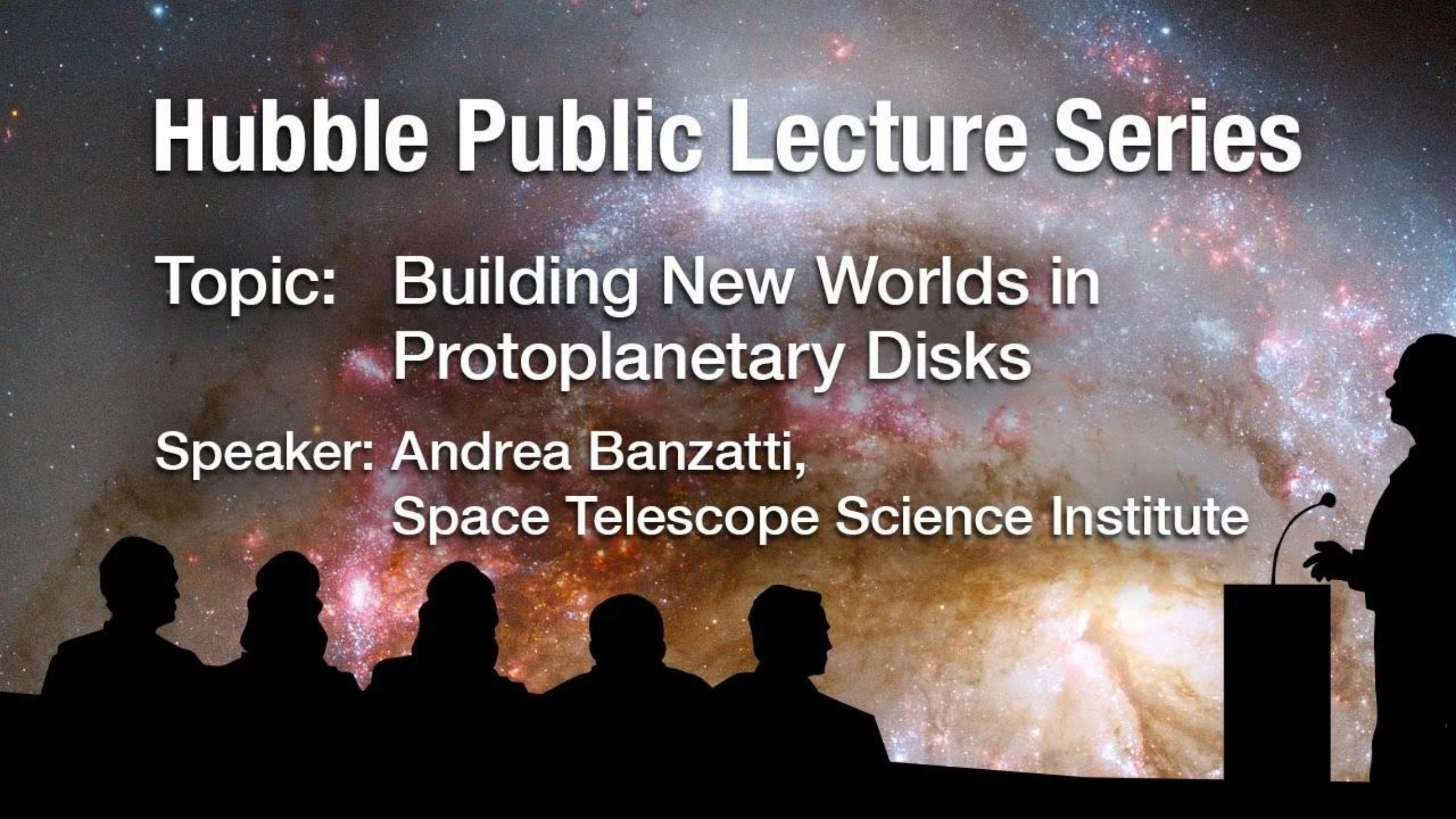
Hubble Public Lecture Series
Topic: Building New Worlds in Protoplanetary Disks
Speaker: Andrea Banzatti,
Space Telescope Science Institute

1
00:00:04,280 --> 00:00:01,189
okay now that I've got your attention

2
00:00:06,499 --> 00:00:04,290
because they're changing pictures I'd

3
00:00:10,430 --> 00:00:06,509
like to welcome everybody to our July

4
00:00:12,110 --> 00:00:10,440
open night your guests usual host Frank

5
00:00:14,240 --> 00:00:12,120
summers is on travel

6
00:00:16,640 --> 00:00:14,250
that means you'll get home early enough

7
00:00:18,800 --> 00:00:16,650
to let the cat out tonight I'm just

8
00:00:21,769 --> 00:00:18,810
teasing and there won't be a quiz after

9
00:00:23,090 --> 00:00:21,779
the talk my name is Ray Vallarta I'm the

10
00:00:25,580 --> 00:00:23,100
news director here at the Space

11
00:00:28,220 --> 00:00:25,590
Telescope Institute we've got a

12
00:00:30,710 --> 00:00:28,230
fascinating talk tonight dealing with

13
00:00:34,850 --> 00:00:30,720

our cosmic origins the origin of the

14
00:00:37,069 --> 00:00:34,860
solar system and the planets the Frank

15
00:00:38,780 --> 00:00:37,079
usually gives you the big Hubble news

16
00:00:41,540 --> 00:00:38,790
rundown I have the Reader's Digest

17
00:00:43,729 --> 00:00:41,550
version and I'm going to show you one

18
00:00:45,920 --> 00:00:43,739
item and I wanted to show you this

19
00:00:50,389 --> 00:00:45,930
tonight because it dovetails with what

20
00:00:53,029 --> 00:00:50,399
our guests will be talking about but the

21
00:00:55,459 --> 00:00:53,039
the the news just came out today so you

22
00:00:56,900 --> 00:00:55,469
may not have heard about it so I'm not

23
00:01:04,429 --> 00:00:56,910
going to give you a quiz but who can

24
00:01:12,550 --> 00:01:04,439
tell me what spacecraft is that now

25
00:01:15,230 --> 00:01:12,560
you're off by 40 years nobody okay

26
00:01:19,969 --> 00:01:15,240
no but you're getting warmer

27
00:01:21,649 --> 00:01:19,979
or should I say colder come on you guys

28
00:01:24,160 --> 00:01:21,659
paid a billion dollars for this

29
00:01:26,810 --> 00:01:24,170
spacecraft

30
00:01:31,069 --> 00:01:26,820
oh you're getting colder you keep track

31
00:01:33,590 --> 00:01:31,079
for any money goes yes not Voyager

32
00:01:34,880 --> 00:01:33,600
that's way the hell out and it's I don't

33
00:01:38,990 --> 00:01:34,890
think it's beyond the edge of the solar

34
00:01:42,050 --> 00:01:39,000
system that's my person right here okay

35
00:01:46,160 --> 00:01:42,060
I will because times going this is the

36
00:01:47,660 --> 00:01:46,170
New Horizons craft headed for Pluto it

37
00:01:51,050 --> 00:01:47,670
is controlled here at the Applied

38
00:01:54,980 --> 00:01:51,060

Physics lab down outside of Columbia and

39
00:01:56,870 --> 00:01:54,990
this craft was launched 10 years ago it

40
00:02:00,020 --> 00:01:56,880
is the fastest man-made object ever

41
00:02:03,139 --> 00:02:00,030
built and this is a trajectory as of

42
00:02:05,120 --> 00:02:03,149
today it is a marathon runner it has

43
00:02:08,210 --> 00:02:05,130
sprinted across the orbits of all the

44
00:02:10,419 --> 00:02:08,220
major planets it is a year from flying

45
00:02:12,819 --> 00:02:10,429
by the planet Pluto

46
00:02:17,619 --> 00:02:12,829
and with Frank not here I can say planet

47
00:02:20,710 --> 00:02:17,629
tweet are actually was Pluto is a dwarf

48
00:02:23,830 --> 00:02:20,720
binary planet an interesting idea which

49
00:02:25,210 --> 00:02:23,840
gets lost in all the silly fight over

50
00:02:27,699 --> 00:02:25,220
the semantics of what to call it

51
00:02:31,869 --> 00:02:27,709
whatever Pluto is it's very interesting

52
00:02:33,970 --> 00:02:31,879
it will reach Pluto in July but the

53
00:02:37,030 --> 00:02:33,980
people running new horizons would like

54
00:02:40,809 --> 00:02:37,040
to go farther they'd like to boldly go

55
00:02:44,050 --> 00:02:40,819
even deeper into the solar system so the

56
00:02:47,140 --> 00:02:44,060
outer rim of the solar system is a vast

57
00:02:49,890 --> 00:02:47,150
undiscovered country stretching from 3

58
00:02:52,809 --> 00:02:49,900
billion to 5 billion miles from the Sun

59
00:02:55,179 --> 00:02:52,819
it contains primordial debris going back

60
00:02:58,089 --> 00:02:55,189
to the birth of our solar system 4.6

61
00:03:00,550 --> 00:02:58,099
billion years ago we've never been there

62
00:03:04,720 --> 00:03:00,560
and we only know it about objects out

63
00:03:06,640 --> 00:03:04,730

there since the 1990s the folks on the

64
00:03:09,129 --> 00:03:06,650
new Horizons probe after they fly by

65
00:03:11,940 --> 00:03:09,139
Pluto wanted to visit a Kuiper belt

66
00:03:14,619 --> 00:03:11,950
object these are objects that range in a

67
00:03:16,720 --> 00:03:14,629
variety of sizes typically the one that

68
00:03:19,420 --> 00:03:16,730
the one they want to fly by is about the

69
00:03:22,240 --> 00:03:19,430
size of Manhattan Island but we have to

70
00:03:24,129 --> 00:03:22,250
find it and only Hubble only Hubble not

71
00:03:26,259 --> 00:03:24,139
any ground-based telescope has the

72
00:03:29,020 --> 00:03:26,269
ability to look for targets for the new

73
00:03:31,509 --> 00:03:29,030
Horizons probe so just released today

74
00:03:34,839 --> 00:03:31,519
our pictures of two Kuiper belt objects

75
00:03:36,399 --> 00:03:34,849
these are extraordinarily faint they're

76
00:03:38,649 --> 00:03:36,409
about as faint as the glow of a

77
00:03:41,289 --> 00:03:38,659
flashlight on the moon if you could see

78
00:03:43,539 --> 00:03:41,299
it from Earth now how do we know that

79
00:03:49,370 --> 00:03:43,549
these are Kuiper belt objects because

80
00:03:56,130 --> 00:03:53,040
god these are these two objects are four

81
00:03:57,390 --> 00:03:56,140
billion miles from the Sun well how do

82
00:03:59,400 --> 00:03:57,400
we know they belong in the Kuiper belt

83
00:04:01,680 --> 00:03:59,410
because they're moving against the

84
00:04:03,570 --> 00:04:01,690
background of stars that background is

85
00:04:05,490 --> 00:04:03,580
in the summer constellation Sagittarius

86
00:04:08,760 --> 00:04:05,500
so finding these was like playing a game

87
00:04:11,010 --> 00:04:08,770
of Where's Waldo it was it was a needle

88
00:04:13,050 --> 00:04:11,020

in haystack search we announced today

89
00:04:15,510 --> 00:04:13,060
that we found two of them this means

90
00:04:17,400 --> 00:04:15,520
that more than 140 Hubble orbits will be

91
00:04:19,199 --> 00:04:17,410
dedicated to looking for more Kuiper

92
00:04:23,460 --> 00:04:19,209
belt objects which would be suitable

93
00:04:26,700 --> 00:04:23,470
targets for new horizons so but probably

94
00:04:29,670 --> 00:04:26,710
by the year 2020 if we find if that team

95
00:04:31,590 --> 00:04:29,680
finds a suitable Kuiper belt object it

96
00:04:34,260 --> 00:04:31,600
will fly by that object and what this

97
00:04:35,850 --> 00:04:34,270
will be this will complete mankind's

98
00:04:38,450 --> 00:04:35,860
initial reconnaissance of the solar

99
00:04:40,800 --> 00:04:38,460
system going back to the early 60s

100
00:04:43,020 --> 00:04:40,810
because these Kuiper belt objects are

101
00:04:45,450 --> 00:04:43,030
the last class of object in the solar

102
00:04:48,090 --> 00:04:45,460
system we will have completed the

103
00:04:59,150 --> 00:04:48,100
chapter of our initial exploration of

104
00:05:01,760 --> 00:04:59,160
that yes yes yeah why was right no they

105
00:05:04,409 --> 00:05:01,770
the Hubble survey finds an ideal target

106
00:05:07,770 --> 00:05:04,419
the new horizons will be redirected

107
00:05:10,469 --> 00:05:07,780
after it passes Pluto to flyby this

108
00:05:12,480 --> 00:05:10,479
object again finding these is like

109
00:05:15,210 --> 00:05:12,490
trying to find a said Manhattan Island

110
00:05:19,920 --> 00:05:15,220
but imagine Manhattan Island covered in

111
00:05:26,520 --> 00:05:19,930
black velvet four billion miles away and

112
00:05:28,409 --> 00:05:26,530
Hubble found it the almighty Hubble no

113
00:05:31,790 --> 00:05:28,419

that's about our clouds like your away

114
00:05:35,070 --> 00:05:31,800
so unless you invent immortality it's

115
00:05:37,400 --> 00:05:35,080
the I don't want to digress with the

116
00:05:40,110 --> 00:05:37,410
Voyager spacecraft that that sound the

117
00:05:42,950 --> 00:05:40,120
on the way out it'll take it I think

118
00:05:45,600 --> 00:05:42,960
10,000 years to reach the earth clap so

119
00:05:48,780 --> 00:05:45,610
again that's about 50,000 astronomical

120
00:05:51,810 --> 00:05:48,790
units Kuiper belt is no more than five

121
00:05:54,930 --> 00:05:51,820
astronomical units now I wanted to bring

122
00:05:57,450 --> 00:05:54,940
this up because the talk tonight deals

123
00:05:59,850 --> 00:05:57,460
with disks around other stars for

124
00:06:01,010 --> 00:05:59,860
planets are forming so this is a Hubble

125
00:06:02,960 --> 00:06:01,020
picture and nobody

126
00:06:05,839 --> 00:06:02,970
to ink on it they just blocked out the

127
00:06:08,510 --> 00:06:05,849
star but this is a Kuiper belt like disc

128
00:06:10,879 --> 00:06:08,520
around another star and it's really

129
00:06:13,850 --> 00:06:10,889
evidence circumstantial evidence for the

130
00:06:16,159 --> 00:06:13,860
formation of planets around other stars

131
00:06:18,170 --> 00:06:16,169
and that's really the talk tonight and I

132
00:06:20,480 --> 00:06:18,180
think these discs are important they've

133
00:06:23,689 --> 00:06:20,490
only been known about for about 15 years

134
00:06:24,800 --> 00:06:23,699
or so you know if you ask a child where

135
00:06:27,290 --> 00:06:24,810
did they come from they'll say the

136
00:06:31,369 --> 00:06:27,300
hospital but studying the Kuiper belt

137
00:06:34,040 --> 00:06:31,379
discs go back to 4.6 billion years word

138
00:06:36,409 --> 00:06:34,050

of the solar system comes from so we

139
00:06:38,779 --> 00:06:36,419
have a wonderfully of enthusiastic

140
00:06:41,930 --> 00:06:38,789
speaker tonight andrea

141
00:06:43,909 --> 00:06:41,940
ben sati who has specialized in the

142
00:06:46,370 --> 00:06:43,919
chemistry and physics of how planets

143
00:06:49,550 --> 00:06:46,380
form inside these circumstellar disks

144
00:06:52,279 --> 00:06:49,560
he's a postdoctoral fellow here at the

145
00:06:55,370 --> 00:06:52,289
Space Telescope Institute now he got his

146
00:06:58,969 --> 00:06:55,380
PhD from the Institute for technology

147
00:07:00,680 --> 00:06:58,979
and Europe in Zurich Switzerland I

148
00:07:04,879 --> 00:07:00,690
forget the name of that right

149
00:07:07,879 --> 00:07:04,889
close sir Institute for technology in

150
00:07:09,260 --> 00:07:07,889
astronomy he got his master's working at

151
00:07:13,249 --> 00:07:09,270
the European Southern Observatory's

152
00:07:17,749 --> 00:07:13,259
headquarters in Garching Germany and he

153
00:07:25,830 --> 00:07:17,759
got his masters and bachelor's in Italy

154
00:07:55,320 --> 00:07:49,320
Oh is another Kuiper belt I see 100 G hi

155
00:07:57,570 --> 00:07:55,330
hello hello okay so I have different

156
00:08:02,159 --> 00:07:57,580
instruments here I think I need only

157
00:08:05,670 --> 00:08:02,169
this one from now so Frank is not here

158
00:08:09,000 --> 00:08:05,680
tonight but actually he's the inventor

159
00:08:10,770 --> 00:08:09,010
of the name he made up the the title of

160
00:08:13,440 --> 00:08:10,780
this talk building new words in

161
00:08:14,820 --> 00:08:13,450
protoplanetary discs I simply told him

162
00:08:17,250 --> 00:08:14,830
that I was working for information and

163
00:08:20,060 --> 00:08:17,260

we came up with this appealing title and

164
00:08:22,890 --> 00:08:20,070
we did when he told me this this title I

165
00:08:46,460 --> 00:08:22,900
actually felt a bit of vertigo and the

166
00:09:04,860 --> 00:09:00,660
you hear me okay okay so I was saying

167
00:09:07,020 --> 00:09:04,870
that I I was tempted so Frank made up

168
00:09:08,670 --> 00:09:07,030
this this time the title of his talk and

169
00:09:10,290 --> 00:09:08,680
I was telling some wanted to change it

170
00:09:16,560 --> 00:09:10,300
then to narrow it down on the capital of

171
00:09:18,720 --> 00:09:16,570
things on which I am working on but in

172
00:09:23,400 --> 00:09:18,730
the end I decided to keep the challenge

173
00:09:25,680 --> 00:09:23,410
and keep the title for for one reason

174
00:09:27,390 --> 00:09:25,690
mainly I thought about it and for one

175
00:09:31,470 --> 00:09:27,400
reason I decided to keep the title as

176
00:09:34,710 --> 00:09:31,480
broad as it is because of the mystery

177
00:09:37,949 --> 00:09:34,720
I feel attracted to I know that even

178
00:09:38,750 --> 00:09:37,959
with an entire life dedicated to working

179
00:09:44,300 --> 00:09:38,760
on

180
00:09:46,310 --> 00:09:44,310
and yet I feel attracted to it like for

181
00:09:48,680 --> 00:09:46,320
example like Shahrukh Khan's who cannot

182
00:09:51,110 --> 00:09:48,690
stay away from intriguing facts that he

183
00:09:52,850 --> 00:09:51,120
reads on newspapers okay and like

184
00:09:55,280 --> 00:09:52,860
Sherlock Holmes I like to go on the

185
00:09:56,990 --> 00:09:55,290
crime scene to see what what happened

186
00:09:59,810 --> 00:09:57,000
okay

187
00:10:03,020 --> 00:09:59,820
in other words I am an observer I like

188
00:10:06,140 --> 00:10:03,030

to look at facts collect hints and try

189
00:10:10,130 --> 00:10:06,150
to see the story hidden beyond the

190
00:10:14,210 --> 00:10:10,140
appearance of things I think that all of

191
00:10:16,640 --> 00:10:14,220
you understand the kind of investigative

192
00:10:18,920 --> 00:10:16,650
our president talking about because this

193
00:10:21,590 --> 00:10:18,930
is not something for astronomers or for

194
00:10:23,600 --> 00:10:21,600
scientists only otherwise you will not

195
00:10:27,140 --> 00:10:23,610
be here tonight this is something that

196
00:10:29,240 --> 00:10:27,150
we discover in our cells at least at

197
00:10:31,820 --> 00:10:29,250
some point in life at least where we are

198
00:10:36,650 --> 00:10:31,830
kids okay and and in fact astronomers

199
00:10:38,060 --> 00:10:36,660
are a kind of never growing kids but

200
00:10:41,810 --> 00:10:38,070
what is the mystery that I'm talking

201
00:10:47,630 --> 00:10:41,820
about so let's imagine for a moment that

202
00:10:50,360 --> 00:10:47,640
we are Sherlock Holmes it's the morning

203
00:10:52,370 --> 00:10:50,370
and after a delicate British breakfast

204
00:10:56,480 --> 00:10:52,380
we are ready to read the daily

205
00:10:58,880 --> 00:10:56,490
newspapers okay since we are experienced

206
00:11:01,660 --> 00:10:58,890
investigators we know that the news we

207
00:11:04,640 --> 00:11:01,670
can be in big capitals on the front page

208
00:11:07,160 --> 00:11:04,650
they are the least reliable the most

209
00:11:10,040 --> 00:11:07,170
contaminated so as experienced

210
00:11:13,100 --> 00:11:10,050
investigators we go for the news with a

211
00:11:14,990 --> 00:11:13,110
small in the corner those news that are

212
00:11:17,300 --> 00:11:15,000
dedicated a few paragraphs at the end of

213
00:11:18,980 --> 00:11:17,310

the newspaper okay the section that you

214
00:11:20,570 --> 00:11:18,990
would read on if you have a lot of spare

215
00:11:26,210 --> 00:11:20,580
time during the day and be happy because

216
00:11:28,910 --> 00:11:26,220
we are Sherlock Holmes we have not so

217
00:11:32,510 --> 00:11:28,920
today this morning we open the newspaper

218
00:11:37,340 --> 00:11:32,520
and we read a title it title written

219
00:11:40,100 --> 00:11:37,350
small catches our attention a title the

220
00:11:42,950 --> 00:11:40,110
wheels a story the begins in a

221
00:11:45,950 --> 00:11:42,960
breathtaking beauty and then in an

222
00:11:48,230 --> 00:11:45,960
unexpected way unexpected this is this

223
00:11:50,630 --> 00:11:48,240
is for eyes so we immediately go to the

224
00:11:50,990 --> 00:11:50,640
section section Bly at the end of the

225
00:11:57,199 --> 00:11:51,000
news

226
00:12:09,460 --> 00:11:57,209
okay and this is what we will do let me

227
00:12:14,780 --> 00:12:12,590
with increasing telescopic capabilities

228
00:12:17,449 --> 00:12:14,790
it turned out that the interstellar

229
00:12:20,480 --> 00:12:17,459
space is not as black and empty as it

230
00:12:22,910 --> 00:12:20,490
looks to human hands from earth diffuse

231
00:12:25,400 --> 00:12:22,920
gas and dust are present everywhere in

232
00:12:28,220 --> 00:12:25,410
our galaxy we ten use a mission that can

233
00:12:31,579 --> 00:12:28,230
be seen with modern telescopes like the

234
00:12:34,550 --> 00:12:31,589
NASA Hubble Space Telescope these

235
00:12:38,509 --> 00:12:34,560
regions are primarily made of gas 99% in

236
00:12:40,550 --> 00:12:38,519
mass with only 1% is more dust grains it

237
00:12:43,129 --> 00:12:40,560
is from the interplay of gas and dust

238
00:12:46,069 --> 00:12:43,139

and the surrounding radiation that

239
00:12:48,590 --> 00:12:46,079
amazing figures are carved deep into the

240
00:12:50,809 --> 00:12:48,600
interstellar space providing undoubtedly

241
00:12:54,980 --> 00:12:50,819
some of the most beautiful images of the

242
00:12:58,249 --> 00:12:54,990
local universe driven by observational

243
00:13:00,920 --> 00:12:58,259
evidence scientists propose that stars

244
00:13:05,150 --> 00:13:00,930
are formed by collapse of droplets of

245
00:13:07,699 --> 00:13:05,160
material in these regions for reasons

246
00:13:09,769 --> 00:13:07,709
that are not yet fully understood at

247
00:13:11,179 --> 00:13:09,779
some point dense course become

248
00:13:15,220 --> 00:13:11,189
gravitationally unstable and rapidly

249
00:13:17,720 --> 00:13:15,230
collapse in a flattened rotating disc

250
00:13:22,449 --> 00:13:17,730
which in turn a crease material on to

251
00:13:25,389 --> 00:13:22,459
form a star a protostar at the center

252
00:13:29,540 --> 00:13:25,399
the reading sorry

253
00:13:31,999 --> 00:13:29,550
with time disks disappear and the

254
00:13:35,210 --> 00:13:32,009
newborn star is ready for its mature

255
00:13:37,759 --> 00:13:35,220
phases on the main sequence burning

256
00:13:40,280 --> 00:13:37,769
heavier and heavier elements in its core

257
00:13:43,429 --> 00:13:40,290
and eventually releasing them back into

258
00:13:44,840 --> 00:13:43,439
the interstellar space but this is

259
00:13:48,710 --> 00:13:44,850
another story and we shall not get

260
00:13:50,780 --> 00:13:48,720
distracted as it is right now the we

261
00:13:54,170 --> 00:13:50,790
unexpectedly knot is something that was

262
00:13:56,509 --> 00:13:54,180
not previously under focus scientists

263
00:14:01,819 --> 00:13:56,519

proposed that this physics would let us

264
00:14:04,170 --> 00:14:01,829
believe that the surco stellar matter is

265
00:14:06,450 --> 00:14:04,180
quickly accreted onto the star

266
00:14:09,360 --> 00:14:06,460
or dispersed by high-energy radiation

267
00:14:13,139 --> 00:14:09,370
and this has been largely confirmed by

268
00:14:15,200 --> 00:14:13,149
observations but the sequence teller

269
00:14:18,740 --> 00:14:15,210
material does not completely disappear

270
00:14:21,720 --> 00:14:18,750
some spherical bodies solid and gaseous

271
00:14:25,710 --> 00:14:21,730
rotate in orbits flatten on a plane that

272
00:14:27,769 --> 00:14:25,720
resembles the initial disc so at the end

273
00:14:31,260 --> 00:14:27,779
of the star formation process we find

274
00:14:32,970 --> 00:14:31,270
planets the reader could gently remind

275
00:14:34,829 --> 00:14:32,980
us that this is not surprising and then

276
00:14:36,720 --> 00:14:34,839
if that were not true

277
00:14:40,380 --> 00:14:36,730
we would not be here for soon with these

278
00:14:42,360 --> 00:14:40,390
maps nor with any other we would then

279
00:14:44,639 --> 00:14:42,370
gently remind the reader that it was

280
00:14:47,160 --> 00:14:44,649
only yesterday that planets have been

281
00:14:49,889 --> 00:14:47,170
found to be the natural outcome of star

282
00:14:52,050 --> 00:14:49,899
formation and scientists are still

283
00:14:54,570 --> 00:14:52,060
struggling to find a comprehensive way

284
00:14:58,260 --> 00:14:54,580
to make this happen naturally in their

285
00:15:00,540 --> 00:14:58,270
models this is why circumstellar disks

286
00:15:03,660 --> 00:15:00,550
are increasingly dedicated efforts in

287
00:15:06,480 --> 00:15:03,670
astronomical research today to unveil

288
00:15:09,720 --> 00:15:06,490

what they secretly do inside themselves

289
00:15:11,880 --> 00:15:09,730
in order to build new world and such a

290
00:15:14,940 --> 00:15:11,890
variety of words that can be so

291
00:15:17,670 --> 00:15:14,950
different from our own a challenging

292
00:15:20,250 --> 00:15:17,680
task if we consider that since the

293
00:15:22,160 --> 00:15:20,260
beginning this field of research has

294
00:15:25,680 --> 00:15:22,170
been driven by observations and

295
00:15:28,050 --> 00:15:25,690
unexpected discoveries but challenges

296
00:15:30,480 --> 00:15:28,060
and the unexpected are the two pillars

297
00:15:35,310 --> 00:15:30,490
of cutting-edge research and triggers

298
00:15:37,050 --> 00:15:35,320
for investigative Minds so let me now

299
00:15:42,090 --> 00:15:37,060
draw let's now drop the Sherlock Holmes

300
00:15:45,990 --> 00:15:42,100
character and get back into myself if I

301
00:15:50,010 --> 00:15:46,000
can distinguish the two I choose this

302
00:15:51,930 --> 00:15:50,020
article - to set the stage of the of the

303
00:15:54,090 --> 00:15:51,940
topic of the night of the mystery that

304
00:15:56,790 --> 00:15:54,100
we address tonight how planets and not

305
00:16:00,389 --> 00:15:56,800
only planets but worlds can form inside

306
00:16:08,220 --> 00:16:00,399
protoplanetary disks and the crime scene

307
00:16:09,990 --> 00:16:08,230
that we need to go to our second stellar

308
00:16:11,490 --> 00:16:10,000
disk or protoplanet at least likely like

309
00:16:14,130 --> 00:16:11,500
those that we see this beautiful he

310
00:16:15,990 --> 00:16:14,140
image of the of the of the Hubble from

311
00:16:19,140 --> 00:16:16,000
from the Hubble Space Telescope here you

312
00:16:23,550 --> 00:16:19,150
see images and there you see an artist's

313
00:16:26,220 --> 00:16:23,560

impression and so the mystery we address

314
00:16:28,560 --> 00:16:26,230
tonight is a story that begins in a

315
00:16:31,550 --> 00:16:28,570
breathtaking beauty and thence in an

316
00:16:49,920 --> 00:16:47,430
so as a first team let's let's look

317
00:16:52,260 --> 00:16:49,930
first at this at a couple of of things

318
00:16:55,019 --> 00:16:52,270
to understand better what what we read

319
00:16:58,170 --> 00:16:55,029
in the article okay and let's start from

320
00:17:00,000 --> 00:16:58,180
where shallow cones would serve as well

321
00:17:02,579 --> 00:17:00,010
as any astronomer would start where

322
00:17:06,659 --> 00:17:02,589
where when we address a new unknown

323
00:17:08,490 --> 00:17:06,669
problem the library okay my I remember

324
00:17:11,100 --> 00:17:08,500
my PhD supervisor used to tell me that

325
00:17:14,819 --> 00:17:11,110
when he started in astronomy some 25

326
00:17:22,799 --> 00:17:14,829
years ago he used to to go am I going to

327
00:17:25,860 --> 00:17:22,809
- so I still remember then my PhD

328
00:17:30,020 --> 00:17:25,870
supervisor told me that when he started

329
00:17:33,720 --> 00:17:30,030
in astronomy some twenty-five years ago

330
00:17:36,799 --> 00:17:33,730
he used to go regularly to the library

331
00:17:39,630 --> 00:17:36,809
physically and be able to read all

332
00:17:43,640 --> 00:17:39,640
astronomy papers would the deck they

333
00:17:46,380 --> 00:17:43,650
were published worldwide okay now it's

334
00:17:49,230 --> 00:17:46,390
more difficult because something like a

335
00:17:52,080 --> 00:17:49,240
hundred new papers in astronomy every

336
00:17:54,950 --> 00:17:52,090
day so if you spend your time reading

337
00:17:59,880 --> 00:17:54,960
them you spend your life reading them

338
00:18:01,919 --> 00:17:59,890

but now we have a wonderful online tool

339
00:18:05,610 --> 00:18:01,929
which is an online library where we can

340
00:18:09,570 --> 00:18:05,620
search for papers even back in history

341
00:18:11,730 --> 00:18:09,580
using keywords and this is what we are

342
00:18:15,299 --> 00:18:11,740
going to do now okay so let's use two

343
00:18:17,540 --> 00:18:15,309
keywords using the things that we have

344
00:18:20,610 --> 00:18:17,550
that were mentioned in the article

345
00:18:23,280 --> 00:18:20,620
psycho stellar disk and exoplanet okay

346
00:18:26,610 --> 00:18:23,290
in this plot you see the number of

347
00:18:31,039 --> 00:18:26,620
published papers in force lots of years

348
00:18:36,330 --> 00:18:33,960
let's look at exoplanets what happened

349
00:18:37,799 --> 00:18:36,340
at the exoplanet so these are papers

350
00:18:42,389 --> 00:18:37,809
they were published within the planet in

351
00:18:52,409 --> 00:18:42,399
the title sorry but we are going to stay

352
00:18:54,419 --> 00:18:52,419
here for two hours if I don't so this is

353
00:18:56,930 --> 00:18:54,429
what happened in the field of exoplanets

354
00:18:59,820 --> 00:18:56,940
what do we see from here that the

355
00:19:06,620 --> 00:18:59,830
interest in exoplanet has grown

356
00:19:11,700 --> 00:19:10,529
this is what we find okay so while we

357
00:19:14,190 --> 00:19:11,710
see that the interest in exoplanet

358
00:19:15,810 --> 00:19:14,200
hasn't blown along it seems that the

359
00:19:18,210 --> 00:19:15,820
interest the number of publications

360
00:19:20,430 --> 00:19:18,220
interesting circumstellar disk is is not

361
00:19:22,799 --> 00:19:20,440
really growing anymore actually we can

362
00:19:24,930 --> 00:19:22,809
imagine from this become conclude that

363
00:19:27,320 --> 00:19:24,940

the interest in circle stellar disk is

364
00:19:32,220 --> 00:19:27,330
going to die very soon because

365
00:19:34,889 --> 00:19:32,230
exoplanets are the sexy thing now that

366
00:19:37,409 --> 00:19:34,899
we want to look at okay and here is

367
00:19:39,720 --> 00:19:37,419
where an investigative mind is triggered

368
00:19:41,970 --> 00:19:39,730
because maybe we don't have the full

369
00:19:46,560 --> 00:19:41,980
evidence in front of us maybe we are

370
00:19:49,740 --> 00:19:46,570
asking the wrong question you have heard

371
00:19:52,200 --> 00:19:49,750
the day in the title that here I'm

372
00:19:54,509 --> 00:19:52,210
talking about circumstellar disks but

373
00:19:58,019 --> 00:19:54,519
they are now more known with the name

374
00:20:01,649 --> 00:19:58,029
protoplanetary okay and this word was

375
00:20:03,870 --> 00:20:01,659
created to suggest the idea that planets

376
00:20:05,340 --> 00:20:03,880
are formed inside circle solid discs

377
00:20:08,279 --> 00:20:05,350
okay we are talking about the same thing

378
00:20:11,460 --> 00:20:08,289
okay but they are called saku Stella or

379
00:20:13,860 --> 00:20:11,470
protoplanet okay and this idea that

380
00:20:17,009 --> 00:20:13,870
planets are form a circle solid disk is

381
00:20:19,529 --> 00:20:17,019
much older than exoplanets that they did

382
00:20:23,009 --> 00:20:19,539
the discoveries of exoplanets okay and

383
00:20:25,620 --> 00:20:23,019
was born by by considering the an

384
00:20:27,930 --> 00:20:25,630
interesting similarity between the the

385
00:20:30,000 --> 00:20:27,940
orbits of the planets of our own solar

386
00:20:32,820 --> 00:20:30,010
system that are flattened on on a plane

387
00:20:35,789 --> 00:20:32,830
and the first images of protoplanet of

388
00:20:37,590 --> 00:20:35,799

circumstellar disk that where a disk so

389
00:20:41,049 --> 00:20:37,600
flattened on a plane

390
00:20:49,740 --> 00:20:41,059
so now let's look at papers publications

391
00:20:52,900 --> 00:20:49,750
with protoplanetary discs so this is

392
00:20:57,310 --> 00:20:52,910
interesting because it's telling us one

393
00:20:59,049 --> 00:20:57,320
thing well two things first we find what

394
00:21:00,850 --> 00:20:59,059
the article was saying so indeed the

395
00:21:03,549 --> 00:21:00,860
interest in protoplanetary discs

396
00:21:05,710 --> 00:21:03,559
Israelis is increasing and has been

397
00:21:10,230 --> 00:21:05,720
increasing a lot lately okay in the last

398
00:21:13,870 --> 00:21:10,240
two decades and second thing is that

399
00:21:17,020 --> 00:21:13,880
exoplanets seems to be the driving the

400
00:21:21,100 --> 00:21:17,030
driving force shifting the focus from

401
00:21:22,570 --> 00:21:21,110
the origin of stars in the in the world

402
00:21:24,490 --> 00:21:22,580
that silk Estella to the origin of

403
00:21:26,410 --> 00:21:24,500
planets now we are talking about the

404
00:21:28,600 --> 00:21:26,420
same thing but now instead of calling it

405
00:21:30,940 --> 00:21:28,610
circles that we call it protoplanet okay

406
00:21:33,310 --> 00:21:30,950
so this strongly suggest that we see

407
00:21:36,010 --> 00:21:33,320
indeed you see that the rise of the

408
00:21:41,200 --> 00:21:36,020
protoplanetary name the use of the name

409
00:21:45,880 --> 00:21:41,210
is together with okay but now let me ask

410
00:21:47,919 --> 00:21:45,890
you this question if by now if right now

411
00:21:50,950 --> 00:21:47,929
there is a huge interest in exoplanets

412
00:21:54,130 --> 00:21:50,960
and if by now its upper end it's clear

413
00:21:56,919 --> 00:21:54,140

that exoplanets are common around other

414
00:22:04,180 --> 00:21:56,929
stars why should we care how they form

415
00:22:07,630 --> 00:22:04,190
no they simply are and to address this

416
00:22:11,410 --> 00:22:07,640
question let's go let me let me bring

417
00:22:15,640 --> 00:22:11,420
you to the big today back in time to the

418
00:22:18,460 --> 00:22:15,650
time when the curves here stars start to

419
00:22:21,370 --> 00:22:18,470
diverge to the early 1990s when the

420
00:22:23,080 --> 00:22:21,380
first exoplanets were well found here

421
00:22:26,740 --> 00:22:23,090
you find here you see the first two

422
00:22:29,740 --> 00:22:26,750
papers 1992 and 1995 that we are

423
00:22:32,650 --> 00:22:29,750
presenting they the first example

424
00:22:36,820 --> 00:22:32,660
discovers okay and now to understand the

425
00:22:39,250 --> 00:22:36,830
key point of these two papers I want to

426
00:22:41,700 --> 00:22:39,260
do an experiment with you and they need

427
00:22:45,120 --> 00:22:41,710
one or two volunteers

428
00:22:53,590 --> 00:22:45,130
who feel like dr. Watson they want to

429
00:23:10,990 --> 00:22:53,600
play with Rochelle bombs come in even

430
00:23:13,720 --> 00:23:11,000
two people spam there is one test you

431
00:23:26,890 --> 00:23:13,730
have to pass to participate to this test

432
00:23:49,580 --> 00:23:26,900
to this experiment what is this okay you

433
00:23:57,539 --> 00:23:54,870
so this favorite I want to do is to we

434
00:24:01,890 --> 00:23:57,549
have our star this is as you see it's a

435
00:24:12,330 --> 00:24:01,900
star and now we take the material of

436
00:24:14,279 --> 00:24:12,340
which the star is made which is so we

437
00:24:16,019 --> 00:24:14,289
are using the same material to make the

438
00:24:18,810 --> 00:24:16,029

disc because this time is made from the

439
00:24:21,360 --> 00:24:18,820
disk okay so I'm allowed to do that okay

440
00:24:24,060 --> 00:24:21,370
so we use the material of which the star

441
00:24:26,580 --> 00:24:24,070
is made let's do it you you make two

442
00:24:29,820 --> 00:24:26,590
rings one very close one very close so

443
00:24:33,450 --> 00:24:29,830
put it here and the other one as far as

444
00:24:42,659 --> 00:24:33,460
you can to within the limits of this

445
00:24:44,250 --> 00:24:42,669
table that's for this time okay so in

446
00:24:47,100 --> 00:24:44,260
the and so you do this small one you do

447
00:24:51,779 --> 00:24:47,110
the large one doesn't matter if it's not

448
00:24:55,860 --> 00:24:51,789
super okay and please pay attention

449
00:25:01,060 --> 00:24:58,900
so in the meantime I have something also

450
00:25:42,900 --> 00:25:01,070
for the rest of the audience you can you

451
00:25:53,140 --> 00:25:48,610
alright now next step I want you to form

452
00:25:54,490 --> 00:25:53,150
two clans at the two distances from the

453
00:25:56,830 --> 00:25:54,500
start that we have here where we have

454
00:25:58,000 --> 00:25:56,840
material ok using only the material that

455
00:26:23,020 --> 00:25:58,010
we have at that radius

456
00:26:26,020 --> 00:26:23,030
ok so let's do that let's assume the

457
00:26:34,900 --> 00:26:26,030
baby let's assume that plan for measure

458
00:26:37,480 --> 00:26:34,910
works better than this ok now in this

459
00:26:39,760 --> 00:26:37,490
kind of scenario where would you form

460
00:26:44,710 --> 00:26:39,770
the most massive planet and where would

461
00:26:50,169 --> 00:26:44,720
you form the least massive planet for

462
00:27:07,740 --> 00:26:50,179
the ratio for the radius Y you can also

463
00:27:12,250 --> 00:27:10,870

wait wait wait don't go too far let's go

464
00:27:16,450 --> 00:27:12,260
let's go step by step

465
00:27:18,310 --> 00:27:16,460
okay so in if this were a scaled version

466
00:27:18,940 --> 00:27:18,320
of our solar system where would you from

467
00:27:26,490 --> 00:27:18,950
Jupiter

468
00:27:32,710 --> 00:27:26,500
well would you form mercury or wonderful

469
00:27:35,400 --> 00:27:32,720
now push back now let's look at the

470
00:27:38,340 --> 00:27:35,410
90-95 what they differ

471
00:27:43,270 --> 00:27:38,350
they found the jupiter-mass companion

472
00:27:47,530 --> 00:27:43,280
well inside the orbit of mercury this

473
00:27:49,750 --> 00:27:47,540
was very unexpected I can tell you that

474
00:27:53,410 --> 00:27:49,760
I had the pleasure you stay here

475
00:27:57,130 --> 00:27:53,420
the pleasure of two personal meetings

476
00:27:58,840 --> 00:27:57,140
with this guy here it's from Switzerland

477
00:28:02,230 --> 00:27:58,850
I did my business bits alone for a

478
00:28:05,500 --> 00:28:02,240
reason well imagine there and then a

479
00:28:10,690 --> 00:28:05,510
very heard from him the story and he the

480
00:28:13,270 --> 00:28:10,700
solar to be scorned and he has a

481
00:28:15,880 --> 00:28:13,280
wonderful story to tell about finding

482
00:28:18,580 --> 00:28:15,890
something unexpected something that for

483
00:28:22,450 --> 00:28:18,590
the theories at that time was completely

484
00:28:24,790 --> 00:28:22,460
impossible was impossible such that when

485
00:28:29,440 --> 00:28:24,800
they started to have the idea of what

486
00:28:33,520 --> 00:28:29,450
they were finding was at the time he was

487
00:28:35,650 --> 00:28:33,530
very young he was worried because he

488
00:28:38,020 --> 00:28:35,660

said this is not possible if it cannot

489
00:28:39,730 --> 00:28:38,030
be a Jupiter around the Stars so close

490
00:28:41,550 --> 00:28:39,740
to the star it's impossible nobody

491
00:28:45,760 --> 00:28:41,560
nobody would believe that because

492
00:28:47,470 --> 00:28:45,770
theories cannot explain that okay but I

493
00:28:50,920 --> 00:28:47,480
need turned out to be true and now we

494
00:28:51,860 --> 00:28:50,930
have many ok let's go back to our

495
00:29:02,000 --> 00:28:51,870
experiment

496
00:29:05,120 --> 00:29:02,010
now so now let's say that at some point

497
00:29:48,120 --> 00:29:05,130
the star explodes in a supernova what do

498
00:29:48,130 --> 00:30:24,290
this is what

499
00:30:31,020 --> 00:30:28,290
so let's move 1992 paper what did they

500
00:30:34,830 --> 00:30:31,030
find they found not not not one but two

501
00:30:37,590 --> 00:30:34,840
planets where around a pulsar a pulsar

502
00:30:40,200 --> 00:30:37,600
is the neutron star the neutron remnant

503
00:30:46,650 --> 00:30:40,210
star after supernova supernova explosion

504
00:30:49,320 --> 00:30:46,660
and even back then so you cannot say

505
00:30:50,970 --> 00:30:49,330
well optimistically I was they are far

506
00:30:53,220 --> 00:30:50,980
enough out that they don't feel the

507
00:30:55,080 --> 00:30:53,230
supernova supernova explosion they were

508
00:30:58,830 --> 00:30:55,090
very close inside the orbit of Earth

509
00:31:02,490 --> 00:30:58,840
they would be destroyed for sure so what

510
00:31:05,310 --> 00:31:02,500
was what is the point that I that I for

511
00:31:09,480 --> 00:31:05,320
which we we we made the this experiment

512
00:31:11,880 --> 00:31:09,490
I made to make here one thing that since

513
00:31:13,980 --> 00:31:11,890

the very beginning the field of

514
00:31:19,140 --> 00:31:13,990
exoplanet research has been the reign of

515
00:31:22,080 --> 00:31:19,150
the unexpected okay and it is so even

516
00:31:26,640 --> 00:31:22,090
now let's look for example at this plot

517
00:31:29,130 --> 00:31:26,650
that is more recent this is 2013 when we

518
00:31:31,560 --> 00:31:29,140
see a representation of the population

519
00:31:34,410 --> 00:31:31,570
of planets that the exoplanets that we

520
00:31:42,269 --> 00:31:34,420
have been detected so far this is going

521
00:31:49,289 --> 00:31:45,580
so even here you see that the known

522
00:31:52,570 --> 00:31:49,299
population of exoplanets we have a

523
00:31:54,820 --> 00:31:52,580
population here of planets that are more

524
00:31:57,489 --> 00:31:54,830
massive than Earth this is the mass and

525
00:32:00,700 --> 00:31:57,499
this is the peer proportion today they

526
00:32:02,739 --> 00:32:00,710
are the distance from the star okay so

527
00:32:05,889 --> 00:32:02,749
this planets here are more massive than

528
00:32:07,629 --> 00:32:05,899
Earth but close the ring and this kind

529
00:32:09,190 --> 00:32:07,639
of super day they are called super

530
00:32:11,320 --> 00:32:09,200
Earths because they are more massive and

531
00:32:13,269 --> 00:32:11,330
they seem to be really the rule in plan

532
00:32:17,349 --> 00:32:13,279
formation it seems that every EXO

533
00:32:19,029 --> 00:32:17,359
planetary system has one okay and we

534
00:32:21,519 --> 00:32:19,039
have a population also of Jupiter's

535
00:32:24,039 --> 00:32:21,529
which are called hot Jupiters well

536
00:32:27,129 --> 00:32:24,049
especially this one that are closer win

537
00:32:29,889 --> 00:32:27,139
again then our Jupiter okay here we have

538
00:32:33,099 --> 00:32:29,899

our Jupiter here we have been a very

539
00:32:34,899 --> 00:32:33,109
nice honor okay and this is just

540
00:32:38,109 --> 00:32:34,909
considering two properties of the

541
00:32:42,149 --> 00:32:38,119
planets the mass and the distance from

542
00:32:44,859 --> 00:32:42,159
the star okay many scientists say that

543
00:32:48,009 --> 00:32:44,869
when we will be able to study more

544
00:32:51,219 --> 00:32:48,019
details the composition of the planets

545
00:32:54,009 --> 00:32:51,229
of the atmospheres and the bulk

546
00:32:57,899 --> 00:32:54,019
composition of the of the core we will

547
00:33:00,849 --> 00:32:57,909
be very likely surprised by unexpected

548
00:33:02,859 --> 00:33:00,859
discoveries at this point we expect to

549
00:33:06,249 --> 00:33:02,869
be surprised by the unexpected in this

550
00:33:08,820 --> 00:33:06,259
field okay so let me answer now the

551
00:33:10,930 --> 00:33:08,830
question why should we care about

552
00:33:13,719 --> 00:33:10,940
protoplanetary discs why should we study

553
00:33:15,999 --> 00:33:13,729
them because we are surprised by the

554
00:33:19,239 --> 00:33:16,009
unexpected discoveries in the exoplanet

555
00:33:22,210 --> 00:33:19,249
field and so we would like to understand

556
00:33:24,580 --> 00:33:22,220
how we can form such a variety of

557
00:33:26,889 --> 00:33:24,590
different exoplanets as well as

558
00:33:32,339 --> 00:33:26,899
understand how our own planets and our

559
00:33:37,930 --> 00:33:36,159
let's now go step by step what do we

560
00:33:44,560 --> 00:33:37,940
know about the planet formation process

561
00:33:51,140 --> 00:33:48,590
from the composition okay let's look at

562
00:33:55,820 --> 00:33:51,150
our the most familiar case of our solar

563
00:33:59,360 --> 00:33:55,830

system we have the star the Sun mostly

564
00:34:01,970 --> 00:33:59,370
made by hydrogen and helium and the the

565
00:34:03,530 --> 00:34:01,980
gas giants in our solar system as well

566
00:34:06,980 --> 00:34:03,540
they are mostly made by hydrogen and

567
00:34:10,330 --> 00:34:06,990
helium ok so our little experiment that

568
00:34:15,950 --> 00:34:10,340
we did here see it's a simplified

569
00:34:18,169 --> 00:34:15,960
version for me might have probably

570
00:34:22,790 --> 00:34:18,179
worked ok we are using the same material

571
00:34:23,780 --> 00:34:22,800
to form big planets in the disk ok but

572
00:34:26,900 --> 00:34:23,790
we have a problem

573
00:34:30,470 --> 00:34:26,910
for these planets here their composition

574
00:34:34,190 --> 00:34:30,480
is instead is very dissimilar from this

575
00:34:37,820 --> 00:34:34,200
stuff so if the disk has the same

576
00:34:39,919 --> 00:34:37,830
composition this planets are peculiar

577
00:34:41,930 --> 00:34:39,929
because they are mainly first they are

578
00:34:46,030 --> 00:34:41,940
mainly solid and they they they have a

579
00:34:49,159 --> 00:34:46,040
composition that is mostly made by

580
00:34:54,169 --> 00:34:49,169
compounds of iron oxygen silicon and

581
00:34:56,180 --> 00:34:54,179
magnesium okay in in in in short it they

582
00:35:01,040 --> 00:34:56,190
are mainly solid this is the evident

583
00:35:04,250 --> 00:35:01,050
okay gas giants solid rocky if you think

584
00:35:09,320 --> 00:35:04,260
that this approach is trivial to start

585
00:35:10,820 --> 00:35:09,330
from the bulk composition ok please

586
00:35:13,550 --> 00:35:10,830
consider that this is what we are still

587
00:35:15,890 --> 00:35:13,560
doing now with exoplanets this is a very

588
00:35:17,900 --> 00:35:15,900

recent paper where we have the planet

589
00:35:20,540 --> 00:35:17,910
the planet radius here in the planet

590
00:35:26,060 --> 00:35:20,550
Mars on this axis ok this this one is a

591
00:35:28,670 --> 00:35:26,070
zooming in this the plot when we are

592
00:35:32,390 --> 00:35:28,680
able to measure the mass and the radius

593
00:35:35,650 --> 00:35:32,400
of an exoplanet we can measure a mean

594
00:35:39,230 --> 00:35:35,660
density mass divided by the volume and

595
00:35:41,630 --> 00:35:39,240
from the mean density we can estimate

596
00:35:44,720 --> 00:35:41,640
the bulk composition as if the planet

597
00:35:47,480 --> 00:35:44,730
was made by a single thing okay so for

598
00:35:49,640 --> 00:35:47,490
example we can see a planet made of

599
00:35:50,820 --> 00:35:49,650
water the time of water would lie on

600
00:35:54,090 --> 00:35:50,830
this curve depend

601
00:35:56,400 --> 00:35:54,100
on the mass and they reduce okay Oliver

602
00:35:59,820 --> 00:35:56,410
Oliver I know I run eccentric setter

603
00:36:02,310 --> 00:35:59,830
here we have for example the in this

604
00:36:05,790 --> 00:36:02,320
paper they were presenting a discovery

605
00:36:09,000 --> 00:36:05,800
of one of the most earth-like planets in

606
00:36:11,280 --> 00:36:09,010
terms of bulk composition okay you see

607
00:36:14,490 --> 00:36:11,290
that the planets that they found is here

608
00:36:16,800 --> 00:36:14,500
Earth and Venus okay and so it's it's

609
00:36:23,490 --> 00:36:16,810
the closest compared to other kepler

610
00:36:25,530 --> 00:36:23,500
planet okay so historically and

611
00:36:30,390 --> 00:36:25,540
classically the problem of planet

612
00:36:34,200 --> 00:36:30,400
formation is a problem of solids so the

613
00:36:36,650 --> 00:36:34,210

property to build bodies of at least the

614
00:36:39,000 --> 00:36:36,660
kilometers inside a kilometer in size

615
00:36:40,620 --> 00:36:39,010
starting from the dust grains that at

616
00:36:42,510 --> 00:36:40,630
the beginning of the story we said in

617
00:36:44,160 --> 00:36:42,520
the planet formation regions in this

618
00:36:47,700 --> 00:36:44,170
nebula planet formation which is a well

619
00:36:51,180 --> 00:36:47,710
that we observe the the size of this

620
00:36:53,730 --> 00:36:51,190
dust grains that we observe there is one

621
00:36:57,540 --> 00:36:53,740
micron or less 10 to the minus 6 meters

622
00:37:05,070 --> 00:36:57,550
okay so this is a jump of at least nine

623
00:37:06,900 --> 00:37:05,080
orders of magnitude okay in size think

624
00:37:10,710 --> 00:37:06,910
for example of going to the to the beach

625
00:37:13,170 --> 00:37:10,720
and if you take sand of grain it's the

626
00:37:16,260 --> 00:37:13,180
it's even more than the jump from that

627
00:37:19,380 --> 00:37:16,270
send of grain and and earth even more

628
00:37:23,460 --> 00:37:19,390
than that because grains here are

629
00:37:28,440 --> 00:37:23,470
smaller than the same weights so we are

630
00:37:31,080 --> 00:37:28,450
just history yes because we know of

631
00:37:33,180 --> 00:37:31,090
thousands of exoplanets but we still

632
00:37:37,160 --> 00:37:33,190
haven't figured out the details of how

633
00:37:41,220 --> 00:37:37,170
this job happens of this process happens

634
00:37:44,130 --> 00:37:41,230
what we know however is that at least

635
00:37:46,850 --> 00:37:44,140
the first step happens in protoplanetary

636
00:37:49,860 --> 00:37:46,860
disk in circumstellar disks because

637
00:37:52,620 --> 00:37:49,870
scientists have been able to measure the

638
00:37:56,190 --> 00:37:52,630

size of dust grains in these discs and

639
00:37:59,100 --> 00:37:56,200
found one millimeter one centimeter okay

640
00:38:01,230 --> 00:37:59,110
so it's it's it's an increase of three

641
00:38:03,150 --> 00:38:01,240
four orders of magnitude and I've been

642
00:38:03,569 --> 00:38:03,160
working when I was in Germany these oh I

643
00:38:06,539 --> 00:38:03,579
was

644
00:38:08,749 --> 00:38:06,549
on this this field measuring the the

645
00:38:12,569 --> 00:38:08,759
signs of the quincy protoplanetary disk

646
00:38:15,959 --> 00:38:12,579
it's a first step and yet we still have

647
00:38:24,089 --> 00:38:15,969
to grow at least six orders of magnitude

648
00:38:27,150 --> 00:38:24,099
more good so i said this is still an

649
00:38:29,940 --> 00:38:27,160
unsolved mystery you know strong me but

650
00:38:32,069 --> 00:38:29,950
huh is it possible that I mean again we

651
00:38:35,940 --> 00:38:32,079
know of so many exoplanets and we still

652
00:38:39,059 --> 00:38:35,950
don't know of this which is like if you

653
00:38:42,359 --> 00:38:39,069
cannot grow this the solids you cannot

654
00:38:45,809 --> 00:38:42,369
be black we we still don't know because

655
00:38:48,920 --> 00:38:45,819
of due to problems mainly the first

656
00:38:52,620 --> 00:38:48,930
problem is a problem of observations

657
00:38:54,599 --> 00:38:52,630
while gas is mainly optically thin in

658
00:38:56,519 --> 00:38:54,609
these regions okay this is the artists

659
00:39:00,150 --> 00:38:56,529
impression of a protoplanetary disk okay

660
00:39:01,789 --> 00:39:00,160
so while gas is primarily optically thin

661
00:39:04,620 --> 00:39:01,799
so we can see through it

662
00:39:07,189 --> 00:39:04,630
duster is instead of instead of túcume

663
00:39:11,609 --> 00:39:07,199

thick so we cannot see inside the disk

664
00:39:13,319 --> 00:39:11,619
exactly where planets are formed okay to

665
00:39:15,900 --> 00:39:13,329
give you an analogy imagine that you are

666
00:39:18,269 --> 00:39:15,910
driving in the fog and you are trying to

667
00:39:21,539 --> 00:39:18,279
guess if what you have in front of you

668
00:39:24,120 --> 00:39:21,549
is a car a motorcycle or a deer okay

669
00:39:27,239 --> 00:39:24,130
for the same reason in protoplanetary

670
00:39:30,420 --> 00:39:27,249
disk we even though the small dust

671
00:39:32,870 --> 00:39:30,430
grains are small implants that are

672
00:39:35,640 --> 00:39:32,880
forming there are possibly already big

673
00:39:38,910 --> 00:39:35,650
they the opacity is dominated by the

674
00:39:41,069 --> 00:39:38,920
small grains and so we see only do only

675
00:39:44,279 --> 00:39:41,079
them and we cannot see the big bodies

676
00:39:47,099 --> 00:39:44,289
okay and all consider in addition to

677
00:39:50,219 --> 00:39:47,109
that that given the distance of these

678
00:39:52,199 --> 00:39:50,229
disks from Arthur they look to our eyes

679
00:39:53,489 --> 00:39:52,209
very small in the sky like in these

680
00:39:58,219 --> 00:39:53,499
images from the Hubble Space Telescope

681
00:40:02,189 --> 00:39:58,229
ok and what we are trying to find to see

682
00:40:04,109 --> 00:40:02,199
forming planets inside them at most a

683
00:40:08,430 --> 00:40:04,119
hundred thousand times smaller than

684
00:40:11,730 --> 00:40:08,440
these blobs ok so no way

685
00:40:14,150 --> 00:40:11,740
but I said that this moon disgraces that

686
00:40:16,800 --> 00:40:14,160
became measure know the size I said

687
00:40:19,050 --> 00:40:16,810
stromer's have been able to measure the

688
00:40:21,840 --> 00:40:19,060

signs of the Samantha's grains for the

689
00:40:23,790 --> 00:40:21,850
same reason why did the small that's why

690
00:40:27,570 --> 00:40:23,800
the small particles in the form they

691
00:40:30,090 --> 00:40:27,580
dominate in opacity okay and for example

692
00:40:33,780 --> 00:40:30,100
with the VLE in New Mexico or the Alma

693
00:40:35,550 --> 00:40:33,790
on unmanned chillin nowadays we are able

694
00:40:37,560 --> 00:40:35,560
to measure the thermal emission from

695
00:40:39,510 --> 00:40:37,570
this model screens and measure this and

696
00:40:44,520 --> 00:40:39,520
estimate their Sciences okay you find

697
00:40:48,510 --> 00:40:44,530
again the K visa has for some

698
00:40:51,810 --> 00:40:48,520
microgreens in the nebula second problem

699
00:40:54,780 --> 00:40:51,820
we have the chroming of timescales so

700
00:40:57,180 --> 00:40:54,790
one transformation happens very very

701
00:41:01,190 --> 00:40:57,190
quickly it's very fast compared to the

702
00:41:04,530 --> 00:41:01,200
to the lifetime of star it's very slow

703
00:41:07,070 --> 00:41:04,540
compared to our lifetime okay so we

704
00:41:09,710 --> 00:41:07,080
would have to leave 10000 times an

705
00:41:13,680 --> 00:41:09,720
entire human life to be able to follow

706
00:41:18,060 --> 00:41:13,690
planet formation a planet forming okay

707
00:41:21,840 --> 00:41:18,070
all the stages so we have to two ways

708
00:41:24,360 --> 00:41:21,850
out when when we can know when we cannot

709
00:41:27,330 --> 00:41:24,370
directly see what we are looking for

710
00:41:29,340 --> 00:41:27,340
either we we try to imagine it to in

711
00:41:33,810 --> 00:41:29,350
making models we try to imagine how that

712
00:41:35,670 --> 00:41:33,820
could happen or we try to look at the

713
00:41:39,180 --> 00:41:35,680

same object but in different phases of

714
00:41:40,820 --> 00:41:39,190
evolution okay and then we try to

715
00:41:43,200 --> 00:41:40,830
connect the points and build a story

716
00:41:44,250 --> 00:41:43,210
okay and these two approaches the

717
00:41:46,200 --> 00:41:44,260
theoretical approach and the

718
00:41:48,210 --> 00:41:46,210
observational approach are both are both

719
00:41:52,230 --> 00:41:48,220
fundamental and they sustain and help

720
00:41:53,010 --> 00:41:52,240
each other to build the the story of

721
00:41:56,090 --> 00:41:53,020
planet formation

722
00:41:59,760 --> 00:41:56,100
okay let's look for example at how

723
00:42:03,630 --> 00:41:59,770
theories theoretical models trying to

724
00:42:06,630 --> 00:42:03,640
explain how we can grow dustin disks

725
00:42:09,000 --> 00:42:06,640
from the dust from from the small sizes

726
00:42:12,180 --> 00:42:09,010
of 1 micron as i said 10 to the minus 6

727
00:42:13,440 --> 00:42:12,190
meters up to planet sizes of more than

728
00:42:16,290 --> 00:42:13,450
economic ok

729
00:42:17,920 --> 00:42:16,300
this is from a recent review where a

730
00:42:20,829 --> 00:42:17,930
number of models are put

731
00:42:26,079 --> 00:42:20,839
gather you know the twist plain how it

732
00:42:28,690 --> 00:42:26,089
may be possible to to to climb this

733
00:42:30,849 --> 00:42:28,700
ladder in Sciences and go for dust two

734
00:42:34,059 --> 00:42:30,859
planets okay in in the in the so called

735
00:42:37,390 --> 00:42:34,069
the core accretion scenario so I cannot

736
00:42:40,930 --> 00:42:37,400
go into the details here but this is to

737
00:42:43,990 --> 00:42:40,940
give you an idea that we have we have at

738
00:42:46,690 --> 00:42:44,000

least a few ideas how with following

739
00:42:49,030 --> 00:42:46,700
steps ok different different processes

740
00:42:52,359 --> 00:42:49,040
one after the other or probably

741
00:42:55,030 --> 00:42:52,369
happening the same time the different

742
00:42:56,740 --> 00:42:55,040
Vaidya in the disk again we can go from

743
00:43:00,370 --> 00:42:56,750
dust to to two planets okay

744
00:43:02,620 --> 00:43:00,380
the first step this one number one that

745
00:43:06,309 --> 00:43:02,630
that brings the dust from from here to

746
00:43:09,339 --> 00:43:06,319
millimeter in sizes is believed to be

747
00:43:11,410 --> 00:43:09,349
the one responsible for the emission

748
00:43:14,109 --> 00:43:11,420
that we see with interferometers as i

749
00:43:17,530 --> 00:43:14,119
said before okay so the millimeter sized

750
00:43:19,690 --> 00:43:17,540
grains that we measure in the be

751
00:43:21,760 --> 00:43:19,700
detecting in protoplanetary disk are

752
00:43:25,059 --> 00:43:21,770
probably formed by speaking of small

753
00:43:27,579 --> 00:43:25,069
part okay for the rest the the next

754
00:43:29,470 --> 00:43:27,589
steps are very much still unconstrained

755
00:43:32,319 --> 00:43:29,480
and a mostly theoretical and they are

756
00:43:34,180 --> 00:43:32,329
very difficult to go through a classical

757
00:43:38,289 --> 00:43:34,190
problem this scenario is for example

758
00:43:40,270 --> 00:43:38,299
they so-called meter-sized earlier in

759
00:43:44,260 --> 00:43:40,280
this models it is expected that the soon

760
00:43:46,930 --> 00:43:44,270
as dust grains stick together and they

761
00:43:50,500 --> 00:43:46,940
grow in sizes enough and they reach the

762
00:43:52,990 --> 00:43:50,510
meter one meter inside as an order of

763
00:43:55,660 --> 00:43:53,000

magnitude at one you the distance of

764
00:43:58,839 --> 00:43:55,670
Earth from the Sun they would start to

765
00:44:00,789 --> 00:43:58,849
feel a gas drag that would such that

766
00:44:04,359 --> 00:44:00,799
they would be sucked onto the star very

767
00:44:06,370 --> 00:44:04,369
quickly okay so we have a problem of

768
00:44:08,440 --> 00:44:06,380
time scales here because the the

769
00:44:11,020 --> 00:44:08,450
material of which planets are made need

770
00:44:14,500 --> 00:44:11,030
to stay in the disk long enough for the

771
00:44:16,089 --> 00:44:14,510
planets to to be to be made okay if you

772
00:44:18,970 --> 00:44:16,099
suck all the material to start to

773
00:44:21,740 --> 00:44:18,980
quickly nothing is left no then you

774
00:44:24,740 --> 00:44:21,750
cannot from the planet

775
00:44:29,930 --> 00:44:24,750
but with this with these other

776
00:44:32,510 --> 00:44:29,940
mechanisms here there is the hypothesis

777
00:44:35,180 --> 00:44:32,520
that there can't that there are over

778
00:44:38,330 --> 00:44:35,190
densities in over densities of on

779
00:44:45,010 --> 00:44:38,340
material in disks okay or the so called

780
00:44:53,420 --> 00:44:49,880
and once the the planet did these solids

781
00:44:56,690 --> 00:44:53,430
bodies grow enough okay at some point

782
00:44:58,520 --> 00:44:56,700
gravity kicks in strongly and so all the

783
00:45:01,520 --> 00:44:58,530
smaller bodies are fitted onto this

784
00:45:03,770 --> 00:45:01,530
planet a similar protoplanet and at some

785
00:45:05,630 --> 00:45:03,780
point also also and also the gas

786
00:45:08,990 --> 00:45:05,640
participate with this flow so that you

787
00:45:11,780 --> 00:45:09,000
can it is expected that you can build a

788
00:45:15,020 --> 00:45:11,790

rocky planet with also another gases

789
00:45:18,440 --> 00:45:15,030
atmosphere okay and now very recently

790
00:45:22,370 --> 00:45:18,450
this is of the last few years these dust

791
00:45:24,920 --> 00:45:22,380
traps start to be seen so they they may

792
00:45:27,500 --> 00:45:24,930
they may show us that they did indeed

793
00:45:28,970 --> 00:45:27,510
some kind of things some of these models

794
00:45:30,440 --> 00:45:28,980
that proposed these dust traps are

795
00:45:32,089 --> 00:45:30,450
really happening in viscous so to

796
00:45:35,510 --> 00:45:32,099
allowed to jump from one side to the

797
00:45:38,120 --> 00:45:35,520
other and then okay for example this

798
00:45:44,120 --> 00:45:38,130
observation is from Alma this is the

799
00:45:48,400 --> 00:45:44,130
location of they detected millimeter

800
00:45:50,510 --> 00:45:48,410
sized grains only in this vision okay

801
00:45:54,800 --> 00:45:50,520
showing that these grains are not

802
00:45:58,520 --> 00:45:54,810
distributed on on a disk as ingeniously

803
00:46:01,670 --> 00:45:58,530
okay as one would expect but they are

804
00:46:04,609 --> 00:46:01,680
sort of trapped by some mechanism in

805
00:46:06,680 --> 00:46:04,619
that region and these regions called the

806
00:46:08,780 --> 00:46:06,690
straps are believed to be regions of

807
00:46:12,020 --> 00:46:08,790
efficient planet formation because they

808
00:46:14,900 --> 00:46:12,030
you bring solids on on a smaller portion

809
00:46:20,450 --> 00:46:14,910
of the disk and and you you increase the

810
00:46:24,980 --> 00:46:20,460
probability of interactions and and the

811
00:46:28,040 --> 00:46:24,990
build-up of larger bodies okay now so

812
00:46:29,300 --> 00:46:28,050
while this first step is observed these

813
00:46:33,190 --> 00:46:29,310

intermediate steps

814
00:46:37,070 --> 00:46:33,200
maybe they start to be observed an

815
00:46:39,650 --> 00:46:37,080
Australian at the very end the final

816
00:46:43,240 --> 00:46:39,660
accretion of gas and material on the DS

817
00:46:49,190 --> 00:46:43,250
and on the plan on the protoplanet

818
00:46:52,070 --> 00:46:49,200
is only very very recently that we

819
00:46:54,560 --> 00:46:52,080
started to see also the last steps and

820
00:46:57,800 --> 00:46:54,570
this is a very exciting observations

821
00:47:01,460 --> 00:46:57,810
that it's from was published in 2013

822
00:47:03,830 --> 00:47:01,470
actually Sasha once he was a colleague

823
00:47:08,000 --> 00:47:03,840
of mine at the ETH in Zurich in

824
00:47:10,970 --> 00:47:08,010
Switzerland so what they were they

825
00:47:14,450 --> 00:47:10,980
showed here this is an op Hubble image

826
00:47:17,540 --> 00:47:14,460
of this protoplanetary disc they started

827
00:47:19,730 --> 00:47:17,550
to detect kind of point like not not

828
00:47:22,430 --> 00:47:19,740
exactly point like plane by small

829
00:47:25,310 --> 00:47:22,440
sources of emission inside the disc

830
00:47:28,780 --> 00:47:25,320
still embedded ok and they interpret

831
00:47:32,000 --> 00:47:28,790
these these observations as observing

832
00:47:35,510 --> 00:47:32,010
protoplanets where the disc material is

833
00:47:38,840 --> 00:47:35,520
still tweeting ok onto the protoplanet

834
00:47:42,140 --> 00:47:38,850
and these new observations are starting

835
00:47:47,030 --> 00:47:42,150
to connect the two ends of the story

836
00:47:49,880 --> 00:47:47,040
that until couple of years ago were the

837
00:47:53,150 --> 00:47:49,890
only things we have see coastal discs

838
00:47:55,370 --> 00:47:53,160

and exoplanet okay in between again the

839
00:47:57,650 --> 00:47:55,380
stories very still very unknown because

840
00:48:00,230 --> 00:47:57,660
we cannot see inside discs it seems that

841
00:48:02,390 --> 00:48:00,240
we start in some cases to be able to see

842
00:48:04,250 --> 00:48:02,400
also the emission of some protoplanets

843
00:48:06,140 --> 00:48:04,260
this is still a candidate okay it's not

844
00:48:08,630 --> 00:48:06,150
confirmed yet but I believe that

845
00:48:11,500 --> 00:48:08,640
observations like this will will

846
00:48:16,070 --> 00:48:11,510
increase in number in the near future

847
00:48:19,460 --> 00:48:16,080
ok let's say that now we are able to

848
00:48:21,530 --> 00:48:19,470
overcome the problems and the barriers

849
00:48:23,060 --> 00:48:21,540
that are in our theoretical

850
00:48:29,260 --> 00:48:23,070
understanding and we're able to form

851
00:48:41,680 --> 00:48:35,020
still we don't have yet

852
00:48:44,380 --> 00:48:41,690
planets okay the next step from rocky

853
00:48:46,930 --> 00:48:44,390
balls and define rocky balls to planets

854
00:48:51,310 --> 00:48:46,940
let's address the composition in a bit

855
00:48:55,140 --> 00:48:51,320
in more details okay and let's look

856
00:48:58,300 --> 00:48:55,150
again at our solar system in this scale

857
00:49:00,250 --> 00:48:58,310
representation one of the first things

858
00:49:03,670 --> 00:49:00,260
that struck me when I when I look at

859
00:49:10,090 --> 00:49:03,680
this representation is what you see

860
00:49:16,470 --> 00:49:10,100
immediately so gas giants rocky planets

861
00:49:20,770 --> 00:49:16,480
in rocky planets small gas giants big

862
00:49:22,600 --> 00:49:20,780
there are solid bodies all over the the

863
00:49:24,370 --> 00:49:22,610

solar system okay we heard them even

864
00:49:26,380 --> 00:49:24,380
into in the introduction okay all over

865
00:49:29,050 --> 00:49:26,390
even in the outer regions but as far as

866
00:49:34,570 --> 00:49:29,060
planets are concerned the rocky planets

867
00:49:40,960 --> 00:49:34,580
are the gas giants around so there seems

868
00:49:42,220 --> 00:49:40,970
to be something there between the rocky

869
00:49:46,510 --> 00:49:42,230
and the giant it seems to give

870
00:49:49,359 --> 00:49:46,520
discontinuity some critical change

871
00:49:52,120 --> 00:49:49,369
between the inside and the outside so

872
00:49:54,940 --> 00:49:52,130
the simple idea that this visualization

873
00:49:59,859 --> 00:49:54,950
seems to suggest was proposed in a paper

874
00:50:02,200 --> 00:49:59,869
in 1981 where and here I'm showing the

875
00:50:03,910 --> 00:50:02,210
key figure where we have the density of

876
00:50:08,080 --> 00:50:03,920
material in the disk and the distance

877
00:50:10,120 --> 00:50:08,090
from the Sun where any spill an

878
00:50:13,060 --> 00:50:10,130
experiment similar to what we did here

879
00:50:15,400 --> 00:50:13,070
but reversed was done which is to take

880
00:50:17,650 --> 00:50:15,410
the mass that is nowadays in the planet

881
00:50:21,960 --> 00:50:17,660
okay in our solar system planets and

882
00:50:24,400 --> 00:50:21,970
spread it all the rings of material

883
00:50:27,250 --> 00:50:24,410
assuming that every planet contributes

884
00:50:30,310 --> 00:50:27,260
only to enamels and at its distance on

885
00:50:32,340 --> 00:50:30,320
the star from the Sun okay so to build a

886
00:50:34,930 --> 00:50:32,350
representation of what our own

887
00:50:38,650 --> 00:50:34,940
protoplanetary disk would probably

888
00:50:41,150 --> 00:50:38,660

possibly have looked like and what they

889
00:50:44,329 --> 00:50:41,160
what he found

890
00:50:46,880 --> 00:50:44,339
is a discontinued

891
00:50:49,069 --> 00:50:46,890
okay this is the density of material and

892
00:50:51,349 --> 00:50:49,079
you see but if you connect the points

893
00:50:54,289 --> 00:50:51,359
here we have a discontinuity between the

894
00:50:58,279 --> 00:50:54,299
rocky planets and the giant planet and

895
00:51:00,829 --> 00:50:58,289
this discontinuity was in the in that

896
00:51:04,370 --> 00:51:00,839
paper attributed to a so called snow

897
00:51:06,559 --> 00:51:04,380
line as which is the line marking the

898
00:51:11,620 --> 00:51:06,569
separation between regions where water

899
00:51:14,150 --> 00:51:11,630
is in the is in the is in the ice phase

900
00:51:16,039 --> 00:51:14,160
outside of this line and in the gas

901
00:51:18,410 --> 00:51:16,049
phase inside because of the temperature

902
00:51:20,630 --> 00:51:18,420
okay when the temperature that decreases

903
00:51:24,049 --> 00:51:20,640
with the distance from the star drops

904
00:51:26,029 --> 00:51:24,059
enough so to water to freeze out then

905
00:51:27,529 --> 00:51:26,039
you have on the ice on one side and an

906
00:51:30,710 --> 00:51:27,539
angle on the other one okay

907
00:51:35,529 --> 00:51:30,720
such that inside inside the snow line

908
00:51:37,819 --> 00:51:35,539
only compounds and molecules more

909
00:51:40,910 --> 00:51:37,829
resistant to heat them water could

910
00:51:44,359 --> 00:51:40,920
survive okay like silicates for example

911
00:51:45,829 --> 00:51:44,369
and and so only rocky bodies were formed

912
00:51:48,950 --> 00:51:45,839
with the material the solid material

913
00:51:53,599 --> 00:51:48,960

inside outside is tell is that rock and

914
00:51:57,260 --> 00:51:53,609
ice would have allowed for larger faster

915
00:52:01,120 --> 00:51:57,270
buildup of planetary cores and then a

916
00:52:03,890 --> 00:52:01,130
faster accretion of gas to be the big

917
00:52:10,010 --> 00:52:03,900
gas atmospheres of the gas giants

918
00:52:13,940 --> 00:52:10,020
okay now this simplified story that I

919
00:52:17,240 --> 00:52:13,950
just told still still very much assumed

920
00:52:19,480 --> 00:52:17,250
nowadays okay and it has important

921
00:52:23,480 --> 00:52:19,490
implications on what we can learn about

922
00:52:26,870 --> 00:52:23,490
exoplanet composition by looking at from

923
00:52:29,329 --> 00:52:26,880
looking at protoplanetary discs so let's

924
00:52:30,980 --> 00:52:29,339
look at the section of a protein from

925
00:52:37,849 --> 00:52:30,990
the vendor disc okay let's take it and

926
00:52:39,859 --> 00:52:37,859
let's take a section star and here and

927
00:52:42,650 --> 00:52:39,869
let's summarize in a cartoon the

928
00:52:45,470 --> 00:52:42,660
ingredients the factors that the process

929
00:52:47,690 --> 00:52:45,480
that we have taught so far okay so we

930
00:52:50,660 --> 00:52:47,700
have the dust grains small dust grains

931
00:52:52,819 --> 00:52:50,670
that grow in sizes okay at some point

932
00:52:53,690 --> 00:52:52,829
that they grow enough to fill a gas

933
00:52:55,910 --> 00:52:53,700
track and they

934
00:52:58,640 --> 00:52:55,920
feel they feel aghast ragged they

935
00:53:01,760 --> 00:52:58,650
migrate inward toward was the toward the

936
00:53:04,190 --> 00:53:01,770
star at some point for because of some

937
00:53:05,780 --> 00:53:04,200
processes they are kept they are stopped

938
00:53:10,400 --> 00:53:05,790

in their migration some of them are

939
00:53:13,010 --> 00:53:10,410
stopped and and they in this for example

940
00:53:15,140 --> 00:53:13,020
in these dust traps okay so that they

941
00:53:18,020 --> 00:53:15,150
can stay there long enough to build

942
00:53:19,760 --> 00:53:18,030
beginning mass and reached the

943
00:53:22,310 --> 00:53:19,770
planetesimals side the kilometer size

944
00:53:24,800 --> 00:53:22,320
and then start Procrit also also gaseous

945
00:53:26,450 --> 00:53:24,810
atmospheres okay those ways that make it

946
00:53:29,120 --> 00:53:26,460
to be inside the what is known I mean

947
00:53:30,890 --> 00:53:29,130
here has this strange because of the

948
00:53:32,960 --> 00:53:30,900
thermal temperature and density

949
00:53:35,090 --> 00:53:32,970
structure of the disk which is more

950
00:53:37,760 --> 00:53:35,100
complicated than a simple mind okay

951
00:53:48,950 --> 00:53:37,770
inside we have we have a separation so

952
00:53:52,550 --> 00:53:48,960
on will agree on for example of so while

953
00:53:54,530 --> 00:53:52,560
the processes that happen in the planet

954
00:53:56,870 --> 00:53:54,540
formation region inside the disk are

955
00:54:02,150 --> 00:53:56,880
hidden to our eyes we cannot see them

956
00:54:04,730 --> 00:54:02,160
okay we can observe the molecular gas in

957
00:54:08,330 --> 00:54:04,740
the inner disk through the infrared

958
00:54:14,000 --> 00:54:08,340
radiation of the gas okay and it is very

959
00:54:18,080 --> 00:54:14,010
recent in the last years that warm water

960
00:54:20,090 --> 00:54:18,090
and emission from molecules with carbon

961
00:54:22,490 --> 00:54:20,100
inside has been discovered in

962
00:54:24,770 --> 00:54:22,500
protoplanetary disk and another this is

963
00:54:26,600 --> 00:54:24,780

another achieved an achievement of

964
00:54:29,060 --> 00:54:26,610
another NASA Telescope the Spitzer Space

965
00:54:30,410 --> 00:54:29,070
Telescope okay and here you see here we

966
00:54:34,190 --> 00:54:30,420
use the trois copy inference

967
00:54:36,170 --> 00:54:34,200
spectroscopy to identify the molecules

968
00:54:39,170 --> 00:54:36,180
in the gas that produced the emission

969
00:54:41,240 --> 00:54:39,180
okay we have here the observations and

970
00:54:43,310 --> 00:54:41,250
here a model where you basically see

971
00:54:45,380 --> 00:54:43,320
that all the Wiggles you see well the

972
00:54:49,490 --> 00:54:45,390
majority of the Wiggles are due to water

973
00:54:53,630 --> 00:54:49,500
vapour and this colored ones are due to

974
00:54:56,870 --> 00:54:53,640
molecules that contain carbon okay so

975
00:54:59,510 --> 00:54:56,880
this tells us that now we are able to

976
00:55:00,980 --> 00:54:59,520
trace some molecules and not some

977
00:55:04,600 --> 00:55:00,990
irrelevant ones we are talking about

978
00:55:08,230 --> 00:55:04,610
water and carbon carbon B molecules okay

979
00:55:10,420 --> 00:55:08,240
back when they were in the disk okay and

980
00:55:13,690 --> 00:55:10,430
we can try to come to make a spirit to

981
00:55:17,190 --> 00:55:13,700
connect them to the composition of the

982
00:55:19,780 --> 00:55:17,200
exoplanets okay let's see what we can do

983
00:55:21,970 --> 00:55:19,790
one one example what what we can do with

984
00:55:24,910 --> 00:55:21,980
these kind of observations for example

985
00:55:28,360 --> 00:55:24,920
let's take the composition of one of our

986
00:55:34,210 --> 00:55:28,370
earth and the Sun okay and let's compare

987
00:55:39,190 --> 00:55:34,220
them so the the black line here is where

988
00:55:41,050 --> 00:55:39,200

all elements that we consider would lie

989
00:55:42,670 --> 00:55:41,060
they would lie on this land is the

990
00:55:45,220 --> 00:55:42,680
composition of Earth and the Sun is

991
00:55:50,350 --> 00:55:45,230
exactly the same okay and we see that

992
00:55:54,550 --> 00:55:50,360
this is this is true for many elements

993
00:55:55,980 --> 00:55:54,560
lie at least close to this line okay but

994
00:55:59,200 --> 00:55:55,990
some do not

995
00:56:02,560 --> 00:55:59,210
for example let me draw your attention

996
00:56:05,200 --> 00:56:02,570
to carbon that is under a bundle toward

997
00:56:07,330 --> 00:56:05,210
okay if it is lower than the line it

998
00:56:11,530 --> 00:56:07,340
means that this under abundant north by

999
00:56:14,800 --> 00:56:11,540
it by at most by almost a factor 10,000

1000
00:56:16,960 --> 00:56:14,810
okay if you think how much carbon is is

1001
00:56:19,600 --> 00:56:16,970
essential for for life on Earth you may

1002
00:56:22,860 --> 00:56:19,610
be you may be surprised by by by seeing

1003
00:56:31,090 --> 00:56:22,870
how little carbon there is on earth okay

1004
00:56:33,850 --> 00:56:31,100
now this may find an explanation in the

1005
00:56:37,750 --> 00:56:33,860
observations of protoplanetary discs and

1006
00:56:40,810 --> 00:56:37,760
in particular in the in the imprint that

1007
00:56:43,150 --> 00:56:40,820
is given by no lines in protoplanetary

1008
00:56:46,630 --> 00:56:43,160
discs to the composition of exoplanets

1009
00:56:50,350 --> 00:56:46,640
let's look at this plot from people in

1010
00:56:54,040 --> 00:56:50,360
2011 so far I've talked only about only

1011
00:56:56,200 --> 00:56:54,050
of one snow line the water snow line but

1012
00:56:58,630 --> 00:56:56,210
actually in in protoplanetary discs

1013
00:57:01,540 --> 00:56:58,640

every molecule has its own stone on

1014
00:57:04,600 --> 00:57:01,550
which is the location in the disk okay

1015
00:57:05,180 --> 00:57:04,610
the star is here we go further round the

1016
00:57:07,599 --> 00:57:05,190
temperature

1017
00:57:14,510 --> 00:57:07,609
Croesus in this direction the star okay

1018
00:57:17,210 --> 00:57:14,520
so all every molecule has its own snow

1019
00:57:20,480 --> 00:57:17,220
line where on one side further from the

1020
00:57:23,680 --> 00:57:20,490
star it's a nice only nice for him in

1021
00:57:27,349 --> 00:57:23,690
the ice form and closely easing the gas

1022
00:57:28,790 --> 00:57:27,359
okay so you have it for example waters

1023
00:57:32,480 --> 00:57:28,800
you to a co okay

1024
00:57:34,910 --> 00:57:32,490
co freezes at much lower temperatures

1025
00:57:38,079 --> 00:57:34,920
than water so there's no line of CO is

1026
00:57:43,280 --> 00:57:38,089
much further out okay in the disk and

1027
00:57:46,220 --> 00:57:43,290
co2 in between water as you so in this

1028
00:57:47,900 --> 00:57:46,230
plot here that is really a very

1029
00:57:51,410 --> 00:57:47,910
interesting result from the last years

1030
00:57:55,099 --> 00:57:51,420
and even this one will grow in interest

1031
00:58:00,069 --> 00:57:55,109
and in related papers in the next years

1032
00:58:04,370 --> 00:58:00,079
for sure we see that the composition the

1033
00:58:08,329 --> 00:58:04,380
composition of the gas this line and the

1034
00:58:11,210 --> 00:58:08,339
solids the solid grains in the disk this

1035
00:58:14,960 --> 00:58:11,220
this one line the composition in terms

1036
00:58:17,930 --> 00:58:14,970
of karbala balances as compared to

1037
00:58:20,599 --> 00:58:17,940
oxygen amount the number of carbon atoms

1038
00:58:23,180 --> 00:58:20,609

compared to oxygen atoms okay the

1039
00:58:28,099 --> 00:58:23,190
composition changes every time that

1040
00:58:30,170 --> 00:58:28,109
there is no line okay because a in any

1041
00:58:32,210 --> 00:58:30,180
given location of the disk we have

1042
00:58:34,339 --> 00:58:32,220
different contributions to the gas to

1043
00:58:35,930 --> 00:58:34,349
the solids depending on which molecules

1044
00:58:37,990 --> 00:58:35,940
are in the gas phase only the solid

1045
00:58:41,650 --> 00:58:38,000
phase okay

1046
00:58:45,170 --> 00:58:41,660
such that we can imagine that if

1047
00:58:47,839 --> 00:58:45,180
depending on where in exoplanet

1048
00:58:50,510 --> 00:58:47,849
forms in the linker it will have a

1049
00:58:52,250 --> 00:58:50,520
different composition okay depending on

1050
00:58:55,550 --> 00:58:52,260
the location where it forms in the disk

1051
00:58:57,680 --> 00:58:55,560
and not only the planet but also plan

1052
00:59:01,190 --> 00:58:57,690
the planet atmosphere as compared to the

1053
00:59:09,650 --> 00:59:01,200
planet surface in particular we will

1054
00:59:12,859 --> 00:59:09,660
have carbon rich atmospheres for for for

1055
00:59:15,829 --> 00:59:12,869
a large extent in radii while we will

1056
00:59:17,270 --> 00:59:15,839
have carbon poor surfaces for foreign

1057
00:59:22,260 --> 00:59:17,280
foreign

1058
00:59:25,200 --> 00:59:22,270
okay and this could explain a recent

1059
00:59:27,510 --> 00:59:25,210
exotic example the pizza panel was well

1060
00:59:30,299 --> 00:59:27,520
being who was proposed to have looking

1061
00:59:34,710 --> 00:59:30,309
at its atmosphere it's not Jupiter this

1062
00:59:36,450 --> 00:59:34,720
one looking at it at my atmosphere it

1063
00:59:39,000 --> 00:59:36,460

was proposed that the seat wall ratio

1064
00:59:42,210 --> 00:59:39,010
the composition in terms of siendo was

1065
00:59:44,819 --> 00:59:42,220
close to one must be close to one okay

1066
00:59:47,010 --> 00:59:44,829
this was what was proposed and this is

1067
00:59:48,450 --> 00:59:47,020
very exotic very strange compared to

1068
00:59:50,789 --> 00:59:48,460
what we find in the in the solar system

1069
00:59:54,210 --> 00:59:50,799
this is the seat wall the composition of

1070
00:59:56,670 --> 00:59:54,220
the Sun okay in terms of siendo and and

1071
00:59:59,309 --> 00:59:56,680
the the an exoplanet like this could be

1072
01:00:02,039 --> 00:59:59,319
explained if it formed in a location in

1073
01:00:05,609 --> 01:00:02,049
a comparable location in its own

1074
01:00:12,029 --> 01:00:05,619
protoplanetary disk okay this could also

1075
01:00:14,400 --> 01:00:12,039
explain maybe why is carbon poor okay if

1076
01:00:17,329 --> 01:00:14,410
it formed in a location of the proto

1077
01:00:20,039 --> 01:00:17,339
plant our protoplanetary disk where

1078
01:00:23,750 --> 01:00:20,049
carbon was primarily in the gas phase

1079
01:00:27,089 --> 01:00:23,760
not in the solid phase for example in co

1080
01:00:33,630 --> 01:00:27,099
so this is where we are going now in

1081
01:00:35,430 --> 01:00:33,640
this field we are working on finding a

1082
01:00:38,220 --> 01:00:35,440
link between the composition of

1083
01:00:40,500 --> 01:00:38,230
protoplanetary disks and the composition

1084
01:00:42,510 --> 01:00:40,510
of planets exoplanets and plants that

1085
01:00:45,569 --> 01:00:42,520
phone is a protoplanetary disc in an

1086
01:00:46,950 --> 01:00:45,579
attempt to build a story to build to

1087
01:00:50,490 --> 01:00:46,960
build a scenario where ever we

1088
01:00:52,680 --> 01:00:50,500

understand why and how certain kinds of

1089
01:00:55,349 --> 01:00:52,690
planets can form in certain discs and

1090
01:01:00,380 --> 01:00:55,359
why not others for example it's very

1091
01:01:05,490 --> 01:01:00,390
early in this okay

1092
01:01:12,080 --> 01:01:05,500
and now we are at the end so we made it

1093
01:01:19,970 --> 01:01:14,660
a rocket ball let's say even with

1094
01:01:21,770 --> 01:01:19,980
another sphere okay second step we

1095
01:01:23,630 --> 01:01:21,780
addressed also the composition so we

1096
01:01:25,670 --> 01:01:23,640
don't have only a rocket ball but we

1097
01:01:29,150 --> 01:01:25,680
have something that we can call a planet

1098
01:01:31,790 --> 01:01:29,160
okay and we saw how the composition of

1099
01:01:33,380 --> 01:01:31,800
the natural disk may imprint the

1100
01:01:37,700 --> 01:01:33,390
composition of the exoplanet of the

1101
01:01:41,450 --> 01:01:37,710
planet but the talk tonight the title

1102
01:01:46,730 --> 01:01:41,460
says new worlds not simply planets okay

1103
01:01:49,730 --> 01:01:46,740
and the end world suggests something

1104
01:01:53,690 --> 01:01:49,740
more than simply a rocky ball with some

1105
01:01:57,880 --> 01:01:53,700
composition floating into space world

1106
01:02:01,490 --> 01:01:57,890
suggests complexity diversity and life

1107
01:02:04,550 --> 01:02:01,500
so at the end of this talk I have to at

1108
01:02:06,230 --> 01:02:04,560
least mention an interesting symposium

1109
01:02:09,070 --> 01:02:06,240
that we had just a couple of months ago

1110
01:02:12,380 --> 01:02:09,080
here a space telescope in this room

1111
01:02:15,530 --> 01:02:12,390
called habitable worlds across time and

1112
01:02:18,020 --> 01:02:15,540
space we talked for days and we

1113
01:02:20,930 --> 01:02:18,030

discussed for days about the details and

1114
01:02:24,680 --> 01:02:20,940
many facets of the of this exciting

1115
01:02:28,820 --> 01:02:24,690
topic and that day I was I was surprised

1116
01:02:32,060 --> 01:02:28,830
that the final discussion we found

1117
01:02:34,670 --> 01:02:32,070
ourselves still addressing some

1118
01:02:38,060 --> 01:02:34,680
fundamental questions what is

1119
01:02:40,130 --> 01:02:38,070
habitability how can we define it for it

1120
01:02:44,000 --> 01:02:40,140
so planets and how can we search for

1121
01:02:48,380 --> 01:02:44,010
life beyond Earth and the all these

1122
01:02:50,600 --> 01:02:48,390
questions are still very often so if the

1123
01:02:54,290 --> 01:02:50,610
mystery addressed tonight was not enough

1124
01:02:57,170 --> 01:02:54,300
intriguing so far the problem of

1125
01:03:00,770 --> 01:02:57,180
habitability makes it the challenge that

1126
01:03:02,390 --> 01:03:00,780
we that is and will drive research for

1127
01:03:05,360 --> 01:03:02,400
for many years to come and also the

1128
01:03:08,260 --> 01:03:05,370
interest of the public for sure and no

1129
01:03:12,230 --> 01:03:08,270
doubt that we will be surprised

1130
01:03:15,260 --> 01:03:12,240
respectively scholars but desperately in

1131
01:03:17,390 --> 01:03:15,270
the article challenges and the

1132
01:03:20,600 --> 01:03:17,400
unexpected are the two pillars of

1133
01:03:23,750 --> 01:03:20,610
cutting-edge research and triggers for

1134
01:03:23,760 --> 01:03:47,480
thank you

1135
01:03:57,290 --> 01:03:49,820
anyway we've got time for some questions

1136
01:04:04,970 --> 01:03:57,300
please raise your hands if you want to

1137
01:04:10,370 --> 01:04:04,980
repeat experiment please okay let me try

1138
01:04:11,120 --> 01:04:10,380

one of the gas giant Saturn how does it

1139
01:04:13,190 --> 01:04:11,130
get stirred

1140
01:04:15,710 --> 01:04:13,200
what's down inside this drawls the gas

1141
01:04:20,390 --> 01:04:15,720
it they probably have trouble keeping

1142
01:04:23,060 --> 01:04:20,400
gas on Mars because it's too light so

1143
01:04:26,090 --> 01:04:23,070
you're asking what's inside and settle

1144
01:04:33,580 --> 01:04:26,100
just a loser get started and what's

1145
01:04:36,620 --> 01:04:33,590
there so the idea is that you made or

1146
01:04:42,170 --> 01:04:36,630
rocky terrestrial planets in the inner

1147
01:04:45,020 --> 01:04:42,180
disk closer to the star and apply rocky

1148
01:04:47,660 --> 01:04:45,030
cores for the four giant planets if they

1149
01:04:50,450 --> 01:04:47,670
have rocky cores III don't think it's

1150
01:04:52,850 --> 01:04:50,460
still super clear for our own giant

1151
01:04:55,790 --> 01:04:52,860
plants so it's not clear in general but

1152
01:04:58,610 --> 01:04:55,800
the idea is that even even gas giants

1153
01:05:14,390 --> 01:04:58,620
have a rocky calling in in them that

1154
01:05:17,510 --> 01:05:14,400
maybe the size of the of the rocky rocky

1155
01:05:21,050 --> 01:05:17,520
fast enough to to form when there is

1156
01:05:23,540 --> 01:05:21,060
still a lot of gas around then as I said

1157
01:05:27,020 --> 01:05:23,550
at some point the gravity kicks in a lot

1158
01:05:29,150 --> 01:05:27,030
and so you create a lot of gas from from

1159
01:05:31,490 --> 01:05:29,160
the surrounding from from the wing of

1160
01:05:34,280 --> 01:05:31,500
material okay at that location

1161
01:05:36,770 --> 01:05:34,290
okay and so it's a problem also of

1162
01:05:39,590 --> 01:05:36,780
timescales how fast you can build up

1163
01:05:41,960 --> 01:05:39,600

this course okay so in in the reaches

1164
01:05:46,510 --> 01:05:41,970
outside this simplified view of there's

1165
01:05:50,570 --> 01:05:46,520
no line being their eyes other than rock

1166
01:05:53,960 --> 01:05:50,580
solid material rock and ice

1167
01:05:56,720 --> 01:05:53,970
it's it's also seen by from experiments

1168
01:05:58,730 --> 01:05:56,730
that dyes helps a lot in building up

1169
01:06:01,640 --> 01:05:58,740
material because it's more sticky there

1170
01:06:04,100 --> 01:06:01,650
are a lot of experiments done with this

1171
01:06:06,290 --> 01:06:04,110
little quiz and try to see how they

1172
01:06:08,780 --> 01:06:06,300
stick and if they stick or not depending

1173
01:06:11,390 --> 01:06:08,790
on the velocity and but it seems that

1174
01:06:13,370 --> 01:06:11,400
the ice helps a lot okay so if if

1175
01:06:16,760 --> 01:06:13,380
outside of is known and you can build up

1176
01:06:21,110 --> 01:06:16,770
quickly a rocky core made of rock and

1177
01:06:25,430 --> 01:06:21,120
and dies then there is a runaway process

1178
01:06:56,270 --> 01:06:25,440
that accretes gas and this is a way to

1179
01:06:59,600 --> 01:06:56,280
explain everything you can think of is

1180
01:07:01,700 --> 01:06:59,610
there so I cannot tell you a specific

1181
01:07:12,670 --> 01:07:01,710
example we can look it up afterwards

1182
01:07:22,970 --> 01:07:17,510
created by NASA so the dead I'm sure we

1183
01:07:26,180 --> 01:07:22,980
can find one we have now so we can find

1184
01:07:31,640 --> 01:07:26,190
one there is really a big large variety

1185
01:07:34,310 --> 01:07:31,650
of compositions and size unless the

1186
01:07:39,110 --> 01:07:34,320
universe is not stranger than we

1187
01:07:47,640 --> 01:07:43,890
the the moons of Saturn and Jupiter are

1188
01:07:58,110 --> 01:07:47,650

they considered mainly rocky or are they

1189
01:08:02,390 --> 01:07:58,120
mostly they mix dynamics so some of very

1190
01:08:06,660 --> 01:08:02,400
much eyes some rocky with with yeah

1191
01:08:23,160 --> 01:08:06,670
actually interestingly in in the plot

1192
01:08:26,760 --> 01:08:23,170
that I showed here this one here the the

1193
01:08:29,040 --> 01:08:26,770
green points and III it's hidden okay

1194
01:08:31,770 --> 01:08:29,050
because I wanted to make it simpler but

1195
01:08:34,620 --> 01:08:31,780
the green points are the satellites of

1196
01:08:36,900 --> 01:08:34,630
gas giants so there is an interesting

1197
01:08:41,850 --> 01:08:36,910
overlap between the super Earths

1198
01:08:50,840 --> 01:08:41,860
population and the gas giant satellite

1199
01:08:54,060 --> 01:08:50,850
population there is this interesting

1200
01:09:07,620 --> 01:08:54,070
similarity that may suggest of a similar

1201
01:09:15,490 --> 01:09:10,689
it's a planetary system and these super

1202
01:09:19,390 --> 01:09:15,500
rods and then here the mass is scared

1203
01:09:21,789 --> 01:09:19,400
with the rate with the mass of the star

1204
01:09:23,709 --> 01:09:21,799
and for the giant line satellites is

1205
01:09:26,499 --> 01:09:23,719
scaled with the mass of the giant gas

1206
01:09:29,789 --> 01:09:26,509
giant okay so there is some story behind

1207
01:09:32,220 --> 01:09:29,799
that but but there is this seminar

1208
01:09:41,559 --> 01:09:32,230
hinting at the possibility in our

1209
01:09:43,149 --> 01:09:41,569
process there are first time yes yes so

1210
01:09:47,559 --> 01:09:43,159
you might have mentioned this but like

1211
01:09:49,839 --> 01:09:47,569
you said when they for like was it 1

1212
01:09:54,189 --> 01:09:49,849
meter bigots some of them get like

1213
01:09:57,729 --> 01:09:54,199

sucked into the start yeah what-what

1214
01:10:06,609 --> 01:09:57,739
exactly softly all all the planets that

1215
01:10:10,359 --> 01:10:06,619
were formed so what exactly we don't

1216
01:10:11,649 --> 01:10:10,369
know okay but we have to again we have

1217
01:10:13,720 --> 01:10:11,659
the theoretical approach and the

1218
01:10:20,250 --> 01:10:13,730
observation approach observationally

1219
01:10:26,200 --> 01:10:24,209
millimeter sized grains that are not

1220
01:10:28,839 --> 01:10:26,210
homogeneously distributed in the disk

1221
01:10:31,209 --> 01:10:28,849
but clamped in one region okay so that

1222
01:10:34,209 --> 01:10:31,219
that thing that observation is telling

1223
01:10:36,879 --> 01:10:34,219
us that there is some process that is it

1224
01:10:38,589 --> 01:10:36,889
that is keeping them there okay even if

1225
01:10:40,870 --> 01:10:38,599
we don't know what it is okay

1226
01:10:42,370 --> 01:10:40,880
on the theoretical side that there there

1227
01:10:44,680 --> 01:10:42,380
have been a lot of creativity and

1228
01:10:47,320 --> 01:10:44,690
imagination to try to explain that okay

1229
01:10:50,589 --> 01:10:47,330
and so that the idea is that that there

1230
01:10:53,950 --> 01:10:50,599
that there are these regions of over

1231
01:10:55,810 --> 01:10:53,960
density over densities in in that is

1232
01:11:00,459 --> 01:10:55,820
such that the density is not the same

1233
01:11:03,640 --> 01:11:00,469
okay so these these these grains while

1234
01:11:06,189 --> 01:11:03,650
they for example one is this I said one

1235
01:11:08,840 --> 01:11:06,199
is the snowline okay there's no name is

1236
01:11:10,760 --> 01:11:08,850
the region where you have

1237
01:11:13,190 --> 01:11:10,770
one side ice and the other side gas okay

1238
01:11:15,110 --> 01:11:13,200

if you have a sharp region where on the

1239
01:11:17,480 --> 01:11:15,120
on one side you have a lot of gas on the

1240
01:11:20,540 --> 01:11:17,490
other side you you don't you have the

1241
01:11:22,490 --> 01:11:20,550
same matter the same monocle for the

1242
01:11:27,230 --> 01:11:22,500
river water but in solid there is a

1243
01:11:29,090 --> 01:11:27,240
discontinuity so in in density of gas

1244
01:11:30,800 --> 01:11:29,100
material okay because on one side you

1245
01:11:34,040 --> 01:11:30,810
have a lot on the absolute you have less

1246
01:11:38,360 --> 01:11:34,050
okay that would be a a density region

1247
01:11:41,600 --> 01:11:38,370
where when the swings could be stopped

1248
01:11:43,790 --> 01:11:41,610
okay even though some still make it

1249
01:11:45,800 --> 01:11:43,800
through and produce the gas that is seen

1250
01:11:47,540 --> 01:11:45,810
in the inner disk of the in the in

1251
01:11:49,400 --> 01:11:47,550
England disk because they evaporate ice

1252
01:11:51,770 --> 01:11:49,410
is evaporate there and then there is

1253
01:11:55,850 --> 01:11:51,780
this proposed that there is a pre

1254
01:11:57,470 --> 01:11:55,860
diffusion of gas outside beyond the

1255
01:11:59,900 --> 01:11:57,480
stone and again building up again

1256
01:12:04,010 --> 01:11:59,910
freezing out water for example and

1257
01:12:07,730 --> 01:12:04,020
building up again material the solid

1258
01:12:09,170 --> 01:12:07,740
bodies beyond this one okay we don't

1259
01:12:11,110 --> 01:12:09,180
have a clear idea that there are many

1260
01:12:14,150 --> 01:12:11,120
complicated models to try to explain how

1261
01:12:16,910 --> 01:12:14,160
you can stop this grains there okay but

1262
01:12:52,569 --> 01:12:16,920
we have evidence that that happens okay

1263
01:13:09,169 --> 01:13:07,069

the answer to his question ishow two

1264
01:13:13,459 --> 01:13:09,179
unexpected things but Denis explain them

1265
01:13:19,279 --> 01:13:13,469
okay and actually one is still very

1266
01:13:21,169 --> 01:13:19,289
mysterious the idea is that and a lot of

1267
01:13:24,260 --> 01:13:21,179
development has been done even at that

1268
01:13:31,279 --> 01:13:24,270
time when these two Swiss guys were able

1269
01:13:33,410 --> 01:13:31,289
to from the theoretical side they had to

1270
01:13:36,649 --> 01:13:33,420
come up with something okay because they

1271
01:13:39,859 --> 01:13:36,659
had to explain it in some way and the

1272
01:13:42,140 --> 01:13:39,869
idea was that the the planet forms outer

1273
01:13:44,839 --> 01:13:42,150
for further out in the disk but then

1274
01:13:47,359 --> 01:13:44,849
migrates in okay I talked about the

1275
01:13:50,229 --> 01:13:47,369
migration of the small solids but the

1276
01:13:54,680 --> 01:13:50,239
similar migration may happen for

1277
01:13:56,419 --> 01:13:54,690
protoplanets or all planets okay by

1278
01:13:58,430 --> 01:13:56,429
interaction with the gas again so the

1279
01:14:00,439 --> 01:13:58,440
idea to explain there to explain the

1280
01:14:04,040 --> 01:14:00,449
population of hot Jupiter is that they

1281
01:14:04,689 --> 01:14:04,050
migrate towards the star after they are

1282
01:14:12,200 --> 01:14:04,699
formed

1283
01:14:16,209 --> 01:14:12,210
that's the sorry back there yes the

1284
01:14:20,479 --> 01:14:16,219
given radius from any Sun in this early

1285
01:14:22,160 --> 01:14:20,489
formation time are they all going at the

1286
01:14:25,100 --> 01:14:22,170
same rate of speed or do they go at

1287
01:14:28,310 --> 01:14:25,110
different speed I'm sorry can you did

1288
01:14:32,390 --> 01:14:28,320

the particles going which might vary in

1289
01:14:34,549 --> 01:14:32,400
terms of size do they end composition do

1290
01:14:38,060 --> 01:14:34,559
they all go at the same speed at a given

1291
01:14:42,109 --> 01:14:38,070
radius from some star or do they go at

1292
01:14:46,790 --> 01:14:42,119
different speeds it's an interesting

1293
01:14:54,870 --> 01:14:51,149
they go at different speeds when it

1294
01:14:57,270 --> 01:14:54,880
frozen when the soil particles are still

1295
01:14:59,550 --> 01:14:57,280
in random in the gas so when the disk is

1296
01:15:04,290 --> 01:14:59,560
still in the early phases and you have

1297
01:15:06,300 --> 01:15:04,300
gas and dust together at that point when

1298
01:15:08,790 --> 01:15:06,310
the particles the solid particles are

1299
01:15:15,750 --> 01:15:08,800
small enough they simply follow the gas

1300
01:15:18,479 --> 01:15:15,760
okay the reason why there is this

1301
01:15:23,640 --> 01:15:18,489
meter-sized barrier problem one of the

1302
01:15:26,459 --> 01:15:23,650
reasons is that when the solid particles

1303
01:15:33,689 --> 01:15:26,469
stick together and grow enough in size

1304
01:15:36,600 --> 01:15:33,699
at some point when they grow enough in

1305
01:15:38,520 --> 01:15:36,610
solids they start to be to decouple from

1306
01:15:42,149 --> 01:15:38,530
the gas because they are too big to

1307
01:15:45,689 --> 01:15:42,159
follow entirely the gas when they start

1308
01:15:47,280 --> 01:15:45,699
to do that they start to interact with

1309
01:15:49,020 --> 01:15:47,290
the gas in a different way okay they

1310
01:15:51,660 --> 01:15:49,030
start to go at their own velocity em

1311
01:15:53,640 --> 01:15:51,670
feel the gas drag okay that's that this

1312
01:15:56,040 --> 01:15:53,650
is the reason of the gas drag that then

1313
01:15:58,950 --> 01:15:56,050

they feel sucked in really sucked in

1314
01:16:02,609 --> 01:15:58,960
through the disc okay onto the star so

1315
01:16:04,830 --> 01:16:02,619
it is indeed a man so different sizes of

1316
01:16:07,140 --> 01:16:04,840
the earth particles have do have

1317
01:16:09,959 --> 01:16:07,150
different different velocities because

1318
01:16:12,479 --> 01:16:09,969
they they interact in a different way

1319
01:16:17,270 --> 01:16:12,489
with the environment okay also the shape

1320
01:16:29,160 --> 01:16:17,280
matters to some extent the composition

1321
01:16:32,040 --> 01:16:29,170
not and I don't think the shape also so

1322
01:16:34,200 --> 01:16:32,050
in this kind of studies use that from

1323
01:16:36,979 --> 01:16:34,210
assuming the simplest conditions and you

1324
01:16:39,570 --> 01:16:36,989
assume dust grains that are spheres just

1325
01:16:44,070 --> 01:16:39,580
compact spheres with some composition

1326
01:16:46,229 --> 01:16:44,080
against a mass if they grow by speaking

1327
01:16:48,120 --> 01:16:46,239
of small particles is very happy they

1328
01:16:49,310 --> 01:16:48,130
are not spheres for they are fluffier

1329
01:16:52,330 --> 01:16:49,320
okay so

1330
01:16:54,860 --> 01:16:52,340
love experiments we see that when we

1331
01:16:57,440 --> 01:16:54,870
lower self when when we stick together

1332
01:17:00,080 --> 01:16:57,450
these dis particles they are not never

1333
01:17:03,470 --> 01:17:00,090
his fear but they are fluffier and then

1334
01:17:06,520 --> 01:17:03,480
again that would affect their lost yes

1335
01:17:17,960 --> 01:17:06,530
people could not an account for a

1336
01:17:24,080 --> 01:17:20,910
maybe in some in something III would

1337
01:17:27,530 --> 01:17:24,090
have to think in more details about that

1338
01:17:31,710 --> 01:17:27,540

sounds like a rolling back up on the

1339
01:17:35,100 --> 01:17:31,720
classic classically you would expect

1340
01:17:37,170 --> 01:17:35,110
that when you reach a certain size maybe

1341
01:17:38,700 --> 01:17:37,180
even assuming the simplified sphere okay

1342
01:17:40,350 --> 01:17:38,710
but when you reach a certain size you

1343
01:17:44,820 --> 01:17:40,360
start to the capital from the gas and

1344
01:17:48,270 --> 01:17:44,830
keep this gas track if the shady the

1345
01:17:49,979 --> 01:17:48,280
shape fluffier or less fluffy can matter

1346
01:17:54,960 --> 01:17:49,989
on this death-trap

1347
01:17:57,720 --> 01:17:54,970
III don't know in this detail I'd like

1348
01:18:00,330 --> 01:17:57,730
to thank doctor been solid for his time

1349
01:18:01,770 --> 01:18:00,340
tonight very excellent questions your

1350
01:18:04,350 --> 01:18:01,780
really deep thank you sir

1351
01:18:06,780 --> 01:18:04,360
I forgot to mention at the beginning

1352
01:18:11,130 --> 01:18:06,790
there is no observatory tonight we have