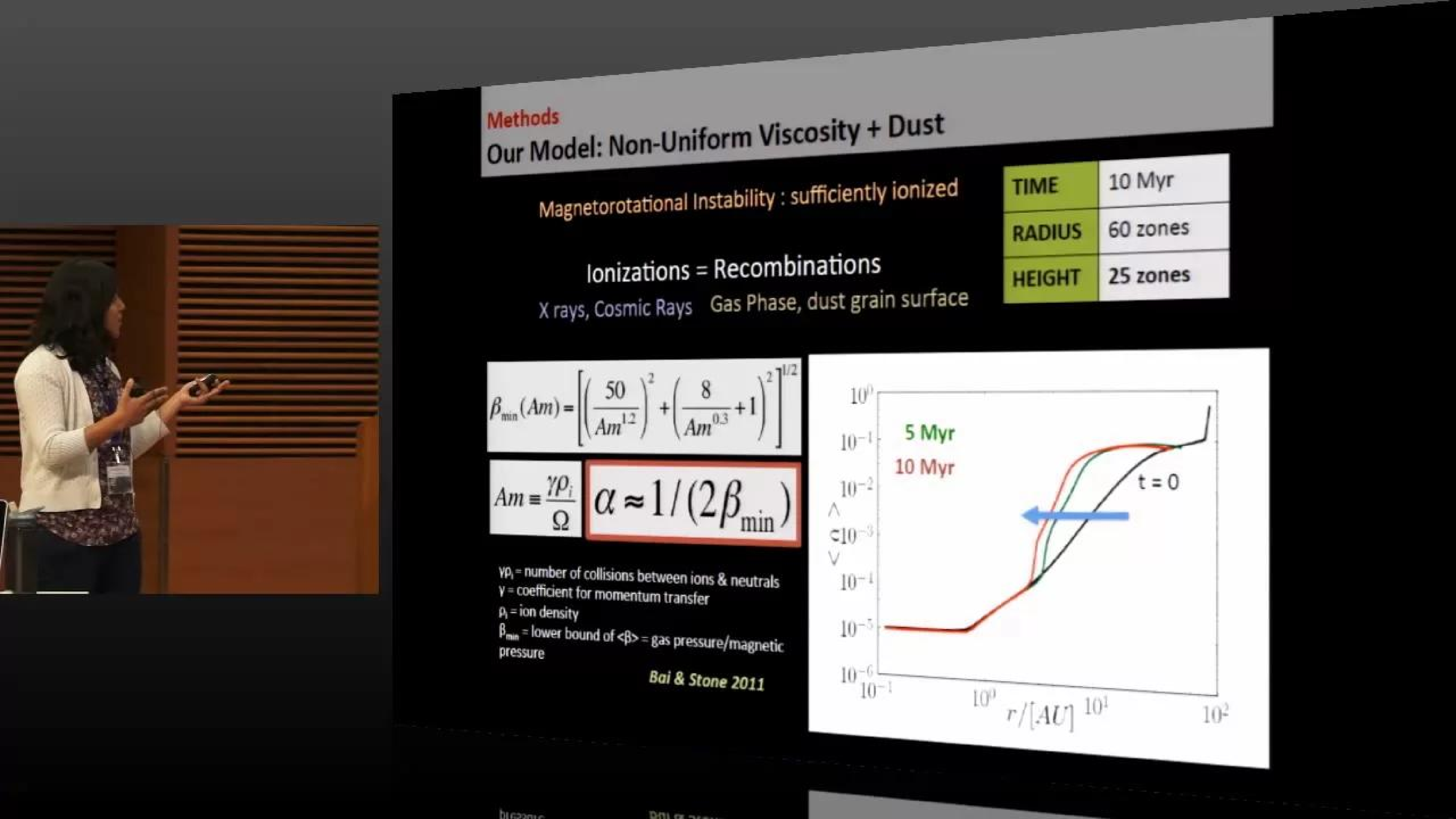
Methods
Our Model: Non-Uniform Viscosity + Dust
Magnetorotational Instability : sufficiently ionized
TIME 10 Myr
RADIUS 60 zones
HEIGHT 25 zones
Ionizations = Recombinations
X rays, Cosmic Rays
Gas Phase, dust grain surface
$\beta_{min}(Am) = \left[\left(\frac{50}{Am^{1.2}}\right)^2 + \left(\frac{8}{Am^{0.3}}+1\right)^2\right]^{1/2}$
$Am \equiv \frac{\gamma\rho_i}{\Omega}$
$\alpha \approx 1/(2\beta_{min})$
$\gamma\rho_i$ = number of collisions between ions & neutrals
γ = coefficient for momentum transfer
ρ_i = ion density
β_{min} = lower bound of <β> = gas pressure/magnetic pressure
Bai & Stone 2011
5 Myr
10 Myr
t = 0
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-1}
10^0
10^1
10^2
$r/[AU]$

1
00:00:12,379 --> 00:00:09,919
yeah so I'll be talking about snow lines

2
00:00:16,779 --> 00:00:12,389
in external evaporated Florida flank

3
00:00:20,450 --> 00:00:16,789
readers that's my shorter title so

4
00:00:22,849 --> 00:00:20,460
actually the previous speaker gave give

5
00:00:25,189 --> 00:00:22,859
a really nice introduction to what I'm

6
00:00:38,799 --> 00:00:25,199
going to be talking about and I thank

7
00:00:41,799 --> 00:00:38,809
off for that so to motivate my talk

8
00:00:45,470 --> 00:00:41,809
basically I'm listed here a couple of

9
00:00:47,569 --> 00:00:45,480
like the water content by weight of some

10
00:00:49,880 --> 00:00:47,579
of the bodies in our solar system and

11
00:00:54,080 --> 00:00:49,890
you can kind of see that they really

12
00:00:56,590 --> 00:00:54,090
vary from a word like say point one

13
00:00:59,119 --> 00:00:56,600

percent or tens of percent and

14
00:01:02,090 --> 00:00:59,129
impossible exhaust successful our

15
00:01:03,770 --> 00:01:02,100
planetary I mean whatever else you you

16
00:01:05,329 --> 00:01:03,780
could probably have like up to fifty

17
00:01:08,149 --> 00:01:05,339
percent of water by weight so what

18
00:01:12,170 --> 00:01:08,159
really decides the water content of you

19
00:01:15,859 --> 00:01:12,180
know the planets and to get into this

20
00:01:18,649 --> 00:01:15,869
question we talking about snow lines the

21
00:01:21,530 --> 00:01:18,659
last bit again like introduces so a snow

22
00:01:24,440 --> 00:01:21,540
line is basically the region that kind

23
00:01:26,690 --> 00:01:24,450
of demarcates where water condenses his

24
00:01:28,399 --> 00:01:26,700
eyes and where where it doesn't so you

25
00:01:31,880 --> 00:01:28,409
can kind of see a snow line on a

26
00:01:34,550 --> 00:01:31,890
mountain here and but in a

27
00:01:38,510 --> 00:01:34,560
protoplanetary disk what is sublimates

28
00:01:40,670 --> 00:01:38,520
at once empty Kelvin and so this was

29
00:01:44,539 --> 00:01:40,680
initially thought to exist at like two

30
00:01:47,870 --> 00:01:44,549
point seven EU from the Sun and so here

31
00:01:50,590 --> 00:01:47,880
shown us here so it was theorized that

32
00:01:54,499 --> 00:01:50,600
you know bodies that formed within this

33
00:01:56,270 --> 00:01:54,509
snow line would be whatever dry and the

34
00:01:59,149 --> 00:01:56,280
bodies that formed outside fit would be

35
00:02:02,389 --> 00:01:59,159
water rich and subsequently a lot of

36
00:02:06,800 --> 00:02:02,399
more like detailed / a plant various

37
00:02:10,190 --> 00:02:06,810
models that kind of assume more accurate

38
00:02:12,710 --> 00:02:10,200

dust properties and temperature profiles

39
00:02:13,580 --> 00:02:12,720
in this kind of came to the conclusion

40
00:02:15,170 --> 00:02:13,590
that

41
00:02:17,240 --> 00:02:15,180
the snowline need not necessarily be at

42
00:02:21,850 --> 00:02:17,250
this value it could be much more closer

43
00:02:24,410 --> 00:02:21,860
in even as close as one AU and also

44
00:02:26,030 --> 00:02:24,420
subsequently models found that like

45
00:02:28,759 --> 00:02:26,040
temperatures probably not the only

46
00:02:31,160 --> 00:02:28,769
criterion but a radial transport of

47
00:02:35,449 --> 00:02:31,170
volatiles across the snow line also

48
00:02:37,789 --> 00:02:35,459
matters so probably the picture of the

49
00:02:39,350 --> 00:02:37,799
snow line is not a static and clear as

50
00:02:43,520 --> 00:02:39,360
this but probably something a little bit

51
00:02:45,229 --> 00:02:43,530
more murky so what do I mean by radial

52
00:02:48,620 --> 00:02:45,239
transport of volatiles there could be

53
00:02:50,539 --> 00:02:48,630
like different types of like wall tile

54
00:02:53,000 --> 00:02:50,549
processes happening across this new line

55
00:02:56,030 --> 00:02:53,010
you could have a continuous output

56
00:02:58,460 --> 00:02:56,040
diffusion of vapor outside this new line

57
00:03:02,619 --> 00:02:58,470
and then you could have like an inward

58
00:03:06,610 --> 00:03:02,629
drift of icy particles which kind of

59
00:03:08,809 --> 00:03:06,620
orbit at the different frequency orbit

60
00:03:11,960 --> 00:03:08,819
like yeah at a different frequency than

61
00:03:13,699 --> 00:03:11,970
the pressure supported gas and because

62
00:03:16,339 --> 00:03:13,709
of which they would like spiral inwards

63
00:03:20,660 --> 00:03:16,349

and upon reaching the snow line they

64
00:03:22,340 --> 00:03:20,670
would melt and kind of you know so you

65
00:03:24,650 --> 00:03:22,350
would have liked cyclically like

66
00:03:28,520 --> 00:03:24,660
transport of water vapor outside and

67
00:03:31,220 --> 00:03:28,530
inside the snow line and to this

68
00:03:33,589 --> 00:03:31,230
scenario if we were to add the process

69
00:03:37,000 --> 00:03:33,599
of external for evaporation let it could

70
00:03:40,330 --> 00:03:37,010
be a little bit more complicated so what

71
00:03:45,199 --> 00:03:40,340
what external photo operation is is that

72
00:03:46,819 --> 00:03:45,209
the Sun was born in a massive it's very

73
00:03:49,099 --> 00:03:46,829
likely that the Sun was born in a

74
00:03:52,150 --> 00:03:49,109
massive star forming region and it's

75
00:03:55,670 --> 00:03:52,160
disc was sort of intensely irradiated by

76
00:04:00,680 --> 00:03:55,680
radiation from nearby massive stars so

77
00:04:02,539 --> 00:04:00,690
if that was the case then it could you

78
00:04:05,629 --> 00:04:02,549
know frustrate this inward drift and

79
00:04:09,470 --> 00:04:05,639
kind of enhanced in outward a wall tile

80
00:04:13,339 --> 00:04:09,480
transport like outside from the outer

81
00:04:18,129 --> 00:04:13,349
edge of the disk so we kind of consider

82
00:04:21,229 --> 00:04:18,139
this process as well in our modeling of

83
00:04:24,649 --> 00:04:21,239
this structure so what what what this

84
00:04:27,170 --> 00:04:24,659
project is about is basically riedl

85
00:04:29,180 --> 00:04:27,180
transport of Walter's would be

86
00:04:32,360 --> 00:04:29,190
sort of intimately connected to the

87
00:04:34,310 --> 00:04:32,370
destruction of the protoplanetary disk

88
00:04:37,790 --> 00:04:34,320

and we kind of probe the dress structure

89
00:04:40,040 --> 00:04:37,800
a little bit more so to very simply

90
00:04:42,409 --> 00:04:40,050
represent our density structure and it

91
00:04:44,510 --> 00:04:42,419
is you kind of like a call it by a

92
00:04:48,650 --> 00:04:44,520
radial power log with with an exponent

93
00:04:51,020 --> 00:04:48,660
of fee or here and this density

94
00:04:52,550 --> 00:04:51,030
structure would be like very intimately

95
00:04:55,939 --> 00:04:52,560
connected with the temperature in a disk

96
00:05:00,080 --> 00:04:55,949
so if you represent that as well as a

97
00:05:02,990 --> 00:05:00,090
power loss with with Q we go back to a

98
00:05:04,850 --> 00:05:03,000
result by like 2k chicken Lynn who say

99
00:05:08,360 --> 00:05:04,860
that if the sum of these two exponents

100
00:05:10,790 --> 00:05:08,370
is greater than two then the net volar

101
00:05:14,270 --> 00:05:10,800
transport is likely to be outward and we

102
00:05:18,350 --> 00:05:14,280
kind of test what this is likely to be

103
00:05:21,260 --> 00:05:18,360
so if you assume like a standard value

104
00:05:24,770 --> 00:05:21,270
of the temperature power law are you

105
00:05:28,219 --> 00:05:24,780
know over the q of point five so we are

106
00:05:30,499 --> 00:05:28,229
like left to determine what is P and the

107
00:05:32,480 --> 00:05:30,509
previous speaker again spoke about the

108
00:05:34,969 --> 00:05:32,490
minimum master intervenor model where

109
00:05:38,750 --> 00:05:34,979
each of the giant planets kind of like

110
00:05:41,629 --> 00:05:38,760
smear in their current annuli and you

111
00:05:45,560 --> 00:05:41,639
you can infer surface density profile

112
00:05:51,010 --> 00:05:45,570
the slope of 1.5 with with such a model

113
00:05:54,379 --> 00:05:51,020

just shown here later dash 2007 kind of

114
00:05:58,790 --> 00:05:54,389
included the positions of the giant

115
00:06:01,820 --> 00:05:58,800
giant planets from the nice model and he

116
00:06:04,370 --> 00:06:01,830
found a slope that was more steeper for

117
00:06:07,370 --> 00:06:04,380
the surface density profile he basically

118
00:06:09,860 --> 00:06:07,380
thought that okay the nice model a

119
00:06:11,629 --> 00:06:09,870
position the giant planets is a more

120
00:06:14,870 --> 00:06:11,639
reasonable assumption to make because a

121
00:06:18,710 --> 00:06:14,880
lot of migration in the planets like

122
00:06:23,390 --> 00:06:18,720
father word after from hundreds of

123
00:06:26,360 --> 00:06:23,400
millions of years so we so basically in

124
00:06:28,879 --> 00:06:26,370
in this project we model destruction and

125
00:06:31,010 --> 00:06:28,889
evolution and try to see what effects de

126
00:06:33,770 --> 00:06:31,020
structure how for the operation of extra

127
00:06:36,110 --> 00:06:33,780
structure and also we consider a

128
00:06:39,350 --> 00:06:36,120
non-uniform as a viscosity of LP

129
00:06:40,590 --> 00:06:39,360
explaining so we take an account the

130
00:06:43,800 --> 00:06:40,600
standard

131
00:06:48,330 --> 00:06:43,810
equations of bisque evolution by Lynn

132
00:06:50,880 --> 00:06:48,340
melanin belen Pringle and where this

133
00:06:52,890 --> 00:06:50,890
equation our talks about the evolution

134
00:06:57,860 --> 00:06:52,900
of the surface density and the rate of

135
00:07:01,590 --> 00:06:57,870
mass flow and we also assume like this

136
00:07:04,680 --> 00:07:01,600
the standard viscosity parameterization

137
00:07:06,660 --> 00:07:04,690
where a new is given as alpha times San

138
00:07:09,510 --> 00:07:06,670

speed squared divided by orbital

139
00:07:14,220 --> 00:07:09,520
frequency and so mostest models just

140
00:07:16,560 --> 00:07:14,230
assume just an invariable alpha offers

141
00:07:19,350 --> 00:07:16,570
the same throughout the disk with height

142
00:07:22,850 --> 00:07:19,360
and width or radius and it's and it's

143
00:07:25,890 --> 00:07:22,860
also the same with time but we kind of

144
00:07:28,770 --> 00:07:25,900
kind of derive this alpha from Magneto

145
00:07:30,780 --> 00:07:28,780
rotation instabilities and kind of find

146
00:07:32,250 --> 00:07:30,790
that it varies quite a bit and this has

147
00:07:35,670 --> 00:07:32,260
to be considered in risk evaluation

148
00:07:39,120 --> 00:07:35,680
models so magneto rotational

149
00:07:41,700 --> 00:07:39,130
instabilities simply put is like in a

150
00:07:45,060 --> 00:07:41,710
fluid instability that occurs in a

151
00:07:47,280 --> 00:07:45,070
creationist it occurs only if there's

152
00:07:50,430 --> 00:07:47,290
the if the region in the discus like

153
00:07:52,590 --> 00:07:50,440
sufficiently ionized and so for this we

154
00:07:54,420 --> 00:07:52,600
calculate the ionization state at each

155
00:07:56,760 --> 00:07:54,430
region in the disk so we consider

156
00:08:00,750 --> 00:07:56,770
ionizations by x-rays and cosmic rays

157
00:08:02,970 --> 00:08:00,760
and we consider recombinations of these

158
00:08:05,400 --> 00:08:02,980
ionic species and electrons and the gas

159
00:08:07,440 --> 00:08:05,410
phase is this dust green surfaces I

160
00:08:11,790 --> 00:08:07,450
could I could talk about more details

161
00:08:14,280 --> 00:08:11,800
later so what we do then is we consider

162
00:08:20,640 --> 00:08:14,290
the treatment treatment of buyin stone

163
00:08:24,360 --> 00:08:20,650

2011 well be basically determine the

164
00:08:27,930 --> 00:08:24,370
Alfred each each region in the disk from

165
00:08:30,360 --> 00:08:27,940
the ionizing ionization state and we

166
00:08:34,230 --> 00:08:30,370
find that on incorporating these

167
00:08:37,560 --> 00:08:34,240
equations in our disk model that alpha

168
00:08:39,600 --> 00:08:37,570
does really change a lot like oh for

169
00:08:41,670 --> 00:08:39,610
more do some attitude throughout the

170
00:08:44,310 --> 00:08:41,680
radius of the disk from about likes a

171
00:08:46,800 --> 00:08:44,320
point or less than point 5 15 the flower

172
00:08:51,930 --> 00:08:46,810
here I'm sorry 10 to the 10 to the minus

173
00:08:54,100 --> 00:08:51,940
5 and 2.1 in the outer regions the disk

174
00:09:00,400 --> 00:08:54,110
and it also changes

175
00:09:03,699 --> 00:09:00,410
dramatically with time so and finally we

176
00:09:07,810 --> 00:09:03,709
also include photo operation using the

177
00:09:09,940 --> 00:09:07,820
the treatment and the result of Food

178
00:09:14,800 --> 00:09:09,950
Association models from Adams at all

179
00:09:17,980 --> 00:09:14,810
where they basically the massless rates

180
00:09:24,519 --> 00:09:17,990
your for evaporation mainly depend on

181
00:09:28,030 --> 00:09:24,529
the the disc radius at ya on the disc

182
00:09:31,210 --> 00:09:28,040
radius as well as G naught which is kind

183
00:09:37,030 --> 00:09:31,220
of like the parameter for describing the

184
00:09:41,170 --> 00:09:37,040
radiation intensity that the disc point

185
00:09:43,720 --> 00:09:41,180
is finds itself in so here we find we we

186
00:09:47,230 --> 00:09:43,730
use a value of a GNote of a thousand to

187
00:09:53,139 --> 00:09:47,240
be be considered that to be typical of

188
00:09:57,880 --> 00:09:53,149

what this are likely to face and in like

189
00:10:01,240 --> 00:09:57,890
rich star forming regions and finally do

190
00:10:05,980 --> 00:10:01,250
go to our results so I'm showing you the

191
00:10:08,980 --> 00:10:05,990
first sort of viscously evolving disc

192
00:10:11,519 --> 00:10:08,990
case and to kind of describe this graph

193
00:10:15,100 --> 00:10:11,529
a little bit this is the surface density

194
00:10:17,920 --> 00:10:15,110
on a log-log with a log-log plot with

195
00:10:22,180 --> 00:10:17,930
the radius so the radius curve goes from

196
00:10:26,050 --> 00:10:22,190
point 1 au to 180 here and each of these

197
00:10:29,670 --> 00:10:26,060
um so this is the initial the door line

198
00:10:31,780 --> 00:10:29,680
or the dashed line is in is the initial

199
00:10:35,590 --> 00:10:31,790
profile of the disc and each of these

200
00:10:38,710 --> 00:10:35,600
lines are solid lines at each subsequent

201
00:10:41,170 --> 00:10:38,720
here or milliner of evolution from 1

202
00:10:45,090 --> 00:10:41,180
million years 10 min years so you can

203
00:10:47,769 --> 00:10:45,100
see that the disc obviously becomes less

204
00:10:50,889 --> 00:10:47,779
massive with time and you can also see

205
00:10:53,019 --> 00:10:50,899
it sort of expand outwards that's what I

206
00:10:54,850 --> 00:10:53,029
viscously evolving this without any of

207
00:11:05,050 --> 00:10:54,860
the effects that i described about good

208
00:11:06,970 --> 00:11:05,060
what kind of I mean react so so after 10

209
00:11:10,389 --> 00:11:06,980
million years of evolution

210
00:11:12,730 --> 00:11:10,399
only like half of the disc remains and

211
00:11:14,439 --> 00:11:12,740
you could kind of like keep keep in mind

212
00:11:18,370 --> 00:11:14,449
this number as I show you different

213
00:11:21,220 --> 00:11:18,380

cases so then so the other thing we do

214
00:11:23,829 --> 00:11:21,230
is we also track the slope of the

215
00:11:27,100 --> 00:11:23,839
surface density profile between five and

216
00:11:32,139 --> 00:11:27,110
thirty you and here we find that the

217
00:11:34,150 --> 00:11:32,149
slope p is about one so next we go to a

218
00:11:37,240 --> 00:11:34,160
photo operated case so it's basically a

219
00:11:40,509 --> 00:11:37,250
viscously evolving disk without Amara

220
00:11:43,540 --> 00:11:40,519
alpha with with for with for evaporation

221
00:11:45,759 --> 00:11:43,550
and you can see that this the slope that

222
00:11:48,879 --> 00:11:45,769
we keep track off between five thirty au

223
00:11:52,480 --> 00:11:48,889
it's slightly steeper right now and the

224
00:11:54,550 --> 00:11:52,490
disc is less less massive even more only

225
00:11:57,009 --> 00:11:54,560
five percent of the disc remains after

226
00:12:01,990 --> 00:11:57,019
ten million years of evolution and it's

227
00:12:06,879 --> 00:12:02,000
also truncated to about fifty fifty a

228
00:12:10,300 --> 00:12:06,889
you so the other interesting thing that

229
00:12:11,920 --> 00:12:10,310
you can find in this this type of disc

230
00:12:14,590 --> 00:12:11,930
is that is the behavior of the

231
00:12:16,540 --> 00:12:14,600
transition radius so in a in a viscously

232
00:12:18,639 --> 00:12:16,550
evolving disk this transition radius

233
00:12:23,829 --> 00:12:18,649
usually moves outward with time and we

234
00:12:26,860 --> 00:12:23,839
find that this this radius which is

235
00:12:28,990 --> 00:12:26,870
basically the radius where the net mass

236
00:12:32,019 --> 00:12:29,000
flow changes from inward operational

237
00:12:34,449 --> 00:12:32,029
flow to outward this moves inward with

238
00:12:38,019 --> 00:12:34,459

time and in in this disk it actually

239
00:12:39,519 --> 00:12:38,029
moves as closes 17a you from the start

240
00:12:42,790 --> 00:12:39,529
so basically what this means is that

241
00:12:44,410 --> 00:12:42,800
mass as close as 17 au is drawn out

242
00:12:49,079 --> 00:12:44,420
words from from the outer edge of the

243
00:12:52,750 --> 00:12:49,089
disk then we take the third case where

244
00:12:55,480 --> 00:12:52,760
we include MRI azva and 40 operation and

245
00:12:58,030 --> 00:12:55,490
we find that the disk rapidly dispatch

246
00:13:01,120 --> 00:12:58,040
within just seven point seven point five

247
00:13:03,579 --> 00:13:01,130
million years of evolution so what what

248
00:13:05,980 --> 00:13:03,589
happens is the slope becomes really

249
00:13:09,370 --> 00:13:05,990
really steep and most of the disk is

250
00:13:13,569 --> 00:13:09,380
just gone in within 7.5 million years

251
00:13:15,939 --> 00:13:13,579
and but when we include dust in the

252
00:13:19,730 --> 00:13:15,949
scenario the previous case do not have

253
00:13:22,130 --> 00:13:19,740
any dust in it it kind of has it

254
00:13:26,420 --> 00:13:22,140
has an totally opposite effect from what

255
00:13:29,390 --> 00:13:26,430
we just saw what we see here is the dust

256
00:13:31,760 --> 00:13:29,400
kind of stalls the inner disk evolution

257
00:13:34,700 --> 00:13:31,770
by sort of absorbing charges in the

258
00:13:36,950 --> 00:13:34,710
theory of the disk and the rest of the

259
00:13:40,010 --> 00:13:36,960
disk just files on on top of the inner

260
00:13:42,800 --> 00:13:40,020
disk kind of erecting this really steep

261
00:13:46,580 --> 00:13:42,810
profile you know where p is like much

262
00:13:49,820 --> 00:13:46,590
greater than 3 and so this is kind of

263
00:13:53,540 --> 00:13:49,830

really interesting of course we don't

264
00:13:56,720 --> 00:13:53,550
include grain growth here so that is an

265
00:13:59,510 --> 00:13:56,730
important caveat so conclusions for

266
00:14:02,290 --> 00:13:59,520
evaporation does cause steep profiles so

267
00:14:04,850 --> 00:14:02,300
we get a large p and this is likely to

268
00:14:08,720 --> 00:14:04,860
create like more outward transferred

269
00:14:10,490 --> 00:14:08,730
from the result by decay chain then my

270
00:14:13,610 --> 00:14:10,500
alpha is very sensitive to the presence

271
00:14:15,230 --> 00:14:13,620
of dust and dust causes the style

272
00:14:17,930 --> 00:14:15,240
evolution of the inner disk it doesn't

273
00:14:20,090 --> 00:14:17,940
let it evolve disk dispersal would

274
00:14:23,030 --> 00:14:20,100
require would require grain growth which

275
00:14:25,730 --> 00:14:23,040
we don't model here and the transition

276
00:14:28,190 --> 00:14:25,740
radius moves in so the gas is removed

277
00:14:30,770 --> 00:14:28,200
from the inner disk and in this previous

278
00:14:34,130 --> 00:14:30,780
case it moves as close as three a year

279
00:14:36,080 --> 00:14:34,140
which is why it's very important from

280
00:14:38,840 --> 00:14:36,090
the for the terrestrial planet region

281
00:14:41,450 --> 00:14:38,850
point of view so dehydration of the

282
00:14:44,990 --> 00:14:41,460
inner disk especially wood is important

283
00:14:56,890 --> 00:14:45,000
especially for dis in rich clusters so

284
00:15:03,470 --> 00:15:01,160
huh so um have you done a sensitivity

285
00:15:07,060 --> 00:15:03,480
studied to see if you turn off the MRI

286
00:15:09,230 --> 00:15:07,070
alpha and just include the dust if it

287
00:15:11,300 --> 00:15:09,240
essentially reproduces the same shaped

288
00:15:20,690 --> 00:15:11,310

is just completely overwhelmed the alpha

289
00:15:24,530 --> 00:15:20,700
variability no actually that would be

290
00:15:26,300 --> 00:15:24,540
interesting to see all right let's thank