1
00:00:00,570 --> 00:00:05,549
all right welcome everyone to the

2
00:00:03,569 --> 00:00:09,000
December edition of the public lecture

3
00:00:05,549 --> 00:00:11,250
series i'm joel green i'm playing dr.

4
00:00:09,000 --> 00:00:12,570
frank summers for the evening I'm the

5
00:00:11,250 --> 00:00:13,859
project scientist in the office of

6
00:00:12,570 --> 00:00:16,440
public outreach so I work with Frank

7
00:00:13,859 --> 00:00:18,179
quite a bit he is actually currently on

8
00:00:16,440 --> 00:00:20,640
a flight back from I believe San

9
00:00:18,179 --> 00:00:22,829
Francisco as we speak so he will be back

10
00:00:20,640 --> 00:00:25,439
tomorrow but that's too late for tonight

11
00:00:22,829 --> 00:00:28,639
so you're stuck with me please take a

12
00:00:25,439 --> 00:00:30,899
example of our holiday greeting cards

13
00:00:28,640 --> 00:00:35,070
one per person and there might be a few

14
00:00:30,899 --> 00:00:36,808
extras left at the end our speaker

15
00:00:35,070 --> 00:00:40,170
tonight who will be speaking I'll give a

16
00:00:36,808 --> 00:00:41,609
short introduction prior to that and our

17
00:00:40,170 --> 00:00:44,160
speaker tonight will be Chris dr.

18
00:00:41,609 --> 00:00:46,649
Christine Chen I'll introduce you in a

19
00:00:44,159 --> 00:00:49,439
moment as we get through and she will be

20
00:00:46,649 --> 00:00:52,189
talking about debris disks and other the

21
00:00:49,439 --> 00:00:54,539
formation of young planetary systems

22
00:00:52,189 --> 00:00:56,789
upcoming talks upcoming public lecture

23
00:00:54,539 --> 00:00:59,070
series talks our January 3rd or 10th

24
00:00:56,789 --> 00:01:00,510
I guess it's TB I think that's why Frank

25
00:00:59,070 --> 00:01:03,149
has Frank gave me these slides so you

26
00:01:00,509 --> 00:01:04,438
can blame him I think I think he

27
00:01:03,149 --> 00:01:07,859
basically hasn't decided what today it

28
00:01:04,438 --> 00:01:10,379
is the 3rd of the 10th the February date

29

00:01:07,859 --> 00:01:13,349
is set that is the 7th the talk there

30
00:01:10,379 --> 00:01:17,158
will be mapping the heavens and on March

31
00:01:13,349 --> 00:01:19,859
7th will be another talk bye-bye lauren

32
00:01:17,159 --> 00:01:25,380
Corley's from johns hopkins with a TBA

33
00:01:19,859 --> 00:01:27,780
title you've probably already noticed

34
00:01:25,379 --> 00:01:30,539
this but there's still construction on

35
00:01:27,780 --> 00:01:33,000
San Martin Drive so if you are coming

36
00:01:30,540 --> 00:01:33,890
from the South it's pretty easy but if

37
00:01:33,000 --> 00:01:36,209
you're coming from the north you've

38
00:01:33,890 --> 00:01:37,709
either got a park on University Parkway

39
00:01:36,209 --> 00:01:39,478
or drive all the way around so hopefully

40
00:01:37,709 --> 00:01:41,429
everyone found their way here easy used

41
00:01:39,478 --> 00:01:42,959
to approach from the south but the good

42
00:01:41,430 --> 00:01:45,000
news is this will all stop in the new

43
00:01:42,959 --> 00:01:46,048

year so hopefully this won't be the last

44
00:01:45,000 --> 00:01:49,438
one of these where you have to worry

45
00:01:46,049 --> 00:01:51,600
about this and this is the schedule see

46
00:01:49,438 --> 00:01:54,658
it says through December 2016 so

47
00:01:51,599 --> 00:01:56,908
hopefully the writ so currently the red

48
00:01:54,659 --> 00:02:00,750
part and the yellow are the closed parts

49
00:01:56,909 --> 00:02:02,579
the blue part is done so anyway the key

50
00:02:00,750 --> 00:02:04,769
is to approach from the south on San

51
00:02:02,578 --> 00:02:09,000
Martin Drive

52
00:02:04,769 --> 00:02:11,280
keep keep turning I think weather does

53
00:02:09,000 --> 00:02:13,199
not permit us to go to the observatory

54
00:02:11,280 --> 00:02:15,709
but that usually is something that

55
00:02:13,199 --> 00:02:21,959
happens afterward I I assume relevant

56
00:02:15,709 --> 00:02:22,979
people know what to do there and I'm

57
00:02:21,959 --> 00:02:25,890
just gonna give a quick introduction

58
00:02:22,979 --> 00:02:27,419
talk about a funny experience I had

59
00:02:25,889 --> 00:02:29,429
rather than I know Frank sometimes does

60
00:02:27,419 --> 00:02:31,619
news and updates I thought it might be

61
00:02:29,430 --> 00:02:33,090
fun to kind of tell you a tale of one of

62
00:02:31,620 --> 00:02:35,219
the most unusual observing runs I've

63
00:02:33,090 --> 00:02:40,709
been on and it's called why I had a

64
00:02:35,219 --> 00:02:42,479
Boeing 747 almost to myself so when I'm

65
00:02:40,709 --> 00:02:43,979
when people find out I'm an astronomer

66
00:02:42,479 --> 00:02:46,500
the first question I invariably get

67
00:02:43,979 --> 00:02:49,348
asked in a kind of angry aggressive tone

68
00:02:46,500 --> 00:02:52,669
is why is Pluto not a planet anymore I

69
00:02:49,348 --> 00:02:55,469
people really outraged by this right so

70
00:02:52,669 --> 00:02:58,078
you know the correct the question you

71
00:02:55,469 --> 00:02:59,340
should be asking and I'm sure that that

72
00:02:58,079 --> 00:03:02,310
everyone here has thought about this the

73
00:02:59,340 --> 00:03:05,039
real question is what is a planet right

74
00:03:02,310 --> 00:03:06,329
why is Pluto not one or is it one why

75
00:03:05,039 --> 00:03:09,840
should we even be concerned about that

76
00:03:06,329 --> 00:03:11,189
and there are many answers to this

77
00:03:09,840 --> 00:03:12,659
question about what does the planet it

78
00:03:11,189 --> 00:03:14,340
could be you could call it a round thing

79
00:03:12,659 --> 00:03:17,430
above a certain size it could be

80
00:03:14,340 --> 00:03:19,139
something that orbits a star that

81
00:03:17,430 --> 00:03:20,760
doesn't you know have a larger object

82
00:03:19,139 --> 00:03:23,459
orbiting it or something and there are

83
00:03:20,759 --> 00:03:24,870
lots of semantic definitions but both

84
00:03:23,459 --> 00:03:27,659
Christine and I work in the field of

85
00:03:24,870 --> 00:03:29,789
formation of planets and that's the way

86

00:03:27,659 --> 00:03:33,568
I think about planets is a planet is

87
00:03:29,789 --> 00:03:36,209
something that formed around a star in

88
00:03:33,568 --> 00:03:37,708
its disk so I mean these are the

89
00:03:36,209 --> 00:03:39,389
traditional planets right these are this

90
00:03:37,709 --> 00:03:41,489
is planet was the definition of planet

91
00:03:39,389 --> 00:03:42,900
until 2006 was just something the

92
00:03:41,489 --> 00:03:48,090
ancient Greeks thought wandered in the

93
00:03:42,900 --> 00:03:50,280
sky but the real thing to think about is

94
00:03:48,090 --> 00:03:51,689
when you approach a planetary system I

95
00:03:50,280 --> 00:03:54,719
was having a fun discussion at lunch a

96
00:03:51,689 --> 00:03:55,829
few days ago about this when you if you

97
00:03:54,719 --> 00:03:57,120
let's say you were on the bridge of the

98
00:03:55,829 --> 00:03:58,469
Starship Enterprise or something like

99
00:03:57,120 --> 00:04:00,569
that and you were flying it to your star

100
00:03:58,469 --> 00:04:02,280

system and you wanted to say something

101
00:04:00,568 --> 00:04:04,138
useful about it you were surveying it

102
00:04:02,280 --> 00:04:05,489
what would you want to know you want to

103
00:04:04,139 --> 00:04:07,169
know what are the objects in orbit

104
00:04:05,489 --> 00:04:09,269
around the star what are they made out

105
00:04:07,169 --> 00:04:10,980
of what are they like how many of each

106
00:04:09,269 --> 00:04:12,180
are there and what temperature are they

107
00:04:10,979 --> 00:04:15,000
what are their gases

108
00:04:12,180 --> 00:04:17,160
do they have surfaces and what this is

109
00:04:15,000 --> 00:04:18,180
really a question about is how did we

110
00:04:17,160 --> 00:04:19,769
what we want to understand is

111
00:04:18,180 --> 00:04:25,280
how do you form all of these different

112
00:04:19,769 --> 00:04:27,689
kinds of objects our solar system is a

113
00:04:25,279 --> 00:04:29,758
morass of different kinds of objects

114
00:04:27,689 --> 00:04:33,629
ranging from planetary bodies down to

115
00:04:29,759 --> 00:04:35,129
dust particles and the solar system as

116
00:04:33,629 --> 00:04:38,279
it looks today is this kind of neatly

117
00:04:35,129 --> 00:04:40,379
organized mostly neatly organized system

118
00:04:38,279 --> 00:04:42,029
with the rocky inner planets sort of an

119
00:04:40,379 --> 00:04:43,978
asteroid belt that's not the only place

120
00:04:42,029 --> 00:04:46,138
where asteroids are but that's one of

121
00:04:43,978 --> 00:04:47,930
the most common places to find them the

122
00:04:46,139 --> 00:04:50,728
gas giant outer planets

123
00:04:47,930 --> 00:04:54,689
objects in the Kuiper belt with the ski

124
00:04:50,728 --> 00:04:56,848
orbits ice Dwarfs and what's interesting

125
00:04:54,689 --> 00:04:59,310
is if you were to rewind the clock 4.5

126
00:04:56,848 --> 00:05:00,930
billion years to when the solar system

127
00:04:59,310 --> 00:05:02,129
was less than a million years old you

128
00:05:00,930 --> 00:05:06,269
probably would see it looking something

129
00:05:02,129 --> 00:05:08,909
like this a swirling disk of gas with

130
00:05:06,269 --> 00:05:10,889
tiny dust particles hanging suspended in

131
00:05:08,910 --> 00:05:13,979
that gas about a hundred times as much

132
00:05:10,889 --> 00:05:16,259
gas as dust and that is a planet making

133
00:05:13,978 --> 00:05:18,029
factory that's where solar systems come

134
00:05:16,259 --> 00:05:18,598
from and we know this because we look at

135
00:05:18,029 --> 00:05:21,179
other ones

136
00:05:18,598 --> 00:05:23,069
all of these are ingredients of things

137
00:05:21,180 --> 00:05:27,509
that have been found in space using

138
00:05:23,069 --> 00:05:29,819
space telescopes actually can skip this

139
00:05:27,509 --> 00:05:33,478
one so how do we know that planets form

140
00:05:29,819 --> 00:05:35,699
in these discs if you take a meteorite

141
00:05:33,478 --> 00:05:38,490
and you carve it open as this actual

142
00:05:35,699 --> 00:05:40,740
meteorite shows they are matchups of

143

00:05:38,490 --> 00:05:42,990
little pebbles that have been plastered

144
00:05:40,740 --> 00:05:45,538
together to build into bigger and bigger

145
00:05:42,990 --> 00:05:47,939
objects this is the building blocks of

146
00:05:45,538 --> 00:05:49,288
planets it starts it may start big or it

147
00:05:47,939 --> 00:05:51,930
starts small but whatever it is you

148
00:05:49,288 --> 00:05:52,829
generate into these massive objects that

149
00:05:51,930 --> 00:05:54,598
we know today so these are

150
00:05:52,829 --> 00:05:57,779
collaborations and Christine is gonna

151
00:05:54,598 --> 00:06:00,360
talk I suspect quite a bit about this so

152
00:05:57,779 --> 00:06:02,519
in order to study the infrared the most

153
00:06:00,360 --> 00:06:04,710
powerful instrument ever developed for

154
00:06:02,519 --> 00:06:06,930
infrared study is the James Webb Space

155
00:06:04,709 --> 00:06:09,689
Telescope which it will be controlled

156
00:06:06,930 --> 00:06:11,370
upstairs just one floor above us after

157
00:06:09,689 --> 00:06:13,408

it launches in 2018 about 2 minutes

158
00:06:11,370 --> 00:06:15,360
after that control will shift to this

159
00:06:13,408 --> 00:06:17,490
building and we're all very excited and

160
00:06:15,360 --> 00:06:21,449
it's a great tool for studying dusty

161
00:06:17,490 --> 00:06:24,780
infrared bright young stars and here's a

162
00:06:21,449 --> 00:06:26,400
picture of me in front of the mirrors of

163
00:06:24,779 --> 00:06:27,809
the James Webb so that's that's gonna be

164
00:06:26,399 --> 00:06:30,418
in space what's sitting behind me right

165
00:06:27,810 --> 00:06:32,009
there so that's pretty amazing now when

166
00:06:30,418 --> 00:06:33,659
I wanted to study young stars

167
00:06:32,009 --> 00:06:35,250
there's one problem which is that the

168
00:06:33,660 --> 00:06:36,450
telescope that I want to use is sitting

169
00:06:35,250 --> 00:06:39,569
in a clean room in Goddard Space Flight

170
00:06:36,449 --> 00:06:41,909
Center and not in space so I had to use

171
00:06:39,569 --> 00:06:45,540
the current state of the art in the

172
00:06:41,910 --> 00:06:47,130
infrared which is airborne astronomy so

173
00:06:45,540 --> 00:06:48,840
I'm going to talk not at all about the

174
00:06:47,129 --> 00:06:50,279
James Webb Space Telescope and tell you

175
00:06:48,839 --> 00:06:54,779
about another tale of a very unusual

176
00:06:50,279 --> 00:06:56,789
observatory in Palmdale California with

177
00:06:54,779 --> 00:06:58,019
its many residents and you don't look

178
00:06:56,790 --> 00:07:01,819
too closely the picture you might see

179
00:06:58,019 --> 00:07:04,889
some that you recognize from other shows

180
00:07:01,819 --> 00:07:07,319
is a an area called Armstrong Flight

181
00:07:04,889 --> 00:07:09,479
Research Center or Dryden Air Force Base

182
00:07:07,319 --> 00:07:13,620
and in that Air Force Base is an

183
00:07:09,480 --> 00:07:14,550
airplane that NASA bought it's not the

184
00:07:13,620 --> 00:07:16,829
vomit comet

185
00:07:14,550 --> 00:07:18,240
so when people think of NASA airplanes

186
00:07:16,829 --> 00:07:19,740
they ask me oh did you fly in the vomit

187
00:07:18,240 --> 00:07:22,050
combat nights that's exactly the

188
00:07:19,740 --> 00:07:23,910
opposite of what I wanted to do flying

189
00:07:22,050 --> 00:07:26,670
up and down like you know that's a we

190
00:07:23,910 --> 00:07:29,700
want super stable this is this is why I

191
00:07:26,670 --> 00:07:31,770
would never do well in space I just I

192
00:07:29,699 --> 00:07:34,349
would lose lose my contents of my

193
00:07:31,769 --> 00:07:34,709
stomach very quickly so not the Vomit

194
00:07:34,350 --> 00:07:36,780
Comet

195
00:07:34,709 --> 00:07:39,719
it's the stratospheric Observatory for

196
00:07:36,779 --> 00:07:41,729
infrared astronomy Sofia and what they

197
00:07:39,720 --> 00:07:45,030
did was they took a 747 and actually an

198
00:07:41,730 --> 00:07:48,110
old-style 747 from the 70s bought it and

199
00:07:45,029 --> 00:07:53,219
they cut a hole in the side of the plane

200

00:07:48,110 --> 00:07:55,290
and in that hole is a telescope so

201
00:07:53,220 --> 00:07:57,540
there's a telescope about 2.4 meters in

202
00:07:55,290 --> 00:07:59,670
diameter James Webb is 6.5 meters for

203
00:07:57,540 --> 00:08:00,720
comparison so this is small but it's

204
00:07:59,670 --> 00:08:03,629
larger than most of our ground-based

205
00:08:00,720 --> 00:08:05,430
telescopes and they carry it to 42,000

206
00:08:03,629 --> 00:08:07,379
feet because the atmosphere of our earth

207
00:08:05,430 --> 00:08:08,879
is one of the things that you know

208
00:08:07,379 --> 00:08:10,740
shields us from a lot of things but it

209
00:08:08,879 --> 00:08:12,659
also makes infrared astronomy very

210
00:08:10,740 --> 00:08:14,460
tricky so that less air that you have to

211
00:08:12,660 --> 00:08:16,110
go through the better it is that's why

212
00:08:14,459 --> 00:08:17,819
we usually put these things into space

213
00:08:16,110 --> 00:08:18,870
the nice thing about an airplane is you

214
00:08:17,819 --> 00:08:21,060

can bring it down to the end of the day

215
00:08:18,870 --> 00:08:22,350
and do repairs and change out the

216
00:08:21,060 --> 00:08:24,480
instruments and things like that and

217
00:08:22,350 --> 00:08:26,520
what's really neat is I can't go to

218
00:08:24,480 --> 00:08:29,250
James Webb or Hubble and use them

219
00:08:26,519 --> 00:08:33,120
directly I couldn't fly with Sophia and

220
00:08:29,250 --> 00:08:34,799
in fact I did it takes a lot of people

221
00:08:33,120 --> 00:08:40,460
to flip plan one of these flights I have

222
00:08:34,799 --> 00:08:40,459
to tell you that on my flight there were

223
00:08:40,669 --> 00:08:45,559
two flight planners the two pilot or

224
00:08:44,219 --> 00:08:48,740
pilot and co-pilot

225
00:08:45,559 --> 00:08:51,829
sort of a amidships person to safety

226
00:08:48,740 --> 00:08:54,440
officers to telescope operators and to

227
00:08:51,830 --> 00:08:57,110
instrument scientists and an outreach

228
00:08:54,440 --> 00:08:58,370
and education specialist and then six

229
00:08:57,110 --> 00:09:00,050
teachers in the California Science

230
00:08:58,370 --> 00:09:02,960
Center who come along to check out how

231
00:09:00,049 --> 00:09:04,429
science worked so it was about 20 people

232
00:09:02,960 --> 00:09:05,629
on the flight and that's only a small

233
00:09:04,429 --> 00:09:08,539
fraction when we went through the

234
00:09:05,629 --> 00:09:10,159
initial briefing we had to come up with

235
00:09:08,539 --> 00:09:12,439
a flight plan and so they came up with a

236
00:09:10,159 --> 00:09:14,329
plan now they have now this this map

237
00:09:12,440 --> 00:09:16,940
right so it takes off from Southern

238
00:09:14,330 --> 00:09:20,720
California we can't fly over Mexico for

239
00:09:16,940 --> 00:09:22,100
various obscure legal reasons so we you

240
00:09:20,720 --> 00:09:24,920
have to avoid Mexico you have to avoid

241
00:09:22,100 --> 00:09:27,769
military no-fly zones and you have to

242
00:09:24,919 --> 00:09:29,269
fly in such a direction that you can

243
00:09:27,769 --> 00:09:30,919
observe your target so think about this

244
00:09:29,269 --> 00:09:33,169
all right let me go back to for a second

245
00:09:30,919 --> 00:09:35,569
if you look at this airplane so the

246
00:09:33,169 --> 00:09:38,329
telescope can only point out the left

247
00:09:35,570 --> 00:09:41,000
side of the plane so you have to fly the

248
00:09:38,330 --> 00:09:43,460
plane such that the direction it's

249
00:09:41,000 --> 00:09:45,019
facing has the telescope pointed toward

250
00:09:43,460 --> 00:09:47,680
the star you want to look at or the

251
00:09:45,019 --> 00:09:50,659
galaxy you want to look at so you fly it

252
00:09:47,679 --> 00:09:51,649
in a straight line as long as you

253
00:09:50,659 --> 00:09:53,809
possibly can

254
00:09:51,649 --> 00:09:56,629
pointing toward your target with no

255
00:09:53,809 --> 00:10:01,099
particular destination in mind this

256
00:09:56,629 --> 00:10:02,509
drives air traffic controllers crazy and

257

00:10:01,100 --> 00:10:04,310
what's one of the neat things is you

258
00:10:02,509 --> 00:10:05,149
have a headset because it I'll show you

259
00:10:04,309 --> 00:10:07,099
later they ripped out all the

260
00:10:05,149 --> 00:10:08,240
installations so it's quite loud inside

261
00:10:07,100 --> 00:10:12,080
this plane it's kind of like being in a

262
00:10:08,240 --> 00:10:13,339
noisy bar and but you could get to

263
00:10:12,080 --> 00:10:14,810
listen to the pilot chatter with the

264
00:10:13,339 --> 00:10:17,540
very confused air traffic controllers

265
00:10:14,809 --> 00:10:19,269
the callsign of the plane is NASA 747

266
00:10:17,539 --> 00:10:21,679
you could follow it on flight aware

267
00:10:19,269 --> 00:10:27,949
every one of its flights and they're all

268
00:10:21,679 --> 00:10:29,449
posted and the so the the trajectory you

269
00:10:27,950 --> 00:10:31,339
make ask you have to end up back where

270
00:10:29,450 --> 00:10:33,680
you started so you fly for 10 hours and

271
00:10:31,339 --> 00:10:35,180

end up nowhere when you're gone nowhere

272
00:10:33,679 --> 00:10:37,129
ultimately but you've done it's been

273
00:10:35,179 --> 00:10:38,958
quite a journey on the way so each of

274
00:10:37,129 --> 00:10:41,570
these legs of this flight was a

275
00:10:38,958 --> 00:10:43,219
different target and my two targets were

276
00:10:41,570 --> 00:10:45,770
when we were out over the Pacific so we

277
00:10:43,220 --> 00:10:48,139
flew around into the Pacific just

278
00:10:45,769 --> 00:10:51,169
skirting Mexico kind of halfway out to

279
00:10:48,139 --> 00:10:53,990
Hawaii up over Juneau Alaska and back

280
00:10:51,169 --> 00:10:56,419
down the entire west coast of the US so

281
00:10:53,990 --> 00:10:58,870
we had to have contingency plans in case

282
00:10:56,419 --> 00:11:02,559
we had to land at Mexico City Hana

283
00:10:58,870 --> 00:11:04,960
Lulu Fairbanks this was February and I

284
00:11:02,559 --> 00:11:07,269
said they're Fairbanks are you insane I

285
00:11:04,960 --> 00:11:09,129
have a like a light jacket on for Los

286
00:11:07,269 --> 00:11:10,778
Angeles weather like we had to land in

287
00:11:09,129 --> 00:11:14,588
Fairbanks in February I think I would

288
00:11:10,778 --> 00:11:17,649
have you know jumped out with anyway so

289
00:11:14,589 --> 00:11:19,450
we didn't you all went great this is me

290
00:11:17,649 --> 00:11:21,039
before we're getting ready to take off I

291
00:11:19,450 --> 00:11:22,028
have a little protective reflector so

292
00:11:21,039 --> 00:11:24,519
that I don't get run over

293
00:11:22,028 --> 00:11:26,019
you cannot point the camera this way it

294
00:11:24,519 --> 00:11:29,740
turns out there's some other plane and

295
00:11:26,019 --> 00:11:31,539
hangar that they don't wanna show no I

296
00:11:29,740 --> 00:11:35,080
think it's some work they do for someone

297
00:11:31,539 --> 00:11:36,549
else the that was my seat for takeoff

298
00:11:35,080 --> 00:11:39,310
and landing those chairs at that table

299
00:11:36,549 --> 00:11:40,329
and those are our headsets so you you

300
00:11:39,309 --> 00:11:42,549
know when you fly on this thing you

301
00:11:40,330 --> 00:11:44,470
basically you kind of wait and then they

302
00:11:42,549 --> 00:11:46,059
announce they're taking off and they go

303
00:11:44,470 --> 00:11:48,670
and you basically just go you know

304
00:11:46,059 --> 00:11:50,588
they're pretty sharply upward to get to

305
00:11:48,669 --> 00:11:53,620
forty to that or at least 39,000 feet as

306
00:11:50,589 --> 00:11:55,990
quickly as possible and once you're up

307
00:11:53,620 --> 00:11:57,700
there it is about five minutes in they

308
00:11:55,990 --> 00:11:58,870
open the door for the telescope they

309
00:11:57,700 --> 00:12:00,160
don't even tell you they're doing it you

310
00:11:58,870 --> 00:12:01,870
would have no idea it's perfectly

311
00:12:00,159 --> 00:12:04,000
pressurized they open a hole in the side

312
00:12:01,870 --> 00:12:06,429
of the plane and the telescope sticks

313
00:12:04,000 --> 00:12:08,500
out and it's little harness where it is

314

00:12:06,429 --> 00:12:10,528
capped you know incredibly carefully in

315
00:12:08,500 --> 00:12:12,789
place it's kind of an amazing technology

316
00:12:10,528 --> 00:12:14,439
so it's not worried about we're not

317
00:12:12,789 --> 00:12:17,799
worried about wobble and stuff like that

318
00:12:14,440 --> 00:12:19,089
it's basically under control the safety

319
00:12:17,799 --> 00:12:21,519
briefing is a bit more extensive than

320
00:12:19,089 --> 00:12:23,440
you hit out for a commercial flight but

321
00:12:21,519 --> 00:12:26,559
it's a lot more comfortable so you

322
00:12:23,440 --> 00:12:28,680
imagine 20 people in a plane a 747 where

323
00:12:26,559 --> 00:12:31,028
they ripped out most of the seats and

324
00:12:28,679 --> 00:12:34,059
put in some computer desks but it's a

325
00:12:31,028 --> 00:12:35,860
cavernous space actually this is a

326
00:12:34,059 --> 00:12:37,449
pretty nice flight it's a little cold

327
00:12:35,860 --> 00:12:39,669
because the insulation is kind of gone

328
00:12:37,450 --> 00:12:42,100

from a lot of the sides and the back

329
00:12:39,669 --> 00:12:44,708
third of the plane is a telescope but

330
00:12:42,100 --> 00:12:47,620
it's a pretty neat situation this is

331
00:12:44,708 --> 00:12:49,329
actually this this picture may be

332
00:12:47,620 --> 00:12:50,440
nostalgic because the very first project

333
00:12:49,330 --> 00:12:52,480
I ever did as an undergraduate

334
00:12:50,440 --> 00:12:56,860
astronomer was to work with dr. Terry

335
00:12:52,480 --> 00:12:58,750
herder on the forecast camera which is

336
00:12:56,860 --> 00:13:02,470
the red instrument with the Cornell Red

337
00:12:58,750 --> 00:13:04,870
Bear on it so when I was about 20 years

338
00:13:02,470 --> 00:13:06,610
ago almost but I was there I was working

339
00:13:04,870 --> 00:13:08,709
on that I can't say well I say working

340
00:13:06,610 --> 00:13:10,300
on it I was doing a little bit of

341
00:13:08,708 --> 00:13:11,559
programming anyway it was fun it was

342
00:13:10,299 --> 00:13:12,490
really nice to be able to use the

343
00:13:11,559 --> 00:13:13,959
instrument that I remem

344
00:13:12,490 --> 00:13:16,330
being there for some of the testing of

345
00:13:13,960 --> 00:13:20,710
when it was first proposed it's a long

346
00:13:16,330 --> 00:13:22,150
life cycle so it's it's so the the

347
00:13:20,710 --> 00:13:23,950
instrument is out here on the side that

348
00:13:22,149 --> 00:13:25,360
I'm on but it's anchored to the

349
00:13:23,950 --> 00:13:29,290
telescope which is on the far side of

350
00:13:25,360 --> 00:13:30,970
that sort of circular safe looking thing

351
00:13:29,289 --> 00:13:36,099
so the telescope is inside on the other

352
00:13:30,970 --> 00:13:37,480
side in a shock frame and from this side

353
00:13:36,100 --> 00:13:38,830
you could just sort of see it adjusting

354
00:13:37,480 --> 00:13:40,210
it back and forth now the key essentials

355
00:13:38,830 --> 00:13:42,100
on the flight are that they have a

356
00:13:40,210 --> 00:13:44,170
built-in coffee maker with like a bolt

357
00:13:42,100 --> 00:13:46,750
that holds the coffee I don't know I

358
00:13:44,169 --> 00:13:48,189
just imagined hot coffee whipping across

359
00:13:46,750 --> 00:13:50,070
the plane at hundreds of miles an hour

360
00:13:48,190 --> 00:13:54,100
or something but nothing happened

361
00:13:50,070 --> 00:13:55,240
there's a microwave oven and so you

362
00:13:54,100 --> 00:13:56,740
bring your snacks on board and you can

363
00:13:55,240 --> 00:13:58,240
have dinner and it's nice because they

364
00:13:56,740 --> 00:13:59,860
left some of the first-class cabin seats

365
00:13:58,240 --> 00:14:03,340
so after your observations done you can

366
00:13:59,860 --> 00:14:05,019
kind of take a nap and you can go check

367
00:14:03,340 --> 00:14:06,399
out what we're looking at so you can

368
00:14:05,019 --> 00:14:08,350
look at the Stars you can see what our

369
00:14:06,399 --> 00:14:11,079
targets are our amazing science that was

370
00:14:08,350 --> 00:14:13,330
ongoing and the best picture I got of

371

00:14:11,080 --> 00:14:16,330
the entire flight they let I got to fly

372
00:14:13,330 --> 00:14:20,139
in the cockpit for a little bit at the

373
00:14:16,330 --> 00:14:21,639
top you know the jump seat and the you

374
00:14:20,139 --> 00:14:23,110
know so that's a pretty open section of

375
00:14:21,639 --> 00:14:25,330
the plane and the nice thing was when we

376
00:14:23,110 --> 00:14:26,680
were over Juno there were the northern

377
00:14:25,330 --> 00:14:28,300
this is a terrible picture but the

378
00:14:26,679 --> 00:14:30,129
northern lights occupied the entire left

379
00:14:28,299 --> 00:14:31,329
side of the plane so it's the most

380
00:14:30,129 --> 00:14:33,460
stunning view of the Northern Lights I'm

381
00:14:31,330 --> 00:14:34,720
ever gonna get so that was really

382
00:14:33,460 --> 00:14:36,670
probably the best picture in the flight

383
00:14:34,720 --> 00:14:39,820
but we did get some data and some

384
00:14:36,669 --> 00:14:41,500
science happened and this fun press

385
00:14:39,820 --> 00:14:43,450

release on gluttonous stars that you can

386
00:14:41,500 --> 00:14:46,240
read and I'm happy to explain some other

387
00:14:43,450 --> 00:14:47,710
time and you know my press briefing

388
00:14:46,240 --> 00:14:50,169
happened and I was really excited about

389
00:14:47,710 --> 00:14:52,990
the big news and you know I hope to go

390
00:14:50,169 --> 00:14:54,250
back again soon and in terms of the

391
00:14:52,990 --> 00:14:55,629
actual science that we discovered I

392
00:14:54,250 --> 00:14:59,320
think I'm gonna leave that to our main

393
00:14:55,629 --> 00:15:01,649
speaker let me introduce dr. Christine

394
00:14:59,320 --> 00:15:01,650
Chen

395
00:15:03,090 --> 00:15:09,509
[Applause]

396
00:15:05,870 --> 00:15:11,580
so Christine got did her undergraduate

397
00:15:09,509 --> 00:15:15,750
at Caltech she's from California

398
00:15:11,580 --> 00:15:19,410
originally she got her PhD from UCLA yes

399
00:15:15,750 --> 00:15:20,730
and became a Spitzer fellow so she was

400
00:15:19,409 --> 00:15:22,230
working on the spitzer space telescope

401
00:15:20,730 --> 00:15:25,139
she was actually funded directly by

402
00:15:22,230 --> 00:15:26,039
their grants program and she worked on

403
00:15:25,139 --> 00:15:28,199
that for a number of years where we

404
00:15:26,039 --> 00:15:31,289
collaborated on projects when I was a

405
00:15:28,200 --> 00:15:33,450
little wee graduate student and then she

406
00:15:31,289 --> 00:15:34,860
became the miry one of the miry

407
00:15:33,450 --> 00:15:37,340
instrument scientists here at the Space

408
00:15:34,860 --> 00:15:39,539
Telescope Science Institute in 2008 and

409
00:15:37,340 --> 00:15:41,460
she remained in that position until this

410
00:15:39,539 --> 00:15:42,959
year where she when she became the

411
00:15:41,460 --> 00:15:45,330
deputy project scientist for the entire

412
00:15:42,960 --> 00:15:47,160
James Webb Space Telescope so she knows

413
00:15:45,330 --> 00:15:48,720
a lot about that and she can tell you a

414
00:15:47,159 --> 00:15:51,209
lot about young stars and really cool

415
00:15:48,720 --> 00:15:54,540
stuff about planets and take it away

416
00:15:51,210 --> 00:15:56,310
Christine thanks for the introduction

417
00:15:54,539 --> 00:15:59,279
Joel I'm gonna talk about things that

418
00:15:56,309 --> 00:16:01,439
are very related to what Joel just kind

419
00:15:59,279 --> 00:16:03,720
of told you about so in particular

420
00:16:01,440 --> 00:16:06,330
electoral I'm an infrared astronomer and

421
00:16:03,720 --> 00:16:10,820
I'm also interested in how planetary

422
00:16:06,330 --> 00:16:12,870
systems form and evolve so Joel the

423
00:16:10,820 --> 00:16:16,170
targets that Joel was looking at were

424
00:16:12,870 --> 00:16:18,419
fairly young stars that still have these

425
00:16:16,169 --> 00:16:21,689
nascent clouds of gas and dust and are

426
00:16:18,419 --> 00:16:23,490
still forming giant planets the targets

427
00:16:21,690 --> 00:16:25,710
that I tend to look at our planetary

428

00:16:23,490 --> 00:16:28,680
systems that are somewhat older and that

429
00:16:25,710 --> 00:16:30,750
are perhaps more analogous to our own

430
00:16:28,679 --> 00:16:33,029
solar system although some of these

431
00:16:30,750 --> 00:16:35,159
systems can be young too the defining

432
00:16:33,029 --> 00:16:36,509
difference between the systems that I

433
00:16:35,159 --> 00:16:38,370
look at and some of the ones that Joel

434
00:16:36,509 --> 00:16:41,970
showed you some nice observations from

435
00:16:38,370 --> 00:16:44,549
is the presence or absence of molecular

436
00:16:41,970 --> 00:16:47,310
gas so if you think about the

437
00:16:44,549 --> 00:16:50,370
interstellar medium and what's contained

438
00:16:47,309 --> 00:16:54,239
in the region between stars we know that

439
00:16:50,370 --> 00:16:57,659
it's largely gas and dust and with about

440
00:16:54,240 --> 00:16:59,430
a hundred times more gas by mass than

441
00:16:57,659 --> 00:17:02,339
dust and predominantly a lot of this is

442
00:16:59,429 --> 00:17:04,698

contained in molecular hydrogen for the

443
00:17:02,340 --> 00:17:07,078
the systems that I'm going to talk about

444
00:17:04,699 --> 00:17:09,600
we think that in the majority of them

445
00:17:07,078 --> 00:17:12,480
the giant planets have already formed

446
00:17:09,599 --> 00:17:14,938
and so in that process all of the gas

447
00:17:12,480 --> 00:17:15,599
that was in the disk has accreted on to

448
00:17:14,939 --> 00:17:17,730
the star

449
00:17:15,599 --> 00:17:20,279
or created onto the atmospheres of

450
00:17:17,730 --> 00:17:22,860
jovian planets or been expelled out of

451
00:17:20,279 --> 00:17:25,109
the planetary system so these are much

452
00:17:22,859 --> 00:17:29,699
more analogous to our own solar system

453
00:17:25,109 --> 00:17:31,649
than protoplanetary discs so if you were

454
00:17:29,700 --> 00:17:33,600
to try to take a high-resolution image

455
00:17:31,650 --> 00:17:35,970
of some of the systems that I study

456
00:17:33,599 --> 00:17:37,589
these so-called debris disks this is

457
00:17:35,970 --> 00:17:39,000
actually a picture that you might see

458
00:17:37,589 --> 00:17:40,889
this is a picture that was obtained with

459
00:17:39,000 --> 00:17:43,048
the Hubble Space Telescope the advanced

460
00:17:40,890 --> 00:17:45,710
camera for surveys it has what's known

461
00:17:43,048 --> 00:17:47,970
as a corona graphic instrument so

462
00:17:45,710 --> 00:17:50,340
coronagraphs were developed to study the

463
00:17:47,970 --> 00:17:53,480
corona of the Sun and essentially what

464
00:17:50,339 --> 00:17:56,158
they contain is a physical mechanism

465
00:17:53,480 --> 00:17:58,860
something mechanical for blocking out

466
00:17:56,159 --> 00:18:00,960
the bright disk of the Sun and allowing

467
00:17:58,859 --> 00:18:03,569
you to study the faint Corona of the

468
00:18:00,960 --> 00:18:06,419
star or the Sun and in this particular

469
00:18:03,569 --> 00:18:08,158
case what we're doing instead is we're

470
00:18:06,419 --> 00:18:10,950
blocking out the light from the central

471
00:18:08,159 --> 00:18:14,280
star in the planetary system and by

472
00:18:10,950 --> 00:18:16,319
doing so having the possibility then of

473
00:18:14,279 --> 00:18:16,859
detecting fainter material around the

474
00:18:16,319 --> 00:18:20,730
star

475
00:18:16,859 --> 00:18:23,548
whether that is faint planets Jovian

476
00:18:20,730 --> 00:18:25,470
mass planets or lower mass planets or in

477
00:18:23,548 --> 00:18:28,048
this particular case what you see is a

478
00:18:25,470 --> 00:18:31,380
ring of dust which is around this star

479
00:18:28,048 --> 00:18:34,259
so this is the star Fomalhaut it's a one

480
00:18:31,380 --> 00:18:36,390
of the nearest stars to our Sun it's

481
00:18:34,259 --> 00:18:38,609
about 10 parsecs away and this is a

482
00:18:36,390 --> 00:18:42,360
intermediate-mass star so it's mass is

483
00:18:38,609 --> 00:18:44,428
about twice the mass of our Sun so when

484
00:18:42,359 --> 00:18:46,048
I think of these systems this is kind of

485

00:18:44,429 --> 00:18:49,140
the typical kind of picture that I have

486
00:18:46,048 --> 00:18:51,179
in my head although many of the systems

487
00:18:49,140 --> 00:18:53,509
that we observe and try to learn about

488
00:18:51,179 --> 00:18:56,519
we don't have such pretty pictures for

489
00:18:53,509 --> 00:18:59,700
so this is just a quick outline of my

490
00:18:56,519 --> 00:19:02,158
talk so again many of these systems are

491
00:18:59,700 --> 00:19:03,870
very analogous to our solar system so

492
00:19:02,159 --> 00:19:07,919
it's useful to stand back and to think

493
00:19:03,869 --> 00:19:09,629
about our solar system and the the

494
00:19:07,919 --> 00:19:11,820
demographics of bodies in our solar

495
00:19:09,630 --> 00:19:13,200
system so there are the giant planets

496
00:19:11,819 --> 00:19:14,668
the terrestrial planets there's

497
00:19:13,200 --> 00:19:17,100
asteroids and comets and there's

498
00:19:14,669 --> 00:19:18,809
actually dust as well so I'll tell you a

499
00:19:17,099 --> 00:19:21,329

little bit about the solar system dust

500
00:19:18,808 --> 00:19:23,730
and then there's actually forces that

501
00:19:21,329 --> 00:19:25,980
act on the dust that rearrange the dust

502
00:19:23,730 --> 00:19:28,169
in our solar system so for example

503
00:19:25,980 --> 00:19:29,460
there's radiation pressure which can

504
00:19:28,169 --> 00:19:31,679
blow dust out

505
00:19:29,460 --> 00:19:33,929
and there's also something called

506
00:19:31,679 --> 00:19:36,450
pointing robertson drag which is a

507
00:19:33,929 --> 00:19:38,009
relativistic effect which causes larger

508
00:19:36,450 --> 00:19:39,298
dust grains to spiral into the central

509
00:19:38,009 --> 00:19:41,158
star so I'll tell you about some of

510
00:19:39,298 --> 00:19:43,168
these forces that rearrange dust in our

511
00:19:41,159 --> 00:19:45,750
own solar system

512
00:19:43,169 --> 00:19:47,538
so these populations this population of

513
00:19:45,750 --> 00:19:50,819
dust that we see in our own solar system

514
00:19:47,538 --> 00:19:53,038
has now been analogous populations have

515
00:19:50,819 --> 00:19:56,700
been seen around other stars other

516
00:19:53,038 --> 00:19:57,839
main-sequence other midlife stars and

517
00:19:56,700 --> 00:20:00,360
I'll tell you about some of the

518
00:19:57,839 --> 00:20:02,819
demographics from the early iris

519
00:20:00,359 --> 00:20:04,849
discoveries and then Spitzer was a

520
00:20:02,819 --> 00:20:07,470
tremendous boon to this area of study

521
00:20:04,849 --> 00:20:09,808
where iris discovered maybe about a

522
00:20:07,470 --> 00:20:11,579
hundred targets Spitzer told us about

523
00:20:09,808 --> 00:20:13,769
maybe a thousand so an order of

524
00:20:11,579 --> 00:20:16,500
magnitude more and gave us much more

525
00:20:13,769 --> 00:20:19,019
detailed spectroscopic information about

526
00:20:16,500 --> 00:20:20,548
these targets and then because as dole

527
00:20:19,019 --> 00:20:22,740
mentioned I worked on JB St I'm

528
00:20:20,548 --> 00:20:25,619
tremendously excited about the gains

529
00:20:22,740 --> 00:20:27,000
that jade was T will make especially in

530
00:20:25,619 --> 00:20:29,298
this area of science and I'll try to

531
00:20:27,000 --> 00:20:32,429
give you a hint of what that looks like

532
00:20:29,298 --> 00:20:33,929
so I put this outline on top of this

533
00:20:32,429 --> 00:20:36,840
really beautiful picture of the night

534
00:20:33,929 --> 00:20:39,900
sky and this is just to remind you of

535
00:20:36,839 --> 00:20:42,538
what the dust in our solar system looks

536
00:20:39,900 --> 00:20:45,240
like so there is the zodiacal dust in

537
00:20:42,538 --> 00:20:47,009
our solar system which is produced it's

538
00:20:45,240 --> 00:20:49,679
in the region of the asteroid belt and

539
00:20:47,009 --> 00:20:52,679
you can see it here at a time that's

540
00:20:49,679 --> 00:20:54,120
pretty much close to sunset so that

541
00:20:52,679 --> 00:20:56,250
you're not looking very far away from

542

00:20:54,119 --> 00:20:58,439
the Sun but you can see from the dark

543
00:20:56,250 --> 00:20:59,909
site here this is the Milky Way and then

544
00:20:58,440 --> 00:21:03,179
you can see this sort of linear feature

545
00:20:59,909 --> 00:21:04,860
here in sort of reflected light this is

546
00:21:03,179 --> 00:21:06,870
light that's reflected off of dust

547
00:21:04,859 --> 00:21:09,149
grains in our solar system again this is

548
00:21:06,869 --> 00:21:11,369
called zodiacal light and it's produced

549
00:21:09,150 --> 00:21:16,080
by sunlight scattered off of what's

550
00:21:11,369 --> 00:21:18,750
called as a dial dust so this is just a

551
00:21:16,079 --> 00:21:21,058
reminder agile already spoke about this

552
00:21:18,750 --> 00:21:23,339
a little bit about the bodies that we

553
00:21:21,058 --> 00:21:24,538
find in our own solar system of course

554
00:21:23,339 --> 00:21:27,058
we're the most familiar with the

555
00:21:24,538 --> 00:21:28,890
terrestrial planets and there are so

556
00:21:27,058 --> 00:21:31,019

many really beautiful images of the

557
00:21:28,890 --> 00:21:34,440
jovian planets and we've learned so much

558
00:21:31,019 --> 00:21:36,418
about them but in addition to the

559
00:21:34,440 --> 00:21:39,808
planets there's also a number of

560
00:21:36,419 --> 00:21:41,520
populations of minor bodies so the ones

561
00:21:39,808 --> 00:21:43,730
that most people are familiar with are

562
00:21:41,519 --> 00:21:49,158
the asteroid belt

563
00:21:43,730 --> 00:21:51,980
these are a kilometer up to tens of

564
00:21:49,159 --> 00:21:56,269
kilometers sighs bodies that live

565
00:21:51,980 --> 00:21:58,970
between Mars and Jupiter and then in the

566
00:21:56,269 --> 00:22:00,798
outer reaches of the solar system beyond

567
00:21:58,970 --> 00:22:05,028
the orbit of Neptune there is the Kuiper

568
00:22:00,798 --> 00:22:08,210
belt and the largest objects and the

569
00:22:05,028 --> 00:22:10,730
Kuiper belts have been named I store

570
00:22:08,210 --> 00:22:12,798
planets so adul also mentioned this

571
00:22:10,730 --> 00:22:13,399
controversy about what is the status of

572
00:22:12,798 --> 00:22:15,230
Pluto

573
00:22:13,398 --> 00:22:18,048
so as you call it was originally a

574
00:22:15,230 --> 00:22:20,720
planet that has been reclassified as an

575
00:22:18,048 --> 00:22:23,028
ice storm planet so for the most part

576
00:22:20,720 --> 00:22:26,870
all of these objects play and the

577
00:22:23,028 --> 00:22:31,069
zodiacal in those a vehicle plane in the

578
00:22:26,869 --> 00:22:33,229
plane of the solar system and but the

579
00:22:31,069 --> 00:22:36,740
last population which is called the Oort

580
00:22:33,230 --> 00:22:39,710
cloud actually lies in a spherical

581
00:22:36,740 --> 00:22:41,990
distribution around the Sun and these

582
00:22:39,710 --> 00:22:44,149
are small bodies that are sort of

583
00:22:41,990 --> 00:22:45,679
analogous to Kuiper belt objects obses

584
00:22:44,148 --> 00:22:47,508
furred they've been scattered out to

585
00:22:45,679 --> 00:22:49,669
very large distances in all different

586
00:22:47,509 --> 00:22:53,089
directions from the Sun and this happens

587
00:22:49,669 --> 00:22:55,370
because the small bodies for example in

588
00:22:53,089 --> 00:22:56,898
the Kuiper belt might have migrated into

589
00:22:55,369 --> 00:22:58,548
the inner solar system and then

590
00:22:56,898 --> 00:23:01,579
gravitationally encountered Jupiter

591
00:22:58,548 --> 00:23:04,548
Saturn and then slung into the outer

592
00:23:01,579 --> 00:23:07,579
part of the solar system so when I think

593
00:23:04,548 --> 00:23:09,859
about the solar system this is what I

594
00:23:07,579 --> 00:23:11,178
think about this is the part of the

595
00:23:09,859 --> 00:23:13,278
solar system that were most familiar

596
00:23:11,179 --> 00:23:15,350
with the inner 5au with the terrestrial

597
00:23:13,278 --> 00:23:18,798
planets and the asteroid belts and then

598
00:23:15,349 --> 00:23:22,878
moving out to the outer solar system you

599

00:23:18,798 --> 00:23:25,278
can see the orbits here for the giant

600
00:23:22,878 --> 00:23:28,689
planets the gas giants and then this

601
00:23:25,278 --> 00:23:30,919
population of Kuiper belt objects and

602
00:23:28,690 --> 00:23:33,048
both in the Kuiper belt in the asteroid

603
00:23:30,919 --> 00:23:36,110
belt those small bodies collide ground

604
00:23:33,048 --> 00:23:38,720
down and produce dust strains and then

605
00:23:36,109 --> 00:23:41,240
on larger scales the spherical

606
00:23:38,720 --> 00:23:45,919
distribution of small bodies that makes

607
00:23:41,240 --> 00:23:49,099
up that were cloud so I showed you a

608
00:23:45,919 --> 00:23:52,759
nice scattered light image of dust in

609
00:23:49,099 --> 00:23:54,289
our solar system that beautiful panorama

610
00:23:52,759 --> 00:23:57,200
of the Milky Way and then

611
00:23:54,289 --> 00:23:59,839
the zodiacal light this is another way

612
00:23:57,200 --> 00:24:01,340
to look at the sky and this is an image

613
00:23:59,839 --> 00:24:03,819

that was taken from the infrared

614
00:24:01,339 --> 00:24:07,699
astronomical satellite so this was a

615
00:24:03,819 --> 00:24:09,619
satellite that launched in 1983 and it

616
00:24:07,700 --> 00:24:13,700
surveyed the entire sky in the infrared

617
00:24:09,619 --> 00:24:16,969
so it mapped the sky at 1225 60 and 100

618
00:24:13,700 --> 00:24:19,309
microns when you look at this map it

619
00:24:16,970 --> 00:24:21,980
doesn't look like most maps that you're

620
00:24:19,309 --> 00:24:25,730
familiar with because you're seeing the

621
00:24:21,980 --> 00:24:27,829
heat signature from bodies both in the

622
00:24:25,730 --> 00:24:31,430
Milky Way so this is the Galactic plane

623
00:24:27,829 --> 00:24:33,529
here so this is the our galaxy and then

624
00:24:31,430 --> 00:24:36,620
also the heat signature for foreground

625
00:24:33,529 --> 00:24:39,410
closer objects so this thing tilted here

626
00:24:36,619 --> 00:24:41,539
this is dust this is a dial dust in our

627
00:24:39,410 --> 00:24:43,880
solar system so you can see the plane of

628
00:24:41,539 --> 00:24:47,509
our solar system is canted compared to

629
00:24:43,880 --> 00:24:49,670
the plane of the Milky Way so this is to

630
00:24:47,509 --> 00:24:53,029
illustrate that when you look at these

631
00:24:49,670 --> 00:24:54,500
maps of heat you're seeing in the far

632
00:24:53,029 --> 00:24:57,259
infrared you're looking at maps of heat

633
00:24:54,500 --> 00:25:00,980
and this is an incredibly efficient way

634
00:24:57,259 --> 00:25:02,629
to find dust because the dust for

635
00:25:00,980 --> 00:25:06,289
example that's in our solar system it

636
00:25:02,630 --> 00:25:08,000
absorbs sunlight from our Sun and that

637
00:25:06,289 --> 00:25:11,029
causes the dust grains to heat up to

638
00:25:08,000 --> 00:25:14,450
about 230 K and then those dust grains

639
00:25:11,029 --> 00:25:17,500
are irradiate temperature heat which is

640
00:25:14,450 --> 00:25:19,910
detectable in the far infrared is light

641
00:25:17,500 --> 00:25:22,160
what's particularly powerful is that

642
00:25:19,910 --> 00:25:25,519
with the dust grains is that if you

643
00:25:22,160 --> 00:25:27,920
think of a particular mass of stuff and

644
00:25:25,519 --> 00:25:31,099
small dust grains you have a lot of

645
00:25:27,920 --> 00:25:33,830
surface area for those small dust grains

646
00:25:31,099 --> 00:25:35,899
compared to like a planet so for example

647
00:25:33,829 --> 00:25:37,970
if you were to imagine Jupiter broken up

648
00:25:35,900 --> 00:25:40,220
into micron sized dust grains there's

649
00:25:37,970 --> 00:25:41,930
much more surface area in those micron

650
00:25:40,220 --> 00:25:44,089
sized dust grains compared to the planet

651
00:25:41,930 --> 00:25:46,660
Jupiter and this is what makes it so

652
00:25:44,089 --> 00:25:51,279
easy to detect those dust grains then

653
00:25:46,660 --> 00:25:54,650
through the infrared thermal emission so

654
00:25:51,279 --> 00:25:57,769
so if this is the is a die of coal it--

655
00:25:54,650 --> 00:26:01,310
which was maps so beautifully here by

656

00:25:57,769 --> 00:26:03,740
the IR s satellite you know it's

657
00:26:01,309 --> 00:26:06,710
interesting to try to understand what is

658
00:26:03,740 --> 00:26:08,120
the connection between this dust and for

659
00:26:06,710 --> 00:26:11,240
example the miner bodies

660
00:26:08,119 --> 00:26:13,839
our solar system so this is a plot

661
00:26:11,240 --> 00:26:16,370
showing you the orbital parameters of

662
00:26:13,839 --> 00:26:19,039
asteroids in the main asteroid belt in

663
00:26:16,369 --> 00:26:21,169
particular the y-axis here shows you the

664
00:26:19,039 --> 00:26:23,389
inclination of their orbits plot as a

665
00:26:21,170 --> 00:26:25,670
function of their semi-major axis and

666
00:26:23,390 --> 00:26:29,060
every little dot on this plot represents

667
00:26:25,670 --> 00:26:30,529
a single asteroid a plot like this was

668
00:26:29,059 --> 00:26:33,470
first made by an astronomer named

669
00:26:30,529 --> 00:26:36,559
Hariyama in 1918 and one of the stunning

670
00:26:33,470 --> 00:26:37,850

things that he discovered was that and

671
00:26:36,559 --> 00:26:40,069
you can see this when you look at this

672
00:26:37,849 --> 00:26:42,399
more modern plot today is that there is

673
00:26:40,069 --> 00:26:45,799
structure in this plot so for example

674
00:26:42,400 --> 00:26:48,290
there's a gap here an absence of

675
00:26:45,799 --> 00:26:53,059
asteroids this is the Kirkwood gap and

676
00:26:48,289 --> 00:26:54,829
so this is a location where if a body

677
00:26:53,059 --> 00:26:57,289
was here it would be in resonance with

678
00:26:54,829 --> 00:26:59,419
Jupiter and that resonance then makes

679
00:26:57,289 --> 00:27:02,210
the object unstable gravitationally

680
00:26:59,420 --> 00:27:04,009
unstable so it gets ejected out of that

681
00:27:02,210 --> 00:27:06,680
orbit so that's why this whole region is

682
00:27:04,009 --> 00:27:09,259
clear but in addition to structures like

683
00:27:06,680 --> 00:27:12,470
that you can actually also see clumping

684
00:27:09,259 --> 00:27:14,900
of objects in this plot and when this

685
00:27:12,470 --> 00:27:17,089
was first noticed it was hypothesized

686
00:27:14,900 --> 00:27:19,970
that the reason why you have so many

687
00:27:17,089 --> 00:27:21,289
objects that are in these clumps is that

688
00:27:19,970 --> 00:27:24,319
they were originally part of a larger

689
00:27:21,289 --> 00:27:27,230
object that broke apart into smaller

690
00:27:24,319 --> 00:27:31,069
pieces and so they still retained the

691
00:27:27,230 --> 00:27:34,940
overall same orbital parameters that you

692
00:27:31,069 --> 00:27:37,250
see you know on this plot but there's

693
00:27:34,940 --> 00:27:41,529
now a little bit of dispersion from

694
00:27:37,250 --> 00:27:45,410
having broken up you can imagine that

695
00:27:41,529 --> 00:27:47,809
when you have the breakup of an asteroid

696
00:27:45,410 --> 00:27:49,550
you create not just large objects but

697
00:27:47,809 --> 00:27:51,919
actually a whole size distribution of

698
00:27:49,549 --> 00:27:54,259
particles so not just things that have

699
00:27:51,920 --> 00:27:56,450
sizes of a kilometer or ten kilometers

700
00:27:54,259 --> 00:27:58,700
but things all the way down to fine

701
00:27:56,450 --> 00:28:00,980
grain dust things with the size of a

702
00:27:58,700 --> 00:28:04,130
micron or so and those are things that

703
00:28:00,980 --> 00:28:07,579
again have a lot of surface area for

704
00:28:04,130 --> 00:28:09,500
their mass and so they're very

705
00:28:07,579 --> 00:28:12,049
efficiently warmed up and they very

706
00:28:09,500 --> 00:28:15,349
efficiently radiate that the heat the

707
00:28:12,049 --> 00:28:17,389
energy that they absorb and so one of

708
00:28:15,349 --> 00:28:20,569
the really interesting discoveries of

709
00:28:17,390 --> 00:28:21,950
the i-rath satellite was structures in

710
00:28:20,569 --> 00:28:24,918
the zodiacal light in

711
00:28:21,950 --> 00:28:28,850
vehicle dust and in particular so these

712
00:28:24,919 --> 00:28:30,740
are sort of zoomed in pictures of the

713

00:28:28,849 --> 00:28:34,189
sadaqa light in which you can see that

714
00:28:30,740 --> 00:28:36,528
there's actually these bands where you

715
00:28:34,190 --> 00:28:39,019
have an enhancement of small particles

716
00:28:36,528 --> 00:28:42,288
and the dust and the inner part of the

717
00:28:39,019 --> 00:28:44,329
solar system you can go through and

718
00:28:42,288 --> 00:28:46,398
model in better detail what the orbital

719
00:28:44,329 --> 00:28:48,259
parameters are associated with these

720
00:28:46,398 --> 00:28:52,099
dust bands and you find that they're

721
00:28:48,259 --> 00:28:53,839
actually coincident with for the

722
00:28:52,099 --> 00:28:55,759
particular case of these dust bands so

723
00:28:53,839 --> 00:28:58,480
alpha beta and gamma dust bands they're

724
00:28:55,759 --> 00:29:02,929
orbital parameters are coincident with

725
00:28:58,480 --> 00:29:04,759
the famous es and Cronus families and so

726
00:29:02,929 --> 00:29:07,190
this tells you that this these are the

727
00:29:04,759 --> 00:29:09,169

small particles that were formed when

728
00:29:07,190 --> 00:29:10,639
the larger body broke up so not only do

729
00:29:09,169 --> 00:29:13,399
you see the large bodies in this

730
00:29:10,638 --> 00:29:16,969
asteroid plot orbital parameter plot but

731
00:29:13,398 --> 00:29:18,558
then you also see in maps the sky the

732
00:29:16,970 --> 00:29:22,278
fine dust grains that are created and

733
00:29:18,558 --> 00:29:24,440
when they break up so so infrared a lot

734
00:29:22,278 --> 00:29:27,500
of infrared astronomy is about detecting

735
00:29:24,440 --> 00:29:29,409
the heat signature from dust and so I

736
00:29:27,500 --> 00:29:33,138
just wanted to remind you about

737
00:29:29,409 --> 00:29:36,710
blackbody emission and how it works so

738
00:29:33,138 --> 00:29:39,859
this particular plot shows you intensity

739
00:29:36,710 --> 00:29:43,159
as a function of wavelength so this side

740
00:29:39,859 --> 00:29:44,990
is blue and this side is red for in this

741
00:29:43,159 --> 00:29:48,049
particular case it would be stars of

742
00:29:44,990 --> 00:29:51,470
various temperatures so 3,000 4,000

743
00:29:48,048 --> 00:29:53,658
5,000 6,000 Kelvin so our Sun has a

744
00:29:51,470 --> 00:29:55,490
temperature of about 5800 Kelvin so it's

745
00:29:53,659 --> 00:29:58,549
approximately like this 6,000 Kelvin

746
00:29:55,490 --> 00:30:02,569
star so in the particular case of our

747
00:29:58,548 --> 00:30:04,579
sign you can see that the peak of the

748
00:30:02,569 --> 00:30:07,189
light that comes out is about 5500

749
00:30:04,579 --> 00:30:10,759
angstroms it sort of corresponds to

750
00:30:07,190 --> 00:30:13,639
yellow-green but if you imagine stars

751
00:30:10,759 --> 00:30:16,429
that have decreasing temperatures the

752
00:30:13,638 --> 00:30:19,250
peak in this blackbody function actually

753
00:30:16,429 --> 00:30:21,019
shifts to the right and so the energy

754
00:30:19,250 --> 00:30:22,940
that comes out for lower and lower

755
00:30:21,019 --> 00:30:24,589
temperature stars is redder and redder

756
00:30:22,940 --> 00:30:26,509
so they have redder and redder colors

757
00:30:24,589 --> 00:30:28,398
the other thing that you notice is that

758
00:30:26,509 --> 00:30:29,960
as you lower the temperature the

759
00:30:28,398 --> 00:30:32,509
brightness or the intensity of the

760
00:30:29,960 --> 00:30:34,848
object also decreases so when you lower

761
00:30:32,509 --> 00:30:37,848
the temperatures for things

762
00:30:34,848 --> 00:30:40,638
radiation becomes longer and wavelength

763
00:30:37,848 --> 00:30:42,979
more red and it also diminishes lowers

764
00:30:40,638 --> 00:30:45,798
and intensity so that's one of the major

765
00:30:42,979 --> 00:30:48,259
tools that we look at is detecting the

766
00:30:45,798 --> 00:30:51,618
heat and I'll tell you more about the

767
00:30:48,259 --> 00:30:53,569
observations for the dust in our

768
00:30:51,618 --> 00:30:55,939
particular solar system it turns out

769
00:30:53,569 --> 00:30:58,729
that it doesn't really stay put from

770

00:30:55,940 --> 00:31:01,909
where it's generated so you can imagine

771
00:30:58,729 --> 00:31:04,609
for example asteroids that collide

772
00:31:01,909 --> 00:31:06,379
together and as they do so they grind

773
00:31:04,608 --> 00:31:08,749
down and produce little tiny dust grains

774
00:31:06,378 --> 00:31:10,759
it turns out that for the smallest

775
00:31:08,749 --> 00:31:12,528
screens and the size distribution they

776
00:31:10,759 --> 00:31:14,538
have a lot of surface area for their

777
00:31:12,528 --> 00:31:17,088
volume so they have a lot of surface

778
00:31:14,538 --> 00:31:18,558
area for their mass and so that actually

779
00:31:17,088 --> 00:31:20,479
means that they're not gravitationally

780
00:31:18,558 --> 00:31:23,239
bound to the star and so they act like

781
00:31:20,479 --> 00:31:25,969
tiny sails and so the radiation pressure

782
00:31:23,239 --> 00:31:27,919
just drives them blows them out of our

783
00:31:25,969 --> 00:31:30,109
solar system and so in some sense

784
00:31:27,919 --> 00:31:31,819

there's a minimum size to the dust

785
00:31:30,108 --> 00:31:35,868
grains that are in our in our solar

786
00:31:31,818 --> 00:31:38,418
system for dust grains that are larger

787
00:31:35,868 --> 00:31:41,358
there are no longer sensitive to

788
00:31:38,419 --> 00:31:43,219
radiation pressure in this way but what

789
00:31:41,358 --> 00:31:45,019
happens to them instead is they feel a

790
00:31:43,219 --> 00:31:47,119
relativistic effects called pointing

791
00:31:45,019 --> 00:31:49,190
robertson drag and in that particular

792
00:31:47,118 --> 00:31:51,678
case you can imagine that you're a dust

793
00:31:49,190 --> 00:31:54,199
grain orbiting around the star and as

794
00:31:51,679 --> 00:31:56,959
you do so you feel a headwind of photons

795
00:31:54,199 --> 00:31:59,028
from the star and that causes you to

796
00:31:56,959 --> 00:32:00,769
slow down and so you lose angular

797
00:31:59,028 --> 00:32:01,338
momentum and you slowly spiral into the

798
00:32:00,769 --> 00:32:03,618
star

799
00:32:01,338 --> 00:32:05,479
so the basic takeaway message is the

800
00:32:03,618 --> 00:32:07,548
expectation or what happens in our solar

801
00:32:05,479 --> 00:32:09,409
system is that the small variance get

802
00:32:07,548 --> 00:32:12,348
radiatively blown out and the large

803
00:32:09,409 --> 00:32:18,729
larger ones spiral into the into the

804
00:32:12,348 --> 00:32:22,009
star so it turns out that for our Sun

805
00:32:18,729 --> 00:32:24,078
there's another effect that brings large

806
00:32:22,009 --> 00:32:26,209
dust for instance to the star it's

807
00:32:24,078 --> 00:32:28,368
called solar wind drag and this happens

808
00:32:26,209 --> 00:32:30,379
around active stars too and in this

809
00:32:28,368 --> 00:32:32,028
particular case it's very analogous to

810
00:32:30,378 --> 00:32:34,189
pointing robertson drag i've suffered

811
00:32:32,028 --> 00:32:37,249
the difference is that the star is

812
00:32:34,190 --> 00:32:41,328
emitting not only photons light but it's

813
00:32:37,249 --> 00:32:42,919
also emitting particles protons so and

814
00:32:41,328 --> 00:32:45,558
you can imagine now that what happens

815
00:32:42,919 --> 00:32:46,650
instead is that that orbiting dust grain

816
00:32:45,558 --> 00:32:49,259
feels a headway

817
00:32:46,650 --> 00:32:51,810
and of these protons of particles which

818
00:32:49,259 --> 00:32:53,279
then cause them to slow down lose

819
00:32:51,809 --> 00:32:55,919
angular momentum and spiral into the

820
00:32:53,279 --> 00:32:58,170
star so the just the the main point is

821
00:32:55,920 --> 00:33:01,769
just that dust in the solar system gets

822
00:32:58,170 --> 00:33:04,160
rearranged in these different ways so

823
00:33:01,769 --> 00:33:07,230
the part that really interests me is

824
00:33:04,160 --> 00:33:12,240
what do we know about planetary systems

825
00:33:07,230 --> 00:33:14,339
around other stars do we do we think

826
00:33:12,240 --> 00:33:16,980
that there are lots of other planetary

827

00:33:14,339 --> 00:33:22,109
systems that have analogous belts of

828
00:33:16,980 --> 00:33:24,329
small bodies and you know are they do

829
00:33:22,109 --> 00:33:26,939
they play some sort of role and how

830
00:33:24,329 --> 00:33:30,509
planetary systems form and evolve so for

831
00:33:26,940 --> 00:33:33,029
example if you think about our solar

832
00:33:30,509 --> 00:33:35,039
system and the earth one of the

833
00:33:33,029 --> 00:33:36,660
outstanding questions today is how was

834
00:33:35,039 --> 00:33:38,159
water delivered to the earth how did the

835
00:33:36,660 --> 00:33:39,000
oceans get here and that's that's

836
00:33:38,160 --> 00:33:42,210
actually something that we don't

837
00:33:39,000 --> 00:33:45,119
understand well and one of the ideas for

838
00:33:42,210 --> 00:33:47,039
the origin of the oceans was essentially

839
00:33:45,119 --> 00:33:49,859
they were delivered by comets from the

840
00:33:47,039 --> 00:33:51,329
outer solar system so these minor bodies

841
00:33:49,859 --> 00:33:54,029

might actually be a very important

842
00:33:51,329 --> 00:33:56,609
source of water in extrasolar planetary

843
00:33:54,029 --> 00:33:59,220
systems so the answer is that we've been

844
00:33:56,609 --> 00:34:01,229
able to discover minor bodies so

845
00:33:59,220 --> 00:34:04,079
asteroid and Kuiper belt populations

846
00:34:01,230 --> 00:34:07,110
around other stars and we do this in the

847
00:34:04,079 --> 00:34:09,090
infrared and particularly this started

848
00:34:07,109 --> 00:34:10,829
with the irath satellite so I showed you

849
00:34:09,090 --> 00:34:13,350
the beautiful off sky image and then

850
00:34:10,829 --> 00:34:15,269
showed you the zodiacal dust bands this

851
00:34:13,349 --> 00:34:18,619
was another one of the key contributions

852
00:34:15,269 --> 00:34:21,869
from the i-rath satellite so basically

853
00:34:18,619 --> 00:34:24,269
when IRS was launched they the

854
00:34:21,869 --> 00:34:27,000
astronomers envisioned that they would

855
00:34:24,269 --> 00:34:29,219
use nearby a type stars as calibrators

856
00:34:27,000 --> 00:34:32,159
and they felt that they understood very

857
00:34:29,219 --> 00:34:34,769
well what the flux from those stars

858
00:34:32,159 --> 00:34:37,800
should look like based on how they look

859
00:34:34,769 --> 00:34:39,179
at visual wavelengths and so basically

860
00:34:37,800 --> 00:34:41,399
if you look at these pots their

861
00:34:39,179 --> 00:34:44,550
brightness flux as a function of

862
00:34:41,398 --> 00:34:45,750
wavelength and you can see 12 25 60 100

863
00:34:44,550 --> 00:34:47,820
microns so these are far infrared

864
00:34:45,750 --> 00:34:50,699
wavelengths and these straight lines

865
00:34:47,820 --> 00:34:52,860
show you the expectations that people

866
00:34:50,699 --> 00:34:55,408
had for how bright those stars would be

867
00:34:52,860 --> 00:34:57,420
and you can see these error bars show

868
00:34:55,409 --> 00:34:59,550
you the actual data and what's really

869
00:34:57,420 --> 00:35:00,420
stunning is that these predictions for

870
00:34:59,550 --> 00:35:03,359
how bright the star

871
00:35:00,420 --> 00:35:05,970
should be was a factor of a hundred or

872
00:35:03,358 --> 00:35:09,480
so wrong for these four particular stars

873
00:35:05,969 --> 00:35:12,509
and so when this was discovered it was

874
00:35:09,480 --> 00:35:15,389
immediately hypothesized that the reason

875
00:35:12,510 --> 00:35:16,829
why they're so bright at 60 and 100

876
00:35:15,389 --> 00:35:18,989
microns is because you have

877
00:35:16,829 --> 00:35:21,240
circumstellar dust so dust around the

878
00:35:18,989 --> 00:35:23,879
star which is absorbing light from the

879
00:35:21,239 --> 00:35:27,088
star warming up and reradiating that

880
00:35:23,880 --> 00:35:29,579
energy is thermal emission and so that's

881
00:35:27,088 --> 00:35:33,268
the current understanding and indeed

882
00:35:29,579 --> 00:35:35,548
when astronomers were able to once they

883
00:35:33,268 --> 00:35:38,399
identified these interesting candidate

884

00:35:35,548 --> 00:35:40,768
targets so in this particular case this

885
00:35:38,400 --> 00:35:44,068
is like Vega Fomalhaut beta Pictoris and

886
00:35:40,768 --> 00:35:45,778
Epsilon Eridani they would go to other

887
00:35:44,068 --> 00:35:49,038
facilities and then try to take a

888
00:35:45,778 --> 00:35:51,420
picture of the planetary system and so

889
00:35:49,039 --> 00:35:53,160
when the first ones that they were able

890
00:35:51,420 --> 00:35:55,619
to do this successfully for was beta

891
00:35:53,159 --> 00:35:57,210
Pictoris this is a more modern image

892
00:35:55,619 --> 00:36:00,599
taken with the Hubble Space Telescope

893
00:35:57,210 --> 00:36:03,568
with this disk coronagraph in which the

894
00:36:00,599 --> 00:36:05,430
star has been placed behind an occulting

895
00:36:03,568 --> 00:36:07,528
wedge and you can see that there's this

896
00:36:05,429 --> 00:36:10,379
bright linear feature this is a disc

897
00:36:07,528 --> 00:36:13,469
that's being seen edge on and then you

898
00:36:10,380 --> 00:36:16,259

can see a different stretch here which

899
00:36:13,469 --> 00:36:18,239
shows you more clearly this edge on disc

900
00:36:16,259 --> 00:36:20,670
so this again is what you're seeing is

901
00:36:18,239 --> 00:36:23,518
heat from small dust grains in this

902
00:36:20,670 --> 00:36:25,559
particular system the really interesting

903
00:36:23,518 --> 00:36:28,018
thing about whenever people go out and

904
00:36:25,559 --> 00:36:30,450
take images of the system at higher and

905
00:36:28,018 --> 00:36:33,000
higher angular resolution is they find

906
00:36:30,449 --> 00:36:34,980
detailed structures that imply the

907
00:36:33,000 --> 00:36:36,480
presence of planets so in this

908
00:36:34,980 --> 00:36:38,490
particular case in the case of beta

909
00:36:36,480 --> 00:36:40,199
Pictoris what you can see is that the

910
00:36:38,489 --> 00:36:41,608
inner part of the disc is warped with

911
00:36:40,199 --> 00:36:45,659
respect to the outer part of the disc

912
00:36:41,608 --> 00:36:48,150
and the one of the hypotheses for why

913
00:36:45,659 --> 00:36:50,129
this is true is essentially that there

914
00:36:48,150 --> 00:36:52,889
is a companion that is a planetary mask

915
00:36:50,130 --> 00:36:56,608
size thing in this planetary system

916
00:36:52,889 --> 00:36:59,190
which disrupts the dust and forces the

917
00:36:56,608 --> 00:37:01,768
dust onto these inclined orbits if you

918
00:36:59,190 --> 00:37:04,559
look at the distance of this warp

919
00:37:01,768 --> 00:37:06,598
compared to the star you can then place

920
00:37:04,559 --> 00:37:09,210
constraints on the product of the mass

921
00:37:06,599 --> 00:37:10,570
of the planet and its distance from the

922
00:37:09,210 --> 00:37:12,579
central star

923
00:37:10,570 --> 00:37:15,550
and one of the really exciting things is

924
00:37:12,579 --> 00:37:18,009
in the 20 or 30 years of studying these

925
00:37:15,550 --> 00:37:20,080
particular objects people have been able

926
00:37:18,010 --> 00:37:23,700
to refine their understandings of these

927
00:37:20,079 --> 00:37:27,340
planetary systems and so this is now a

928
00:37:23,699 --> 00:37:29,589
even more recent image of the exact same

929
00:37:27,340 --> 00:37:32,829
system this is now ground-based data

930
00:37:29,590 --> 00:37:35,559
taken with a very large telescope so the

931
00:37:32,829 --> 00:37:37,900
European facility in Chile and it's a

932
00:37:35,559 --> 00:37:41,289
composite image showing you the disk but

933
00:37:37,900 --> 00:37:42,960
now you also see so the disk is taken

934
00:37:41,289 --> 00:37:45,309
with a coronagraph but now you also see

935
00:37:42,960 --> 00:37:48,220
images of a point source that were

936
00:37:45,309 --> 00:37:51,329
discovered very close to the star at

937
00:37:48,219 --> 00:37:54,099
about 10a you from the star this

938
00:37:51,329 --> 00:37:55,719
position on the sort of left side here

939
00:37:54,099 --> 00:37:57,400
was the discovery epoch and then it

940
00:37:55,719 --> 00:37:59,079
appeared to disappear for a while and

941

00:37:57,400 --> 00:38:01,210
then it reappeared so it first was

942
00:37:59,079 --> 00:38:04,960
detected in 2003 and then was reappeared

943
00:38:01,210 --> 00:38:07,119
in 2009 and so it is you're actually

944
00:38:04,960 --> 00:38:09,639
seeing then the orbital motion of a

945
00:38:07,119 --> 00:38:11,739
giant planet in this particular disk

946
00:38:09,639 --> 00:38:14,650
which is consistent with the structures

947
00:38:11,739 --> 00:38:18,519
that were seen in the dust from the

948
00:38:14,650 --> 00:38:21,220
older Hubble Space Telescope images so

949
00:38:18,519 --> 00:38:23,559
why do we want to go out and try to

950
00:38:21,219 --> 00:38:25,929
study these particular planetary systems

951
00:38:23,559 --> 00:38:27,610
we already learned so much from Kepler

952
00:38:25,929 --> 00:38:29,109
and looking at the demographics of

953
00:38:27,610 --> 00:38:30,970
planets that are detected through

954
00:38:29,110 --> 00:38:33,130
transit or radio velocity or other

955
00:38:30,969 --> 00:38:35,649

things and the answer is that it gives

956
00:38:33,130 --> 00:38:37,869
us complimentary information it's very

957
00:38:35,650 --> 00:38:39,639
hard with planets to understand what the

958
00:38:37,869 --> 00:38:42,639
detailed composition of the planet is

959
00:38:39,639 --> 00:38:45,069
because really all you ever met measure

960
00:38:42,639 --> 00:38:46,779
for like the transiting planets is the

961
00:38:45,070 --> 00:38:49,150
mass and the radius and so you get the

962
00:38:46,780 --> 00:38:50,530
density of the planet but in the case of

963
00:38:49,150 --> 00:38:53,079
these particular systems you have the

964
00:38:50,530 --> 00:38:55,420
opportunity to actually measure the

965
00:38:53,079 --> 00:38:57,730
detailed composition of the material and

966
00:38:55,420 --> 00:39:00,760
understand what's really made of and it

967
00:38:57,730 --> 00:39:02,920
also provides insight into particular

968
00:39:00,760 --> 00:39:06,000
epochs that were very violent in the

969
00:39:02,920 --> 00:39:09,400
formation of our own solar system and so

970
00:39:06,000 --> 00:39:11,050
early on in the trend terrestrial planet

971
00:39:09,400 --> 00:39:12,519
formation within the first 30 million

972
00:39:11,050 --> 00:39:15,519
years there are a lot of violent

973
00:39:12,519 --> 00:39:17,559
collisions in which you know things

974
00:39:15,519 --> 00:39:20,949
collided together to build up larger and

975
00:39:17,559 --> 00:39:23,170
larger things to form earth and then at

976
00:39:20,949 --> 00:39:24,399
ages of 30 100 million years we know

977
00:39:23,170 --> 00:39:27,159
that there were giant :

978
00:39:24,400 --> 00:39:30,030
in our solar system so for example we

979
00:39:27,159 --> 00:39:33,609
knew that mars-sized object called Theia

980
00:39:30,030 --> 00:39:36,430
impacted the earth and form the moon and

981
00:39:33,610 --> 00:39:38,590
so you know by studying these other

982
00:39:36,429 --> 00:39:40,449
systems we can understand whether or not

983
00:39:38,590 --> 00:39:43,329
these events in the history of our solar

984
00:39:40,449 --> 00:39:46,929
system are common or rare so this is

985
00:39:43,329 --> 00:39:51,759
just meant to be a nice simulation of I

986
00:39:46,929 --> 00:39:53,710
mentioned to you how giant impacts or

987
00:39:51,760 --> 00:40:00,040
important in the history of our solar

988
00:39:53,710 --> 00:40:03,159
system there goes and so this is just a

989
00:40:00,039 --> 00:40:06,009
simulation of the the moon-forming

990
00:40:03,159 --> 00:40:09,099
impact and in which the Thea sized body

991
00:40:06,010 --> 00:40:10,840
ran into the earth on a glancing sort of

992
00:40:09,099 --> 00:40:14,079
collision course and what you see here

993
00:40:10,840 --> 00:40:17,200
is basically the mantles of the two

994
00:40:14,079 --> 00:40:18,789
objects mixed together spin off and

995
00:40:17,199 --> 00:40:21,789
condense and eventually forming to the

996
00:40:18,789 --> 00:40:27,279
moon and then the core of the impactor

997
00:40:21,789 --> 00:40:30,190
actually sunk into the forming earth and

998

00:40:27,280 --> 00:40:33,550
so this explains a lot of what we know

999
00:40:30,190 --> 00:40:35,860
about the the properties of the moon so

1000
00:40:33,550 --> 00:40:38,200
for example the Apollo astronauts went

1001
00:40:35,860 --> 00:40:40,750
and collected lunar samples and analyzed

1002
00:40:38,199 --> 00:40:42,250
the composition of those and it turns

1003
00:40:40,750 --> 00:40:46,449
out they're very similar to the the

1004
00:40:42,250 --> 00:40:47,679
mantle of our own earth so we can try

1005
00:40:46,449 --> 00:40:49,589
and learn about these violent things

1006
00:40:47,679 --> 00:40:51,819
that happened in our solar system

1007
00:40:49,590 --> 00:40:55,120
whether they're giant collisions early

1008
00:40:51,820 --> 00:40:56,860
on or we also think that there is a an

1009
00:40:55,119 --> 00:40:58,389
interesting period in the evolution of

1010
00:40:56,860 --> 00:41:00,519
our solar system called the period of

1011
00:40:58,389 --> 00:41:02,259
late heavy bombardment but this happens

1012
00:41:00,519 --> 00:41:04,480

when our solar system had an age of

1013
00:41:02,260 --> 00:41:06,640
about 700 million years this is

1014
00:41:04,480 --> 00:41:10,090
preserved in the crater record of old

1015
00:41:06,639 --> 00:41:13,179
terrestrial surfaces such as the moon

1016
00:41:10,090 --> 00:41:15,850
and so these are maps showing you

1017
00:41:13,179 --> 00:41:17,889
highlighted craters I'm left over from

1018
00:41:15,849 --> 00:41:19,750
the period of late heavy bombardment at

1019
00:41:17,889 --> 00:41:21,429
about 700 million years so the

1020
00:41:19,750 --> 00:41:23,829
prevailing idea for how these craters

1021
00:41:21,429 --> 00:41:25,809
got to be there is essentially that the

1022
00:41:23,829 --> 00:41:28,750
giant planets the locations that we see

1023
00:41:25,809 --> 00:41:30,909
them at today are not the locations at

1024
00:41:28,750 --> 00:41:33,219
which those giant planets formed the

1025
00:41:30,909 --> 00:41:34,629
giant planets actually migrated from a

1026
00:41:33,219 --> 00:41:34,989
different location to where they are

1027
00:41:34,630 --> 00:41:37,099
today

1028
00:41:34,989 --> 00:41:39,859
and as they did so do

1029
00:41:37,099 --> 00:41:43,269
Saturn crossed the two Diwan residents

1030
00:41:39,860 --> 00:41:45,620
and basically the resonance crossing

1031
00:41:43,269 --> 00:41:47,389
destabilized all of the minor bodies and

1032
00:41:45,619 --> 00:41:50,480
our solar systems such as the asteroids

1033
00:41:47,389 --> 00:41:54,259
in the Kuiper belt and so basically all

1034
00:41:50,480 --> 00:41:55,849
of the minor bodies became chaotic for a

1035
00:41:54,260 --> 00:41:57,740
brief period and they went all

1036
00:41:55,849 --> 00:41:59,989
throughout the solar system and this is

1037
00:41:57,739 --> 00:42:03,349
sort of you can sort of visualize that

1038
00:41:59,989 --> 00:42:05,569
in this simulation here where the Rings

1039
00:42:03,349 --> 00:42:07,909
show you the orbits of the four

1040
00:42:05,570 --> 00:42:10,070
outermost planets and initially you saw

1041
00:42:07,909 --> 00:42:12,019
those green dots which were each one

1042
00:42:10,070 --> 00:42:13,519
represents the Kuiper belt and then you

1043
00:42:12,019 --> 00:42:15,110
can see the moment when you cross the

1044
00:42:13,519 --> 00:42:16,789
two-to-one resonance and all of those

1045
00:42:15,110 --> 00:42:20,900
things get to stabilize and they go

1046
00:42:16,789 --> 00:42:23,090
everywhere in the solar system so these

1047
00:42:20,900 --> 00:42:25,430
are the kinds of periods in the history

1048
00:42:23,090 --> 00:42:28,550
that we're trying to study so the tool

1049
00:42:25,429 --> 00:42:30,199
that I used and Joel used as well was

1050
00:42:28,550 --> 00:42:32,600
the Spitzer Space Telescope Spitzer

1051
00:42:30,199 --> 00:42:35,480
launched in 2003 it was cryogenic or

1052
00:42:32,599 --> 00:42:38,089
2004 it was cryogenic it was liquid

1053
00:42:35,480 --> 00:42:39,889
helium cooled to about four Kelvin but

1054
00:42:38,090 --> 00:42:44,120
it was a relatively small telescope it

1055

00:42:39,889 --> 00:42:48,440
was only 85 centimeters in diameter but

1056
00:42:44,119 --> 00:42:50,690
because it was so cold and in space it

1057
00:42:48,440 --> 00:42:52,280
had tremendous sensitivity compared to

1058
00:42:50,690 --> 00:42:54,860
any other facility at working at those

1059
00:42:52,280 --> 00:42:58,460
wavelengths prior so wavelengths of you

1060
00:42:54,860 --> 00:43:00,430
know a couple microns 260 microns and it

1061
00:42:58,460 --> 00:43:03,230
really enabled for the first time

1062
00:43:00,429 --> 00:43:07,969
solid-state infrared spectroscopy of

1063
00:43:03,230 --> 00:43:11,210
large samples of young discs and so the

1064
00:43:07,969 --> 00:43:13,359
this is whoops that's an excerpt from a

1065
00:43:11,210 --> 00:43:16,099
paper basically trying to illustrate

1066
00:43:13,360 --> 00:43:18,500
what these solid-state features from

1067
00:43:16,099 --> 00:43:21,529
silicates like olivine look like in the

1068
00:43:18,500 --> 00:43:23,360
infrared so basically you get a peak

1069
00:43:21,530 --> 00:43:25,700

this is like an emission feature around

1070
00:43:23,360 --> 00:43:28,130
10 microns and another one at 20 microns

1071
00:43:25,699 --> 00:43:30,619
it's really fascinating because just

1072
00:43:28,130 --> 00:43:32,960
like atoms when you you can tell the

1073
00:43:30,619 --> 00:43:35,269
composition of a gas by looking at the

1074
00:43:32,960 --> 00:43:38,510
spectrum from it you can tell the

1075
00:43:35,269 --> 00:43:41,630
composition of the dust material by

1076
00:43:38,510 --> 00:43:44,090
looking at the peak position of for

1077
00:43:41,630 --> 00:43:45,920
example of the material that you see the

1078
00:43:44,090 --> 00:43:47,570
spectrum before and the infrared but

1079
00:43:45,920 --> 00:43:49,099
more than that not only can tell you

1080
00:43:47,570 --> 00:43:50,820
tell what it's made of but you can

1081
00:43:49,099 --> 00:43:53,849
actually also tell how large the

1082
00:43:50,820 --> 00:43:56,940
strains are so it turns out that the

1083
00:43:53,849 --> 00:43:58,440
feature actually changes shape so

1084
00:43:56,940 --> 00:44:00,119
against this is brightness as a function

1085
00:43:58,440 --> 00:44:01,800
of wavelength but the feature changes

1086
00:44:00,119 --> 00:44:04,969
shape depending on how large the grains

1087
00:44:01,800 --> 00:44:07,950
are so for small grains the feature is

1088
00:44:04,969 --> 00:44:11,309
sort of triangular so it's tall and

1089
00:44:07,949 --> 00:44:14,069
pointy and if as the grains grow the

1090
00:44:11,309 --> 00:44:17,309
feature actually becomes more broad and

1091
00:44:14,070 --> 00:44:19,769
trapezoidal in shape and so by fitting

1092
00:44:17,309 --> 00:44:22,259
the shapes of these features you can

1093
00:44:19,769 --> 00:44:24,800
tell the composition of the dust and you

1094
00:44:22,260 --> 00:44:29,570
can also say how big the dust grains are

1095
00:44:24,800 --> 00:44:32,840
so these are some examples of spectra

1096
00:44:29,570 --> 00:44:36,150
from targets that I was interested in

1097
00:44:32,840 --> 00:44:38,519
which actually helped to constrain the

1098
00:44:36,150 --> 00:44:41,160
evolutionary phase of these particular

1099
00:44:38,519 --> 00:44:43,019
objects so again this is flux as a

1100
00:44:41,159 --> 00:44:45,659
function of wavelength and then this is

1101
00:44:43,019 --> 00:44:47,250
again that 10 micron feature and then

1102
00:44:45,659 --> 00:44:48,690
here it's harder to see the 20 micron

1103
00:44:47,250 --> 00:44:50,909
feature but again the 10 micron feature

1104
00:44:48,690 --> 00:44:52,559
in the 20 micron feature you can see in

1105
00:44:50,909 --> 00:44:54,899
this particular case it's not purely

1106
00:44:52,559 --> 00:44:56,909
just simple olivines or proxy and simple

1107
00:44:54,900 --> 00:44:59,190
silicates there's actually a number of

1108
00:44:56,909 --> 00:45:01,129
different materials that go into

1109
00:44:59,190 --> 00:45:03,960
modeling this particular feature

1110
00:45:01,130 --> 00:45:06,030
including materials that are altered at

1111
00:45:03,960 --> 00:45:08,010
high pressures and temperatures so

1112

00:45:06,030 --> 00:45:10,970
things like obsidian that you find on

1113
00:45:08,010 --> 00:45:15,450
earth or tektite that you find in the

1114
00:45:10,969 --> 00:45:19,109
eject envelopes of craters and possibly

1115
00:45:15,449 --> 00:45:20,759
sio silicon monoxide gas this is the

1116
00:45:19,110 --> 00:45:23,849
sort of feature that might be indicative

1117
00:45:20,760 --> 00:45:26,040
of a giant hypervelocity collision so a

1118
00:45:23,849 --> 00:45:28,469
collision in which you have a moon

1119
00:45:26,039 --> 00:45:30,750
forming events because you produce all

1120
00:45:28,469 --> 00:45:32,639
this material it's altered at high

1121
00:45:30,750 --> 00:45:34,980
pressures and temperatures in the

1122
00:45:32,639 --> 00:45:36,839
terrestrial planet zone this is in

1123
00:45:34,980 --> 00:45:38,969
contrast to something that has a feature

1124
00:45:36,840 --> 00:45:40,410
like this where you can see the 10

1125
00:45:38,969 --> 00:45:42,719
micron feature the shape of it looks

1126
00:45:40,409 --> 00:45:44,940

really really different and this is

1127
00:45:42,719 --> 00:45:45,689
because when you decompose it it's made

1128
00:45:44,940 --> 00:45:47,760
out of

1129
00:45:45,690 --> 00:45:50,190
instead things more like water and

1130
00:45:47,760 --> 00:45:52,110
amorphous carbon and so these are very

1131
00:45:50,190 --> 00:45:54,329
pristine things that you might expect to

1132
00:45:52,110 --> 00:45:57,480
find in the outer solar system so this

1133
00:45:54,329 --> 00:45:58,949
might then tell you about a Kuiper belt

1134
00:45:57,480 --> 00:46:01,019
objects from the outer solar system

1135
00:45:58,949 --> 00:46:02,079
coming into the terrestrial planet zone

1136
00:46:01,019 --> 00:46:04,030
and

1137
00:46:02,079 --> 00:46:07,150
you know disintegrating or colliding

1138
00:46:04,030 --> 00:46:09,310
with a terrestrial planet producing the

1139
00:46:07,150 --> 00:46:11,769
sort of spectral feature so spectroscopy

1140
00:46:09,309 --> 00:46:14,049
although you know it's not as pretty to

1141
00:46:11,769 --> 00:46:15,400
look at as nice pictures can actually

1142
00:46:14,050 --> 00:46:17,980
tell you a lot of really detailed

1143
00:46:15,400 --> 00:46:20,230
diagnostic information about the

1144
00:46:17,980 --> 00:46:23,469
composition and the evolutionary phase

1145
00:46:20,230 --> 00:46:25,389
of the target but you can learn not only

1146
00:46:23,469 --> 00:46:28,959
about the composition of the targets but

1147
00:46:25,389 --> 00:46:31,029
also about the spatial distribution of

1148
00:46:28,960 --> 00:46:33,280
the dust and this is really relying on

1149
00:46:31,030 --> 00:46:35,470
the fact that when you look at dust in

1150
00:46:33,280 --> 00:46:38,200
these systems the dust that's closest to

1151
00:46:35,469 --> 00:46:40,000
the star is actually warmest and the

1152
00:46:38,199 --> 00:46:42,819
dust that's further away is actually

1153
00:46:40,000 --> 00:46:45,699
coolest so this just kind of gives you a

1154
00:46:42,820 --> 00:46:48,130
broad idea so if you're looking at

1155
00:46:45,699 --> 00:46:50,639
material that's at point 1 au this

1156
00:46:48,130 --> 00:46:53,410
radiates most strongly at 1 micron

1157
00:46:50,639 --> 00:46:55,509
whereas this material here that's at

1158
00:46:53,409 --> 00:46:58,299
maybe about a hundred au from a solar

1159
00:46:55,510 --> 00:47:01,030
like star radiates more strongly at a

1160
00:46:58,300 --> 00:47:03,490
thousand microns so basically in the

1161
00:47:01,030 --> 00:47:05,680
absence of having a picture that shows

1162
00:47:03,489 --> 00:47:08,259
you where all the dust is located you

1163
00:47:05,679 --> 00:47:10,029
can take measurements of the brightness

1164
00:47:08,260 --> 00:47:13,030
as a function of wavelength and try to

1165
00:47:10,030 --> 00:47:17,500
invert them to figure out where the dust

1166
00:47:13,030 --> 00:47:18,880
is located so that was a project that I

1167
00:47:17,500 --> 00:47:21,190
carried out with an undergraduate

1168
00:47:18,880 --> 00:47:24,700
student here at Johns Hopkins we looked

1169

00:47:21,190 --> 00:47:28,030
at the spectra of some 500 stars and

1170
00:47:24,699 --> 00:47:29,710
each one of these postage stamps is the

1171
00:47:28,030 --> 00:47:32,860
brightness as a function of wavelength

1172
00:47:29,710 --> 00:47:36,460
for a bunch of stars and you can see

1173
00:47:32,860 --> 00:47:38,650
there's these strong sources on the blue

1174
00:47:36,460 --> 00:47:41,199
side this is the emission from the star

1175
00:47:38,650 --> 00:47:45,340
and then the gray things are the

1176
00:47:41,199 --> 00:47:48,449
emission from the dust and so you can

1177
00:47:45,340 --> 00:47:50,710
see that in a lot of cases there are

1178
00:47:48,449 --> 00:47:52,329
sources for which there's not dust very

1179
00:47:50,710 --> 00:47:55,150
close to the star but there is dust

1180
00:47:52,329 --> 00:47:59,799
pretty far away and this tells us

1181
00:47:55,150 --> 00:48:01,869
basically that there is an inner region

1182
00:47:59,800 --> 00:48:03,370
that's devoid of dust and one of the

1183
00:48:01,869 --> 00:48:05,049

possibilities for why there's no dust

1184
00:48:03,369 --> 00:48:06,819
there is that there's a giant planet

1185
00:48:05,050 --> 00:48:08,920
which is basically clearing the inner

1186
00:48:06,820 --> 00:48:12,340
part of the planetary system from dust

1187
00:48:08,920 --> 00:48:15,369
so just to look at a

1188
00:48:12,340 --> 00:48:17,050
more detailed example this is again one

1189
00:48:15,369 --> 00:48:18,639
of these spectral energy distributions

1190
00:48:17,050 --> 00:48:21,220
brightness as a function of wavelength

1191
00:48:18,639 --> 00:48:23,969
for a particular star which is HR 8799

1192
00:48:21,219 --> 00:48:27,189
and you see here's the big bump from the

1193
00:48:23,969 --> 00:48:29,019
emission from the star and then the red

1194
00:48:27,190 --> 00:48:30,190
stuff here these are data points and

1195
00:48:29,019 --> 00:48:32,829
it's hard to see but there's some blue

1196
00:48:30,190 --> 00:48:35,170
data points here too but you can see

1197
00:48:32,829 --> 00:48:37,569
that at the long wavelengths here at 30

1198
00:48:35,170 --> 00:48:40,599
microns or so that you get a mission

1199
00:48:37,570 --> 00:48:42,400
that's an excess of what you expect from

1200
00:48:40,599 --> 00:48:44,049
the star and then it actually turns

1201
00:48:42,400 --> 00:48:46,720
upward a little bit and then there's

1202
00:48:44,050 --> 00:48:48,730
these bright points here essentially

1203
00:48:46,719 --> 00:48:51,699
when you try to do the analysis of the

1204
00:48:48,730 --> 00:48:54,219
the heat from this system

1205
00:48:51,699 --> 00:48:56,019
you require having two components a

1206
00:48:54,219 --> 00:48:58,239
warmish component and a coldish

1207
00:48:56,019 --> 00:49:00,489
component and this is very analogous to

1208
00:48:58,239 --> 00:49:02,500
like what you might expect our solar

1209
00:49:00,489 --> 00:49:05,259
system to look like to an observer far

1210
00:49:02,500 --> 00:49:07,360
away we have the asteroid belt and the

1211
00:49:05,260 --> 00:49:09,400
Kuiper belt and then a family of jovian

1212
00:49:07,360 --> 00:49:10,930
planets that live in between and in this

1213
00:49:09,400 --> 00:49:13,210
particular system you're seeing kind of

1214
00:49:10,929 --> 00:49:14,799
the same thing an asteroid belt and a

1215
00:49:13,210 --> 00:49:16,869
Kuiper belt and some space in between

1216
00:49:14,800 --> 00:49:19,920
and so that seems like a really good

1217
00:49:16,869 --> 00:49:22,119
place to go look for planets and indeed

1218
00:49:19,920 --> 00:49:25,240
there are some astronomers using the

1219
00:49:22,119 --> 00:49:27,279
Keck telescope in Hawaii and they were

1220
00:49:25,239 --> 00:49:30,579
they weren't using a coronagraph but

1221
00:49:27,280 --> 00:49:31,960
essentially they were having to subtract

1222
00:49:30,579 --> 00:49:33,759
out the emission from the star so you

1223
00:49:31,960 --> 00:49:35,230
could see faint things so that's why

1224
00:49:33,760 --> 00:49:37,330
there should be a bright star in here

1225
00:49:35,230 --> 00:49:39,990
but it's been subtracted out but they

1226

00:49:37,329 --> 00:49:42,460
actually discovered the presence of four

1227
00:49:39,989 --> 00:49:45,429
Jovian mass planets so planets with

1228
00:49:42,460 --> 00:49:47,559
masses about ten Juber masses in orbit

1229
00:49:45,429 --> 00:49:49,839
around this particular star and those

1230
00:49:47,559 --> 00:49:52,150
planets happen to fall right in between

1231
00:49:49,840 --> 00:49:54,760
where the asteroid and Kuiper belts are

1232
00:49:52,150 --> 00:49:58,240
for this planetary system so we know

1233
00:49:54,760 --> 00:50:00,970
that there are planetary systems with

1234
00:49:58,239 --> 00:50:03,309
architectures like our own but we don't

1235
00:50:00,969 --> 00:50:06,279
really understand maybe what the context

1236
00:50:03,309 --> 00:50:09,639
is for our solar system how common is it

1237
00:50:06,280 --> 00:50:10,660
or how common or how rare is it so one

1238
00:50:09,639 --> 00:50:12,579
of the reasons why I'm tremendously

1239
00:50:10,659 --> 00:50:15,159
excited about the James Webb Space

1240
00:50:12,579 --> 00:50:17,110

Telescope is you can just tell by

1241
00:50:15,159 --> 00:50:19,119
looking at this particular graphic right

1242
00:50:17,110 --> 00:50:20,740
this shows you to scale the difference

1243
00:50:19,119 --> 00:50:22,179
between the Spitzer Space Telescope and

1244
00:50:20,739 --> 00:50:24,069
the James Webb Space Telescope

1245
00:50:22,179 --> 00:50:26,108
so Spitzer was an 85 centimeter

1246
00:50:24,070 --> 00:50:28,269
telescope jdbc is gonna be a

1247
00:50:26,108 --> 00:50:30,278
and a half meter telescope Spitzer was

1248
00:50:28,268 --> 00:50:32,528
phenomenal for this area of study in

1249
00:50:30,278 --> 00:50:36,429
being able to serve a large number of

1250
00:50:32,528 --> 00:50:38,889
stars to be able to discover more than a

1251
00:50:36,429 --> 00:50:41,108
thousand planetary systems with asteroid

1252
00:50:38,889 --> 00:50:42,818
allure Kuiper belt dust in them but what

1253
00:50:41,108 --> 00:50:45,159
JT beasty is really going to bring to

1254
00:50:42,818 --> 00:50:47,528
the table is because it has such a much

1255
00:50:45,159 --> 00:50:50,078
bigger mirror it has much better angular

1256
00:50:47,528 --> 00:50:52,150
resolution and so now instead of seeing

1257
00:50:50,079 --> 00:50:54,309
an unresolved point you'll actually be

1258
00:50:52,150 --> 00:50:56,499
able to look at where the dust is as a

1259
00:50:54,309 --> 00:50:58,690
function of position map out the dust in

1260
00:50:56,498 --> 00:51:03,098
these planetary systems and it'll do

1261
00:50:58,690 --> 00:51:05,019
this for hundreds of nearby stars so

1262
00:51:03,099 --> 00:51:08,079
this is just a direct comparison of what

1263
00:51:05,018 --> 00:51:10,868
our expectations are so this top panel

1264
00:51:08,079 --> 00:51:12,579
here this is actually data from the

1265
00:51:10,869 --> 00:51:13,900
Spitzer Space Telescope this was

1266
00:51:12,579 --> 00:51:17,890
obtained by Kate sue and her

1267
00:51:13,900 --> 00:51:21,220
collaborators this is data for the Vega

1268
00:51:17,889 --> 00:51:23,259
system which was observed at 24 microns

1269
00:51:21,219 --> 00:51:25,439
and you can see here because the

1270
00:51:23,259 --> 00:51:28,119
resolution for Spitzer is so poor

1271
00:51:25,440 --> 00:51:29,980
essentially you take that poor

1272
00:51:28,119 --> 00:51:31,778
resolution and convolve it with this

1273
00:51:29,980 --> 00:51:35,710
planetary system and you just get a big

1274
00:51:31,778 --> 00:51:38,079
blob but JWST we expect to have much

1275
00:51:35,710 --> 00:51:41,019
better angular resolution and so this

1276
00:51:38,079 --> 00:51:43,210
panel here shows you simulations of what

1277
00:51:41,018 --> 00:51:45,129
the possibilities might actually be for

1278
00:51:43,210 --> 00:51:48,298
the configuration of the dust in this

1279
00:51:45,130 --> 00:51:51,009
system this is taking advantage of

1280
00:51:48,298 --> 00:51:52,748
coronagraphs onboard JD was t to block

1281
00:51:51,009 --> 00:51:55,929
out the central light from the star and

1282
00:51:52,748 --> 00:51:58,238
so on the left-hand side you see a top

1283

00:51:55,929 --> 00:51:59,919
model in a bottom model and this is

1284
00:51:58,239 --> 00:52:02,409
without what's called point spread

1285
00:51:59,920 --> 00:52:04,028
function PSF subtraction so this is if

1286
00:52:02,409 --> 00:52:05,409
you were just to use the coronagraph and

1287
00:52:04,028 --> 00:52:05,920
put the star behind the center of the

1288
00:52:05,409 --> 00:52:09,399
coronagraph

1289
00:52:05,920 --> 00:52:11,858
and then what people do to improve their

1290
00:52:09,400 --> 00:52:13,509
images it's essentially they observe

1291
00:52:11,858 --> 00:52:15,460
their target star with a coronagraph and

1292
00:52:13,509 --> 00:52:16,599
they observe another star but their

1293
00:52:15,460 --> 00:52:18,429
cronograph one that doesn't have

1294
00:52:16,599 --> 00:52:20,829
anything around it and they subtract

1295
00:52:18,429 --> 00:52:23,588
those two images so that they can remove

1296
00:52:20,829 --> 00:52:25,720
the residual stellar light and then dig

1297
00:52:23,588 --> 00:52:28,058

in deeper close to the star looking for

1298
00:52:25,719 --> 00:52:31,088
additional material so this is a these

1299
00:52:28,059 --> 00:52:33,249
are PSF subtracted images simulations

1300
00:52:31,088 --> 00:52:34,960
instead and then you can see there's two

1301
00:52:33,248 --> 00:52:37,659
flavors of models here one where the

1302
00:52:34,960 --> 00:52:39,090
dust is symmetric and here it's not I

1303
00:52:37,659 --> 00:52:40,500
mean the

1304
00:52:39,090 --> 00:52:42,840
the key things that you notice here are

1305
00:52:40,500 --> 00:52:44,789
here you don't see this inner hole in

1306
00:52:42,840 --> 00:52:46,140
the disk that's expected to be seen

1307
00:52:44,789 --> 00:52:48,329
based on what the spectral energy

1308
00:52:46,139 --> 00:52:50,279
distribution looks like and then also we

1309
00:52:48,329 --> 00:52:52,889
have questions about what is the

1310
00:52:50,280 --> 00:52:55,860
detailed distribution of the dust is it

1311
00:52:52,889 --> 00:52:57,569
symmetric or is it asymmetric there's a

1312
00:52:55,860 --> 00:53:00,140
possibility that there's a planet in

1313
00:52:57,570 --> 00:53:03,059
this particular system and it traps

1314
00:53:00,139 --> 00:53:06,059
asteroids or Kuiper belt objects into

1315
00:53:03,059 --> 00:53:08,250
exterior mean motion resonances and that

1316
00:53:06,059 --> 00:53:09,750
those bodies collide and grind down and

1317
00:53:08,250 --> 00:53:11,369
produce dust grains which are

1318
00:53:09,750 --> 00:53:13,530
radiatively drunk driven out by

1319
00:53:11,369 --> 00:53:15,750
radiation pressure and blown into these

1320
00:53:13,530 --> 00:53:17,370
spiral structures that then you might be

1321
00:53:15,750 --> 00:53:18,269
able to actually see with the James Webb

1322
00:53:17,369 --> 00:53:21,089
Space Telescope

1323
00:53:18,269 --> 00:53:22,800
so we're tremendously excited about what

1324
00:53:21,090 --> 00:53:25,860
we can do the other thing that's really

1325
00:53:22,800 --> 00:53:28,650
exciting is before I showed you some

1326
00:53:25,860 --> 00:53:30,360
spectra obtained with Spitzer and it was

1327
00:53:28,650 --> 00:53:32,789
just a spectrum of the whole planetary

1328
00:53:30,360 --> 00:53:34,740
system but because James Webb Space

1329
00:53:32,789 --> 00:53:36,960
Telescope has this phenomenal angular

1330
00:53:34,739 --> 00:53:39,329
resolution you'll actually be able to

1331
00:53:36,960 --> 00:53:40,949
take spectra of all the different points

1332
00:53:39,329 --> 00:53:42,869
in the field because you'll spatially

1333
00:53:40,949 --> 00:53:45,089
resolve the whole planetary system and

1334
00:53:42,869 --> 00:53:47,369
so you'll be able to look it for

1335
00:53:45,090 --> 00:53:50,309
gradients in the composition of the dust

1336
00:53:47,369 --> 00:53:51,989
grains as a function of position so this

1337
00:53:50,309 --> 00:53:54,599
has actually been carried out for one

1338
00:53:51,989 --> 00:53:56,789
planetary system beta Pictoris the first

1339
00:53:54,599 --> 00:53:59,279
one that I showed you that we had that

1340

00:53:56,789 --> 00:54:01,800
edge on disk this has been done from the

1341
00:53:59,280 --> 00:54:04,769
Subaru telescope in Hawaii and

1342
00:54:01,800 --> 00:54:07,050
essentially these are spectra from

1343
00:54:04,769 --> 00:54:08,909
different little positions in the disk

1344
00:54:07,050 --> 00:54:10,950
right around 10 microns where that

1345
00:54:08,909 --> 00:54:12,960
silicate feature is and if you squint

1346
00:54:10,949 --> 00:54:14,669
really hard you can see that the shape

1347
00:54:12,960 --> 00:54:17,220
of this 10 micron feature actually

1348
00:54:14,670 --> 00:54:20,369
changes as a function of position along

1349
00:54:17,219 --> 00:54:23,399
the disk and it tells you where the

1350
00:54:20,369 --> 00:54:25,679
small grains are located in this disk it

1351
00:54:23,400 --> 00:54:28,470
turns out that they tend to be it looks

1352
00:54:25,679 --> 00:54:31,139
like that they're predominantly in three

1353
00:54:28,469 --> 00:54:33,269
large rings it also tells you where the

1354
00:54:31,139 --> 00:54:35,759

crystalline material is so we're the

1355
00:54:33,269 --> 00:54:38,039
dust grains that have been annealed by

1356
00:54:35,760 --> 00:54:40,170
interactions with the star are located

1357
00:54:38,039 --> 00:54:43,980
and then they tend to be located near

1358
00:54:40,170 --> 00:54:46,619
the orbit Center so so I just think the

1359
00:54:43,980 --> 00:54:49,380
the spectroscopic power of James T is

1360
00:54:46,619 --> 00:54:52,429
absolutely amazing so not only will we

1361
00:54:49,380 --> 00:54:54,590
be able to take this these kind of space

1362
00:54:52,429 --> 00:54:56,589
resolve thermal emission spectra but

1363
00:54:54,590 --> 00:54:58,700
we're also be able to take hopefully

1364
00:54:56,590 --> 00:55:00,860
spatially resolved scattered light

1365
00:54:58,699 --> 00:55:02,869
spectra so now instead of looking at the

1366
00:55:00,860 --> 00:55:04,910
spectrum from the heat generated by

1367
00:55:02,869 --> 00:55:06,799
these dust grains you'll be able to look

1368
00:55:04,909 --> 00:55:08,960
at the spectrum of the reflected light

1369
00:55:06,800 --> 00:55:11,620
from these dust grains and this just

1370
00:55:08,960 --> 00:55:13,670
shows you there's an instrument on board

1371
00:55:11,619 --> 00:55:17,960
called the near infrared spectrograph

1372
00:55:13,670 --> 00:55:20,210
nurse back and essentially it has an

1373
00:55:17,960 --> 00:55:22,490
image slicer so it divides the field up

1374
00:55:20,210 --> 00:55:25,099
the field of view up into all these

1375
00:55:22,489 --> 00:55:26,629
little tiny rectangles these and then it

1376
00:55:25,099 --> 00:55:28,699
basically it disperses the light from

1377
00:55:26,630 --> 00:55:30,320
each rectangle so in this way you'll be

1378
00:55:28,699 --> 00:55:33,589
able to take spectra at different

1379
00:55:30,320 --> 00:55:35,420
positions for for in particular this

1380
00:55:33,590 --> 00:55:37,250
particular disc and this is really

1381
00:55:35,420 --> 00:55:39,320
interesting in the near infrared because

1382
00:55:37,250 --> 00:55:41,809
in the near-infrared you have access to

1383
00:55:39,320 --> 00:55:45,289
solid-state features now not from

1384
00:55:41,809 --> 00:55:46,820
silicates but from ices and I think ices

1385
00:55:45,289 --> 00:55:48,590
are tremendously exciting because I

1386
00:55:46,820 --> 00:55:50,570
meant as I mentioned before we don't

1387
00:55:48,590 --> 00:55:53,329
understand what the origin of water is

1388
00:55:50,570 --> 00:55:55,039
in our solar system and it would be very

1389
00:55:53,329 --> 00:55:57,259
interesting to understand what the

1390
00:55:55,039 --> 00:55:58,940
reservoirs of water around other

1391
00:55:57,260 --> 00:56:00,380
planetary systems look like and whether

1392
00:55:58,940 --> 00:56:02,210
or not they have the potential to

1393
00:56:00,380 --> 00:56:07,070
deliver oceans to terrestrial planets

1394
00:56:02,210 --> 00:56:08,750
there so this is just my last slide just

1395
00:56:07,070 --> 00:56:10,970
the key points that I wanted to say

1396
00:56:08,750 --> 00:56:12,199
we're these debris disc systems that

1397

00:56:10,969 --> 00:56:14,480
I've been showing you the data from

1398
00:56:12,199 --> 00:56:17,119
their analogs of our solar system when

1399
00:56:14,480 --> 00:56:20,210
it was young or middle-aged and they're

1400
00:56:17,119 --> 00:56:21,859
common around young stars Mitterrand

1401
00:56:20,210 --> 00:56:23,869
fred spectra that we saw these discs

1402
00:56:21,860 --> 00:56:25,280
reveal these solid state features that

1403
00:56:23,869 --> 00:56:26,659
indicate that the dust is composed of

1404
00:56:25,280 --> 00:56:28,730
silicates so these are things like

1405
00:56:26,659 --> 00:56:31,730
olivines like real materials that we're

1406
00:56:28,730 --> 00:56:33,289
familiar with on our own planets so for

1407
00:56:31,730 --> 00:56:35,150
example if you go to South Point and

1408
00:56:33,289 --> 00:56:37,099
y-you can see that all of you in the

1409
00:56:35,150 --> 00:56:39,950
green sand beach there and it's the same

1410
00:56:37,099 --> 00:56:41,480
materials spectrally just energy

1411
00:56:39,949 --> 00:56:42,619

distribution analysis so that was that

1412
00:56:41,480 --> 00:56:45,110
flux as a function of wavelength

1413
00:56:42,619 --> 00:56:47,569
analysis indicates the majority of these

1414
00:56:45,110 --> 00:56:49,760
debris disk systems possess structure

1415
00:56:47,570 --> 00:56:51,260
that means that they have these central

1416
00:56:49,760 --> 00:56:53,300
clearings these regions close to the

1417
00:56:51,260 --> 00:56:55,040
star that are devoid of dust and it

1418
00:56:53,300 --> 00:56:57,230
tells us that there's probably something

1419
00:56:55,039 --> 00:56:59,289
in those cleared out regions

1420
00:56:57,230 --> 00:57:01,940
that's clearing them out such as a

1421
00:56:59,289 --> 00:57:02,480
jovian planets Oh planets may be forming

1422
00:57:01,940 --> 00:57:05,750
or may

1423
00:57:02,480 --> 00:57:07,730
already formed in these systems so thank

1424
00:57:05,750 --> 00:57:10,929
you for your attention and I'm happy to

1425
00:57:07,730 --> 00:57:10,929
take any questions people might have

1426
00:57:16,420 --> 00:57:42,230
questions for dr. Chen yeah so it

1427
00:57:39,289 --> 00:57:43,820
basically the key thing that's important

1428
00:57:42,230 --> 00:57:45,650
is the dispersion velocity so the

1429
00:57:43,820 --> 00:57:47,869
relative velocity between the particles

1430
00:57:45,650 --> 00:57:50,240
so if the relative velocity is

1431
00:57:47,869 --> 00:57:52,430
relatively low then things tend to stick

1432
00:57:50,239 --> 00:57:54,799
but if the relative velocity is very

1433
00:57:52,429 --> 00:57:56,269
high then things tend to shatter so if

1434
00:57:54,800 --> 00:57:58,100
you think about the early phases of our

1435
00:57:56,269 --> 00:57:59,480
solar system the phases that Joel told

1436
00:57:58,099 --> 00:58:00,289
you about when there's a lot of gas in

1437
00:57:59,480 --> 00:58:02,269
the disk

1438
00:58:00,289 --> 00:58:04,369
everything is sort of entrained in the

1439
00:58:02,269 --> 00:58:05,840
gas and so it moves at approximately the

1440
00:58:04,369 --> 00:58:08,450
same velocity and the relative

1441
00:58:05,840 --> 00:58:09,858
velocities are very low and so during

1442
00:58:08,449 --> 00:58:11,750
that phase especially when you have a

1443
00:58:09,858 --> 00:58:14,090
lot of gas in the disc you're in a

1444
00:58:11,750 --> 00:58:17,059
really strong building phase but once

1445
00:58:14,090 --> 00:58:20,030
the gas is dissipated it you don't

1446
00:58:17,059 --> 00:58:21,529
longer maintain similar relative similar

1447
00:58:20,030 --> 00:58:23,750
velocities and the material going around

1448
00:58:21,530 --> 00:58:26,210
the star and so you can get fairly high

1449
00:58:23,750 --> 00:58:28,699
relative velocity so things can be going

1450
00:58:26,210 --> 00:58:30,530
in different directions at fairly good

1451
00:58:28,699 --> 00:58:33,250
speeds so that when they actually hit

1452
00:58:30,530 --> 00:58:36,380
its destructive rather than constructive

1453
00:58:33,250 --> 00:58:36,380
[Music]

1454

00:58:37,300 --> 00:58:41,660
right but there's a little bit of a I

1455
00:58:39,920 --> 00:58:43,550
mean it's not just so you're thinking

1456
00:58:41,659 --> 00:58:46,339
about Kepler's law but I mean in

1457
00:58:43,550 --> 00:58:47,780
addition to you know it's not just the

1458
00:58:46,340 --> 00:58:49,789
orbital velocity because everything

1459
00:58:47,780 --> 00:58:53,240
doesn't orbit in a perfect plane right

1460
00:58:49,789 --> 00:58:56,539
and so there's different semi-major axes

1461
00:58:53,239 --> 00:58:58,009
inclination eccentricity z-- I mean

1462
00:58:56,539 --> 00:59:00,079
you're in a pile of goo right you're

1463
00:58:58,010 --> 00:59:02,150
this gas and you're traveling through

1464
00:59:00,079 --> 00:59:04,369
molasses that is gonna let things sort

1465
00:59:02,150 --> 00:59:07,369
of gently roll into each other whereas

1466
00:59:04,369 --> 00:59:09,829
if you take the gas oh the gas away it's

1467
00:59:07,369 --> 00:59:12,910
open season it's like firing a bullet

1468
00:59:09,829 --> 00:59:12,909

under water versus air

1469
00:59:13,210 --> 00:59:28,220
yes oh that's really interesting so I

1470
00:59:24,349 --> 00:59:30,380
think you're oh okay I'll repeat the

1471
00:59:28,219 --> 00:59:32,629
question sorry am i right the question

1472
00:59:30,380 --> 00:59:35,390
was is is there's any of you research

1473
00:59:32,630 --> 00:59:37,190
focus on potentially large planets in

1474
00:59:35,389 --> 00:59:38,690
our own solar system that we haven't

1475
00:59:37,190 --> 00:59:41,030
found yet like planet nine that could be

1476
00:59:38,690 --> 00:59:43,490
way out in these debris disks yeah so

1477
00:59:41,030 --> 00:59:45,980
planet nine is is really fascinating and

1478
00:59:43,489 --> 00:59:48,199
unfortunately so I tend to focus on

1479
00:59:45,980 --> 00:59:50,059
extrasolar planetary system so planetary

1480
00:59:48,199 --> 00:59:52,639
systems outside of her own but your what

1481
00:59:50,059 --> 00:59:54,798
you're referring to of course is there's

1482
00:59:52,639 --> 00:59:58,308
been this really fascinating work partly

1483
00:59:54,798 --> 01:00:00,108
out of Caltech by Mike Brown and I'm

1484
00:59:58,309 --> 01:00:02,390
blanking on the other fellows name Brad

1485
01:00:00,108 --> 01:00:06,440
the Pluto killer the Pluto killer yes

1486
01:00:02,389 --> 01:00:08,298
exactly where essentially he was so he

1487
01:00:06,440 --> 01:00:11,059
was so you may know him as the

1488
01:00:08,298 --> 01:00:12,739
discoverer of a lot of these ice dwarf

1489
01:00:11,059 --> 01:00:15,260
planets in the outer solar system and

1490
01:00:12,739 --> 01:00:17,389
when he was looking at the orbital

1491
01:00:15,260 --> 01:00:18,980
properties of those ice Dwarfs planets

1492
01:00:17,389 --> 01:00:22,279
he noticed that there is sort of this

1493
01:00:18,980 --> 01:00:23,990
coincidence in their orbital parameters

1494
01:00:22,280 --> 01:00:25,430
that is they were all sort of grouped

1495
01:00:23,989 --> 01:00:28,039
together in one place and you would sort

1496
01:00:25,429 --> 01:00:29,779
of expect you might not even expect that

1497
01:00:28,039 --> 01:00:33,139
they should be they should have sort of

1498
01:00:29,780 --> 01:00:35,900
more random orbital parameters and so

1499
01:00:33,139 --> 01:00:37,909
one of the hypotheses essentially that

1500
01:00:35,900 --> 01:00:41,200
he's been advocating is that there is an

1501
01:00:37,909 --> 01:00:43,899
additional planet that is heretofore

1502
01:00:41,199 --> 01:00:46,219
undetected which is essentially

1503
01:00:43,900 --> 01:00:49,818
interacting gravitationally with these

1504
01:00:46,219 --> 01:00:54,679
ice giants and forcing them into these

1505
01:00:49,818 --> 01:00:58,058
sort of aligned orbits there's actually

1506
01:00:54,679 --> 01:01:00,828
a fabulous I should advertise this Mike

1507
01:00:58,059 --> 01:01:01,970
has this fabulous Coursera course I

1508
01:01:00,829 --> 01:01:05,809
don't know if you've ever seen Coursera

1509
01:01:01,969 --> 01:01:07,789
it's an online learning thing but he has

1510
01:01:05,809 --> 01:01:10,010
a class called physics of the solar

1511

01:01:07,789 --> 01:01:12,108
system or something like that and he

1512
01:01:10,010 --> 01:01:13,910
actually spends two weeks talking about

1513
01:01:12,108 --> 01:01:17,779
small bodies in the outer solar system

1514
01:01:13,909 --> 01:01:19,730
of our solar system it's a great class

1515
01:01:17,780 --> 01:01:21,079
he's a really engaging lecturer I think

1516
01:01:19,730 --> 01:01:23,039
he spends the first four weeks talking

1517
01:01:21,079 --> 01:01:24,360
about Mars

1518
01:01:23,039 --> 01:01:26,820
and then I think he talks about life in

1519
01:01:24,360 --> 01:01:28,920
the university that hypothesized planet

1520
01:01:26,820 --> 01:01:30,720
would be quite large right I think it's

1521
01:01:28,920 --> 01:01:32,010
not like a Pluto is it no no it's like a

1522
01:01:30,719 --> 01:01:34,079
terrestrial planet it's like an

1523
01:01:32,010 --> 01:01:47,700
earth-sized I think it's the or size

1524
01:01:34,079 --> 01:01:50,250
thing yes yeah well these are these are

1525
01:01:47,699 --> 01:01:52,289

debris disks they're debris disks so

1526
01:01:50,250 --> 01:01:54,179
they're older so they're this fate so an

1527
01:01:52,289 --> 01:01:56,159
accretion disk means that you have stuff

1528
01:01:54,179 --> 01:01:58,019
accreting onto the star so that in

1529
01:01:56,159 --> 01:02:00,899
inherently it means that there's gas in

1530
01:01:58,019 --> 01:02:03,869
the disk and so all that motes materials

1531
01:02:00,900 --> 01:02:20,430
entrained and going on to the star it's

1532
01:02:03,869 --> 01:02:21,960
more like a solar system yeah how does

1533
01:02:20,429 --> 01:02:23,730
the modelling work yeah

1534
01:02:21,960 --> 01:02:25,860
so basically this is work that was

1535
01:02:23,730 --> 01:02:29,699
carried out by my friend Casey Lee's at

1536
01:02:25,860 --> 01:02:32,070
APL and he has this huge library of

1537
01:02:29,699 --> 01:02:33,689
emissivities of different materials and

1538
01:02:32,070 --> 01:02:36,059
basically he does like a minimum

1539
01:02:33,690 --> 01:02:38,579
chi-squared analysis so he takes all of

1540
01:02:36,059 --> 01:02:40,529
these components and tries to add them

1541
01:02:38,579 --> 01:02:42,150
up in some sensible way in order to

1542
01:02:40,530 --> 01:02:44,460
reproduce the feature as best as you can

1543
01:02:42,150 --> 01:02:46,349
so you can see in some cases that this

1544
01:02:44,460 --> 01:02:48,510
might be successful if like there are

1545
01:02:46,349 --> 01:02:50,099
features that are distinct wavelengths

1546
01:02:48,510 --> 01:02:52,110
so that they can't be created by

1547
01:02:50,099 --> 01:02:54,150
anything else but you can see that there

1548
01:02:52,110 --> 01:02:55,289
are a lot of things where you know you

1549
01:02:54,150 --> 01:02:57,599
might have spectral features that are

1550
01:02:55,289 --> 01:02:59,309
overlapping and so one of the

1551
01:02:57,599 --> 01:03:01,349
frustrations with this kind of analysis

1552
01:02:59,309 --> 01:03:04,049
is actually it's somewhat degenerate and

1553
01:03:01,349 --> 01:03:06,599
so you can imagine different mixtures of

1554
01:03:04,050 --> 01:03:09,300
materials giving rise to the same

1555
01:03:06,599 --> 01:03:11,219
feature yeah and so when people do this

1556
01:03:09,300 --> 01:03:12,720
kind of analysis basically they have to

1557
01:03:11,219 --> 01:03:14,219
you know if they're being very rigorous

1558
01:03:12,719 --> 01:03:16,469
about it they'll go through and do a

1559
01:03:14,219 --> 01:03:18,000
Monte Carlo analysis and then basically

1560
01:03:16,469 --> 01:03:19,829
they'll show you like a probability

1561
01:03:18,000 --> 01:03:22,829
distribution function so the likelihood

1562
01:03:19,829 --> 01:03:25,500
that you have any given material so it's

1563
01:03:22,829 --> 01:03:28,650
it's not just like oh it's like 50% is

1564
01:03:25,500 --> 01:03:30,719
this it's like you know the most likely

1565
01:03:28,650 --> 01:03:32,250
model is that 50% of it is that but you

1566
01:03:30,719 --> 01:03:34,829
like you know there's also some

1567
01:03:32,250 --> 01:03:37,949
probability that it's like you know 30

1568

01:03:34,829 --> 01:03:41,340
instead so so just to clarify the

1569
01:03:37,949 --> 01:03:43,649
audience so that the the non-experts the

1570
01:03:41,340 --> 01:03:45,570
- the lines at the bottom these olivines

1571
01:03:43,650 --> 01:03:46,950
obsidians etc would you say there a

1572
01:03:45,570 --> 01:03:50,250
library there that means that they were

1573
01:03:46,949 --> 01:03:52,139
measured by in a laboratory so with on

1574
01:03:50,250 --> 01:03:55,170
earth someone took one of these rocks

1575
01:03:52,139 --> 01:03:57,900
used a spectrograph to create an actual

1576
01:03:55,170 --> 01:04:01,579
lab spectrum of that rock and then we're

1577
01:03:57,900 --> 01:04:16,829
using it to as a fingerprint for yeah

1578
01:04:01,579 --> 01:04:18,239
for space-based ones yes yeah actually

1579
01:04:16,829 --> 01:04:20,099
what's about comets and the source of

1580
01:04:18,239 --> 01:04:23,159
the oceans yes that's actually a really

1581
01:04:20,099 --> 01:04:26,549
fascinating field of research

1582
01:04:23,159 --> 01:04:27,750

so basically when one of the things

1583
01:04:26,550 --> 01:04:30,030
about the earth that we don't really

1584
01:04:27,750 --> 01:04:32,849
understand well is like how much water

1585
01:04:30,030 --> 01:04:34,680
is on earth because you know water is

1586
01:04:32,849 --> 01:04:36,480
incorporated in the earth that many

1587
01:04:34,679 --> 01:04:38,609
different locations including in the

1588
01:04:36,480 --> 01:04:41,190
deep interior and so the exact amount of

1589
01:04:38,610 --> 01:04:43,380
water is not known one of the ways that

1590
01:04:41,190 --> 01:04:45,570
people have tried to diagnose what so

1591
01:04:43,380 --> 01:04:47,220
the the fundamental problem is if you

1592
01:04:45,570 --> 01:04:47,940
look at the location of the earth where

1593
01:04:47,219 --> 01:04:49,379
it is today

1594
01:04:47,940 --> 01:04:53,130
and assume that it formed there

1595
01:04:49,380 --> 01:04:55,980
essentially the earth the proto-earth is

1596
01:04:53,130 --> 01:04:59,610
too hot to basically retain water vapour

1597
01:04:55,980 --> 01:05:01,349
and so the going in hypothesis for

1598
01:04:59,610 --> 01:05:04,140
people for decades has been that the

1599
01:05:01,349 --> 01:05:06,059
earth is warm dry because of this and so

1600
01:05:04,139 --> 01:05:08,969
that means that like the water had to

1601
01:05:06,059 --> 01:05:12,239
come from somewhere else and so for a

1602
01:05:08,969 --> 01:05:15,809
long time people had considered comets

1603
01:05:12,239 --> 01:05:18,839
as the source source of water in an

1604
01:05:15,809 --> 01:05:20,009
ocean and one of the diagnostic ways

1605
01:05:18,840 --> 01:05:21,930
that they would try to figure out

1606
01:05:20,010 --> 01:05:24,030
whether or not this was true was looking

1607
01:05:21,929 --> 01:05:27,269
at the deuterium to hydrogen ratio in

1608
01:05:24,030 --> 01:05:30,300
mean ocean seawater and compare that to

1609
01:05:27,269 --> 01:05:32,389
the deuterium to hydrogen ratio in

1610
01:05:30,300 --> 01:05:36,269
comets to see if at all they were common

1611
01:05:32,389 --> 01:05:37,650
it turned out for a long time the the

1612
01:05:36,269 --> 01:05:41,219
distribution of comets that people were

1613
01:05:37,650 --> 01:05:42,960
probing which I think were from fairly

1614
01:05:41,219 --> 01:05:45,719
far out in the solar system they

1615
01:05:42,960 --> 01:05:46,400
actually had a higher deuterium fraction

1616
01:05:45,719 --> 01:05:48,439
I think

1617
01:05:46,400 --> 01:05:50,090
compared to mean ocean seawater so

1618
01:05:48,440 --> 01:05:51,470
people were really uncertain you know

1619
01:05:50,090 --> 01:05:53,630
that was not the most favorite

1620
01:05:51,469 --> 01:05:57,259
explanation for the origin of water on

1621
01:05:53,630 --> 01:06:00,019
earth there was there has it is still a

1622
01:05:57,260 --> 01:06:02,210
really active field of research so there

1623
01:06:00,019 --> 01:06:04,940
was more recent data taken by the

1624
01:06:02,210 --> 01:06:08,449
Herschel Space Telescope around 2010 or

1625

01:06:04,940 --> 01:06:11,269
so of some of these Trojan objects

1626
01:06:08,449 --> 01:06:13,460
instead and those actually tended to

1627
01:06:11,269 --> 01:06:15,440
have d2h ratios that were more similar

1628
01:06:13,460 --> 01:06:18,230
to mean ocean sea water so people are

1629
01:06:15,440 --> 01:06:19,880
not sure what the origin of water on

1630
01:06:18,230 --> 01:06:22,429
Earth is so that's one possibility

1631
01:06:19,880 --> 01:06:25,460
another possibility that's I think

1632
01:06:22,429 --> 01:06:27,769
become more in vogue is the idea that

1633
01:06:25,460 --> 01:06:30,260
the water is actually delivered by water

1634
01:06:27,769 --> 01:06:33,110
rich asteroids so you remember that

1635
01:06:30,260 --> 01:06:35,000
scenario that I told you about the

1636
01:06:33,110 --> 01:06:36,289
period of late heavy bombardment and how

1637
01:06:35,000 --> 01:06:38,090
the migration of the planets

1638
01:06:36,289 --> 01:06:41,000
destabilized the minor bodies in our

1639
01:06:38,090 --> 01:06:43,940

solar system it de stabilized all of

1640
01:06:41,000 --> 01:06:46,519
them including we think the asteroids in

1641
01:06:43,940 --> 01:06:49,159
the main asteroid belt the asteroids

1642
01:06:46,519 --> 01:06:52,340
that are a little bit further out in

1643
01:06:49,159 --> 01:06:54,619
outer parts of the asteroid belt are

1644
01:06:52,340 --> 01:06:58,550
expected to be somewhat volatile rich

1645
01:06:54,619 --> 01:07:01,609
and so they have been hypothesized as

1646
01:06:58,550 --> 01:07:05,390
another source of water for the oceans

1647
01:07:01,610 --> 01:07:07,849
on earth we think we have evidence for

1648
01:07:05,389 --> 01:07:09,859
collisions between those objects and the

1649
01:07:07,849 --> 01:07:11,839
inner solar system when you look at the

1650
01:07:09,860 --> 01:07:13,610
cratering record on like the Moon or

1651
01:07:11,840 --> 01:07:15,620
Mars so you can look at the size

1652
01:07:13,610 --> 01:07:17,960
distribution so how many big craters

1653
01:07:15,619 --> 01:07:20,210
versus how many little craters on the

1654
01:07:17,960 --> 01:07:22,039
moon or Mars or something like that and

1655
01:07:20,210 --> 01:07:23,960
look at the size distribution of

1656
01:07:22,039 --> 01:07:25,789
asteroids how many big asteroids versus

1657
01:07:23,960 --> 01:07:28,250
little asteroids and it turns out the

1658
01:07:25,789 --> 01:07:29,750
size distribution of asteroids in the

1659
01:07:28,250 --> 01:07:33,260
main asteroid belt lines up with the

1660
01:07:29,750 --> 01:07:34,849
size distribution of craters on on old

1661
01:07:33,260 --> 01:07:36,530
terrestrial surfaces so we know those

1662
01:07:34,849 --> 01:07:39,500
things got slung in during the period of

1663
01:07:36,530 --> 01:07:41,030
late heavy bombardment and based on some

1664
01:07:39,500 --> 01:07:43,130
of the spectroscopic analysis we think

1665
01:07:41,030 --> 01:07:44,120
they're water rich - so there another I

1666
01:07:43,130 --> 01:07:46,660
think right now they're actually

1667
01:07:44,119 --> 01:07:50,920
probably the more favorite source of

1668
01:07:46,659 --> 01:07:50,920
water on there on earth

1669
01:07:53,230 --> 01:08:07,099
right but that's a small yeah yes back

1670
01:07:58,579 --> 01:08:09,139
there more question about more

1671
01:08:07,099 --> 01:08:14,029
clarification for icy planets and Planet

1672
01:08:09,139 --> 01:08:15,469
nine yeah that's correct and so so when

1673
01:08:14,030 --> 01:08:17,960
this whole whole controversy was going

1674
01:08:15,469 --> 01:08:20,840
on about Pluto essentially what happened

1675
01:08:17,960 --> 01:08:23,119
was so you know Pluto was discovered

1676
01:08:20,840 --> 01:08:25,610
shoot I think like in 1930 or so at

1677
01:08:23,119 --> 01:08:27,199
Lowell Observatory and you know it would

1678
01:08:25,609 --> 01:08:28,909
for a long time it was the only thing

1679
01:08:27,199 --> 01:08:33,409
kind of known in the outer solar system

1680
01:08:28,909 --> 01:08:37,069
and basically in the 1990s Dave Jewett

1681
01:08:33,409 --> 01:08:39,079
and Jane Lew went out and you know

1682

01:08:37,069 --> 01:08:41,779
basically carried out these deep surveys

1683
01:08:39,079 --> 01:08:45,409
of the sky of the ecliptic plane looking

1684
01:08:41,779 --> 01:08:48,079
for you know additional minor bodies out

1685
01:08:45,409 --> 01:08:51,139
there and so this led to the discovery

1686
01:08:48,079 --> 01:08:53,300
of you know the whole population of

1687
01:08:51,140 --> 01:08:55,550
Kuiper belt objects and so when the

1688
01:08:53,300 --> 01:08:57,140
Kuiper belt objects were discovered you

1689
01:08:55,550 --> 01:08:59,180
know you know and this is again some of

1690
01:08:57,140 --> 01:09:00,860
my Browns really beautiful work they

1691
01:08:59,180 --> 01:09:03,020
discovered that some of the largest

1692
01:09:00,859 --> 01:09:05,359
copper belt objects were even bigger

1693
01:09:03,020 --> 01:09:07,340
than Pluto right and so then there

1694
01:09:05,359 --> 01:09:11,000
became a sort of thing well do you

1695
01:09:07,340 --> 01:09:13,039
consider them planets too and the thing

1696
01:09:11,000 --> 01:09:15,649

that made them very similar to Pluto was

1697
01:09:13,039 --> 01:09:17,720
so Pluto is in a three-to-two resonance

1698
01:09:15,649 --> 01:09:19,609
with Neptune and it turns out there's a

1699
01:09:17,720 --> 01:09:21,170
whole family of other Kuiper belt

1700
01:09:19,609 --> 01:09:23,149
objects that are also in the

1701
01:09:21,170 --> 01:09:26,960
three-to-two resonance so Pluto doesn't

1702
01:09:23,149 --> 01:09:29,029
have a particularly you know unique mass

1703
01:09:26,960 --> 01:09:30,380
or size compared to things in the Kuiper

1704
01:09:29,029 --> 01:09:33,439
belt region and it doesn't have a

1705
01:09:30,380 --> 01:09:35,810
particularly unique orbit and so that

1706
01:09:33,439 --> 01:09:39,259
that was part of the reasoning that the

1707
01:09:35,810 --> 01:09:41,300
IAU used to demote its status from a

1708
01:09:39,260 --> 01:09:42,739
planet to a Kuiper belt objects because

1709
01:09:41,300 --> 01:09:43,970
they said hey there's so many more of

1710
01:09:42,739 --> 01:09:46,699
these other objects that are out there

1711
01:09:43,970 --> 01:09:48,050
it's really not that special and you

1712
01:09:46,699 --> 01:09:50,300
know maybe it's really one of these

1713
01:09:48,050 --> 01:09:52,279
other Kuiper belt objects and you know

1714
01:09:50,300 --> 01:09:54,079
there's a whole like half a dozen of

1715
01:09:52,279 --> 01:09:56,759
them that instead we're gonna designate

1716
01:09:54,079 --> 01:10:03,210
as ice Dwarfs so things like

1717
01:09:56,760 --> 01:10:07,079
and other stuff okay so this is not my

1718
01:10:03,210 --> 01:10:08,970
field of expertise but essentially what

1719
01:10:07,079 --> 01:10:10,289
I recall of Mike Brown's analysis is

1720
01:10:08,970 --> 01:10:12,900
essentially he was looking at the

1721
01:10:10,289 --> 01:10:15,689
orbital parameters for all of those

1722
01:10:12,899 --> 01:10:17,939
large objects you know maybe like the

1723
01:10:15,689 --> 01:10:20,759
largest nine or twelve of them or

1724
01:10:17,939 --> 01:10:24,689
something like that and basically he

1725
01:10:20,760 --> 01:10:26,550
noticed that again if you expect them to

1726
01:10:24,689 --> 01:10:28,739
be randomly scattered out or something

1727
01:10:26,550 --> 01:10:31,440
this should be all over the place

1728
01:10:28,739 --> 01:10:33,689
but he noticed when he made this orbital

1729
01:10:31,439 --> 01:10:36,809
parameter plot that they were all sort

1730
01:10:33,689 --> 01:10:38,969
of clumped in one area or at least

1731
01:10:36,810 --> 01:10:42,870
avoided a particular area of the phase

1732
01:10:38,970 --> 01:10:44,699
space and so based on the dynamical

1733
01:10:42,869 --> 01:10:47,729
evidence like what the orbits look like

1734
01:10:44,699 --> 01:10:50,609
you know essentially that's where the

1735
01:10:47,729 --> 01:10:53,729
hypothesis for this planet 9 came from

1736
01:10:50,609 --> 01:10:56,339
that basically it's exerting a

1737
01:10:53,729 --> 01:10:59,639
gravitational influence on these large

1738
01:10:56,340 --> 01:11:01,890
objects we don't see it directly we just

1739

01:10:59,640 --> 01:11:05,010
see how the other objects feel its

1740
01:11:01,890 --> 01:11:08,100
presence so I really recommend to you I

1741
01:11:05,010 --> 01:11:10,949
think part of that Coursera class that

1742
01:11:08,100 --> 01:11:12,510
Mike Brown has I think it starts up

1743
01:11:10,949 --> 01:11:16,019
every three months or something like

1744
01:11:12,510 --> 01:11:18,989
that because he he and his colleagues

1745
01:11:16,020 --> 01:11:21,690
are the lead proponents for this sort of

1746
01:11:18,989 --> 01:11:23,309
theory I think he has a lecture in in

1747
01:11:21,689 --> 01:11:24,629
this course about it and it's actually a

1748
01:11:23,310 --> 01:11:26,220
really excellent class so if you're

1749
01:11:24,630 --> 01:11:27,690
interested in the solar system

1750
01:11:26,220 --> 01:11:29,640
generically there's a there's a

1751
01:11:27,689 --> 01:11:32,729
beautiful the first four weeks are about

1752
01:11:29,640 --> 01:11:35,310
Mars I hadn't seen the detailed radar

1753
01:11:32,729 --> 01:11:37,349

maps for for Mars and you know seeing

1754
01:11:35,310 --> 01:11:39,390
how much geology people now know from

1755
01:11:37,350 --> 01:11:42,680
our it's it's it's really spectacular I

1756
01:11:39,390 --> 01:11:47,150
highly recommend it

1757
01:11:42,680 --> 01:11:47,150
other questions yes

1758
01:11:52,000 --> 01:11:55,868
[Music]

1759
01:12:00,579 --> 01:12:07,960
so in the particular case of Jupiter

1760
01:12:04,090 --> 01:12:11,659
Jupiter is so massive that essentially

1761
01:12:07,960 --> 01:12:13,908
it tends to it's gravity affects things

1762
01:12:11,658 --> 01:12:17,089
that try to come in to where it's

1763
01:12:13,908 --> 01:12:19,129
located and most of the time if an

1764
01:12:17,090 --> 01:12:21,079
object comes in from the outer solar

1765
01:12:19,130 --> 01:12:23,150
system toward Jupiter it encounters

1766
01:12:21,079 --> 01:12:24,979
Jupiter and it is actually it's a little

1767
01:12:23,149 --> 01:12:26,839
bit counterintuitive but it's actually

1768
01:12:24,979 --> 01:12:29,928
gravitationally slung out of the system

1769
01:12:26,840 --> 01:12:32,260
so most the time Jupiter doesn't you

1770
01:12:29,929 --> 01:12:36,618
know it doesn't either gain or lose mass

1771
01:12:32,260 --> 01:12:39,889
but for smaller objects for some objects

1772
01:12:36,618 --> 01:12:42,368
so comment linear several years ago or

1773
01:12:39,889 --> 01:12:45,289
even shoot what was it though the one

1774
01:12:42,368 --> 01:12:49,189
shoemaker levy that impacted Jupiter and

1775
01:12:45,289 --> 01:12:54,289
they yeah that was a clear case of

1776
01:12:49,189 --> 01:13:00,198
material being a created a ringside T -

1777
01:12:54,289 --> 01:13:02,090
that's right so I mean that I think

1778
01:13:00,198 --> 01:13:04,399
that's an active area of research where

1779
01:13:02,090 --> 01:13:06,110
people actually do real dynamical

1780
01:13:04,399 --> 01:13:08,988
simulations right because they're

1781
01:13:06,109 --> 01:13:11,448
curious what happens when you imagine

1782
01:13:08,988 --> 01:13:13,339
implant a planet in a planetary system

1783
01:13:11,448 --> 01:13:15,439
and watched us come in and how does it

1784
01:13:13,340 --> 01:13:17,119
affect it because if it's if it's a

1785
01:13:15,439 --> 01:13:18,919
small planet you can imagine the gravity

1786
01:13:17,118 --> 01:13:21,408
is not so great and so it doesn't affect

1787
01:13:18,920 --> 01:13:29,440
it as strongly as like a big planet like

1788
01:13:21,408 --> 01:13:29,439
Jupiter any other questions yes

1789
01:13:35,189 --> 01:13:42,110
sure question about the late heavy

1790
01:13:37,198 --> 01:13:44,368
bombardment what was it so this is this

1791
01:13:42,109 --> 01:13:47,069
yeah so this is something that's been

1792
01:13:44,368 --> 01:13:50,698
talked about in planetary science for a

1793
01:13:47,069 --> 01:13:52,469
while essentially people noticed a long

1794
01:13:50,698 --> 01:13:54,149
time ago that when you looked at old

1795
01:13:52,469 --> 01:13:56,639
terrestrial planet surfaces so the

1796

01:13:54,149 --> 01:13:58,618
surfaces of Mercury Mars and the moon

1797
01:13:56,639 --> 01:14:01,529
that they had a lot of craters on them

1798
01:13:58,618 --> 01:14:03,268
so this is just a map of the near side

1799
01:14:01,529 --> 01:14:04,618
and the far side of the Moon and you can

1800
01:14:03,269 --> 01:14:07,409
see the craters are picked out so you

1801
01:14:04,618 --> 01:14:08,908
can see them more easily on the moon you

1802
01:14:07,408 --> 01:14:11,728
can see there are periods where there's

1803
01:14:08,908 --> 01:14:13,768
been geologic resurfacing where lava has

1804
01:14:11,729 --> 01:14:15,479
come up to the surface and formed Marya

1805
01:14:13,769 --> 01:14:18,329
the seas that you see on the surface of

1806
01:14:15,479 --> 01:14:20,639
the Moon right and so it was you know

1807
01:14:18,328 --> 01:14:22,679
based on observations like that you knew

1808
01:14:20,639 --> 01:14:24,418
that there was a violent period in the

1809
01:14:22,679 --> 01:14:26,729
early part of the solar system where you

1810
01:14:24,418 --> 01:14:28,050

had a lot of collisions and you could

1811
01:14:26,729 --> 01:14:30,269
kind of constrain when that happened

1812
01:14:28,050 --> 01:14:34,369
based on looking at where the more like

1813
01:14:30,269 --> 01:14:38,280
the properties of the Maurya right so

1814
01:14:34,368 --> 01:14:39,779
one of the things that people have been

1815
01:14:38,279 --> 01:14:42,868
struggling to understand for a long time

1816
01:14:39,779 --> 01:14:45,359
is when those observations were first

1817
01:14:42,868 --> 01:14:48,089
made and noticed people sort of thought

1818
01:14:45,359 --> 01:14:49,438
that all of these collisions happened at

1819
01:14:48,090 --> 01:14:51,659
the same time like it was kind of like a

1820
01:14:49,439 --> 01:14:53,579
delta function when all the cratering

1821
01:14:51,658 --> 01:14:55,018
like all the collisions went up you know

1822
01:14:53,578 --> 01:14:56,429
the collision rate went up really high

1823
01:14:55,019 --> 01:14:59,519
just went up really high and came down

1824
01:14:56,429 --> 01:15:02,788
really fast there's been a lot of really

1825
01:14:59,519 --> 01:15:06,208
nice work by a researcher named Bill

1826
01:15:02,788 --> 01:15:09,018
baki particularly you know studying

1827
01:15:06,208 --> 01:15:13,979
these surfaces and trying to understand

1828
01:15:09,019 --> 01:15:16,679
this cratering period and I honestly I

1829
01:15:13,979 --> 01:15:19,590
don't remember the exact details but my

1830
01:15:16,679 --> 01:15:22,288
impression has been that over time our

1831
01:15:19,590 --> 01:15:24,059
thinking of the cratering record is that

1832
01:15:22,288 --> 01:15:26,988
you know essentially these craters were

1833
01:15:24,059 --> 01:15:30,208
actually formed over time and

1834
01:15:26,988 --> 01:15:31,888
essentially you know people then are of

1835
01:15:30,208 --> 01:15:36,319
course very interested in what are the

1836
01:15:31,889 --> 01:15:39,949
mechanisms to create the creators and so

1837
01:15:36,319 --> 01:15:42,408
this idea that I was describing for you

1838
01:15:39,948 --> 01:15:46,018
this is actually called the nice model

1839
01:15:42,408 --> 01:15:47,559
because it was first hypothesized by a

1840
01:15:46,019 --> 01:15:51,940
number of astronomers in

1841
01:15:47,560 --> 01:15:55,539
in Nice and France and essentially it it

1842
01:15:51,939 --> 01:15:57,879
basically tried to account for a number

1843
01:15:55,539 --> 01:15:59,350
of things observations that people made

1844
01:15:57,880 --> 01:16:02,050
of the solar system that seems sort of

1845
01:15:59,350 --> 01:16:03,700
startling so one of them was for example

1846
01:16:02,050 --> 01:16:05,800
when you look at the mass of the

1847
01:16:03,699 --> 01:16:07,059
asteroid belt and compare it to the mass

1848
01:16:05,800 --> 01:16:09,430
and the terrestrial planets and the

1849
01:16:07,060 --> 01:16:11,710
jovian planets around it if you were to

1850
01:16:09,430 --> 01:16:13,150
smooth out all of that mass you actually

1851
01:16:11,710 --> 01:16:15,279
get a divot in the amount of stuff

1852
01:16:13,149 --> 01:16:17,409
around the asteroid belt and so people

1853

01:16:15,279 --> 01:16:20,019
knew essentially that the asteroid belt

1854
01:16:17,409 --> 01:16:22,119
the premortal asteroid belt was actually

1855
01:16:20,020 --> 01:16:24,220
a lot more massive than the asteroid

1856
01:16:22,119 --> 01:16:25,989
belt that we see today then this sort of

1857
01:16:24,220 --> 01:16:28,300
leads to the question of life well what

1858
01:16:25,989 --> 01:16:31,899
happened to all those objects right and

1859
01:16:28,300 --> 01:16:33,940
so you know you know it was noticed that

1860
01:16:31,899 --> 01:16:36,819
there were these Kirkwood gaps that I

1861
01:16:33,939 --> 01:16:39,639
talked about where you have mean motion

1862
01:16:36,819 --> 01:16:44,439
resonances where you you you lose

1863
01:16:39,640 --> 01:16:46,060
material but the nice model which has

1864
01:16:44,439 --> 01:16:48,219
really come into fashion in the past few

1865
01:16:46,060 --> 01:16:49,780
years and described a lot of reasons why

1866
01:16:48,220 --> 01:16:51,909
you see certain properties of the solar

1867
01:16:49,779 --> 01:16:54,849

system such as the diminished asteroid

1868
01:16:51,909 --> 01:16:57,430
belt is has become the leading

1869
01:16:54,850 --> 01:16:59,350
explanation so again this is that the

1870
01:16:57,430 --> 01:17:01,300
location of Jupiter and Saturn in our

1871
01:16:59,350 --> 01:17:03,579
solar system today are not the locations

1872
01:17:01,300 --> 01:17:06,130
where Jupiter and Saturn formed and that

1873
01:17:03,579 --> 01:17:08,079
Jupiter and Saturn migrated from their

1874
01:17:06,130 --> 01:17:10,239
formation locations to their present day

1875
01:17:08,079 --> 01:17:12,039
locations and as they did so they cost

1876
01:17:10,239 --> 01:17:14,529
across the two-to-one resonance so this

1877
01:17:12,039 --> 01:17:16,810
means that for every two times Jupiter

1878
01:17:14,529 --> 01:17:20,519
goes around the Sun Saturn goes around

1879
01:17:16,810 --> 01:17:22,600
once and when you do that it actually

1880
01:17:20,520 --> 01:17:28,090
destabilizes the orbits of the minor

1881
01:17:22,600 --> 01:17:30,180
bodies because they get a you know you

1882
01:17:28,090 --> 01:17:32,230
know this gravitational pull that's

1883
01:17:30,180 --> 01:17:33,970
exacerbated by the two planets because

1884
01:17:32,229 --> 01:17:35,919
they're both in the same positions like

1885
01:17:33,970 --> 01:17:38,800
they they both come around to being at

1886
01:17:35,920 --> 01:17:40,960
the same place around the Sun right so

1887
01:17:38,800 --> 01:17:46,300
that that's what destabilizes the Minor

1888
01:17:40,960 --> 01:17:49,569
bodies so so basically I spoke a little

1889
01:17:46,300 --> 01:17:53,500
bit of some of the sort of planetary

1890
01:17:49,569 --> 01:17:55,779
science evidence for this so for example

1891
01:17:53,500 --> 01:17:57,970
so one we think the asteroid belt had to

1892
01:17:55,779 --> 01:18:00,128
be more massive to when you look at the

1893
01:17:57,970 --> 01:18:02,530
size distribution of craters on

1894
01:18:00,128 --> 01:18:04,569
the moon it matches with the size

1895
01:18:02,529 --> 01:18:05,378
distribution of bodies in the mean

1896
01:18:04,569 --> 01:18:07,358
asteroid belt

1897
01:18:05,378 --> 01:18:09,729
so that tells you that the projectiles

1898
01:18:07,359 --> 01:18:14,919
are consistent with coming from the main

1899
01:18:09,729 --> 01:18:18,070
asteroid belt so so it's really become

1900
01:18:14,918 --> 01:18:19,689
like the accepted sort of mechanism

1901
01:18:18,069 --> 01:18:23,768
describing the period of late heavy

1902
01:18:19,689 --> 01:18:28,499
bombardment today I think we have time

1903
01:18:23,769 --> 01:18:28,498
for one final question if there's one I

1904
01:18:28,948 --> 01:18:35,158
think maybe we've we've done it alright

1905
01:18:32,019 --> 01:18:35,159
well thank you everyone for coming

1906
01:18:37,529 --> 01:18:43,800
thanks again to dr. Christine Chen and

1907
01:18:40,469 --> 01:18:43,800
see you in a month