of gas lasting for um

1525
00:53:25,910 --> 00:53:24,000
uh tens of millions of years which would

1526
00:53:28,710 --> 00:53:25,920
then circularize the planet the orbits

1527
00:53:30,549 --> 00:53:28,720
of the earth size or the of lunar-sized

1528
00:53:33,270 --> 00:53:30,559
planets and prevent them from forming

1529
00:53:35,510 --> 00:53:33,280
earth-sized planets

1530
00:53:37,589 --> 00:53:35,520
so i i wanted to sort of finish on some

1531
00:53:39,430 --> 00:53:37,599
caveats though remember that

1532
00:53:40,870 --> 00:53:39,440
for this that lose their mass in less

1533
00:53:43,349 --> 00:53:40,880
than three million years which is what

1534
00:53:44,870 --> 00:53:43,359
i've been focusing on by this process of

1535
00:53:47,030 --> 00:53:44,880
photo evaporation

1536
00:53:48,790 --> 00:53:47,040
in with viscous evolution

1537
00:53:50,790 --> 00:53:48,800
certainly giant plant formation is

1538
00:53:52,630 --> 00:53:50,800

suppressed if it's if it's caused by

1539
00:53:54,230 --> 00:53:52,640
core accretion which

1540
00:53:56,950 --> 00:53:54,240
many of us think is the dominant way to

1541
00:53:59,109 --> 00:53:56,960
make gas giants so

1542
00:54:01,910 --> 00:53:59,119
giant plants are likely to be suppressed

1543
00:54:03,430 --> 00:54:01,920
now they may have an effect on uh on the

1544
00:54:04,790 --> 00:54:03,440
likelihood of life we know i mean

1545
00:54:05,990 --> 00:54:04,800
because we know that for example in the

1546
00:54:08,309 --> 00:54:06,000
earth system

1547
00:54:09,670 --> 00:54:08,319
jupiter has a protective effect dave

1548
00:54:11,430 --> 00:54:09,680
morrison is actually an audience so i

1549
00:54:14,069 --> 00:54:11,440
can check with him but i think it

1550
00:54:16,309 --> 00:54:14,079
protects us from uh from a too high a

1551
00:54:19,589 --> 00:54:16,319
bombardment by the kuiper belt objects

1552
00:54:21,589 --> 00:54:19,599
and by objects that form comets uh

1553
00:54:23,109 --> 00:54:21,599
that the giant planets have a protective

1554
00:54:25,030 --> 00:54:23,119
effect that way we might get bombarded

1555
00:54:26,470 --> 00:54:25,040
too rapidly

1556
00:54:28,630 --> 00:54:26,480
if we didn't have

1557
00:54:29,510 --> 00:54:28,640
jupiter there

1558
00:54:30,710 --> 00:54:29,520
now

1559
00:54:32,950 --> 00:54:30,720
okay so

1560
00:54:34,309 --> 00:54:32,960
these giant plants then may have some

1561
00:54:36,549 --> 00:54:34,319
effect on the habitability of

1562
00:54:38,309 --> 00:54:36,559
terrestrial planets and uh and what

1563
00:54:40,710 --> 00:54:38,319

we're see and of course if we're talking

1564
00:54:42,230 --> 00:54:40,720
about moons around giant planets then uh

1565
00:54:43,910 --> 00:54:42,240
they're they're uh

1566
00:54:46,069 --> 00:54:43,920
the giant planet will be suppressed in

1567
00:54:48,470 --> 00:54:46,079
these cases uh we're talking about

1568
00:54:51,589 --> 00:54:48,480
habitable life forming around moons

1569
00:54:53,349 --> 00:54:51,599
now less certain uh is how is the comets

1570
00:54:55,270 --> 00:54:53,359
themselves or the kuiper belt objects

1571
00:54:57,670 --> 00:54:55,280
themselves that form comets that have

1572
00:54:59,829 --> 00:54:57,680
all these ice and and volatile rich

1573
00:55:02,230 --> 00:54:59,839
material they may be suppressed because

1574
00:55:03,910 --> 00:55:02,240
you see that we rap and very rapidly get

1575
00:55:06,470 --> 00:55:03,920
rid of this outer material and so if we

1576
00:55:08,710 --> 00:55:06,480
can get rid of the dust faster than it

1577
00:55:10,630 --> 00:55:08,720
can coagulate into big enough sizes and

1578
00:55:12,150 --> 00:55:10,640
by big enough sizes i mean you know

1579
00:55:14,950 --> 00:55:12,160
things that are centimeters are bigger

1580
00:55:18,309 --> 00:55:14,960
in size if it can happen faster than

1581
00:55:19,270 --> 00:55:18,319
that then it won't form uh these comets

1582
00:55:21,030 --> 00:55:19,280
these uh

1583
00:55:22,870 --> 00:55:21,040
kuiper belt objects

1584
00:55:24,549 --> 00:55:22,880
but terrestrial planet formation help

1585
00:55:27,109 --> 00:55:24,559
may not be suppressed even in those

1586
00:55:28,870 --> 00:55:27,119
cases where we we disperse the disc in

1587
00:55:31,270 --> 00:55:28,880
say a million years because this

1588
00:55:33,510 --> 00:55:31,280

coagulation at 1au of the of the dust

1589
00:55:34,630 --> 00:55:33,520
particles sizes big big enough to form

1590
00:55:37,109 --> 00:55:34,640
rocks

1591
00:55:39,990 --> 00:55:37,119
is very rapid we think and so even if

1592
00:55:41,990 --> 00:55:40,000
the gas got evaporated in in a few times

1593
00:55:43,750 --> 00:55:42,000
the fifth years there may be rocks left

1594
00:55:45,190 --> 00:55:43,760
which then can slowly build up a

1595
00:55:47,990 --> 00:55:45,200
terrestrial earth

1596
00:55:49,750 --> 00:55:48,000
so that so we may have a class of system

1597
00:55:51,030 --> 00:55:49,760
where there's a class of stars where

1598
00:55:52,789 --> 00:55:51,040
they have terrestrial planets but they

1599
00:55:55,190 --> 00:55:52,799
don't have giant planets and possibly no

1600
00:55:57,829 --> 00:55:55,200
kuiper belts uh it's impossible

1601
00:55:59,670 --> 00:55:57,839
so i'll leave you with that thought uh

1602
00:56:00,829 --> 00:55:59,680
and conclude and ask for questions if

1603
00:56:06,630 --> 00:56:00,839
there are some

1604
00:56:12,309 --> 00:56:09,030
okay if you have questions please raise

1605
00:56:15,190 --> 00:56:12,319
your hand on webex and i'll take

1606
00:56:17,910 --> 00:56:15,200
advantage of hosting over here to start

1607
00:56:19,750 --> 00:56:17,920
off the questioning uh dave

1608
00:56:24,870 --> 00:56:19,760
if

1609
00:56:26,789 --> 00:56:24,880
long enough to circularize orbits of

1610
00:56:28,630 --> 00:56:26,799
terrestrial planets how do you get

1611
00:56:30,950 --> 00:56:28,640
circular orbits

1612
00:56:34,230 --> 00:56:30,960
in a solar system like ours

1613
00:56:38,870 --> 00:56:35,829

yeah i have to say that it's a matter of

1614
00:56:41,109 --> 00:56:38,880
degree that the models that uh don't

1615
00:56:43,270 --> 00:56:41,119
have gas in them uh and and don't have

1616
00:56:44,470 --> 00:56:43,280
any anything else to circularize the

1617
00:56:47,910 --> 00:56:44,480
orbits

1618
00:56:49,990 --> 00:56:47,920
that elliptical but they are more

1619
00:56:52,150 --> 00:56:50,000
elliptical than the earth is i mean i'll

1620
00:56:54,069 --> 00:56:52,160
say that so they're the so there has

1621
00:56:55,670 --> 00:56:54,079
been when they do these models where the

1622
00:56:57,990 --> 00:56:55,680
the sort of the moons crash into each

1623
00:56:59,750 --> 00:56:58,000
other and so forth you end up with a an

1624
00:57:01,270 --> 00:56:59,760
earth that's on a somewhat elliptical

1625
00:57:03,349 --> 00:57:01,280
orbit it's pretty circular but it is

1626
00:57:06,150 --> 00:57:03,359
elliptical and it's more elliptical than

1627
00:57:08,549 --> 00:57:06,160
the earth is observed to orbit so

1628
00:57:10,309 --> 00:57:08,559
there's been this was a this mechanism

1629
00:57:12,150 --> 00:57:10,319
the gas was an attempt to actually

1630
00:57:14,069 --> 00:57:12,160
explain that uh was an attempt to say

1631
00:57:16,710 --> 00:57:14,079
well what then did circularize the earth

1632
00:57:19,190 --> 00:57:16,720
to the to the almost exact circle that

1633
00:57:21,750 --> 00:57:19,200
we're in uh and it would it was intense

1634
00:57:23,430 --> 00:57:21,760
and i i think that these models seem to

1635
00:57:25,030 --> 00:57:23,440
indicate that that probably won't work

1636
00:57:27,349 --> 00:57:25,040
and so we need something else another

1637
00:57:29,430 --> 00:57:27,359
suggestion is that if you have if when

1638
00:57:31,430 --> 00:57:29,440

the earth formed there's a lot of small

1639
00:57:33,829 --> 00:57:31,440
rocky objects around they can have the

1640
00:57:35,190 --> 00:57:33,839
same kind of effect they can produce

1641
00:57:36,630 --> 00:57:35,200
this sort of dynamic but you need a

1642
00:57:38,230 --> 00:57:36,640
fairly high mass of these things you

1643
00:57:39,910 --> 00:57:38,240
need something that's comparable to the

1644
00:57:40,950 --> 00:57:39,920
earth mass in order to

1645
00:57:42,309 --> 00:57:40,960
are bigger than the earth somewhat

1646
00:57:44,390 --> 00:57:42,319
bigger than the earth mass in order to

1647
00:57:47,349 --> 00:57:44,400
circularize here so maybe it's

1648
00:57:48,470 --> 00:57:47,359
it's uh it's not gas it's it's objects

1649
00:57:50,309 --> 00:57:48,480
that are

1650
00:57:53,270 --> 00:57:50,319
you know rocks or moon or you know

1651
00:57:56,069 --> 00:57:53,280
smaller size things that circularize it

1652
00:57:57,829 --> 00:57:56,079
thank you i see we have at least one

1653
00:58:00,150 --> 00:57:57,839
hand raised on webex so i'll turn over

1654
00:58:01,910 --> 00:58:00,160
to marco

1655
00:58:04,950 --> 00:58:01,920
um

1656
00:58:07,510 --> 00:58:06,309
okay

1657
00:58:08,789 --> 00:58:07,520
thank you

1658
00:58:11,510 --> 00:58:08,799
hi

1659
00:58:13,829 --> 00:58:11,520
very nice talk great uh i have a few

1660
00:58:16,470 --> 00:58:13,839
questions i'm not sure if i have the

1661
00:58:19,750 --> 00:58:16,480
time to ask all of them but

1662
00:58:23,109 --> 00:58:19,760
let me ask you two first uh this is a

1663
00:58:26,230 --> 00:58:23,119

probably technical point so uh

1664
00:58:29,270 --> 00:58:26,240
you said that a one a gap is formed by

1665
00:58:30,390 --> 00:58:29,280
the uv photon evaporation of the inside

1666
00:58:31,670 --> 00:58:30,400
of the

1667
00:58:34,950 --> 00:58:31,680
disc then

1668
00:58:37,109 --> 00:58:34,960
mass will flow inside from some uh

1669
00:58:40,230 --> 00:58:37,119
perhaps the

1670
00:58:42,309 --> 00:58:40,240
most massive location but does the same

1671
00:58:45,190 --> 00:58:42,319
thing happen when the

1672
00:58:46,470 --> 00:58:45,200
fuv photons evaporate the outside part

1673
00:58:49,670 --> 00:58:46,480
of the disk

1674
00:58:51,430 --> 00:58:49,680
that mass will flow outside outward

1675
00:58:53,109 --> 00:58:51,440
does that occur

1676
00:58:53,910 --> 00:58:53,119
yes it does uh

1677
00:58:54,950 --> 00:58:53,920
the

1678
00:58:56,309 --> 00:58:54,960
is that

1679
00:58:58,309 --> 00:58:56,319
in fact

1680
00:59:01,190 --> 00:58:58,319
what happens in the in the cases that i

1681
00:59:02,870 --> 00:59:01,200
showed with the combination of say the

1682
00:59:04,789 --> 00:59:02,880
fuv photons which are heating the outer

1683
00:59:07,109 --> 00:59:04,799
part of the disc and viscous evolution

1684
00:59:08,710 --> 00:59:07,119
what's going on is a competition between

1685
00:59:10,470 --> 00:59:08,720
the viscous accretion is trying to

1686
00:59:12,150 --> 00:59:10,480
spread the disc out further but then

1687
00:59:13,750 --> 00:59:12,160
evaporation is trying to truncate it and

1688
00:59:15,910 --> 00:59:13,760

so you sort of reach a kind of a

1689
00:59:17,670 --> 00:59:15,920
quasi-steady-state

1690
00:59:19,430 --> 00:59:17,680
distribution of surface density such

1691
00:59:21,510 --> 00:59:19,440
that the viscous evolution is pushing

1692
00:59:23,190 --> 00:59:21,520
things out and then the uh the photo

1693
00:59:25,349 --> 00:59:23,200
evaporation is driving things in and so

1694
00:59:27,030 --> 00:59:25,359
that the solutions you saw sort of

1695
00:59:28,710 --> 00:59:27,040
reflect that tension between the two

1696
00:59:29,910 --> 00:59:28,720
processes

1697
00:59:32,549 --> 00:59:29,920
great thank you

1698
00:59:34,470 --> 00:59:32,559
the other part where the gap is uh yeah

1699
00:59:36,390 --> 00:59:34,480
it's just that the once the gap forms

1700
00:59:37,190 --> 00:59:36,400
due to the euv photons

1701
00:59:39,510 --> 00:59:37,200
then

1702
00:59:41,910 --> 00:59:39,520
the inside no longer is getting the the

1703
00:59:43,829 --> 00:59:41,920
outside can't accrete onto to replace

1704
00:59:45,750 --> 00:59:43,839
the inside because there's this gap and

1705
00:59:47,829 --> 00:59:45,760
because everything that comes in is

1706
00:59:50,069 --> 00:59:47,839
being evaporated by the euv photons at

1707
00:59:52,230 --> 00:59:50,079
that gap and so nothing is replenishing

1708
00:59:54,309 --> 00:59:52,240
the inside so when the inside doesn't

1709
00:59:55,910 --> 00:59:54,319
have a outside source to replenish it it

1710
00:59:57,829 --> 00:59:55,920
very rapidly just decreases onto the

1711
01:00:00,309 --> 00:59:57,839
central star

1712
01:00:01,750 --> 01:00:00,319
great and uh in one of your slides i

1713
01:00:03,910 --> 01:00:01,760

think it's a

1714
01:00:07,190 --> 01:00:03,920
very new result continue

1715
01:00:09,510 --> 01:00:07,200
probably uh has a six uh but basically

1716
01:00:13,510 --> 01:00:09,520
what i want to ask is uh in though all

1717
01:00:15,670 --> 01:00:13,520
those figures uh ua for fuv

1718
01:00:18,549 --> 01:00:15,680
those are only considering the

1719
01:00:21,270 --> 01:00:18,559
contribution from the central star not

1720
01:00:23,430 --> 01:00:21,280
the external star is that correct

1721
01:00:25,510 --> 01:00:23,440
yes i i think i don't know if you can

1722
01:00:27,030 --> 01:00:25,520
see my view graphs but yeah although

1723
01:00:29,349 --> 01:00:27,040
very new results

1724
01:00:30,789 --> 01:00:29,359
yeah that yes what happened uh

1725
01:00:32,630 --> 01:00:30,799
historically was that i worked on the

1726
01:00:35,349 --> 01:00:32,640
external stars first and so the newer

1727
01:00:37,109 --> 01:00:35,359
results are the internal stars in some

1728
01:00:38,309 --> 01:00:37,119
sense the external stars are simpler

1729
01:00:40,309 --> 01:00:38,319
case uh

1730
01:00:42,390 --> 01:00:40,319
because the um

1731
01:00:44,549 --> 01:00:42,400
the radius well it's just

1732
01:00:47,589 --> 01:00:44,559
the problem with the the central star is

1733
01:00:49,270 --> 01:00:47,599
that the disc flares in response to this

1734
01:00:50,950 --> 01:00:49,280
heating of the surface and then the

1735
01:00:53,109 --> 01:00:50,960
radius of transfer to calculate the

1736
01:00:54,309 --> 01:00:53,119
heating depends on all your solutions on

1737
01:00:55,670 --> 01:00:54,319
the inside

1738
01:00:57,190 --> 01:00:55,680

and how the how the photons from the

1739
01:00:58,630 --> 01:00:57,200
central star can make it through the

1740
01:01:00,309 --> 01:00:58,640
inner part of the disc out to the outer

1741
01:01:01,589 --> 01:01:00,319
part of the disc and so it's it's more

1742
01:01:02,470 --> 01:01:01,599
complicated when you have an external

1743
01:01:03,589 --> 01:01:02,480
star

1744
01:01:05,910 --> 01:01:03,599
basically

1745
01:01:07,829 --> 01:01:05,920
what the the most of the photons are

1746
01:01:09,349 --> 01:01:07,839
evaporating the outside rim of the star

1747
01:01:10,950 --> 01:01:09,359
first and then working their way inward

1748
01:01:12,950 --> 01:01:10,960
and there isn't this complicated uh

1749
01:01:15,589 --> 01:01:12,960
treatment of the rate of transfer of the

1750
01:01:17,270 --> 01:01:15,599
photons going in yes all these were just

1751
01:01:18,789 --> 01:01:17,280
from the central star at the end here

1752
01:01:21,109 --> 01:01:18,799
yeah

1753
01:01:22,230 --> 01:01:21,119
do you always assume that the disk mass

1754
01:01:23,109 --> 01:01:22,240
is a

1755
01:01:25,109 --> 01:01:23,119
10

1756
01:01:27,109 --> 01:01:25,119
of the star mass

1757
01:01:28,230 --> 01:01:27,119
no we can vary that the reason that i

1758
01:01:29,589 --> 01:01:28,240
chose that

1759
01:01:31,190 --> 01:01:29,599
was that based on the sort of

1760
01:01:32,390 --> 01:01:31,200
theoretical idea

1761
01:01:35,190 --> 01:01:32,400
that

1762
01:01:37,190 --> 01:01:35,200
uh in the initial formation of the disc

1763
01:01:39,589 --> 01:01:37,200

the disc mass builds up until it becomes

1764
01:01:41,270 --> 01:01:39,599
gravitationally unstable so it's hard to

1765
01:01:42,950 --> 01:01:41,280
get it more massive than point one of

1766
01:01:45,190 --> 01:01:42,960
the stellar mass because then it really

1767
01:01:47,270 --> 01:01:45,200
gets violently gravitationally unstable

1768
01:01:50,230 --> 01:01:47,280
and it starts to really rapidly either

1769
01:01:51,990 --> 01:01:50,240
form a binary or or a creed onto the

1770
01:01:53,030 --> 01:01:52,000
central star and actually the first

1771
01:01:54,549 --> 01:01:53,040
thing that happens is it starts to

1772
01:01:55,510 --> 01:01:54,559
really accrete rapidly under the central

1773
01:01:59,349 --> 01:01:55,520
star

1774
01:02:00,870 --> 01:01:59,359
that idea is that's a threshold just

1775
01:02:03,589 --> 01:02:00,880
where you start to get gravitationally

1776
01:02:06,870 --> 01:02:03,599
unstable and it's a roughly 0.1 solar

1777
01:02:08,470 --> 01:02:06,880
masses it can be a little more or less

1778
01:02:10,230 --> 01:02:08,480
but we can in our models of course we

1779
01:02:11,589 --> 01:02:10,240
can start with any mass we want if we

1780
01:02:13,270 --> 01:02:11,599
start with lower masses then we get

1781
01:02:14,309 --> 01:02:13,280
shorter time speeds

1782
01:02:17,270 --> 01:02:14,319
okay

1783
01:02:18,710 --> 01:02:17,280
dave dave let me ask a different sort of

1784
01:02:22,069 --> 01:02:18,720
question

1785
01:02:24,549 --> 01:02:22,079
we often hear of planetary rings being

1786
01:02:26,870 --> 01:02:24,559
proposed as analogs for protoplanetary

1787
01:02:28,390 --> 01:02:26,880
disks in particular saturn's rings and

1788
01:02:30,789 --> 01:02:28,400

of course there's been a lot of study

1789
01:02:32,230 --> 01:02:30,799
from the cassini mission in particular

1790
01:02:35,270 --> 01:02:32,240
of uh

1791
01:02:38,230 --> 01:02:35,280
gravity waves etc and other features in

1792
01:02:40,549 --> 01:02:38,240
saturn's rings to what degree

1793
01:02:42,470 --> 01:02:40,559
are planetary rings and saturn's rings

1794
01:02:44,710 --> 01:02:42,480
in particular a good analog for

1795
01:02:46,549 --> 01:02:44,720
protoplanetary disks and to what degree

1796
01:02:50,230 --> 01:02:46,559
would we expect to see

1797
01:02:51,910 --> 01:02:50,240
the same kind of physical phenomena in a

1798
01:02:55,430 --> 01:02:51,920
protoplanetary disk that we see in

1799
01:03:00,390 --> 01:02:58,549
question um well of course

1800
01:03:02,710 --> 01:03:00,400
a big difference in compared with these

1801
01:03:04,069 --> 01:03:02,720
models is that if you have the rings

1802
01:03:05,030 --> 01:03:04,079
around saturn

1803
01:03:07,589 --> 01:03:05,040
the thing that's going to photo

1804
01:03:10,549 --> 01:03:07,599
evaporate them will probably be the sun

1805
01:03:12,870 --> 01:03:10,559
and so then the question is uh you know

1806
01:03:14,789 --> 01:03:12,880
at what point does the stellar photons

1807
01:03:16,549 --> 01:03:14,799
make it to saturn's rings i mean if

1808
01:03:18,470 --> 01:03:16,559
saturn formed and the rings are starting

1809
01:03:20,950 --> 01:03:18,480
to form in a situation where you still

1810
01:03:22,710 --> 01:03:20,960
have a gas disc presence and dust disk

1811
01:03:24,549 --> 01:03:22,720
then the stellar photons

1812
01:03:26,150 --> 01:03:24,559
won't make it in

1813
01:03:28,309 --> 01:03:26,160

there they're sort of analogous in the

1814
01:03:30,549 --> 01:03:28,319
sense that it's true that in these rings

1815
01:03:32,549 --> 01:03:30,559
there's the same processes of

1816
01:03:33,829 --> 01:03:32,559
of coagulation of particles you know

1817
01:03:35,990 --> 01:03:33,839
sort of settling

1818
01:03:38,309 --> 01:03:36,000
to the midplane and the coagulation of

1819
01:03:40,470 --> 01:03:38,319
particles so that that part of it is is

1820
01:03:47,750 --> 01:03:40,480
similar

1821
01:03:51,670 --> 01:03:49,750
yeah i mean saturn's rings in the in the

1822
01:03:53,829 --> 01:03:51,680
in the planet system there's been time

1823
01:03:55,670 --> 01:03:53,839
enough so that there's been a kind of a

1824
01:03:57,829 --> 01:03:55,680
sweeping out there's there's a growth of

1825
01:03:59,589 --> 01:03:57,839
these particles to the point where they

1826
01:04:01,029 --> 01:03:59,599
actually get gravitationally important

1827
01:04:02,870 --> 01:04:01,039
and they start to sort of focus other

1828
01:04:05,109 --> 01:04:02,880
particles in saturn's rings everything

1829
01:04:06,470 --> 01:04:05,119
is small still and so there isn't any of

1830
01:04:10,470 --> 01:04:06,480
this and there isn't just sweeping up so

1831
01:04:13,109 --> 01:04:11,589
you know it's a good question i haven't

1832
01:04:14,069 --> 01:04:13,119
really thought about it that much but

1833
01:04:15,430 --> 01:04:14,079
the uh

1834
01:04:17,670 --> 01:04:15,440
um

1835
01:04:20,069 --> 01:04:17,680
uh you know it's certainly possible that

1836
01:04:22,870 --> 01:04:20,079
in the formation of the rings around the

1837
01:04:25,109 --> 01:04:22,880
the planets that uh photo evaporation by

1838
01:04:27,349 --> 01:04:25,119

the by the sun may have played a role in

1839
01:04:28,789 --> 01:04:27,359
affecting the evolution of these rings

1840
01:04:30,069 --> 01:04:28,799
if they if they

1841
01:04:33,190 --> 01:04:30,079
if they didn't

1842
01:04:34,549 --> 01:04:33,200
get exposed to the solar radiation

1843
01:04:36,309 --> 01:04:34,559
thanks

1844
01:04:37,750 --> 01:04:36,319
we have a question from the ames team

1845
01:04:39,670 --> 01:04:37,760
okay

1846
01:04:41,430 --> 01:04:39,680
and then from

1847
01:04:42,870 --> 01:04:41,440
this is dave dimare i have a just wonder

1848
01:04:44,870 --> 01:04:42,880
if you can make some comment about

1849
01:04:46,390 --> 01:04:44,880
volatiles in the in the context of this

1850
01:04:48,230 --> 01:04:46,400
and i'm thinking about that that poor

1851
01:04:50,069 --> 01:04:48,240
oort cloud out there which that sounds

1852
01:04:52,390 --> 01:04:50,079
like a pretty brutal place to be based

1853
01:04:55,029 --> 01:04:52,400
on your evaporation models and then also

1854
01:04:56,549 --> 01:04:55,039
just what the impact of your models have

1855
01:04:57,670 --> 01:04:56,559
on the delivery of volatiles to the

1856
01:04:59,270 --> 01:04:57,680
earth i mean

1857
01:05:01,510 --> 01:04:59,280
it seems like many people think that

1858
01:05:03,109 --> 01:05:01,520
this is a later stage kind of thing and

1859
01:05:04,390 --> 01:05:03,119
it sounds pretty brutal in the later

1860
01:05:05,990 --> 01:05:04,400
stages of your model so i was just

1861
01:05:08,470 --> 01:05:06,000
wondering if you could comment about

1862
01:05:10,630 --> 01:05:08,480
where our volatiles end up

1863
01:05:12,870 --> 01:05:10,640

okay um well the art cloud you know is

1864
01:05:14,630 --> 01:05:12,880
supposed to originate actually from

1865
01:05:16,230 --> 01:05:14,640
material that formed

1866
01:05:18,630 --> 01:05:16,240
probably uh

1867
01:05:20,230 --> 01:05:18,640
you know around neptune or

1868
01:05:21,910 --> 01:05:20,240
and so

1869
01:05:23,430 --> 01:05:21,920
it's true that the art cloud's way out

1870
01:05:25,029 --> 01:05:23,440
there now and that seems like a very

1871
01:05:26,549 --> 01:05:25,039
brutal place in terms of this photo

1872
01:05:29,190 --> 01:05:26,559
evaporation model where things on the

1873
01:05:31,029 --> 01:05:29,200
outside happen very rapidly but i think

1874
01:05:34,309 --> 01:05:31,039
the art cloud is the sort of ejecta

1875
01:05:35,910 --> 01:05:34,319
material that formed in closer at say

1876
01:05:36,870 --> 01:05:35,920
tens of au

1877
01:05:37,750 --> 01:05:36,880
and so

1878
01:05:38,549 --> 01:05:37,760
uh

1879
01:05:44,710 --> 01:05:38,559
the

1880
01:05:47,029 --> 01:05:44,720
that are probably kilometers in size or

1881
01:05:48,710 --> 01:05:47,039
are bigger or hundreds it could be up to

1882
01:05:50,390 --> 01:05:48,720
100 kilometers in size but you know

1883
01:05:51,109 --> 01:05:50,400
things of that size

1884
01:05:53,349 --> 01:05:51,119
and

1885
01:05:54,230 --> 01:05:53,359
if you can just form the

1886
01:05:58,710 --> 01:05:54,240
if

1887
01:06:00,230 --> 01:05:58,720
rock icy rocks

1888
01:06:02,069 --> 01:06:00,240

big enough so that they'll withstand

1889
01:06:04,069 --> 01:06:02,079
this evaporation and then they can

1890
01:06:05,750 --> 01:06:04,079
eventually coagulate into the objects

1891
01:06:08,230 --> 01:06:05,760
that form comets so the question really

1892
01:06:11,029 --> 01:06:08,240
is is can you evaporate faster than the

1893
01:06:12,309 --> 01:06:11,039
material can coagulate into bodies that

1894
01:06:15,910 --> 01:06:12,319
are big enough to withstand the

1895
01:06:18,309 --> 01:06:15,920
evaporation and that i'm not so sure of

1896
01:06:20,069 --> 01:06:18,319
because this time scales for coagulation

1897
01:06:22,789 --> 01:06:20,079
of these particles building up to sort

1898
01:06:25,510 --> 01:06:22,799
of uh centimeters or meters in size is

1899
01:06:28,069 --> 01:06:25,520
not so clearly understood yet uh

1900
01:06:29,990 --> 01:06:28,079
coagulation is sort of a dicey topic

1901
01:06:32,710 --> 01:06:30,000
so it's possible that's why i sort of

1902
01:06:34,230 --> 01:06:32,720
i'm a little waffling on this uh this

1903
01:06:36,150 --> 01:06:34,240
when i've mentioned these fiber belts

1904
01:06:38,150 --> 01:06:36,160
that they may be suppressed but i'm not

1905
01:06:40,549 --> 01:06:38,160
sure it just depends on how long the

1906
01:06:42,150 --> 01:06:40,559
coagulation process takes to get them

1907
01:06:44,069 --> 01:06:42,160
big enough to withstand

1908
01:06:45,430 --> 01:06:44,079
things that tends of a you

1909
01:06:48,549 --> 01:06:45,440
because the photo evaporation is going

1910
01:06:50,789 --> 01:06:48,559
to remove all the small icy bodies and

1911
01:06:53,109 --> 01:06:50,799
you know less than a millimeter in size

1912
01:06:54,950 --> 01:06:53,119
and the gas you know in and as you see

1913
01:06:56,710 --> 01:06:54,960

in time scales can be time scales of

1914
01:06:58,710 --> 01:06:56,720
less than a million years

1915
01:07:01,029 --> 01:06:58,720
and the coagulation time scales in the

1916
01:07:03,270 --> 01:07:01,039
in the solar nebula get bigger longer as

1917
01:07:04,950 --> 01:07:03,280
you go out and so there's a point where

1918
01:07:06,870 --> 01:07:04,960
the coagulation time skills just even to

1919
01:07:08,630 --> 01:07:06,880
build up a millimeter size particle gets

1920
01:07:10,549 --> 01:07:08,640
to be pretty long

1921
01:07:12,789 --> 01:07:10,559
and at that point you will just truncate

1922
01:07:14,789 --> 01:07:12,799
the ability to form any kind of ice

1923
01:07:16,150 --> 01:07:14,799
now i know that there's been a lot of

1924
01:07:18,789 --> 01:07:16,160
work done on what's delivering the

1925
01:07:20,950 --> 01:07:18,799
volatiles to the earth and the one

1926
01:07:22,789 --> 01:07:20,960
i think the lead author was morbidelli

1927
01:07:24,630 --> 01:07:22,799
but

1928
01:07:26,470 --> 01:07:24,640
talked about the reservoir maybe from

1929
01:07:28,390 --> 01:07:26,480
the asteroid belt with some sort of

1930
01:07:29,750 --> 01:07:28,400
water-rich objects in the asteroid belt

1931
01:07:30,789 --> 01:07:29,760
which is sort of you know inside of

1932
01:07:33,589 --> 01:07:30,799
jupiter

1933
01:07:35,750 --> 01:07:33,599
and those regions

1934
01:07:37,589 --> 01:07:35,760
again are fairly close in

1935
01:07:39,109 --> 01:07:37,599
and they're subject to this

1936
01:07:40,710 --> 01:07:39,119
i mean in these models where you have

1937
01:07:42,870 --> 01:07:40,720
the photo evaporation combining with

1938
01:07:44,230 --> 01:07:42,880

viscous evolution eventually the viscous

1939
01:07:46,470 --> 01:07:44,240
evolution does get rid of that inner

1940
01:07:48,470 --> 01:07:46,480
part of the gas and the dust but that

1941
01:07:50,549 --> 01:07:48,480
does take typically takes millions of

1942
01:07:53,109 --> 01:07:50,559
years and presumably there would be time

1943
01:07:54,230 --> 01:07:53,119
to form some of those objects uh

1944
01:07:56,230 --> 01:07:54,240
so i

1945
01:07:59,829 --> 01:07:56,240
i think that in terms of the just to

1946
01:08:02,630 --> 01:07:59,839
summarize my guess is that

1947
01:08:05,109 --> 01:08:02,640
in the extreme cases where you evaporate

1948
01:08:06,789 --> 01:08:05,119
the whole discs are evaporated in like

1949
01:08:08,630 --> 01:08:06,799
less than a million years and maybe even

1950
01:08:10,390 --> 01:08:08,640
less than 10 or 50 years like an extreme

1951
01:08:12,309 --> 01:08:10,400
case of a disk around a very high

1952
01:08:13,750 --> 01:08:12,319
massive star or a low mass star very

1953
01:08:15,990 --> 01:08:13,760
close to inestar

1954
01:08:18,550 --> 01:08:16,000
then you may affect the volatiles but uh

1955
01:08:20,309 --> 01:08:18,560
in a case where the discs take a like in

1956
01:08:22,229 --> 01:08:20,319
the sun's case it just takes you

1957
01:08:26,149 --> 01:08:22,239
millions of years to evaporate then i

1958
01:08:32,550 --> 01:08:28,070
dave

1959
01:08:34,470 --> 01:08:32,560
over my head in many ways but i'm going

1960
01:08:35,990 --> 01:08:34,480
to try to give you a hard time in any

1961
01:08:39,189 --> 01:08:36,000
case

1962
01:08:41,030 --> 01:08:39,199
because of the element that that you

1963
01:08:43,189 --> 01:08:41,040

that after the disc has largely

1964
01:08:44,550 --> 01:08:43,199
dissipated i had the impression you were

1965
01:08:47,189 --> 01:08:44,560
talking about the

1966
01:08:49,749 --> 01:08:47,199
the planetesimals kind of automatically

1967
01:08:51,829 --> 01:08:49,759
coming together and surely that depends

1968
01:08:54,229 --> 01:08:51,839
on whether or not there is a giant

1969
01:08:56,709 --> 01:08:54,239
planet like jupiter but just as today

1970
01:08:58,870 --> 01:08:56,719
the stability of objects in the asteroid

1971
01:09:01,669 --> 01:08:58,880
belt depends on jupiter and i'm just

1972
01:09:03,910 --> 01:09:01,679
curious about about that that role i

1973
01:09:07,110 --> 01:09:03,920
surely you cannot completely decouple

1974
01:09:08,789 --> 01:09:07,120
the presence of external giant planets

1975
01:09:10,630 --> 01:09:08,799
from what's happening in the terrestrial

1976
01:09:11,590 --> 01:09:10,640
realm inside

1977
01:09:13,269 --> 01:09:11,600
right

1978
01:09:15,430 --> 01:09:13,279
and that's a that's a really good point

1979
01:09:17,430 --> 01:09:15,440
and i should that's one that uh i would

1980
01:09:20,309 --> 01:09:17,440
like to understand further because

1981
01:09:22,070 --> 01:09:20,319
i think that what my work or the work of

1982
01:09:23,829 --> 01:09:22,080
my group is showing is that the gas

1983
01:09:25,269 --> 01:09:23,839
giants if they form by core christian

1984
01:09:27,510 --> 01:09:25,279
can really be affected by these

1985
01:09:29,269 --> 01:09:27,520
processes and i think that it's even

1986
01:09:30,550 --> 01:09:29,279
happened to here in probably the solar

1987
01:09:33,189 --> 01:09:30,560
system that

1988
01:09:35,030 --> 01:09:33,199

the evaporation by the sun the early sun

1989
01:09:36,630 --> 01:09:35,040
probably got rid of the gas which is why

1990
01:09:39,110 --> 01:09:36,640
uranus and neptune don't have much gas

1991
01:09:41,590 --> 01:09:39,120
and why we don't have that much material

1992
01:09:43,990 --> 01:09:41,600
outside i think it's already has had an

1993
01:09:45,669 --> 01:09:44,000
effect on the plant formation

1994
01:09:47,030 --> 01:09:45,679
but you're certainly right that the

1995
01:09:48,789 --> 01:09:47,040
giant plants

1996
01:09:50,550 --> 01:09:48,799
not only sir i was sort of mentioning

1997
01:09:52,070 --> 01:09:50,560
this idea of protecting us from comets

1998
01:09:54,470 --> 01:09:52,080
or something but they also serve to sort

1999
01:09:56,550 --> 01:09:54,480
of stir things up and therefore affect

2000
01:09:57,990 --> 01:09:56,560
the collision rates of things and so

2001
01:09:59,350 --> 01:09:58,000
forth and that's not something that i've

2002
01:10:00,709 --> 01:09:59,360
really looked into but i think it's a

2003
01:10:03,990 --> 01:10:00,719
good point that

2004
01:10:06,070 --> 01:10:04,000
it would be good uh for us to understand

2005
01:10:08,709 --> 01:10:06,080
you know all the different effects that

2006
01:10:11,030 --> 01:10:08,719
giant plants have on the habitability of

2007
01:10:13,669 --> 01:10:11,040
say terrestrial plants in the system

2008
01:10:16,470 --> 01:10:13,679
my guess is that for all the fact that

2009
01:10:17,990 --> 01:10:16,480
jupiter now protects us from comets

2010
01:10:19,030 --> 01:10:18,000
coming in most of the comets that are

2011
01:10:20,870 --> 01:10:19,040
coming in

2012
01:10:22,870 --> 01:10:20,880
were placed there originally

2013
01:10:24,870 --> 01:10:22,880

gravitationally by the giant planets so

2014
01:10:28,830 --> 01:10:24,880
uh you know it's just protecting against

2015
01:10:33,270 --> 01:10:31,189
place but what if there wouldn't if

2016
01:10:35,590 --> 01:10:33,280
there hadn't been a jupiter

2017
01:10:36,390 --> 01:10:35,600
you would have formed all these icy con

2018
01:10:38,470 --> 01:10:36,400
i mean

2019
01:10:39,510 --> 01:10:38,480
and and wouldn't they still be coming in

2020
01:10:42,390 --> 01:10:39,520
i mean

2021
01:10:43,830 --> 01:10:42,400
maybe it was the giant plants that threw

2022
01:10:45,189 --> 01:10:43,840
them out there but you'd have a kite

2023
01:10:47,110 --> 01:10:45,199
belt

2024
01:10:48,229 --> 01:10:47,120
right and so it seems like

2025
01:10:49,750 --> 01:10:48,239
you would have

2026
01:10:50,790 --> 01:10:49,760
you might have a very rich type of belt

2027
01:10:52,550 --> 01:10:50,800
i don't know if you didn't have photo

2028
01:10:54,470 --> 01:10:52,560
evaporation

2029
01:10:57,110 --> 01:10:54,480
and so then maybe you'd have some really

2030
01:11:00,630 --> 01:10:57,120
heavy bombardment i don't know

2031
01:11:02,470 --> 01:11:00,640
maybe they will not be disturbed as much

2032
01:11:03,350 --> 01:11:02,480
as they were in the solar system in that

2033
01:11:07,590 --> 01:11:03,360
case

2034
01:11:10,950 --> 01:11:08,870
but i think

2035
01:11:13,910 --> 01:11:10,960
so that's true that's true that big i

2036
01:11:15,270 --> 01:11:13,920
guess the kuiper belt objects

2037
01:11:16,950 --> 01:11:15,280
uh the shirt

2038
01:11:20,790 --> 01:11:16,960

period common object so i mean they're

2039
01:11:20,800 --> 01:11:24,830
it's not like their self interaction

2040
01:11:30,470 --> 01:11:28,310
yeah do we have any other questions any

2041
01:11:31,510 --> 01:11:30,480
hands raised markup

2042
01:11:34,070 --> 01:11:31,520
ah

2043
01:11:35,669 --> 01:11:34,080
thank you hey how about the magnetic

2044
01:11:38,550 --> 01:11:35,679
field of the uh

2045
01:11:40,390 --> 01:11:38,560
the star does that is that a significant

2046
01:11:42,310 --> 01:11:40,400
or not

2047
01:11:44,070 --> 01:11:42,320
well it's significant

2048
01:11:45,510 --> 01:11:44,080
in our

2049
01:11:47,830 --> 01:11:45,520
as i said we've

2050
01:11:50,070 --> 01:11:47,840
we have buried all our ignorance in this

2051
01:11:52,470 --> 01:11:50,080
alpha parameter which is uh that just

2052
01:11:54,470 --> 01:11:52,480
describes how the disc viscously evolves

2053
01:11:55,510 --> 01:11:54,480
it's a dimensionless parameter

2054
01:11:58,229 --> 01:11:55,520
and uh

2055
01:12:00,229 --> 01:11:58,239
and observationally by looking at how

2056
01:12:01,669 --> 01:12:00,239
fast this are accreting onto the star

2057
01:12:04,709 --> 01:12:01,679
which we can measure because as they

2058
01:12:06,709 --> 01:12:04,719
accrete under the star we see

2059
01:12:09,590 --> 01:12:06,719
an extra luminosity in the ultraviolet

2060
01:12:11,830 --> 01:12:09,600
we see spectral lines that can give us

2061
01:12:14,149 --> 01:12:11,840
an estimate of the mass accretion rate

2062
01:12:15,590 --> 01:12:14,159
on the star so by looking at those mass

2063
01:12:17,030 --> 01:12:15,600

secretion rates we get an idea of what

2064
01:12:18,950 --> 01:12:17,040
alpha is now we don't have any

2065
01:12:20,470 --> 01:12:18,960
theoretical understanding of why alpha

2066
01:12:22,110 --> 01:12:20,480
is that value

2067
01:12:24,630 --> 01:12:22,120
and but one idea is this

2068
01:12:26,950 --> 01:12:24,640
magneto-rotational instability now that

2069
01:12:28,630 --> 01:12:26,960
involves the magnetic field of the star

2070
01:12:31,189 --> 01:12:28,640
which then threads through the disk and

2071
01:12:33,270 --> 01:12:31,199
then the disk is sort of or is is

2072
01:12:34,070 --> 01:12:33,280
keplerian orbiting and you get a kind of

2073
01:13:17,110 --> 01:12:34,080
a

2074
01:13:19,430 --> 01:13:17,120
which is most of the disk moving

2075
01:13:21,350 --> 01:13:19,440
and so in this there's these dead zones

2076
01:13:23,270 --> 01:13:21,360
in the disc where there's not enough

2077
01:13:25,270 --> 01:13:23,280
ionization for the ions to actually move

2078
01:13:26,870 --> 01:13:25,280
the neutrals there can be these dead

2079
01:13:28,470 --> 01:13:26,880
zones and of course they may be

2080
01:13:29,990 --> 01:13:28,480
favorable then to plant formation

2081
01:13:31,590 --> 01:13:30,000
because they're not as viscously

2082
01:13:33,430 --> 01:13:31,600
evolving they're sort of sitting there

2083
01:13:35,030 --> 01:13:33,440
waiting for gravity to

2084
01:13:37,590 --> 01:13:35,040
bring things together

2085
01:13:39,430 --> 01:13:37,600
well regardless of the accretion source

2086
01:13:41,510 --> 01:13:39,440
uh you know is the presence of a

2087
01:13:42,709 --> 01:13:41,520
magnetic field sufficient to keep some

2088
01:13:46,229 --> 01:13:42,719

of the

2089
01:13:48,950 --> 01:13:46,239
disk ass around after the fuvs say has

2090
01:13:51,510 --> 01:13:48,960
uh you know liberated it from the disc

2091
01:13:53,669 --> 01:13:51,520
you know uh like for example think about

2092
01:13:56,070 --> 01:13:53,679
uh you know the there's the it's gonna

2093
01:13:58,470 --> 01:13:56,080
get too far into astronomy but there is

2094
01:13:59,910 --> 01:13:58,480
the you know the x-wind scenario

2095
01:14:03,270 --> 01:13:59,920
where there are lines threading through

2096
01:14:05,270 --> 01:14:03,280
the disk you know uh and uh and also

2097
01:14:06,709 --> 01:14:05,280
there's a whole remnant on the large

2098
01:14:08,390 --> 01:14:06,719
scale is interested in that propellant

2099
01:14:11,189 --> 01:14:08,400
you know like way beyond the disk you

2100
01:14:13,270 --> 01:14:11,199
know there is this fev that is uh

2101
01:14:15,030 --> 01:14:13,280
ablating away the cloud but the the

2102
01:14:18,310 --> 01:14:15,040
cloud itself has a remnant magnetic

2103
01:14:20,070 --> 01:14:18,320
field you know how much uh uh do the

2104
01:14:22,630 --> 01:14:20,080
does the fossil fuel from the cloud in

2105
01:14:24,950 --> 01:14:22,640
addition to you know the stars field uh

2106
01:14:27,110 --> 01:14:24,960
helping train this you know obviously at

2107
01:14:29,669 --> 01:14:27,120
some point the fuv wins but is there

2108
01:14:31,510 --> 01:14:29,679
like you know some significant uh effect

2109
01:14:33,510 --> 01:14:31,520
that helps these uh help the gas stick

2110
01:14:35,590 --> 01:14:33,520
around

2111
01:14:38,310 --> 01:14:35,600
um

2112
01:14:39,110 --> 01:14:38,320
i can't think of any to be honest i mean

2113
01:14:40,790 --> 01:14:39,120

the

2114
01:14:43,590 --> 01:14:40,800
uh

2115
01:14:45,030 --> 01:14:43,600
in the first place the

2116
01:14:46,709 --> 01:14:45,040
if there are magnetic field lines

2117
01:14:48,790 --> 01:14:46,719
threading it in some way i mean the

2118
01:14:50,790 --> 01:14:48,800
material can always fall along the lines

2119
01:14:53,110 --> 01:14:50,800
because there's no force along the lines

2120
01:14:54,630 --> 01:14:53,120
only perpendicular to the lines and so

2121
01:14:56,550 --> 01:14:54,640
uh

2122
01:14:58,390 --> 01:14:56,560
you know it would the material this

2123
01:14:59,590 --> 01:14:58,400
thermal evaporation is just one that's

2124
01:15:02,070 --> 01:14:59,600
driven by thermal pressure and it'll

2125
01:15:04,149 --> 01:15:02,080
just move along whatever well if there

2126
01:15:06,070 --> 01:15:04,159
is some sort of external field that

2127
01:15:07,189 --> 01:15:06,080
is actually controlling the motion i

2128
01:15:12,390 --> 01:15:07,199
mean i

2129
01:15:17,030 --> 01:15:14,550
the magnetic fields are pretty weak i

2130
01:15:19,189 --> 01:15:17,040
mean as as in most of our models i mean

2131
01:15:20,390 --> 01:15:19,199
it's true that right near the x-wind

2132
01:15:21,750 --> 01:15:20,400
which is the origin of these

2133
01:15:23,830 --> 01:15:21,760
protostellar winds which is just a few

2134
01:15:25,590 --> 01:15:23,840
stellar radii away in the disc those

2135
01:15:28,390 --> 01:15:25,600
fields tend to be like a kilogaster

2136
01:15:30,630 --> 01:15:28,400
they're quite high but or maybe less but

2137
01:15:32,070 --> 01:15:30,640
they're quite high but as you you get

2138
01:15:33,669 --> 01:15:32,080

out it seems that the magnetic fields

2139
01:15:35,110 --> 01:15:33,679
are getting weaker and weaker and the

2140
01:15:36,870 --> 01:15:35,120
thermal pressures tend to be quite

2141
01:15:38,950 --> 01:15:36,880
strong i have a feeling that thermal

2142
01:15:42,229 --> 01:15:38,960
pressures will pretty much dominate the

2143
01:15:46,149 --> 01:15:43,590
okay well

2144
01:15:48,310 --> 01:15:46,159
let's thank our speaker again

2145
01:15:50,149 --> 01:15:48,320
and

2146
01:15:51,270 --> 01:15:50,159
i would just like to

2147
01:15:54,149 --> 01:15:51,280
let

2148
01:15:55,990 --> 01:15:54,159
you all know that the next two

2149
01:15:58,390 --> 01:15:56,000
seminars

2150
01:16:02,229 --> 01:15:58,400
will be given by

2151
01:16:03,830 --> 01:16:02,239
bill shop on february 25th and by jodi

2152
01:16:05,270 --> 01:16:03,840
deming and

2153
01:16:07,830 --> 01:16:05,280
jim staley of the university of

2154
01:16:09,590 --> 01:16:07,840
washington on march 31st

2155
01:16:11,790 --> 01:16:09,600
bill on february 25th is going to be

2156
01:16:14,669 --> 01:16:11,800
talking about his work on looking at

2157
01:16:16,229 --> 01:16:14,679
microfossils using confocal laser

2158
01:16:18,709 --> 01:16:16,239
spectroscopy

2159
01:16:20,950 --> 01:16:18,719
and raman

2160
01:16:22,709 --> 01:16:20,960
microscopy as well and

2161
01:16:25,350 --> 01:16:22,719
jody and jim are going to be talking

2162
01:16:27,910 --> 01:16:25,360
about psychophiles and particularly

2163
01:16:29,990 --> 01:16:27,920

those organisms as models for potential

2164
01:16:33,350 --> 01:16:30,000
life on europa and mars

2165
01:16:35,350 --> 01:16:33,360
so i hope we will see all of you there

2166
01:16:38,149 --> 01:16:35,360
and others and