



ATMOSPHERIC ESCAPE FROM  
HIGHLY IRRADIATED EXOPLANETS  
*JAMES OWEN*

1  
00:00:10,160 --> 00:00:06,940

[Music]

2  
00:00:11,360 --> 00:00:10,170  
thank you very much it's a great

3  
00:00:14,169 --> 00:00:11,370  
pleasure to be here and it's a great

4  
00:00:16,640 --> 00:00:14,179  
pleasure to be able to give you such a

5  
00:00:19,010 --> 00:00:16,650  
sort of peak given the freedom to give

6  
00:00:21,920 --> 00:00:19,020  
in quite a long talk so I can go into

7  
00:00:25,570 --> 00:00:21,930  
the details which I kind of enjoy from

8  
00:00:28,880 --> 00:00:25,580  
time to time so I was given the topic of

9  
00:00:34,490 --> 00:00:28,890  
atmospheric escape no other qualifiers

10  
00:00:37,189 --> 00:00:34,500  
after that but I've through simplified

11  
00:00:39,530 --> 00:00:37,199  
it slightly to a master escape of highly

12  
00:00:41,000 --> 00:00:39,540  
irradiated exoplanets and there's a good

13  
00:00:41,510 --> 00:00:41,010

reason for that which I'll show you in a

14

00:00:43,520 --> 00:00:41,520

second

15

00:00:46,069 --> 00:00:43,530

and I've also simplified it further that

16

00:00:48,440 --> 00:00:46,079

I'm just going to focus on atmospheric

17

00:00:50,000 --> 00:00:48,450

escape that's thermally driven so driven

18

00:00:54,680 --> 00:00:50,010

by heating rather than any other

19

00:00:56,119 --> 00:00:54,690

processes so the reason why I think we

20

00:00:59,000 --> 00:00:56,129

should be thinking about atmospheric

21

00:01:01,160 --> 00:00:59,010

escape for highly irradiated planets is

22

00:01:03,709 --> 00:01:01,170

when we look at the kind of exoplanets

23

00:01:05,359 --> 00:01:03,719

that we're going to be able to probe

24

00:01:11,000 --> 00:01:05,369

over the coming decade

25

00:01:15,850 --> 00:01:11,010

they are dominated by two a sort of

26

00:01:18,289 --> 00:01:15,860

facts so these are sort of test yields

27

00:01:21,890 --> 00:01:18,299

they're small planets all less than four

28

00:01:23,660 --> 00:01:21,900

Earth radii you can go to this this

29

00:01:26,570 --> 00:01:23,670

catalogue this also includes some sort

30

00:01:28,760 --> 00:01:26,580

of estimation of what the tests extended

31

00:01:30,620 --> 00:01:28,770

mission will do so now we're in the era

32

00:01:32,780 --> 00:01:30,630

that Tess's sort of finished its first

33

00:01:34,850 --> 00:01:32,790

year operations it's into its second

34

00:01:36,440 --> 00:01:34,860

year of operations and now it's going

35

00:01:38,149 --> 00:01:36,450

into the extend emission you find two

36

00:01:40,310 --> 00:01:38,159

things when you go through these yields

37

00:01:42,590 --> 00:01:40,320

firstly that the majority of the planets

38

00:01:45,560 --> 00:01:42,600

that we're gonna find are billions of

39

00:01:48,859 --> 00:01:45,570

years old but they're also incredibly

40

00:01:51,800 --> 00:01:48,869

highly irradiated right so this is earth

41

00:01:54,020 --> 00:01:51,810

down here this is mercury and our solar

42

00:01:56,149 --> 00:01:54,030

system and this is where the majority of

43

00:01:58,580 --> 00:01:56,159

the exoplanets we're gonna discover and

44

00:02:00,920 --> 00:01:58,590

be able to characterize in the next

45

00:02:03,139 --> 00:02:00,930

decade sit so they're sort of at a

46

00:02:05,990 --> 00:02:03,149

radiation level that's a hundred or

47

00:02:07,580 --> 00:02:06,000

hundred times or thirty times bigger

48

00:02:11,289 --> 00:02:07,590

than the earth and our order at least an

49

00:02:14,150 --> 00:02:11,299

order of magnitude larger than mercury

50

00:02:15,740 --> 00:02:14,160

this is even more pronounced when you

51  
00:02:18,050 --> 00:02:15,750  
look at the small planet so the small

52  
00:02:19,190 --> 00:02:18,060  
planets are gonna again be dominated by

53  
00:02:22,460 --> 00:02:19,200  
being these highly

54  
00:02:26,449 --> 00:02:22,470  
radiated plants now this is important

55  
00:02:29,780 --> 00:02:26,459  
because irradiation drives escape and

56  
00:02:35,300 --> 00:02:29,790  
the fact they're also old also has

57  
00:02:39,259 --> 00:02:35,310  
another consequence given that escape

58  
00:02:42,290 --> 00:02:39,269  
tends to be driven by the x-rays and the

59  
00:02:45,680 --> 00:02:42,300  
Eevee that the star outputs which is

60  
00:02:50,119 --> 00:02:45,690  
much much larger in the stars youth than

61  
00:02:52,130 --> 00:02:50,129  
when we see these today this means that

62  
00:02:54,170 --> 00:02:52,140  
for all the small exoplanets that we're

63  
00:02:56,509 --> 00:02:54,180

probably gonna get spectral for the next

64

00:03:00,410 --> 00:02:56,519

10 years atmospheric escape will have

65

00:03:01,850 --> 00:03:00,420

already sculpted their atmosphere so

66

00:03:04,069 --> 00:03:01,860

this is a process that we're gonna need

67

00:03:06,860 --> 00:03:04,079

to understand in order to meet

68

00:03:08,539 --> 00:03:06,870

understand the compositions and those

69

00:03:10,580 --> 00:03:08,549

properties of the atmospheres that we're

70

00:03:12,800 --> 00:03:10,590

going to be detecting over the next 10

71

00:03:14,420 --> 00:03:12,810

years and there's lots of work to do

72

00:03:17,270 --> 00:03:14,430

especially as we move towards the

73

00:03:23,240 --> 00:03:17,280

terrestrial planets this problem is sort

74

00:03:25,640 --> 00:03:23,250

of somewhat unsolved so in this talk I'm

75

00:03:27,979 --> 00:03:25,650

gonna go through a few things I'm gonna

76

00:03:29,990 --> 00:03:27,989

talk about the the very basic physics of

77

00:03:32,120 --> 00:03:30,000

thermal escape what do I mean what are

78

00:03:33,890 --> 00:03:32,130

the the different regimes that you might

79

00:03:35,780 --> 00:03:33,900

think about I'm gonna then talk about

80

00:03:38,840 --> 00:03:35,790

sort of hydrogen helium dominated

81

00:03:40,640 --> 00:03:38,850

atmospheres and this is where in the

82

00:03:42,710 --> 00:03:40,650

exit pipe community we sort of focused

83

00:03:43,910 --> 00:03:42,720

our theoretical work over the last ten

84

00:03:47,240 --> 00:03:43,920

years and we've had quite a bit of a

85

00:03:48,949 --> 00:03:47,250

success then I'm going to talk about

86

00:03:52,160 --> 00:03:48,959

water loss from habitable zone planets

87

00:03:53,569 --> 00:03:52,170

around M dwarfs this is a very important

88

00:03:57,319 --> 00:03:53,579

problem if we want to start thinking

89

00:03:59,270 --> 00:03:57,329

about habitability of M dwarfs is that

90

00:04:01,120 --> 00:03:59,280

they have due to their stellar evolution

91

00:04:04,000 --> 00:04:01,130

they have quite a different track to

92

00:04:07,550 --> 00:04:04,010

temperate planets around sun-like stars

93

00:04:09,410 --> 00:04:07,560

if I if I get time I'm going to allude

94

00:04:11,360 --> 00:04:09,420

to perhaps a pathway to how we can

95

00:04:14,120 --> 00:04:11,370

understand as farik escape from more

96

00:04:17,529 --> 00:04:14,130

complicated heavy element or secondary

97

00:04:19,759 --> 00:04:17,539

atmospheres and that's we're sort of my

98

00:04:21,740 --> 00:04:19,769

favorite topic at the moment which is

99

00:04:23,600 --> 00:04:21,750

sort of silicate vapor atmospheres

100

00:04:24,980 --> 00:04:23,610

around ultra short period planets these

101  
00:04:27,140 --> 00:04:24,990  
are planets that are so close to the

102  
00:04:29,690 --> 00:04:27,150  
star the star is actually able to melt

103  
00:04:31,399 --> 00:04:29,700  
their rocky surface and former that's to

104  
00:04:32,600 --> 00:04:31,409  
look at vapor atmosphere and throughout

105  
00:04:36,320 --> 00:04:32,610  
this talk angular sort of

106  
00:04:38,300 --> 00:04:36,330  
also point to the problems that we need

107  
00:04:43,010 --> 00:04:38,310  
to theoretical problems that we need to

108  
00:04:45,830 --> 00:04:43,020  
address over the next 10 years or so so

109  
00:04:47,450 --> 00:04:45,840  
the physics of family-driven escape so I

110  
00:04:49,490 --> 00:04:47,460  
said in this talking I'm going to only

111  
00:04:52,240 --> 00:04:49,500  
focus on thermally driven escape escape

112  
00:04:55,159 --> 00:04:52,250  
driven by heating there is a poster

113  
00:04:58,760 --> 00:04:55,169

which is on impact driven escape which I

114

00:05:00,950 --> 00:04:58,770

encourage you to go look at as well so

115

00:05:03,679 --> 00:05:00,960

family is driven escape and it's the

116

00:05:08,119 --> 00:05:03,689

most simple keynote cartoon version is

117

00:05:10,159 --> 00:05:08,129

that the star is heating out putting

118

00:05:12,110 --> 00:05:10,169

some photons and it heats the planet's

119

00:05:13,850 --> 00:05:12,120

atmosphere heats the surface layers of

120

00:05:16,070 --> 00:05:13,860

the planet's atmosphere and that

121

00:05:20,719 --> 00:05:16,080

atmosphere becomes hot enough that it

122

00:05:24,709 --> 00:05:20,729

can escape from the planet in more

123

00:05:27,950 --> 00:05:24,719

detail there are a couple of limits of

124

00:05:30,200 --> 00:05:27,960

this process so if you consider the

125

00:05:31,999 --> 00:05:30,210

planet's atmosphere which i've shown

126

00:05:34,399 --> 00:05:32,009

here these are atoms in the planet's

127

00:05:36,290 --> 00:05:34,409

atmosphere the base of the planets down

128

00:05:38,869 --> 00:05:36,300

here and the top of the atmosphere is up

129

00:05:41,570 --> 00:05:38,879

here so under the stratification of

130

00:05:44,119 --> 00:05:41,580

gravity the density is much much lower

131

00:05:45,950 --> 00:05:44,129

close to the surface of the planet and

132

00:05:48,350 --> 00:05:45,960

it sorry it's much the density of the

133

00:05:49,610 --> 00:05:48,360

gas is much much higher lower close to

134

00:05:52,369 --> 00:05:49,620

the surface of the planet but it's much

135

00:05:54,079 --> 00:05:52,379

much lower at higher altitudes and our

136

00:05:57,980 --> 00:05:54,089

photons from our star come in and they

137

00:06:00,469 --> 00:05:57,990

heat and in order to understand what

138

00:06:03,589 --> 00:06:00,479

regimes you are in the thermal escape

139

00:06:07,519 --> 00:06:03,599

there's two sort of critical radii in

140

00:06:10,369 --> 00:06:07,529

this atmosphere so there's the where the

141

00:06:13,309 --> 00:06:10,379

particle mean free path equals the

142

00:06:15,350 --> 00:06:13,319

atmospheric scale height so this is the

143

00:06:17,269 --> 00:06:15,360

distance the particles travel before

144

00:06:20,719 --> 00:06:17,279

they collide with another gas particle

145

00:06:22,790 --> 00:06:20,729

if you reach the point where the mean

146

00:06:25,760 --> 00:06:22,800

free path of the particles is larger

147

00:06:27,499 --> 00:06:25,770

than the planets scale height then the

148

00:06:29,149 --> 00:06:27,509

atoms in the atmosphere essentially sort

149

00:06:33,079 --> 00:06:29,159

of going up and down

150

00:06:34,790 --> 00:06:33,089

never colliding with another atom so

151

00:06:37,879 --> 00:06:34,800

they're behaving in a sort of

152

00:06:40,010 --> 00:06:37,889

collisionless way below this limit where

153

00:06:42,139 --> 00:06:40,020

the density is high enough the mean free

154

00:06:44,839 --> 00:06:42,149

path is shorter than the scale height

155

00:06:45,980 --> 00:06:44,849

the gas behaves more like a fluid the

156

00:06:52,909 --> 00:06:45,990

collisionless process

157

00:06:55,189 --> 00:06:52,919

there's another critical density or

158

00:06:56,809 --> 00:06:55,199

critical radius in the atmosphere it's

159

00:06:59,839 --> 00:06:56,819

where the particles thermal energy

160

00:07:01,520 --> 00:06:59,849

exceeds the bind their binding energy

161

00:07:04,820 --> 00:07:01,530

their gravitational binding energy so if

162

00:07:07,129 --> 00:07:04,830

you're above this radius you have enough

163

00:07:10,879 --> 00:07:07,139

thermal energy to escape from the

164

00:07:14,200 --> 00:07:10,889

planets gravity and the thermal escape

165

00:07:17,659 --> 00:07:14,210

regime you end up sitting in depends on

166

00:07:21,140 --> 00:07:17,669

which of these radii you encounter first

167

00:07:22,670 --> 00:07:21,150

as you go up in the atmosphere so if we

168

00:07:25,490 --> 00:07:22,680

think about a weakly irradiated

169

00:07:31,490 --> 00:07:25,500

atmosphere first it's not very hot it's

170

00:07:33,469 --> 00:07:31,500

not very hot then you need to go high up

171

00:07:36,080 --> 00:07:33,479

into the atmosphere before you have

172

00:07:38,749 --> 00:07:36,090

sufficient thermal energy to be unbound

173

00:07:40,999 --> 00:07:38,759

from the planets gravity so the point at

174

00:07:42,860 --> 00:07:41,009

which the article thermal energy exceeds

175

00:07:46,580 --> 00:07:42,870

the gravitational potential energy is

176  
00:07:48,920 --> 00:07:46,590  
very very high up in the atmosphere and

177  
00:07:51,080 --> 00:07:48,930  
it's higher compared to where the

178  
00:07:52,760 --> 00:07:51,090  
particle mean free path is approximately

179  
00:07:57,460 --> 00:07:52,770  
equal to the scale and this also has

180  
00:07:59,629 --> 00:07:57,470  
another name the exobase now this has a

181  
00:08:04,550 --> 00:07:59,639  
consequence for how you might escape

182  
00:08:07,249 --> 00:08:04,560  
because as I said earlier still getting

183  
00:08:09,649 --> 00:08:07,259  
used to this pointer any of the

184  
00:08:11,779 --> 00:08:09,659  
particles that are above this EXO

185  
00:08:13,300 --> 00:08:11,789  
baseline here where the particle premi

186  
00:08:15,320 --> 00:08:13,310  
path is bigger than the scale height

187  
00:08:18,499 --> 00:08:15,330  
basically don't collide with another

188  
00:08:21,649 --> 00:08:18,509

atom they behave almost in a collision

189

00:08:23,899 --> 00:08:21,659

'less manner so if you envisage that you

190

00:08:26,240 --> 00:08:23,909

have some sort of velocity or energy

191

00:08:29,120 --> 00:08:26,250

distribution for those particles any

192

00:08:32,329 --> 00:08:29,130

particle that gained sufficient kinetic

193

00:08:34,730 --> 00:08:32,339

energy that is no longer bound to the

194

00:08:39,440 --> 00:08:34,740

planets gravity can just freely escape

195

00:08:43,069 --> 00:08:39,450

into space so you sort of lose this tail

196

00:08:44,240 --> 00:08:43,079

of this distribution here is it so if

197

00:08:46,940 --> 00:08:44,250

this was a Maxwell Boltzmann

198

00:08:48,769 --> 00:08:46,950

distribution then this would be sort of

199

00:08:53,210 --> 00:08:48,779

you'd be out in the exponential tail

200

00:08:55,280 --> 00:08:53,220

Maxwell Boltzmann distribution so this

201  
00:08:57,500 --> 00:08:55,290  
tells you because you're out in this

202  
00:08:59,390 --> 00:08:57,510  
Maxwell Boltzmann distribution in its

203  
00:08:59,840 --> 00:08:59,400  
exponential function this is not a very

204  
00:09:06,290 --> 00:08:59,850  
very

205  
00:09:07,910 --> 00:09:06,300  
process of losing your atmosphere so

206  
00:09:11,480 --> 00:09:07,920  
this is the kind of atmospheric escape

207  
00:09:13,999 --> 00:09:11,490  
that's driving some losses from the

208  
00:09:18,079 --> 00:09:14,009  
earth today and the mass loss rate from

209  
00:09:20,780 --> 00:09:18,089  
the Earth's atmosphere is very very long

210  
00:09:23,569 --> 00:09:20,790  
it is longer than sort of one atmosphere

211  
00:09:26,990 --> 00:09:23,579  
per sort of under a billion years which

212  
00:09:28,220 --> 00:09:27,000  
is pretty good for habitability we're

213  
00:09:30,710 --> 00:09:28,230

not gonna lose our atmosphere in the

214

00:09:32,180 --> 00:09:30,720

next few years which is good we might

215

00:09:36,379 --> 00:09:32,190

ruin it in the next few years but we're

216

00:09:38,689 --> 00:09:36,389

not gonna lose it but there's an

217

00:09:41,540 --> 00:09:38,699

opposite limit which is when you become

218

00:09:44,090 --> 00:09:41,550

strongly irradiated and you swish where

219

00:09:49,519 --> 00:09:44,100

those two heights appear in your

220

00:09:51,050 --> 00:09:49,529

atmosphere so now you have your where

221

00:09:52,819 --> 00:09:51,060

your particle thermal energy exceeds

222

00:09:55,639 --> 00:09:52,829

your gravitational potential deep in

223

00:09:57,590 --> 00:09:55,649

your atmosphere compared to where your

224

00:09:59,990 --> 00:09:57,600

EXO bases which is much much higher and

225

00:10:01,370 --> 00:10:00,000

now you have sufficient thermal energy

226

00:10:03,829 --> 00:10:01,380

to escape the planet's gravitational

227

00:10:07,790 --> 00:10:03,839

well and what you do is you drive a

228

00:10:10,040 --> 00:10:07,800

hydrodynamic wind so you drive a

229

00:10:12,019 --> 00:10:10,050

pressure driven wind that escapes from

230

00:10:13,850 --> 00:10:12,029

the planets gravity and instead of

231

00:10:15,199 --> 00:10:13,860

losing just this sort of exponential

232

00:10:17,480 --> 00:10:15,209

tail of your Maxwell Boltzmann

233

00:10:20,179 --> 00:10:17,490

distribution of your gas particles you

234

00:10:23,780 --> 00:10:20,189

lose the bulk now this is a much more

235

00:10:26,269 --> 00:10:23,790

efficient process so once you're in the

236

00:10:28,660 --> 00:10:26,279

hydrodynamic regime or once you're in

237

00:10:30,829 --> 00:10:28,670

this strongly irradiated regime

238

00:10:32,720 --> 00:10:30,839

atmospheric escape and hydrodynamic

239

00:10:34,999 --> 00:10:32,730

escape is a very very efficient process

240

00:10:36,949 --> 00:10:35,009

and it can dramatically alter your

241

00:10:42,530 --> 00:10:36,959

atmosphere over the billions of years

242

00:10:44,809 --> 00:10:42,540

but a planet has to evolve so in a

243

00:10:46,670 --> 00:10:44,819

little more detail this is a now is that

244

00:10:49,759 --> 00:10:46,680

a slice through one of those large

245

00:10:51,710 --> 00:10:49,769

simulations just showing the temperature

246

00:10:53,360 --> 00:10:51,720

structure as a function of altitude in

247

00:10:55,939 --> 00:10:53,370

the velocity structures a function of

248

00:10:57,949 --> 00:10:55,949

altitude so this is for a typical highly

249

00:11:00,439 --> 00:10:57,959

irradiated hydrogen helium dominated

250

00:11:04,100 --> 00:11:00,449

atmosphere that's the route sort of 0.1

251

00:11:06,650 --> 00:11:04,110

au from its star the UV and the x-rays

252

00:11:09,110 --> 00:11:06,660

heat the upper atmospheres to about 10

253

00:11:11,240 --> 00:11:09,120

to the 4 Kelvin and this is sufficient

254

00:11:12,360 --> 00:11:11,250

to drive this very powerful hydrodynamic

255

00:11:14,939 --> 00:11:12,370

outflow

256

00:11:19,259 --> 00:11:14,949

and one of the critical things that also

257

00:11:21,840 --> 00:11:19,269

happens in this process is the gas

258

00:11:24,480 --> 00:11:21,850

starts off subsonic and then it becomes

259

00:11:25,679 --> 00:11:24,490

supersonic at large radius once the gas

260

00:11:28,920 --> 00:11:25,689

is supersonic

261

00:11:32,069 --> 00:11:28,930

there's no way but anything that happens

262

00:11:33,509 --> 00:11:32,079

out here to tell the planet's atmosphere

263

00:11:35,670 --> 00:11:33,519

about what's going on

264

00:11:37,290 --> 00:11:35,680

you can only propagate information at

265

00:11:39,809 --> 00:11:37,300

the sound speed so if you're traveling

266

00:11:41,400 --> 00:11:39,819

faster than the sound speed any

267

00:11:42,869 --> 00:11:41,410

information you try and send backwards

268

00:11:47,629 --> 00:11:42,879

is just going to be infected out with

269

00:11:58,079 --> 00:11:47,639

you so anything that happens outside the

270

00:12:00,569 --> 00:11:58,089

sonic point here which also turns out to

271

00:12:01,949 --> 00:12:00,579

be exactly roughly where the thermal

272

00:12:04,139 --> 00:12:01,959

energy exceeds the gravitational

273

00:12:05,759 --> 00:12:04,149

potential energy is not going to affect

274

00:12:08,100 --> 00:12:05,769

your output so you can do basically

275

00:12:10,049 --> 00:12:08,110

whatever you want outside here and it's

276

00:12:13,110 --> 00:12:10,059

not gonna affect why what happened so

277

00:12:15,239 --> 00:12:13,120

you can put your exobase up here you can

278

00:12:17,639 --> 00:12:15,249

become collisionless or equations of

279

00:12:19,559 --> 00:12:17,649

hydrodynamics no longer apply the flow

280

00:12:22,860 --> 00:12:19,569

doesn't care you still get this

281

00:12:24,929 --> 00:12:22,870

hydrodynamic escape however if you push

282

00:12:27,569 --> 00:12:24,939

your exobase down we're back in the

283

00:12:30,179 --> 00:12:27,579

jeans escapement even though I've solved

284

00:12:32,280 --> 00:12:30,189

the problem assuming the equations of

285

00:12:34,590 --> 00:12:32,290

hydrodynamics apply this is not

286

00:12:38,129 --> 00:12:34,600

applicable so I have to go to the jeans

287

00:12:40,319 --> 00:12:38,139

escape so you can think of the

288

00:12:43,619 --> 00:12:40,329

transition from roughly the transition

289

00:12:46,619 --> 00:12:43,629

from hydrodynamic escape to jeans escape

290

00:12:49,679 --> 00:12:46,629

being roughly when the exo basis of the

291

00:12:51,299 --> 00:12:49,689

sonic point of these output and that's a

292

00:12:56,090 --> 00:12:51,309

good way to think about and that's how

293

00:12:59,309 --> 00:12:56,100

we actually calculate this transition in

294

00:13:01,230 --> 00:12:59,319

numerical simulations so in reality one

295

00:13:03,600 --> 00:13:01,240

would want to solve the collisional

296

00:13:05,249 --> 00:13:03,610

Boltzmann equation that go straight from

297

00:13:07,110 --> 00:13:05,259

the hydrodynamic limit all the way to

298

00:13:09,749 --> 00:13:07,120

the non hydrodynamic collisionless limit

299

00:13:12,299 --> 00:13:09,759

that is computationally impossible so

300

00:13:14,549 --> 00:13:12,309

what we typically do is we solve the

301  
00:13:16,530 --> 00:13:14,559  
equations of hydrodynamics we check that

302  
00:13:18,809 --> 00:13:16,540  
you're in the hydrodynamic limit through

303  
00:13:23,360 --> 00:13:18,819  
this criterion and if you're not then

304  
00:13:33,320 --> 00:13:27,680  
so a little more going into the details

305  
00:13:36,050 --> 00:13:33,330  
so this is our planet's atmosphere here

306  
00:13:38,840 --> 00:13:36,060  
this is a atmosphere surrounding surface

307  
00:13:42,470 --> 00:13:38,850  
of a planet and we have two heating

308  
00:13:45,530 --> 00:13:42,480  
sources in these cases the first heating

309  
00:13:47,360 --> 00:13:45,540  
sources is photons from the star and a

310  
00:13:50,560 --> 00:13:47,370  
second heating source especially if you

311  
00:13:54,500 --> 00:13:50,570  
have a big atmosphere or a young ages is

312  
00:13:56,570 --> 00:13:54,510  
thermal heating from the interior and

313  
00:13:58,880 --> 00:13:56,580

this gives you sort of a layered

314

00:14:01,010 --> 00:13:58,890

structure as to the the heating profile

315

00:14:03,950 --> 00:14:01,020

so in hydrogen helium dominated

316

00:14:07,490 --> 00:14:03,960

atmospheres first you absorb the the EUV

317

00:14:11,840 --> 00:14:07,500

photons then you absorb the x-rays and

318

00:14:14,450 --> 00:14:11,850

the f UV driven photons and then you

319

00:14:16,730 --> 00:14:14,460

have a region with is heated both

320

00:14:21,860 --> 00:14:16,740

bolometric ly by the star and from the

321

00:14:23,600 --> 00:14:21,870

star's interior and all the kind of

322

00:14:25,820 --> 00:14:23,610

atmospheric escape i'm going to talk

323

00:14:27,740 --> 00:14:25,830

about in this talk is driven basically

324

00:14:29,870 --> 00:14:27,750

from these layers here but in Helga's

325

00:14:32,150 --> 00:14:29,880

talk later in the session she's going to

326

00:14:35,710 --> 00:14:32,160

talk about a type of mass law for the

327

00:14:38,270 --> 00:14:35,720

driven by heating from the interior and

328

00:14:44,120 --> 00:14:38,280

you may be aware there's a little bit of

329

00:14:46,160 --> 00:14:44,130

debate as to what is driving mass loss

330

00:14:47,540 --> 00:14:46,170

from sub Neptune's and super Earths and

331

00:14:50,210 --> 00:14:47,550

the reason there's a little bit of

332

00:14:52,220 --> 00:14:50,220

debate is that this entire fluid

333

00:14:55,100 --> 00:14:52,230

structure of heating is not improperly

334

00:14:58,790 --> 00:14:55,110

solved in simulations so what people

335

00:15:02,380 --> 00:14:58,800

like me tend to do is just sort of

336

00:15:04,850 --> 00:15:02,390

ignore this bit and just do this but and

337

00:15:06,650 --> 00:15:04,860

what he'll cos model is doing at the

338

00:15:09,110 --> 00:15:06,660

moment is just doing this part and

339

00:15:10,910 --> 00:15:09,120

ignoring this part so there's a little

340

00:15:13,490 --> 00:15:10,920

bit of debate because these models have

341

00:15:16,790 --> 00:15:13,500

not been combined and this is work in

342

00:15:18,170 --> 00:15:16,800

progress that needs to be done I also

343

00:15:20,990 --> 00:15:18,180

want to point out that this layered

344

00:15:23,090 --> 00:15:21,000

structure is only necessarily true for

345

00:15:25,220 --> 00:15:23,100

hydra dan le marquis and i can imagine

346

00:15:27,110 --> 00:15:25,230

an envisaged because x-rays are

347

00:15:30,410 --> 00:15:27,120

preferentially absorbed by heavy

348

00:15:31,850 --> 00:15:30,420

elements and and metals is that if you

349

00:15:33,740 --> 00:15:31,860

go to secondary atmospheres you could

350

00:15:35,180 --> 00:15:33,750

reverse this kind of legend and this

351

00:15:38,950 --> 00:15:35,190

could have interesting effects for the

352

00:15:44,570 --> 00:15:42,740

so there is a very simple way to

353

00:15:47,019 --> 00:15:44,580

describe this process it's called energy

354

00:15:49,670 --> 00:15:47,029

limited escape you may have heard of it

355

00:15:52,130 --> 00:15:49,680

it's a it's a sort of back of the

356

00:15:54,920 --> 00:15:52,140

envelope calculation and what you do is

357

00:16:02,060 --> 00:15:54,930

you say I have summer radiation from the

358

00:16:04,400 --> 00:16:02,070

star and in some unit time my planets

359

00:16:08,810 --> 00:16:04,410

area the area the planet subtends the

360

00:16:12,079 --> 00:16:08,820

star absorbs that energy and then it

361

00:16:14,990 --> 00:16:12,089

takes that energy and it uses it to

362

00:16:18,530 --> 00:16:15,000

unbind a fraction  $\Delta M$  of the

363

00:16:21,200 --> 00:16:18,540

atmosphere then you go aha

364

00:16:24,460 --> 00:16:21,210

this looks magnificent I have Delta M

365

00:16:31,630 --> 00:16:24,470

here and Delta T here I can rearrange

366

00:16:33,860 --> 00:16:31,640

and I can get a mass loss rate so I have

367

00:16:35,930 --> 00:16:33,870

basically by equating the flux I'm

368

00:16:38,090 --> 00:16:35,940

absorbing from the star with the

369

00:16:40,370 --> 00:16:38,100

potential I'm escaping for all I can get

370

00:16:42,920 --> 00:16:40,380

an approximate expression and I can make

371

00:16:47,120 --> 00:16:42,930

it an exactly it's exact expression by

372

00:16:49,970 --> 00:16:47,130

sticking in a fudge factor and then I

373

00:16:52,490 --> 00:16:49,980

can call this the efficiency and this

374

00:16:54,680 --> 00:16:52,500

efficiency basically accounts for all of

375

00:16:56,840 --> 00:16:54,690

our ignorance it accounts for stuff we

376

00:16:59,450 --> 00:16:56,850

don't under or can't more or need to

377

00:17:02,240 --> 00:16:59,460

model with simulations so some radiative

378

00:17:04,100 --> 00:17:02,250

losses hydrodynamic losses and losses

379

00:17:07,010 --> 00:17:04,110

due to ionization right if you have a a

380

00:17:09,650 --> 00:17:07,020

high energy photon like an e UV photon

381

00:17:12,260 --> 00:17:09,660

come in the way it heats is by ionizing

382

00:17:14,600 --> 00:17:12,270

a hydrogen matter so an enormous amount

383

00:17:16,579 --> 00:17:14,610

of its energy goes into unbinding the

384

00:17:19,550 --> 00:17:16,589

electron from the hydrogen so you don't

385

00:17:22,309 --> 00:17:19,560

can't actually use EUV photons at 100%

386

00:17:24,590 --> 00:17:22,319

efficiency in fact you only use a small

387

00:17:32,460 --> 00:17:24,600

fraction of any UV photon to actually do

388

00:17:38,880 --> 00:17:36,350

the other key point is unsurprisingly

389

00:17:40,800 --> 00:17:38,890

when you do simulations the mass loss

390

00:17:44,280 --> 00:17:40,810

efficiency is not constant this should

391

00:17:46,190 --> 00:17:44,290

not be a shocking result to you and you

392

00:17:50,220 --> 00:17:46,200

can see that it varies this is just one

393

00:17:51,630 --> 00:17:50,230

numerical calculation for one flux a one

394

00:17:54,630 --> 00:17:51,640

stellar age you can see that the

395

00:17:56,460 --> 00:17:54,640

efficiency varies by about an order

396

00:17:58,950 --> 00:17:56,470

matter of magnitude but if you were to

397

00:18:00,990 --> 00:17:58,960

sort of put a gun to my head and force

398

00:18:02,580 --> 00:18:01,000

me I'd say the efficiency is about ten

399

00:18:04,320 --> 00:18:02,590

percent for the sub Neptune's and

400

00:18:09,480 --> 00:18:04,330

super-earth and about one percent for

401  
00:18:11,400 --> 00:18:09,490  
the hot Jupiter you can also see that it

402  
00:18:13,320 --> 00:18:11,410  
doesn't even have to scale linearly with

403  
00:18:14,850 --> 00:18:13,330  
flux so this is a nice plot from

404  
00:18:17,250 --> 00:18:14,860  
ruth-marie clay showing the mass loss

405  
00:18:20,070 --> 00:18:17,260  
rate as a function of input UV flux so

406  
00:18:22,110 --> 00:18:20,080  
low UV fluxes you get an almost linear

407  
00:18:24,630 --> 00:18:22,120  
scaling this is what you would expect

408  
00:18:27,890 --> 00:18:24,640  
from this energy limited process but as

409  
00:18:30,540 --> 00:18:27,900  
you go to higher and higher fluxes the

410  
00:18:32,460 --> 00:18:30,550  
scaling with mass loss rate this box

411  
00:18:34,320 --> 00:18:32,470  
gets weaker and weaker and weaker and

412  
00:18:36,900 --> 00:18:34,330  
this is well understood in terms of a

413  
00:18:39,510 --> 00:18:36,910

physical process this is where radiative

414

00:18:44,880 --> 00:18:39,520

recombinations kick in and you get much

415

00:18:48,150 --> 00:18:44,890

lower efficiency mass loss the other

416

00:18:50,910 --> 00:18:48,160

thing you note is that sort of in the

417

00:18:54,420 --> 00:18:50,920

strictest definition of the word mass

418

00:18:56,700 --> 00:18:54,430

loss is not always energy limited so

419

00:18:59,190 --> 00:18:56,710

what this energy limit really means is

420

00:19:01,500 --> 00:18:59,200

you take your heating and you convert it

421

00:19:03,420 --> 00:19:01,510

into PDV work as you're expanding from

422

00:19:06,210 --> 00:19:03,430

the planets potential and you get mass

423

00:19:08,250 --> 00:19:06,220

loss this means that the sort of

424

00:19:11,130 --> 00:19:08,260

dominant loss mechanism that you would

425

00:19:15,330 --> 00:19:11,140

expect to be playing a role in this

426

00:19:20,220 --> 00:19:15,340

process is energy losses in PDV work and

427

00:19:22,620 --> 00:19:20,230

this isn't actually true for the entire

428

00:19:24,570 --> 00:19:22,630

region of parameter space but again

429

00:19:28,140 --> 00:19:24,580

these are just two examples of two

430

00:19:31,140 --> 00:19:28,150

calculations but two fluxes are higher

431

00:19:34,290 --> 00:19:31,150

flux and a lower flux so this blue

432

00:19:36,600 --> 00:19:34,300

region here for UV heating is what you

433

00:19:41,240 --> 00:19:36,610

would expect roughly energy limited so

434

00:19:44,100 --> 00:19:41,250

the flux in is mostly lost as PDV work

435

00:19:46,290 --> 00:19:44,110

but there are other regions where this

436

00:19:48,930 --> 00:19:46,300

really the recombination process

437

00:19:50,900 --> 00:19:48,940

dominates we're hydrogen atoms recombine

438

00:19:53,040 --> 00:19:50,910

that gives you very efficient cooling

439

00:19:56,370 --> 00:19:53,050

also the other thing you should note

440

00:19:58,110 --> 00:19:56,380

about the energy limited formula is the

441

00:20:00,990 --> 00:19:58,120

mass loss rate goes to infinity as the

442

00:20:05,160 --> 00:20:01,000

mass goes to zero which also sounds a

443

00:20:07,290 --> 00:20:05,170

bit weird and it is weird and it's wrong

444

00:20:10,260 --> 00:20:07,300

and eventually you just you run out of

445

00:20:12,330 --> 00:20:10,270

photons basically if you only have

446

00:20:13,950 --> 00:20:12,340

certain number of photon so you can only

447

00:20:15,360 --> 00:20:13,960

ionize a certain number of hydrogen

448

00:20:19,980 --> 00:20:15,370

atoms and you can only get a certain

449

00:20:22,830 --> 00:20:19,990

amount of mass so a sort of very low

450

00:20:24,510 --> 00:20:22,840

gravities you need to also take into

451  
00:20:26,820 --> 00:20:24,520  
account the number of photons they're

452  
00:20:30,440 --> 00:20:26,830  
going into the output not just the

453  
00:20:34,320 --> 00:20:30,450  
energy of those photons so it seems like

454  
00:20:37,500 --> 00:20:34,330  
perhaps energy limited mass loss it's

455  
00:20:39,480 --> 00:20:37,510  
not a bad approximation for the super

456  
00:20:41,070 --> 00:20:39,490  
Earths and said not Toomes well one of

457  
00:20:43,050 --> 00:20:41,080  
the other things to realize is if they

458  
00:20:45,690 --> 00:20:43,060  
truly are hydrogen helium dominated

459  
00:20:48,080 --> 00:20:45,700  
atmospheres when they formed a very very

460  
00:20:50,640 --> 00:20:48,090  
young ages they were much much larger

461  
00:20:55,650 --> 00:20:50,650  
they would have sort of sat on this side

462  
00:20:57,360 --> 00:20:55,660  
of the lot so while the energy limited

463  
00:20:59,250 --> 00:20:57,370

formalism is a great formalism for

464

00:21:03,210 --> 00:20:59,260

understanding the details of what's

465

00:21:05,910 --> 00:21:03,220

going on and it's a great formalism for

466

00:21:07,350 --> 00:21:05,920

sort of getting an idea of how important

467

00:21:09,690 --> 00:21:07,360

you think atmospheric escape and how

468

00:21:10,560 --> 00:21:09,700

important you think mass loss is if you

469

00:21:13,350 --> 00:21:10,570

really want to do sophisticated

470

00:21:15,960 --> 00:21:13,360

calculations then unfortunately like

471

00:21:18,420 --> 00:21:15,970

many things in modern physics you need

472

00:21:23,220 --> 00:21:18,430

to go to more detailed numerical

473

00:21:25,830 --> 00:21:23,230

calculation so the first part of this

474

00:21:28,530 --> 00:21:25,840

sort of review is I'm going to focus on

475

00:21:30,000 --> 00:21:28,540

kind of key results from escape from

476

00:21:34,860 --> 00:21:30,010

hydrogen helium rich highly irradiated

477

00:21:38,400 --> 00:21:34,870

excellent so we have these two main

478

00:21:41,820 --> 00:21:38,410

sources of heating from stars we have

479

00:21:43,590 --> 00:21:41,830

x-ray photons and EUV photons for

480

00:21:49,230 --> 00:21:43,600

hydrogen helium dominated atmospheres

481

00:21:51,660 --> 00:21:49,240

the e UV is absorbed first so the UV is

482

00:21:53,250 --> 00:21:51,670

absorbed first and then the x-rays go a

483

00:21:59,190 --> 00:21:53,260

bit deeper in the atmosphere and you

484

00:22:01,139 --> 00:21:59,200

drive some output so as I said

485

00:22:03,389 --> 00:22:01,149

earlier the key for understanding what's

486

00:22:05,340 --> 00:22:03,399

going on and what's doing the driving is

487

00:22:07,169 --> 00:22:05,350

where the sonic point sits in the sound

488

00:22:08,940 --> 00:22:07,179

flow because if anything goes on after

489

00:22:11,519 --> 00:22:08,950

the sonic point you can't tell the

490

00:22:13,680 --> 00:22:11,529

planet's atmosphere event so you can

491

00:22:16,110 --> 00:22:13,690

have two different types of outflows you

492

00:22:17,610 --> 00:22:16,120

can have sort of X ray driven outflow

493

00:22:19,830 --> 00:22:17,620

where you get the sonic point in the X

494

00:22:21,990 --> 00:22:19,840

ray driven regime and all the UV photons

495

00:22:23,759 --> 00:22:22,000

are absorbed outside the sign points so

496

00:22:25,799 --> 00:22:23,769

we call this X ray driven flow and the e

497

00:22:29,549 --> 00:22:25,809

UV cannot affect the mass what's right

498

00:22:31,680 --> 00:22:29,559

so when you take that flux in the energy

499

00:22:34,500 --> 00:22:31,690

limited formula and you call it x UV

500

00:22:36,360 --> 00:22:34,510

flux the X ray and UV you have to sort

501  
00:22:37,860 --> 00:22:36,370  
of decide how much of the X rays and how

502  
00:22:41,460 --> 00:22:37,870  
much of the e UV do I put into that

503  
00:22:43,230 --> 00:22:41,470  
block and you need to understand the

504  
00:22:46,110 --> 00:22:43,240  
structure of the outflow to decide how

505  
00:22:48,419 --> 00:22:46,120  
you do obviously you can go to the other

506  
00:22:51,750 --> 00:22:48,429  
limit now where the sonic point now sits

507  
00:22:53,159 --> 00:22:51,760  
in the UV driven flow and the experts

508  
00:22:54,299 --> 00:22:53,169  
are playing a minor role all they're

509  
00:22:58,259 --> 00:22:54,309  
really doing is puffing off the

510  
00:23:00,389 --> 00:22:58,269  
atmosphere slightly more so it turns out

511  
00:23:02,549 --> 00:23:00,399  
that this dominates at high fluxes and

512  
00:23:04,710 --> 00:23:02,559  
hi Stella x-ray luminosities you can

513  
00:23:06,389 --> 00:23:04,720

sort of envisage that it's because the

514

00:23:07,950 --> 00:23:06,399

more and more heating you kind of dump

515

00:23:10,710 --> 00:23:07,960

into this outflow structure the more

516

00:23:12,480 --> 00:23:10,720

powerful the outflow more the faster the

517

00:23:14,250 --> 00:23:12,490

velocity increases so the likelihood

518

00:23:16,620 --> 00:23:14,260

that you cross the sonic point in the X

519

00:23:18,840 --> 00:23:16,630

ray heated regime rather than the e UV

520

00:23:21,810 --> 00:23:18,850

heated regime is gonna be at high

521

00:23:23,789 --> 00:23:21,820

stellar Foxit than high luminosity so

522

00:23:26,310 --> 00:23:23,799

this really matter it means that this

523

00:23:30,180 --> 00:23:26,320

kind of mass loss may be important early

524

00:23:32,779 --> 00:23:30,190

in the planets life so this is perhaps

525

00:23:35,879 --> 00:23:32,789

what's driving the evolution that we see

526

00:23:45,889 --> 00:23:35,889

but when we compare two direct

527

00:23:50,370 --> 00:23:48,600

it's gonna be the e UV that's important

528

00:23:52,379 --> 00:23:50,380

so this is something we also have to

529

00:23:53,759 --> 00:23:52,389

bear in mind that are the simulations

530

00:23:55,950 --> 00:23:53,769

and the models of atmospheric escape

531

00:23:59,190 --> 00:23:55,960

we're comparing to observe exoplanets

532

00:24:01,289 --> 00:23:59,200

today really applicable to what might

533

00:24:02,180 --> 00:24:01,299

have been going on early in the planets

534

00:24:05,700 --> 00:24:02,190

lifetime

535

00:24:09,450 --> 00:24:05,710

that's the complication and also I just

536

00:24:11,639 --> 00:24:09,460

want to sort of emphasize that the UV

537

00:24:13,180 --> 00:24:11,649

and the x-ray flux also is is not

538

00:24:15,220 --> 00:24:13,190

constant with time there's a

539

00:24:17,290 --> 00:24:15,230

actually a very nice correlation between

540

00:24:19,330 --> 00:24:17,300

the UV flux and the x-ray flux as a

541

00:24:23,050 --> 00:24:19,340

function of the x-ray flux will start but

542

00:24:25,330 --> 00:24:23,060

so the stellar x-ray flux is the star puts

543

00:24:27,850 --> 00:24:25,340

more of its energy in the x-rays newbee

544

00:24:30,250 --> 00:24:27,860

so this kind of enhances this idea that

545

00:24:32,260 --> 00:24:30,260

x-ray driven rather than EUV driven flow

546

00:24:36,940 --> 00:24:32,270

is going to be more important at early

547

00:24:39,340 --> 00:24:36,950

times so the all important things are

548

00:24:42,130 --> 00:24:39,350

what are the mass loss rates and what do

549

00:24:44,170 --> 00:24:42,140

they do to the pockets so this is sort

550

00:24:45,940 --> 00:24:44,180

of one example of one calculation for

551  
00:24:47,890 --> 00:24:45,950  
one age of one flux and you can take

552  
00:24:50,140 --> 00:24:47,900  
these calculations and you can put them

553  
00:24:52,870 --> 00:24:50,150  
together and you can sort of model the

554  
00:24:55,360 --> 00:24:52,880  
evolution of planetary atmospheres over

555  
00:24:57,810 --> 00:24:55,370  
that lifetimes so this is a calculation

556  
00:25:00,250 --> 00:24:57,820  
for our highly irradiated hot Jupiter

557  
00:25:02,230 --> 00:25:00,260  
and it doesn't lose very much mass there

558  
00:25:04,990 --> 00:25:02,240  
are two reasons for this right I said

559  
00:25:08,220 --> 00:25:05,000  
earlier that the efficiencies for hot

560  
00:25:10,810 --> 00:25:08,230  
Jupiters are quite low about one percent

561  
00:25:13,060 --> 00:25:10,820  
but also hot Jupiters have a lot of mass

562  
00:25:17,080 --> 00:25:13,070  
to start with so it's quite hard to

563  
00:25:19,080 --> 00:25:17,090

completely remove or completely strip a

564

00:25:23,290 --> 00:25:19,090

giant planet so hot Jupiters are safe

565

00:25:26,020 --> 00:25:23,300

however for these sub Neptune's they are

566

00:25:28,600 --> 00:25:26,030

strongly affected by this process this

567

00:25:30,820 --> 00:25:28,610

is again for the two reasons the mass

568

00:25:34,150 --> 00:25:30,830

loss rates are much more efficient for

569

00:25:35,830 --> 00:25:34,160

these sub Neptune's and they have a lot

570

00:25:41,760 --> 00:25:35,840

less I'd and helium to start with so you

571

00:25:44,290 --> 00:25:41,770

can significantly scope excuse me so

572

00:25:46,630 --> 00:25:44,300

while giant planets are not Jupiter's

573

00:25:48,160 --> 00:25:46,640

are going to be losing mass grandmas

574

00:25:50,980 --> 00:25:48,170

farik escape and it'd be nice to

575

00:25:52,570 --> 00:25:50,990

characterize this observational e the

576  
00:25:54,490 --> 00:25:52,580  
things that are gonna be really affected

577  
00:25:57,400 --> 00:25:54,500  
are these sub natoons in the case of

578  
00:25:59,320 --> 00:25:57,410  
hydrogen helium dominated ones the other

579  
00:26:01,600 --> 00:25:59,330  
thing I want to sort of emphasize is

580  
00:26:03,490 --> 00:26:01,610  
that when we are thinking about

581  
00:26:06,190 --> 00:26:03,500  
comparing our atmospheric model

582  
00:26:08,380 --> 00:26:06,200  
atmospheric escape models to direct

583  
00:26:11,830 --> 00:26:08,390  
observational traces of this the

584  
00:26:14,170 --> 00:26:11,840  
outflows are 3d and this is a really

585  
00:26:16,990 --> 00:26:14,180  
really hard numerical problem so I think

586  
00:26:19,480 --> 00:26:17,000  
still currently there are more observed

587  
00:26:21,250 --> 00:26:19,490  
exoplanets for which we know they are

588  
00:26:25,210 --> 00:26:21,260

undergoing atmospheric escape then there

589

00:26:26,950 --> 00:26:25,220

are 3d simulation and most of the 3d

590

00:26:30,160 --> 00:26:26,960

simulations again for numerical

591

00:26:32,050 --> 00:26:30,170

are not the real planets we kind of sort

592

00:26:36,880 --> 00:26:32,060

of make them extra puffy to help our

593

00:26:38,590 --> 00:26:36,890

numerical simulations or so the kind of

594

00:26:40,510 --> 00:26:38,600

structure you get in pure hydrogen I

595

00:26:42,400 --> 00:26:40,520

make our clothes sort of somewhat

596

00:26:44,170 --> 00:26:42,410

reasonably well-established from these

597

00:26:46,150 --> 00:26:44,180

simulations now so the star is sort of

598

00:26:48,880 --> 00:26:46,160

sitting over here somewhere

599

00:26:50,680 --> 00:26:48,890

it's radiating the planet it drives this

600

00:26:52,810 --> 00:26:50,690

outflow off the dayside of the planet

601  
00:26:55,050 --> 00:26:52,820  
which then sort of wraps around behind

602  
00:26:58,210 --> 00:26:55,060  
the Nightside and you get sort of nice

603  
00:27:01,870 --> 00:26:58,220  
kelvin-helmholtz like instabilities if

604  
00:27:03,700 --> 00:27:01,880  
you then look on the larger scales then

605  
00:27:05,140 --> 00:27:03,710  
these simulations sort of start

606  
00:27:09,040 --> 00:27:05,150  
interacting with the circumstellar

607  
00:27:11,050 --> 00:27:09,050  
environment with some nice recent work

608  
00:27:13,630 --> 00:27:11,060  
by John McCann and he's here and he has

609  
00:27:16,960 --> 00:27:13,640  
a poster on some even newer simulations

610  
00:27:18,910 --> 00:27:16,970  
that he promises are for realistic

611  
00:27:22,990 --> 00:27:18,920  
planets not super puffy planet so I

612  
00:27:24,460 --> 00:27:23,000  
encourage you to check that out so when

613  
00:27:27,520 --> 00:27:24,470

we're thinking about comparing our

614

00:27:29,740 --> 00:27:27,530

simulations to sort of direct

615

00:27:31,240 --> 00:27:29,750

observational traces of atmospheric

616

00:27:33,550 --> 00:27:31,250

escape they're gonna need to sort of

617

00:27:35,350 --> 00:27:33,560

think about this 3d structure and we're

618

00:27:37,450 --> 00:27:35,360

gonna need to try and put some effort

619

00:27:39,220 --> 00:27:37,460

into pushing our numerical models

620

00:27:40,210 --> 00:27:39,230

further and trying to actually finally

621

00:27:44,440 --> 00:27:40,220

get to the point where there are more

622

00:27:46,390 --> 00:27:44,450

models than observations so I'm gonna

623

00:27:47,590 --> 00:27:46,400

sort of briefly cover this because some

624

00:27:50,890 --> 00:27:47,600

of the other speakers are going to talk

625

00:27:52,660 --> 00:27:50,900

more about interpreting observations -

626  
00:27:54,100 --> 00:27:52,670  
that was very escape at the moment there

627  
00:27:57,700 --> 00:27:54,110  
are sort of two good traces of

628  
00:27:59,110 --> 00:27:57,710  
atmospheric escape there's a lyman-alpha

629  
00:28:01,210 --> 00:27:59,120  
transit so this is where you do a

630  
00:28:03,550 --> 00:28:01,220  
transit style observation but instead of

631  
00:28:06,070 --> 00:28:03,560  
doing it in a broad band you do it in a

632  
00:28:08,680 --> 00:28:06,080  
narrow narrow line that has a strong

633  
00:28:10,930 --> 00:28:08,690  
sensitivity to material you might find

634  
00:28:15,220 --> 00:28:10,940  
in the Alpha so the lyman-alpha has a

635  
00:28:17,200 --> 00:28:15,230  
strong up acity to neutral hydrogen so

636  
00:28:19,990 --> 00:28:17,210  
what you can see this is the lyman-alpha

637  
00:28:21,720 --> 00:28:20,000  
profile unfortunately the center of the

638  
00:28:23,920 --> 00:28:21,730

line is completely obscured by

639

00:28:25,660 --> 00:28:23,930

interstellar absorption so we don't know

640

00:28:27,520 --> 00:28:25,670

what's going on here we can only look

641

00:28:29,950 --> 00:28:27,530

what's going on in the wings so the

642

00:28:32,710 --> 00:28:29,960

black line is what the lyman-alpha from

643

00:28:34,870 --> 00:28:32,720

the star looks like when the planet is

644

00:28:37,950 --> 00:28:34,880

behind the star and you can see as the

645

00:28:41,129 --> 00:28:37,960

planet comes into transit you get huge

646

00:28:43,139 --> 00:28:41,139

props in black this is a 50% drop in

647

00:28:46,230 --> 00:28:43,149

pluck so if you remember what a transit

648

00:28:49,590 --> 00:28:46,240

observation means you're obscuring some

649

00:28:51,060 --> 00:28:49,600

fraction of the stellar surface right so

650

00:28:54,119 --> 00:28:51,070

in this case the lyman-alpha is

651  
00:28:57,119 --> 00:28:54,129  
obscuring 50% of the stars right

652  
00:28:59,789 --> 00:28:57,129  
remember in broadband optical a planet

653  
00:29:03,930 --> 00:28:59,799  
typically blocks only sort of less than

654  
00:29:06,210 --> 00:29:03,940  
1% this is a huge block and you actually

655  
00:29:09,239 --> 00:29:06,220  
know this is atmospheric escape because

656  
00:29:11,759 --> 00:29:09,249  
a 50% transit radius would imply this

657  
00:29:15,210 --> 00:29:11,769  
material that is temporarily associated

658  
00:29:16,710 --> 00:29:15,220  
so it's going around with the planet but

659  
00:29:19,470 --> 00:29:16,720  
it's not balanced the bun it's outside

660  
00:29:20,869 --> 00:29:19,480  
the palace roof so the interpretation is

661  
00:29:23,940 --> 00:29:20,879  
something like this that you have some

662  
00:29:28,980 --> 00:29:23,950  
escaping cloud that is obscuring some

663  
00:29:31,560 --> 00:29:28,990

enormous fraction of the star and it's

664

00:29:34,129 --> 00:29:31,570

highly asymmetric in the transit profile

665

00:29:37,859 --> 00:29:34,139

due to the 3d natures of these floats

666

00:29:40,529 --> 00:29:37,869

the really exciting one is these recent

667

00:29:44,159 --> 00:29:40,539

helium detections helium metastable line

668

00:29:46,049 --> 00:29:44,169

I'm not going to talk about this because

669

00:29:49,019 --> 00:29:46,059

Antonia has an entire talk on this topic

670

00:29:50,460 --> 00:29:49,029

later in this session but this is super

671

00:29:52,169 --> 00:29:50,470

exciting because it can be done at high

672

00:29:54,419 --> 00:29:52,179

spectral resolution and as we learned

673

00:29:58,470 --> 00:29:54,429

from Jane earlier in the week high

674

00:30:02,369 --> 00:29:58,480

spectral resolution is really useful for

675

00:30:04,320 --> 00:30:02,379

getting kinematic information so I've

676

00:30:06,389 --> 00:30:04,330

talked a little bit now about the basics

677

00:30:09,779 --> 00:30:06,399

of thermal escape the basic physics of

678

00:30:11,070 --> 00:30:09,789

hydrogen helium dominated thermal escape

679

00:30:15,450 --> 00:30:11,080

are now going to talk about how it

680

00:30:16,889 --> 00:30:15,460

affects the population of exoplanets and

681

00:30:18,899 --> 00:30:16,899

there is a poster on this topic by a

682

00:30:24,629 --> 00:30:18,909

pink kite so I encourage you to give as

683

00:30:27,720 --> 00:30:24,639

well so here's my cartoony picture of

684

00:30:30,299 --> 00:30:27,730

what's going on you have a star which

685

00:30:31,680 --> 00:30:30,309

has some planets which all have I didn't

686

00:30:33,539 --> 00:30:31,690

helium atmospheres when they born so

687

00:30:35,759 --> 00:30:33,549

it's a solid core surrounded by a

688

00:30:38,249 --> 00:30:35,769

hydrogen helium atom and I'm gonna let

689

00:30:40,619 --> 00:30:38,259

this system of all under the influence

690

00:30:43,139 --> 00:30:40,629

that mascara escape so you can see that

691

00:30:45,060 --> 00:30:43,149

all the planets at young times basically

692

00:30:50,249 --> 00:30:45,070

most of them sit up here and quite large

693

00:30:51,630 --> 00:30:50,259

radio look 5 to 10 Earth radii these are

694

00:30:53,640 --> 00:30:51,640

not giant planets these

695

00:30:57,270 --> 00:30:53,650

sort of typical sub Neptune's that have

696

00:30:59,040 --> 00:30:57,280

five to ten earth masses with 10% arjun

697

00:31:00,720 --> 00:30:59,050

helium say so they have very large

698

00:31:02,310 --> 00:31:00,730

radiuses at early time so for the

699

00:31:04,650 --> 00:31:02,320

handful of planets that we can get

700

00:31:06,780 --> 00:31:04,660

constraints on their properties at early

701

00:31:09,000 --> 00:31:06,790

times it's really crucial to testing

702

00:31:11,070 --> 00:31:09,010

these kinds of models as well do our

703

00:31:13,350 --> 00:31:11,080

planets really five to ten a low-mass

704

00:31:16,290 --> 00:31:13,360

fire twenty five to ten Earth radii at a

705

00:31:20,430 --> 00:31:16,300

young ages now I'm going to let this

706

00:31:23,160 --> 00:31:20,440

system evolve so the planets start

707

00:31:25,650 --> 00:31:23,170

losing their hydrogen helium some

708

00:31:27,990 --> 00:31:25,660

planets in fact completely lose their

709

00:31:31,770 --> 00:31:28,000

hydrogen helium atmospheres whereas some

710

00:31:33,420 --> 00:31:31,780

planets retaining and at the end of the

711

00:31:35,580 --> 00:31:33,430

simulation you tend to end up with two

712

00:31:37,110 --> 00:31:35,590

types of paths and it's a completely

713

00:31:39,600 --> 00:31:37,120

lose their hydrogen helium atmosphere so

714

00:31:43,770 --> 00:31:39,610

they become what we've called stripped

715

00:31:45,540 --> 00:31:43,780

cause or they retain I didn't kill him

716

00:31:48,030 --> 00:31:45,550

so you typically have two types of

717

00:31:50,190 --> 00:31:48,040

planets these stripped cores or planets

718

00:31:51,930 --> 00:31:50,200

that have roughly about one percent

719

00:31:55,910 --> 00:31:51,940

I didn't helium in their atmospheres at

720

00:31:59,220 --> 00:31:55,920

the end of this evolution and this is

721

00:32:02,240 --> 00:31:59,230

radio speaker diagram now have this gap

722

00:32:07,410 --> 00:32:02,250

in it in theory terms this is called the

723

00:32:09,030 --> 00:32:07,420

evaporation Balaton so I want to sort of

724

00:32:10,500 --> 00:32:09,040

briefly understand why you get this

725

00:32:14,730 --> 00:32:10,510

valley it's actually quite simple to

726

00:32:17,040 --> 00:32:14,740

understand if you think of the mass loss

727

00:32:19,530 --> 00:32:17,050

timescale so this is the instantaneous

728

00:32:20,760 --> 00:32:19,540

time it would take you to lose the

729

00:32:21,600 --> 00:32:20,770

amount of mass you have in your

730

00:32:23,490 --> 00:32:21,610

atmosphere it's basically your

731

00:32:26,340 --> 00:32:23,500

atmosphere divided by your instantaneous

732

00:32:29,880 --> 00:32:26,350

mass loss rate as a function of your

733

00:32:31,470 --> 00:32:29,890

embolus fraction then in that simple

734

00:32:32,910 --> 00:32:31,480

energy limited argument so this is a

735

00:32:35,220 --> 00:32:32,920

perfect place where you can use that

736

00:32:37,500 --> 00:32:35,230

simple energy limited argument what sets

737

00:32:40,350 --> 00:32:37,510

your mass loss rate is how much of the

738

00:32:42,660 --> 00:32:40,360

Stars flux you can absorb so very very

739

00:32:44,880 --> 00:32:42,670

low enveloped mass fractions oil

740

00:32:49,710 --> 00:32:44,890

atmosphere masses the radius of the

741

00:32:52,200 --> 00:32:49,720

planet is completely set by the radius

742

00:32:53,670 --> 00:32:52,210

of this solid core right so as I add

743

00:32:55,590 --> 00:32:53,680

more and more atmosphere it doesn't

744

00:32:57,720 --> 00:32:55,600

change the radius of the planet a great

745

00:32:59,610 --> 00:32:57,730

deal so it doesn't change the flux I

746

00:33:01,500 --> 00:32:59,620

absorb from the star a great deal the

747

00:33:03,900 --> 00:33:01,510

atmosphere has negligible mass to the

748

00:33:04,529 --> 00:33:03,910

planet's mass so I haven't changed the

749

00:33:10,109 --> 00:33:04,539

mass loss rate

750

00:33:12,389 --> 00:33:10,119

increase my envelope mass fraction for

751  
00:33:14,430 --> 00:33:12,399  
small envelope mass right then I'm going

752  
00:33:17,189 --> 00:33:14,440  
to get to the point where the atmosphere

753  
00:33:19,499 --> 00:33:17,199  
is so big now it dominates the radius of

754  
00:33:22,439 --> 00:33:19,509  
the planet and what sets how this mass

755  
00:33:25,019 --> 00:33:22,449  
loss rate time scale evolved is how big

756  
00:33:26,699 --> 00:33:25,029  
the atmosphere expands as I add mats and

757  
00:33:28,109 --> 00:33:26,709  
it turns out the micro physics of

758  
00:33:31,310 --> 00:33:28,119  
hydrogen helium atmospheres means that

759  
00:33:34,019 --> 00:33:31,320  
the atmospheres expands so rapidly that

760  
00:33:35,399 --> 00:33:34,029  
the they absorb so much more plucks at

761  
00:33:37,889 --> 00:33:35,409  
the mass loss rate goes through the roof

762  
00:33:42,269 --> 00:33:37,899  
and the mass loss rate time scale comes

763  
00:33:46,759 --> 00:33:42,279

back down so they have something that

764

00:33:52,799 --> 00:33:48,839

approximately where the atmosphere or

765

00:33:56,230 --> 00:33:52,809

the envelope doubles the cause radius so

766

00:33:59,950 --> 00:33:56,240

if I have some time

767

00:34:03,520 --> 00:33:59,960

now to lose my atmosphere this is the

768

00:34:05,320 --> 00:34:03,530

sort of time my star is bright then I

769

00:34:08,410 --> 00:34:05,330

can get two types of evolutionary

770

00:34:11,710 --> 00:34:08,420

pathways if I start off here where I

771

00:34:14,290 --> 00:34:11,720

have lots of atmosphere Matt and I start

772

00:34:16,090 --> 00:34:14,300

losing mass right I have my mask lost

773

00:34:18,550 --> 00:34:16,100

timescales less than the time I have to

774

00:34:20,760 --> 00:34:18,560

lose math I'm going to start pushing up

775

00:34:23,860 --> 00:34:20,770

this curve I'm gonna start losing mass

776

00:34:25,390 --> 00:34:23,870

but I'm gonna get to the point where the

777

00:34:27,640 --> 00:34:25,400

mass loss timescale for my current

778

00:34:30,010 --> 00:34:27,650

planet structure now exceeds the amount

779

00:34:31,720 --> 00:34:30,020

of time I have to lose mass and my

780

00:34:34,090 --> 00:34:31,730

planet becomes stable so you can see

781

00:34:36,730 --> 00:34:34,100

that in these trucks yeah you start

782

00:34:39,340 --> 00:34:36,740

losing mass and then atmosphere becomes

783

00:34:43,390 --> 00:34:39,350

stable and you stay there but if I start

784

00:34:45,250 --> 00:34:43,400

on the other side yeah I start losing

785

00:34:47,050 --> 00:34:45,260

mass my mass was time scale gets shorter

786

00:34:50,950 --> 00:34:47,060

and shorter and shorter and I just enter

787

00:34:53,890 --> 00:34:50,960

a runaway so you see that you actually

788

00:34:55,810 --> 00:34:53,900

and it's set by basically the stability

789

00:34:58,150 --> 00:34:55,820

point is where you have an atmosphere

790

00:35:05,410 --> 00:34:58,160

that doubles the cores radius that this

791

00:35:09,070 --> 00:35:05,420

is where the transition takes part so we

792

00:35:11,320 --> 00:35:09,080

have a model and this is one of the few

793

00:35:13,330 --> 00:35:11,330

times where the fluff area has been

794

00:35:16,030 --> 00:35:13,340

slightly ahead of the observations we

795

00:35:18,340 --> 00:35:16,040

had a model and we now have observations

796

00:35:22,660 --> 00:35:18,350

that by I look in pretty good agreement

797

00:35:24,580 --> 00:35:22,670

with the observations so if you look at

798

00:35:26,350 --> 00:35:24,590

it in a bit more detail you find that

799

00:35:28,810 --> 00:35:26,360

the peaks are separated by this factor

800

00:35:31,210 --> 00:35:28,820

of two in radius so we have a very very

801  
00:35:33,490 --> 00:35:31,220  
good simple physical understanding of

802  
00:35:36,400 --> 00:35:33,500  
why they should be separated by a factor

803  
00:35:39,100 --> 00:35:36,410  
of two in radius these are the stripped

804  
00:35:40,690 --> 00:35:39,110  
course and these are the planets with

805  
00:35:42,730 --> 00:35:40,700  
atmospheres that double the cause radius

806  
00:35:49,150 --> 00:35:42,740  
that a maximally stable those that have

807  
00:35:51,970 --> 00:35:49,160  
the longest mass if you look at just

808  
00:35:54,730 --> 00:35:51,980  
planets that have their properties

809  
00:35:56,890 --> 00:35:54,740  
measured from asteroseismology so this

810  
00:35:58,540 --> 00:35:56,900  
is where you use basically the

811  
00:36:01,690 --> 00:35:58,550  
oscillations of the star to get

812  
00:36:03,340 --> 00:36:01,700  
incredibly precise stellar parameters so

813  
00:36:05,080 --> 00:36:03,350

you in turn you can get incredibly

814

00:36:07,210 --> 00:36:05,090

precise planetary parameters so you can

815

00:36:09,160 --> 00:36:07,220

measure the stars the planets radius

816

00:36:10,019 --> 00:36:09,170

down to something like one or two

817

00:36:14,909 --> 00:36:10,029

percent

818

00:36:16,439 --> 00:36:14,919

then you can see that you really this

819

00:36:19,049 --> 00:36:16,449

gap sort of sticks out like a sore thumb

820

00:36:23,459 --> 00:36:19,059

now and you can actually measure the

821

00:36:28,049 --> 00:36:23,469

slope here and what the slope is saying

822

00:36:30,479 --> 00:36:28,059

is that at long periods I have low

823

00:36:33,719 --> 00:36:30,489

fluxes so the only planets I can strip

824

00:36:35,519 --> 00:36:33,729

are those with low masses where as I go

825

00:36:37,049 --> 00:36:35,529

to higher and higher fluxes I can strip

826

00:36:39,359 --> 00:36:37,059

higher and higher mass cores

827

00:36:41,279 --> 00:36:39,369

so the valley should increase in radius

828

00:36:43,019 --> 00:36:41,289

and this is a great test just seeing

829

00:36:46,049 --> 00:36:43,029

that slope is a great test that what's

830

00:36:48,119 --> 00:36:46,059

going on is driven by its evaporation

831

00:36:50,849 --> 00:36:48,129

process but you can also compare it to

832

00:36:53,699 --> 00:36:50,859

detail so this is the slope you would

833

00:36:57,359 --> 00:36:53,709

expect if you had constant efficiency

834

00:36:59,279 --> 00:36:57,369

energy limited this is the observed

835

00:37:02,129 --> 00:36:59,289

slope so you can see there clearly

836

00:37:03,779 --> 00:37:02,139

inconsistent however if you use the

837

00:37:05,549 --> 00:37:03,789

slightly more sophisticated numerical

838

00:37:08,219 --> 00:37:05,559

models you should count for this

839

00:37:09,599 --> 00:37:08,229

variable efficiency then they're in

840

00:37:11,959 --> 00:37:09,609

agreement with observation so what's

841

00:37:14,729 --> 00:37:11,969

essentially going on here is that lower

842

00:37:17,039 --> 00:37:14,739

core radii lower core masses you have a

843

00:37:18,719 --> 00:37:17,049

weap less deep potential so the

844

00:37:20,699 --> 00:37:18,729

atmosphere can escape quite quickly

845

00:37:23,369 --> 00:37:20,709

doesn't have time to lose a lot of

846

00:37:25,559 --> 00:37:23,379

energy to radiation whereas for the deep

847

00:37:27,899 --> 00:37:25,569

potentials a high mass course the large

848

00:37:29,279 --> 00:37:27,909

cause up here it takes a while for the

849

00:37:31,139 --> 00:37:29,289

gas to actually escape the planets

850

00:37:33,419 --> 00:37:31,149

potential so it has a lot of time to

851  
00:37:35,429 --> 00:37:33,429  
lose energy due to radius its efficiency

852  
00:37:36,689 --> 00:37:35,439  
so these flows are quite efficient down

853  
00:37:41,129 --> 00:37:36,699  
here in these flows are fairly

854  
00:37:43,229 --> 00:37:41,139  
inefficient so constant efficiency mass

855  
00:37:46,409 --> 00:37:43,239  
loss is already ruled out but by

856  
00:37:47,999 --> 00:37:46,419  
observations but when we attempt to do

857  
00:37:51,329 --> 00:37:48,009  
something numerically it's in Rafah

858  
00:37:52,949 --> 00:37:51,339  
Greek but one of the key inclusions and

859  
00:37:54,479 --> 00:37:52,959  
this is sort of a segue to the next part

860  
00:37:56,879 --> 00:37:54,489  
of the talk about the habitability of

861  
00:37:59,099 --> 00:37:56,889  
Endor is that the majority of the

862  
00:38:01,499 --> 00:37:59,109  
terrestrial planets we observe in the

863  
00:38:03,419 --> 00:38:01,509

exoplanet form with a large hydrogen

864

00:38:05,699 --> 00:38:03,429

helium atmosphere and I know I have some

865

00:38:07,589 --> 00:38:05,709

science community here so I'm going to

866

00:38:10,109 --> 00:38:07,599

be explicit by what I mean by large

867

00:38:12,449 --> 00:38:10,119

large means several percent

868

00:38:15,149 --> 00:38:12,459

I don't helium atmospheres by mass or in

869

00:38:16,109 --> 00:38:15,159

bars several million bars of hydrogen

870

00:38:18,719 --> 00:38:16,119

helium when they were born

871

00:38:20,309 --> 00:38:18,729

so not sort of large when people say

872

00:38:22,049 --> 00:38:20,319

earth had a large hydrogen helium

873

00:38:23,870 --> 00:38:22,059

atmosphere there was ten or a hundred

874

00:38:26,360 --> 00:38:23,880

baths this is sort of

875

00:38:28,220 --> 00:38:26,370

several thousand times larger so this

876

00:38:31,580 --> 00:38:28,230

has really important consequences for

877

00:38:33,440 --> 00:38:31,590

habitability perhaps if we were having

878

00:38:35,600 --> 00:38:33,450

this conference on a moon surrounding a

879

00:38:38,300 --> 00:38:35,610

giant planet I would be even outrageous

880

00:38:40,490 --> 00:38:38,310

enough to suggest the planets don't form

881

00:38:42,350 --> 00:38:40,500

a natural life fashion they all have to

882

00:38:44,090 --> 00:38:42,360

have hydrogen helium atmospheres the own

883

00:38:45,890 --> 00:38:44,100

interests or pilots we see at ones that

884

00:38:48,500 --> 00:38:45,900

use them but we know from the solar

885

00:38:51,560 --> 00:38:48,510

system that's Moxley so that's a planet

886

00:38:53,110 --> 00:38:51,570

formation puzzle but we also have this

887

00:38:58,130 --> 00:38:53,120

habitability issue

888

00:39:00,310 --> 00:38:58,140

so if planets form predominantly with

889

00:39:02,660 --> 00:39:00,320

large hydrogen helium atmospheres

890

00:39:05,090 --> 00:39:02,670

they're not going to be habitable even

891

00:39:08,560 --> 00:39:05,100

if they said in the habitable zone so

892

00:39:13,180 --> 00:39:08,570

how can we have habitable planets around

893

00:39:15,650 --> 00:39:13,190

stars well fortunately M dwarfs are

894

00:39:17,840 --> 00:39:15,660

incredibly active so perhaps we can blow

895

00:39:20,360 --> 00:39:17,850

off this hydrogen helium atmosphere and

896

00:39:23,330 --> 00:39:20,370

become happy so we have this sort of

897

00:39:25,400 --> 00:39:23,340

three phase suggestion about can

898

00:39:28,100 --> 00:39:25,410

habitable zone planets around them

899

00:39:30,220 --> 00:39:28,110

dwarfs become terrestrial planets so can

900

00:39:33,020 --> 00:39:30,230

they lose their initial hydrogen helium

901  
00:39:35,300 --> 00:39:33,030  
atmosphere inventory then can they

902  
00:39:36,590 --> 00:39:35,310  
retain their secondary atmosphere and if

903  
00:39:40,250 --> 00:39:36,600  
they can retain their atmosphere can

904  
00:39:42,230 --> 00:39:40,260  
they retain water you know so I'm going

905  
00:39:44,360 --> 00:39:42,240  
to focus on the two things that people

906  
00:39:46,040 --> 00:39:44,370  
have actually done work on this is

907  
00:39:50,960 --> 00:39:46,050  
that's the most important part and there

908  
00:39:52,490 --> 00:39:50,970  
is almost nothing on this so and the

909  
00:39:54,350 --> 00:39:52,500  
question you should be asking yourself

910  
00:39:57,230 --> 00:39:54,360  
when I'm gonna talk through some of the

911  
00:39:59,660 --> 00:39:57,240  
latest results is is habitability about

912  
00:40:00,950 --> 00:39:59,670  
around M dwarfs fine-tuned or not I'm

913  
00:40:02,390 --> 00:40:00,960

not going to tell you whether it's

914

00:40:06,050 --> 00:40:02,400

fine-tuned or not I'm going to leave it

915

00:40:09,200 --> 00:40:06,060

up to you so and one of the key

916

00:40:10,850 --> 00:40:09,210

differences is that the evolution of M

917

00:40:12,770 --> 00:40:10,860

dwarfs in terms of their star's

918

00:40:15,830 --> 00:40:12,780

evolution is significantly different for

919

00:40:19,630 --> 00:40:15,840

some like stuff so this is the evolution

920

00:40:23,180 --> 00:40:19,640

of a planet's black body temperature

921

00:40:25,490 --> 00:40:23,190

it's basically in a earth-like orbit at

922

00:40:27,740 --> 00:40:25,500

the earth-like age so this is the

923

00:40:29,300 --> 00:40:27,750

stellar track for the Sun so you can see

924

00:40:31,370 --> 00:40:29,310

that stellar luminosity increasing this

925

00:40:33,290 --> 00:40:31,380

is the faint young Sun problem the

926

00:40:35,060 --> 00:40:33,300

pollen was talking about yesterday if

927

00:40:36,590 --> 00:40:35,070

you go to a low mass star then it has a

928

00:40:38,980 --> 00:40:36,600

completely different rap

929

00:40:41,810 --> 00:40:38,990

Northy understand problem it's a sort of

930

00:40:44,750 --> 00:40:41,820

inferno young sons problem that the star

931

00:40:46,610 --> 00:40:44,760

is much much brighter and if you turn

932

00:40:49,010 --> 00:40:46,620

this into what it's doing to the high

933

00:40:51,130 --> 00:40:49,020

energy output the high energy output of

934

00:40:54,050 --> 00:40:51,140

these two stars is extremely different

935

00:40:56,300 --> 00:40:54,060

so for the M star here two point four

936

00:40:58,040 --> 00:40:56,310

solar mass star you can have a flux that

937

00:41:01,970 --> 00:40:58,050

sort of a thousand times the current

938

00:41:04,790 --> 00:41:01,980

earth irradiation even at Agee so this

939

00:41:07,160 --> 00:41:04,800

is extreme differences in radiation so

940

00:41:10,160 --> 00:41:07,170

only a factor of a sort of roughly more

941

00:41:12,320 --> 00:41:10,170

than two in solar mass can make almost

942

00:41:14,510 --> 00:41:12,330

sort of one or two orders of magnitude

943

00:41:16,670 --> 00:41:14,520

difference in the total amount of high

944

00:41:22,100 --> 00:41:16,680

energy flux you will see over the pumps

945

00:41:24,800 --> 00:41:22,110

right so can you use this extra UV flux

946

00:41:26,750 --> 00:41:24,810

to lose your - team atmosphere well of

947

00:41:29,330 --> 00:41:26,760

course you that it depends on how

948

00:41:31,760 --> 00:41:29,340

massive you are so if you're a a

949

00:41:34,220 --> 00:41:31,770

low-mass planets round a point for solar

950

00:41:35,690 --> 00:41:34,230

mass star and you can completely use

951  
00:41:38,060 --> 00:41:35,700  
your hydrogen helium and become a

952  
00:41:41,600 --> 00:41:38,070  
terrestrial potentially habitable world

953  
00:41:43,550 --> 00:41:41,610  
quite quickly if you're a sort of 0.9 F

954  
00:41:46,340 --> 00:41:43,560  
a star then it sort of depends its

955  
00:41:50,290 --> 00:41:46,350  
initial condition dependent and if you

956  
00:41:55,580 --> 00:41:53,750  
the other key issue right is well

957  
00:41:59,870 --> 00:41:55,590  
perhaps I can lose my hydrogen helium

958  
00:42:03,730 --> 00:41:59,880  
but can I retain my water and because of

959  
00:42:06,950 --> 00:42:03,740  
its pre main sequence evolution of the

960  
00:42:08,600 --> 00:42:06,960  
low mass star even if I'm in the

961  
00:42:11,960 --> 00:42:08,610  
habitable zone at say four and a half

962  
00:42:14,960 --> 00:42:11,970  
billion years I'm always gonna go

963  
00:42:16,670 --> 00:42:14,970

through a runaway greenhouse phase where

964

00:42:18,380 --> 00:42:16,680

I am going to potentially lose water so

965

00:42:20,480 --> 00:42:18,390

this is ice plot from the ground bars

966

00:42:22,400 --> 00:42:20,490

that showing stellar mass as a function

967

00:42:24,230 --> 00:42:22,410

of orbital period here the sort of

968

00:42:28,610 --> 00:42:24,240

habitable burn zone boundaries you

969

00:42:32,030 --> 00:42:28,620

optimistic not optimistic and this is

970

00:42:34,760 --> 00:42:32,040

the time you spend in the runaway

971

00:42:36,590 --> 00:42:34,770

greenhouse space so sort of sun-like

972

00:42:40,430 --> 00:42:36,600

stars it's basically a switch either

973

00:42:42,650 --> 00:42:40,440

nothing or all your time but for lower

974

00:42:44,540 --> 00:42:42,660

mass stars because of this pre main

975

00:42:46,610 --> 00:42:44,550

sequence evolution they spend a decent

976

00:42:49,070 --> 00:42:46,620

fraction five hundred a few hundred

977

00:42:50,010 --> 00:42:49,080

million years of their life in upon away

978

00:42:53,280 --> 00:42:50,020

Green hasn't

979

00:42:55,760 --> 00:42:53,290

so in order to be habitable you need to

980

00:42:58,560 --> 00:42:55,770

be able to retain your water

981

00:43:01,710 --> 00:42:58,570

so these are some against that these are

982

00:43:04,890 --> 00:43:01,720

energy limited calculations constant

983

00:43:06,900 --> 00:43:04,900

efficiency calculations for water loss

984

00:43:09,120 --> 00:43:06,910

as a function of position in the

985

00:43:12,210 --> 00:43:09,130

habitable zone for different masses so

986

00:43:15,030 --> 00:43:12,220

you can see for the sort of unlike low

987

00:43:16,770 --> 00:43:15,040

hi I'm a stars basically you retain all

988

00:43:19,590 --> 00:43:16,780

your water but for the lower mass stars

989

00:43:22,800 --> 00:43:19,600

you get a quick switch to basically you

990

00:43:25,380 --> 00:43:22,810

lose it all so the solution to this is

991

00:43:27,570 --> 00:43:25,390

well if I'm going to lose lots of water

992

00:43:31,290 --> 00:43:27,580

but I still want water I'll just pile a

993

00:43:35,010 --> 00:43:31,300

lot more water on so stop it so you can

994

00:43:36,840 --> 00:43:35,020

do that and you can do a bit better but

995

00:43:38,280 --> 00:43:36,850

this sort of the outcome of this

996

00:43:39,960 --> 00:43:38,290

calculation and you can keep doing this

997

00:43:41,940 --> 00:43:39,970

and keep doing this but the outcome of

998

00:43:43,530 --> 00:43:41,950

this kind of suggestion is that you're

999

00:43:45,810 --> 00:43:43,540

either gonna be in two different

1000

00:43:47,940 --> 00:43:45,820

completely different limits either

1001  
00:43:50,760 --> 00:43:47,950  
you're just gonna be a desert world you

1002  
00:43:52,710 --> 00:43:50,770  
have nothing or you had so much water to

1003  
00:43:56,880 --> 00:43:52,720  
start with that you end up like a

1004  
00:44:01,230 --> 00:43:58,920  
and there's a poster on this topic by

1005  
00:44:04,410 --> 00:44:01,240  
Kevin Moore cajoling courage you to take

1006  
00:44:06,360 --> 00:44:04,420  
a look at so I'm gonna talk a little bit

1007  
00:44:10,550 --> 00:44:06,370  
more about the physics of water loss and

1008  
00:44:13,140 --> 00:44:10,560  
perhaps a possible solution out of this

1009  
00:44:15,840 --> 00:44:13,150  
there's still work in process so this is

1010  
00:44:20,250 --> 00:44:15,850  
my this is my atmosphere again I have my

1011  
00:44:22,170 --> 00:44:20,260  
photons coming in but now I add in now I

1012  
00:44:24,870 --> 00:44:22,180  
add in some water molecules and these

1013  
00:44:27,660 --> 00:44:24,880

are going to be associated by UV photons

1014

00:44:33,830 --> 00:44:27,670

now I have some layer in my atmosphere I

1015

00:44:41,340 --> 00:44:38,370

and my atomic oxygen is gonna start to

1016

00:44:45,810 --> 00:44:41,350

diffuse up through the atmosphere maybe

1017

00:44:48,630 --> 00:44:45,820

because the oxygen has a an atomic mass

1018

00:44:52,230 --> 00:44:48,640

of 16 whereas atomic hydrogen has a

1019

00:44:54,030 --> 00:44:52,240

atomic mass of 1 the oxygen is gonna

1020

00:44:56,070 --> 00:44:54,040

have a slightly smaller scale height so

1021

00:45:10,930 --> 00:44:56,080

once I get high up in the atmosphere

1022

00:45:19,430 --> 00:45:14,890

so I'll continue talking

1023

00:45:24,200 --> 00:45:19,440

so do so obviously the sort of the

1024

00:45:26,599 --> 00:45:24,210

critical process now is I have sort of a

1025

00:45:29,299 --> 00:45:26,609

mixture of hydrogen and oxygen at the

1026  
00:45:32,839 --> 00:45:29,309  
top of the atmosphere but the oxygen is

1027  
00:45:36,680 --> 00:45:32,849  
much more massive than the hydrogen

1028  
00:45:39,740 --> 00:45:36,690  
atoms so the question is is the outflow

1029  
00:45:44,120 --> 00:45:39,750  
powerful enough to drag the oxygen atoms

1030  
00:45:50,599 --> 00:45:44,130  
away or do the oxygen atoms are they

1031  
00:45:52,309 --> 00:45:50,609  
held there under gravity and you can

1032  
00:45:55,130 --> 00:45:52,319  
work this out it's quite simple it's a

1033  
00:45:57,680 --> 00:45:55,140  
simple little calculation and you can

1034  
00:46:00,620 --> 00:45:57,690  
calculate the mass of the atom that you

1035  
00:46:02,690 --> 00:46:00,630  
can drag along it some outflow and

1036  
00:46:04,609 --> 00:46:02,700  
basically 210 depends on the power of

1037  
00:46:10,519 --> 00:46:04,619  
the outflow and the collision cross

1038  
00:46:14,329 --> 00:46:10,529

section between iDEN and oxygen there

1039

00:46:15,859 --> 00:46:14,339

are also some other limits so you can

1040

00:46:18,529 --> 00:46:15,869

also limit your mass loss rate by

1041

00:46:22,670 --> 00:46:18,539

obviously how fast you dissociate the

1042

00:46:26,960 --> 00:46:22,680

water and also how fast you diffuse the

1043

00:46:28,730 --> 00:46:26,970

oxygen through the atmosphere so both

1044

00:46:36,140 --> 00:46:28,740

these processes can slow down the water

1045

00:46:37,789 --> 00:46:36,150

law which is a possible way out the

1046

00:46:39,980 --> 00:46:37,799

critical thing I want to point out is

1047

00:46:41,390 --> 00:46:39,990

that this depends on the property of the

1048

00:46:45,650 --> 00:46:41,400

outflow depends on the temperature of

1049

00:46:47,690 --> 00:46:45,660

the outlet so we did some very simple

1050

00:46:50,799 --> 00:46:47,700

calculations for traffic 1 and

1051  
00:46:52,970 --> 00:46:50,809  
basically assumed the hydrogen helium

1052  
00:46:54,730 --> 00:46:52,980  
properties assume the temperatures we

1053  
00:46:57,410 --> 00:46:54,740  
get from hydrogen helium outflows and

1054  
00:46:59,509 --> 00:46:57,420  
calculated how this might affect the

1055  
00:47:03,440 --> 00:46:59,519  
water loss so this is the standard

1056  
00:47:06,109 --> 00:47:03,450  
energy limited loss but as soon as you

1057  
00:47:08,329 --> 00:47:06,119  
start dragging the oxygen atoms with you

1058  
00:47:10,099 --> 00:47:08,339  
which is what happening in these grey

1059  
00:47:11,809 --> 00:47:10,109  
lines they weigh much more so you need

1060  
00:47:14,080 --> 00:47:11,819  
to use more of your energy to get those

1061  
00:47:17,500 --> 00:47:14,090  
oxygen atoms on your potential you

1062  
00:47:20,110 --> 00:47:17,510  
lower the total watt loss rate so it

1063  
00:47:24,340 --> 00:47:20,120

looks like in these calculations Travis

1064

00:47:28,060 --> 00:47:24,350

one is kind of in these limits the

1065

00:47:29,680 --> 00:47:28,070

Travis one one but we did something I

1066

00:47:31,600 --> 00:47:29,690

did this calculation so I can say this

1067

00:47:33,280 --> 00:47:31,610

we did something fairly stupid which was

1068

00:47:35,680 --> 00:47:33,290

that we use the temperature that came

1069

00:47:37,600 --> 00:47:35,690

from the hydrogen helium dominated

1070

00:47:40,030 --> 00:47:37,610

outlets and there's astronomer I know

1071

00:47:44,050 --> 00:47:40,040

that oxygen is a ridiculously powerful

1072

00:47:46,330 --> 00:47:44,060

cool so these are sort of beautiful

1073

00:47:47,830 --> 00:47:46,340

images of star forming clusters this is

1074

00:47:49,210 --> 00:47:47,840

the kind of thing I did on my PhD there

1075

00:47:50,740 --> 00:47:49,220

about three to ten thousand Kelvin

1076

00:47:52,510 --> 00:47:50,750

roughly what these atmospheres

1077

00:47:54,040 --> 00:47:52,520

temperatures ah and when you look at

1078

00:47:56,740 --> 00:47:54,050

these false color images these are not

1079

00:47:58,600 --> 00:47:56,750

real images right some of the colors in

1080

00:47:59,260 --> 00:47:58,610

here and I think it's blue is an oxygen

1081

00:48:01,510 --> 00:47:59,270

cooling

1082

00:48:05,230 --> 00:48:01,520

oxygen is a very powerful coolant with

1083

00:48:06,700 --> 00:48:05,240

high temperatures even in solar

1084

00:48:09,040 --> 00:48:06,710

metallicity gas so if you're thinking

1085

00:48:10,480 --> 00:48:09,050

about increasing the oxygen abundance by

1086

00:48:12,040 --> 00:48:10,490

several thousand then it's gonna be

1087

00:48:13,870 --> 00:48:12,050

really important so the question that I

1088

00:48:16,570 --> 00:48:13,880

am suggesting that we're working on now

1089

00:48:19,030 --> 00:48:16,580

is this oxygen act as a break to water

1090

00:48:20,830 --> 00:48:19,040

so as you increase the flux you're going

1091

00:48:23,040 --> 00:48:20,840

to increase the temperature so that's

1092

00:48:25,360 --> 00:48:23,050

gonna mean you're gonna increase the

1093

00:48:27,340 --> 00:48:25,370

mass that you can drag and you can start

1094

00:48:28,630 --> 00:48:27,350

to drag oxygen with you if you start

1095

00:48:30,850 --> 00:48:28,640

dragging oxygen with you it's gonna

1096

00:48:32,470 --> 00:48:30,860

start to cool the flow that's gonna do

1097

00:48:34,030 --> 00:48:32,480

reduce this crossover mass and you're

1098

00:48:36,880 --> 00:48:34,040

gonna start not being able to track this

1099

00:48:38,590 --> 00:48:36,890

gently so and then you're going to

1100

00:48:42,850 --> 00:48:38,600

increase the temperature again so do you

1101

00:48:44,950 --> 00:48:42,860

get some sort of stable so if this sort

1102

00:48:48,220 --> 00:48:44,960

of bifurcation between desert world's

1103

00:48:51,040 --> 00:48:48,230

and kevin costner worlds what we're

1104

00:48:53,350 --> 00:48:51,050

really suggesting for these m planets or

1105

00:48:56,770 --> 00:48:53,360

can we end up with something more in

1106

00:49:03,720 --> 00:48:56,780

between so this is work in progress to

1107

00:49:05,710 --> 00:49:03,730

be done so atmospheric loss from

1108

00:49:08,080 --> 00:49:05,720

terrestrial planets and secondary

1109

00:49:09,490 --> 00:49:08,090

element dominated planets and this is

1110

00:49:12,520 --> 00:49:09,500

the key question we should be asking

1111

00:49:14,950 --> 00:49:12,530

ourselves as a field especially for M

1112

00:49:17,320 --> 00:49:14,960

dwarf habitable zone five key targets

1113

00:49:18,970 --> 00:49:17,330

for upcoming missions it can highly

1114

00:49:20,710 --> 00:49:18,980

irradiated terrestrial planets rotate an

1115

00:49:23,790 --> 00:49:20,720

atmosphere or are we just wasting our

1116

00:49:29,410 --> 00:49:27,670

so I'm going to end on a suggestion

1117

00:49:31,210 --> 00:49:29,420

and this is something we're working on

1118

00:49:32,770 --> 00:49:31,220

this but perhaps we have these two

1119

00:49:36,040 --> 00:49:32,780

separate pathways to forming a

1120

00:49:38,380 --> 00:49:36,050

terrestrial planet we have what I'm

1121

00:49:40,060 --> 00:49:38,390

calling born terrestrial planets so

1122

00:49:42,010 --> 00:49:40,070

planets are formed somewhat like solar

1123

00:49:43,750 --> 00:49:42,020

system planets they didn't form fully

1124

00:49:45,370 --> 00:49:43,760

before the gas this dispersed they

1125

00:49:48,790 --> 00:49:45,380

didn't end up with large hydrants named

1126  
00:49:50,980 --> 00:49:48,800  
atmospheres we have terrestrial planets

1127  
00:49:55,750 --> 00:49:50,990  
have formed by a stripping of large

1128  
00:49:57,670 --> 00:49:55,760  
hydrants so obviously the atmospheres

1129  
00:50:04,270 --> 00:49:57,680  
we're gonna get is gonna be some sort of

1130  
00:50:06,190 --> 00:50:04,280  
balance between resupply and loss so if

1131  
00:50:07,660 --> 00:50:06,200  
the answer we're gonna get gonna be

1132  
00:50:09,250 --> 00:50:07,670  
dependent on these two different

1133  
00:50:12,160 --> 00:50:09,260  
evolutionary pathways are there going to

1134  
00:50:14,260 --> 00:50:12,170  
be two distinct separate types of

1135  
00:50:15,880 --> 00:50:14,270  
terrestrial planet atmosphere that point

1136  
00:50:18,880 --> 00:50:15,890  
to their formation mechanisms or is it

1137  
00:50:21,160 --> 00:50:18,890  
more of a continuum and this is a key

1138  
00:50:22,960 --> 00:50:21,170

theoretical problem and observational

1139

00:50:26,590 --> 00:50:22,970

problem right that we need to focus to

1140

00:50:30,520 --> 00:50:26,600

the observations give us and this is

1141

00:50:33,370 --> 00:50:30,530

something we're working on now and I'm

1142

00:50:36,070 --> 00:50:33,380

out of time so I'm gonna skip what I

1143

00:50:38,800 --> 00:50:36,080

think perhaps a sort of way to get at

1144

00:50:40,780 --> 00:50:38,810

these which is loss from highly

1145

00:50:43,480 --> 00:50:40,790

irradiated rocky planet they're so hot

1146

00:50:45,070 --> 00:50:43,490

to melt their surface in the escape we

1147

00:50:47,020 --> 00:50:45,080

can observe them so that this is a good

1148

00:50:49,870 --> 00:50:47,030

way to test our secondary - severe loss

1149

00:50:52,330 --> 00:50:49,880

may quite have time to go through all

1150

00:51:02,940 --> 00:50:52,340

these slides so I finished there and

1151  
00:51:11,670 --> 00:51:07,270  
thank you very thank you very much we

1152  
00:51:18,010 --> 00:51:13,620  
[Music]

1153  
00:51:22,680 --> 00:51:18,020  
this desert please state your name and

1154  
00:51:27,730 --> 00:51:22,690  
affiliation jeremy'll account generous

1155  
00:51:31,300 --> 00:51:27,740  
so I was intrigued by the fact that so

1156  
00:51:34,030 --> 00:51:31,310  
you when we look at this straight course

1157  
00:51:36,460 --> 00:51:34,040  
from from Capra so of course it means

1158  
00:51:41,200 --> 00:51:36,470  
that even the strip course start with a

1159  
00:51:43,960 --> 00:51:41,210  
big hydrogen atmosphere but then this is

1160  
00:51:47,530 --> 00:51:43,970  
for for Capra targets so it means for f

1161  
00:51:50,950 --> 00:51:47,540  
JK stars basically so you can have

1162  
00:51:52,480 --> 00:51:50,960  
implied that for M dwarfs the the

1163  
00:51:55,870 --> 00:51:52,490

mechanism of the formation mechanism

1164

00:51:58,240 --> 00:51:55,880

would be the same but at least I feel

1165

00:52:00,579 --> 00:51:58,250

that around M dwarfs the disc should be

1166

00:52:03,220 --> 00:52:00,589

less massive or or at least comparable

1167

00:52:07,240 --> 00:52:03,230

the the types of further away from the

1168

00:52:10,630 --> 00:52:07,250

star comparable to sides of the the mass

1169

00:52:13,750 --> 00:52:10,640

of the star so do you have evidence to

1170

00:52:19,440 --> 00:52:13,760

support that they should be born with a

1171

00:52:21,820 --> 00:52:19,450

lot of hydrogen so so there is evidence

1172

00:52:23,829 --> 00:52:21,830

so you're right the Kepler data is

1173

00:52:27,099 --> 00:52:23,839

dominated by ftk stars there are some

1174

00:52:29,170 --> 00:52:27,109

few M stars and this whole feature so

1175

00:52:30,839 --> 00:52:29,180

yanti nu has a nice paper from 2018

1176

00:52:34,660 --> 00:52:30,849

where she shows this whole feature

1177

00:52:37,320 --> 00:52:34,670

extends down into the M Dwarfs I'll also

1178

00:52:40,240 --> 00:52:37,330

make a comment about your feeling your

1179

00:52:42,099 --> 00:52:40,250

feeling that the gas disks and dust

1180

00:52:45,370 --> 00:52:42,109

disks are less massive around emboss

1181

00:52:48,400 --> 00:52:45,380

which is the empirical fact right but if

1182

00:52:50,920 --> 00:52:48,410

you look at the mass contained in the

1183

00:52:53,339 --> 00:52:50,930

exoplanet population it's actually more

1184

00:52:58,050 --> 00:52:53,349

massive around the lower mass and

1185

00:53:01,270 --> 00:52:58,060

there's more so that's an intriguing

1186

00:53:03,250 --> 00:53:01,280

question so at the moment given the

1187

00:53:05,140 --> 00:53:03,260

observed data we have there is no

1188

00:53:07,210 --> 00:53:05,150

evidence apart from the terrestrial

1189

00:53:09,940 --> 00:53:07,220

planets in our solar system that planets

1190

00:53:15,160 --> 00:53:09,950

form without large hydrogen which i

1191

00:53:25,640 --> 00:53:23,450

right yes so how well-defined is the the

1192

00:53:26,180 --> 00:53:25,650

core envelope boundary for these sub

1193

00:53:27,830 --> 00:53:26,190

napkins

1194

00:53:29,630 --> 00:53:27,840

given what we're learning about fuzzy

1195

00:53:31,280 --> 00:53:29,640

cores for for Jupiter so that is a

1196

00:53:34,430 --> 00:53:31,290

excellent question

1197

00:53:41,270 --> 00:53:34,440

as a question to which I can answer with

1198

00:53:43,100 --> 00:53:41,280

a feeling so so one of the the things

1199

00:53:46,600 --> 00:53:43,110

that we know about this hydrogen helium

1200

00:53:48,680 --> 00:53:46,610

loss is that the radiative cooling is

1201

00:53:51,440 --> 00:53:48,690

sort of slightly super so low

1202

00:53:54,620 --> 00:53:51,450

metallicity is dominated by the metals

1203

00:53:56,270 --> 00:53:54,630

so if you do have a fuzzy core boundary

1204

00:53:59,510 --> 00:53:56,280

where you start getting into a hydrant

1205

00:54:00,950 --> 00:53:59,520

helium atmosphere that is increasing in

1206

00:54:06,410 --> 00:54:00,960

metals the mass loss rate is going to

1207

00:54:07,700 --> 00:54:06,420

drop like a stone right so it when I say

1208

00:54:09,080 --> 00:54:07,710

they're stripped cause right there

1209

00:54:11,330 --> 00:54:09,090

they're stripped in the sense that we

1210

00:54:13,940 --> 00:54:11,340

have no radius evidence for a large

1211

00:54:15,710 --> 00:54:13,950

hiding claim atmosphere so it may turn

1212

00:54:17,120 --> 00:54:15,720

out when we start looking at these super

1213

00:54:18,920 --> 00:54:17,130

Earths and as part of that suggestion

1214

00:54:21,890 --> 00:54:18,930

these terrestrial planet pathways but

1215

00:54:24,170 --> 00:54:21,900

they do retain a thin veneer of hydrogen

1216

00:54:28,280 --> 00:54:24,180

and that could be coming from this fuzzy

1217

00:54:30,920 --> 00:54:28,290

cool aspect but it's not it can't be a

1218

00:54:32,810 --> 00:54:30,930

very extended fuzzy core other you

1219

00:54:34,850 --> 00:54:32,820

otherwise you wouldn't be able to get

1220

00:54:49,010 --> 00:54:34,860

this process if it was and which is

1221

00:54:51,500 --> 00:54:49,020

wrong anymore with a magnetic field help

1222

00:54:53,960 --> 00:54:51,510

display to do your calculation take that

1223

00:54:58,720 --> 00:54:53,970

yeah yeah so someone always asked me

1224

00:55:06,890 --> 00:55:03,470

so yes so magnetic fields suppress mass

1225

00:55:09,170 --> 00:55:06,900

loss for hydrodynamic driven and they do

1226

00:55:11,900 --> 00:55:09,180

it because you have a these outflows or

1227

00:55:14,000 --> 00:55:11,910

strongly ionized for they're coupled to

1228

00:55:16,820 --> 00:55:14,010

the magnetic fields ideal MHD is a very

1229

00:55:18,740 --> 00:55:16,830

good approximation so you get close

1230

00:55:20,540 --> 00:55:18,750

field lines close to the equator this is

1231

00:55:22,310 --> 00:55:20,550

where most of the energy is the

1232

00:55:24,680 --> 00:55:22,320

positives you only get in efficient flow

1233

00:55:26,690 --> 00:55:24,690

along the poles so this significant

1234

00:55:29,390 --> 00:55:26,700

we reduces the mass loss rate by about

1235

00:55:32,900 --> 00:55:29,400

an order of magnitude so you can play

1236

00:55:37,609 --> 00:55:32,910

this whole game again with this process

1237

00:55:39,800 --> 00:55:37,619

and compared to the radius gap data so

1238

00:55:41,630 --> 00:55:39,810

if you do that as you increase the field

1239

00:55:44,480 --> 00:55:41,640

strength you can still you still get the

1240

00:55:47,480 --> 00:55:44,490

same process you just need to calm p'n

1241

00:55:49,250 --> 00:55:47,490

sait for the reduced last loss rates by

1242

00:55:53,480 --> 00:55:49,260

reducing the mass of the planets you're

1243

00:55:57,050 --> 00:55:53,490

losing so instead of favoring rocky

1244

00:55:59,930 --> 00:55:57,060

cores with basically zero fields we

1245

00:56:02,180 --> 00:55:59,940

favor icy course with strong fields the

1246

00:56:03,920 --> 00:56:02,190

fact that the ten also planets down here

1247

00:56:06,530 --> 00:56:03,930

that have measured masses are all

1248

00:56:10,339 --> 00:56:06,540

consistent with like rock perhaps points

1249

00:56:14,030 --> 00:56:10,349

to me to suggest that these things don't

1250

00:56:17,210 --> 00:56:14,040

have Pankau spills or one gas fields and

1251

00:56:18,859 --> 00:56:17,220

I mean here the field strength at the

1252

00:56:20,690 --> 00:56:18,869

top of the hydrogen helium a pursuer you

1253

00:56:23,510 --> 00:56:20,700

double the core strength so if you have

1254

00:56:25,550 --> 00:56:23,520

a one cows earth-like field it's gonna

1255

00:56:28,130 --> 00:56:25,560

be point one gal by the time you get to

1256

00:56:30,140 --> 00:56:28,140

the pub bar so it doesn't matter so to

1257

00:56:31,849 --> 00:56:30,150

make this work you need dynamo generated

1258

00:56:33,440 --> 00:56:31,859

fields in subnet tune something we don't

1259

00:56:35,839 --> 00:56:33,450

have in the total system so we have no

1260

00:56:37,970 --> 00:56:35,849

idea what it does but at least it's

1261

00:56:47,630 --> 00:56:37,980

saying to me they don't generate a few

1262

00:56:51,980 --> 00:56:47,640

gas fields the mass loss rate by

1263

00:56:53,690 --> 00:56:51,990

diffusion limited process is not not

1264

00:56:55,309 --> 00:56:53,700

relevant here because you have

1265

00:56:59,480 --> 00:56:55,319

considered only the energy limited the

1266

00:57:00,920 --> 00:56:59,490

escape yeah so I I did point out that

1267

00:57:03,319 --> 00:57:00,930

you can slow these processes down

1268

00:57:05,630 --> 00:57:03,329

especially for the water loss by either

1269

00:57:08,480 --> 00:57:05,640

limits due to just associating the water

1270

00:57:10,250 --> 00:57:08,490

or diffusing the hydrogen through a very

1271

00:57:13,010 --> 00:57:10,260

oxygen-rich atmosphere and that does

1272

00:57:14,839 --> 00:57:13,020

slow down the mass loss rates in those

1273

00:57:18,380 --> 00:57:14,849

Lugar and barns calculations I

1274

00:57:20,780 --> 00:57:18,390

considered they also consider the

1275

00:57:22,309 --> 00:57:20,790

diffusion limit and they argued for

1276

00:57:24,380 --> 00:57:22,319

their calculations based on their

1277

00:57:26,390 --> 00:57:24,390

temperatures drop right which is based

1278

00:57:28,130 --> 00:57:26,400

on not including oxygen cooling they

1279

00:57:31,910 --> 00:57:28,140

argued that energy limit was more

1280

00:57:33,470 --> 00:57:31,920

applicable but when the calculation is

1281

00:57:35,480 --> 00:57:33,480

done properly that may not be true and

1282

00:57:38,120 --> 00:57:35,490

the diffusion limit may be another way

1283

00:57:50,670 --> 00:57:38,130

to save our water on