

1
00:00:00,000 --> 00:00:04,589
holiday greeting cards one per person

2
00:00:02,970 --> 00:00:09,029
and there might be a few extras left at

3
00:00:04,589 --> 00:00:10,670
the end our speaker tonight who will be

4
00:00:09,029 --> 00:00:13,649
taking I'll give a short introduction

5
00:00:10,669 --> 00:00:16,589
prior to that and our speaker tonight

6
00:00:13,650 --> 00:00:18,060
will be with daughter Christine Jen I'll

7
00:00:16,589 --> 00:00:20,070
introduce you in a moment as we get

8
00:00:18,059 --> 00:00:23,038
through and she will be talking about

9
00:00:20,070 --> 00:00:26,490
debris disks and other the formation of

10
00:00:23,039 --> 00:00:28,230
young planetary systems upcoming talks

11
00:00:26,489 --> 00:00:31,049
upcoming public lecture series talks or

12
00:00:28,230 --> 00:00:32,880
January third or tenth I guess it's TB I

13
00:00:31,050 --> 00:00:34,759
think that's why Frank has Frank gave me

14
00:00:32,880 --> 00:00:36,899
these slides so you can blame him I

15
00:00:34,759 --> 00:00:41,039
think I think he basically has a decide

16
00:00:36,899 --> 00:00:43,590
which they deserve it the fabricated set

17
00:00:41,039 --> 00:00:46,859
that is the seventh talk there will be

18
00:00:43,590 --> 00:00:50,219
mapping the heavens and on March seventh

19
00:00:46,859 --> 00:00:52,829
will be another talk bye bye Lauren

20
00:00:50,219 --> 00:00:59,219
Cory's from Johns Hopkins with a TBA

21
00:00:52,829 --> 00:01:01,198
title you probably noticed this but

22
00:00:59,219 --> 00:01:03,808
there is still construction on san

23
00:01:01,198 --> 00:01:06,149
martin drive so if you are coming from

24
00:01:03,808 --> 00:01:08,099
the south it's pretty easy but if you're

25
00:01:06,150 --> 00:01:09,659
coming from the north you've either got

26
00:01:08,099 --> 00:01:11,158
a park on university parkway or drive

27
00:01:09,659 --> 00:01:12,900
all the way around so hopefully everyone

28
00:01:11,159 --> 00:01:14,909
found their way here easiest to approach

29

00:01:12,900 --> 00:01:16,439
from the south but the good news is this

30
00:01:14,909 --> 00:01:18,330
will all stop in the new year so

31
00:01:16,438 --> 00:01:20,478
hopefully this will be the last one of

32
00:01:18,329 --> 00:01:22,709
these where you have to worry about this

33
00:01:20,478 --> 00:01:25,679
and this is the schedule see it says

34
00:01:22,709 --> 00:01:28,379
through December 2016 so hopefully the

35
00:01:25,680 --> 00:01:30,180
RIT so currently the red part and the

36
00:01:28,379 --> 00:01:33,959
yellow are the closed parts the blue

37
00:01:30,180 --> 00:01:37,100
part is done so anyway the key is to

38
00:01:33,959 --> 00:01:42,000
approach from the south on san martin dr

39
00:01:37,099 --> 00:01:44,399
keep keep turning I think weather does

40
00:01:42,000 --> 00:01:46,140
not permit us to go to the observatory

41
00:01:44,399 --> 00:01:48,599
but that usually is something that

42
00:01:46,140 --> 00:01:54,960
happens afterward I i assume relevant

43
00:01:48,599 --> 00:01:55,978

people know what to do there and I'm

44

00:01:54,959 --> 00:01:58,890

just going to give a quick introduction

45

00:01:55,978 --> 00:02:00,390

talk about a funny experience I had

46

00:01:58,890 --> 00:02:02,430

rather than I know Frank sometimes does

47

00:02:00,390 --> 00:02:04,920

news and updates I thought it might be

48

00:02:02,430 --> 00:02:07,409

fun to kind of a hail of one of the most

49

00:02:04,920 --> 00:02:09,209

unusual observing runs I've been on and

50

00:02:07,409 --> 00:02:12,390

it's called why I had a Boeing 747

51

00:02:09,209 --> 00:02:15,340

almost to myself

52

00:02:12,389 --> 00:02:16,358

so when I'm when people find out I'm an

53

00:02:15,340 --> 00:02:18,370

astronomer the first question I

54

00:02:16,359 --> 00:02:21,579

invariably get asked in a kind of angry

55

00:02:18,370 --> 00:02:22,959

aggressive tone is why is Pluto not a

56

00:02:21,579 --> 00:02:27,248

planet anymore people are really

57

00:02:22,959 --> 00:02:28,840

outraged by this right so you know the

58
00:02:27,248 --> 00:02:31,479
correct the question you should be

59
00:02:28,840 --> 00:02:32,590
asking and I'm sure that that everyone

60
00:02:31,479 --> 00:02:35,888
here has thought about this the real

61
00:02:32,590 --> 00:02:38,378
question is what is a planet right why

62
00:02:35,889 --> 00:02:41,829
is Pluto not one or is it one why should

63
00:02:38,378 --> 00:02:42,968
we even be concerned about that and Pete

64
00:02:41,829 --> 00:02:44,500
there are many answers to this question

65
00:02:42,968 --> 00:02:46,180
about what does the planet it could be

66
00:02:44,500 --> 00:02:48,479
you could call it a round thing above a

67
00:02:46,180 --> 00:02:51,340
certain size it could be something that

68
00:02:48,479 --> 00:02:53,468
orbits a star that doesn't you know have

69
00:02:51,340 --> 00:02:54,729
a larger object orbiting it or something

70
00:02:53,468 --> 00:02:57,098
and there are lots of semantic

71
00:02:54,729 --> 00:02:59,018
definitions but both Christine and I

72
00:02:57,098 --> 00:03:01,298
work in the field of formation of

73
00:02:59,019 --> 00:03:03,908
planets and that's the way I think about

74
00:03:01,299 --> 00:03:08,590
planets is a planet is something that

75
00:03:03,908 --> 00:03:10,090
formed around a star in its disk so I

76
00:03:08,590 --> 00:03:11,620
mean these are the traditional planets

77
00:03:10,090 --> 00:03:13,750
right these are this is planet was the

78
00:03:11,620 --> 00:03:18,629
definition of planet and to doesn't just

79
00:03:13,750 --> 00:03:21,250
something I need to explore this guy but

80
00:03:18,628 --> 00:03:23,408
the real thing to think about is when

81
00:03:21,250 --> 00:03:24,729
you approach a planetary system I was

82
00:03:23,408 --> 00:03:27,728
having a fun discussion at lunch a few

83
00:03:24,729 --> 00:03:28,840
days ago about this when you if you

84
00:03:27,729 --> 00:03:30,129
let's say you were on the bridge of the

85
00:03:28,840 --> 00:03:31,479
Starship Enterprise or something like

86

00:03:30,128 --> 00:03:33,578
that you were flying it to your star

87
00:03:31,479 --> 00:03:35,290
system and you wanted to say something

88
00:03:33,579 --> 00:03:37,150
useful about it you were surveying it

89
00:03:35,289 --> 00:03:38,318
what would you want to know you want to

90
00:03:37,150 --> 00:03:40,180
know what are the objects in orbit

91
00:03:38,318 --> 00:03:43,119
around the star what are they made out

92
00:03:40,180 --> 00:03:44,889
of they like how many and what

93
00:03:43,120 --> 00:03:48,069
temperature are they were there gases

94
00:03:44,889 --> 00:03:50,259
did it have surfaces and what this is

95
00:03:48,068 --> 00:03:51,518
really a question about is how did we

96
00:03:50,258 --> 00:03:53,168
what we want understand is how do you

97
00:03:51,519 --> 00:03:59,709
form all of these different kinds of

98
00:03:53,169 --> 00:04:01,389
objects our system is a morass of

99
00:03:59,709 --> 00:04:04,650
different kinds of objects ranging from

100
00:04:01,389 --> 00:04:07,120

planetary bodies down to dust particles

101

00:04:04,650 --> 00:04:10,000

and the solar system as it looks today

102

00:04:07,120 --> 00:04:11,979

is this kind of neatly organized mostly

103

00:04:10,000 --> 00:04:14,229

neatly organized system with the rocky

104

00:04:11,979 --> 00:04:15,310

inner planets sort of an asteroid belt

105

00:04:14,229 --> 00:04:17,288

that's not the only place where

106

00:04:15,310 --> 00:04:19,718

asteroids are but that's one of the most

107

00:04:17,288 --> 00:04:22,389

common places to find them the gas giant

108

00:04:19,718 --> 00:04:25,439

outer planets objects from the Kuiper

109

00:04:22,389 --> 00:04:28,418

belt with a ski orbits ice Dwarfs

110

00:04:25,439 --> 00:04:31,478

and what's interesting is if you were to

111

00:04:28,418 --> 00:04:32,889

rewind the clock 4.5 billion years to

112

00:04:31,478 --> 00:04:34,628

when the solar system was less than a

113

00:04:32,889 --> 00:04:36,930

million years old you probably would see

114

00:04:34,629 --> 00:04:40,270

it looking something like this a

115
00:04:36,930 --> 00:04:42,340
swirling disk of gas with tiny dust

116
00:04:40,269 --> 00:04:44,439
particles hanging suspended in that gas

117
00:04:42,339 --> 00:04:47,378
about a hundred times as much gas as

118
00:04:44,439 --> 00:04:50,079
dust and that is a planet making factory

119
00:04:47,379 --> 00:04:51,250
that's where solar systems come from and

120
00:04:50,079 --> 00:04:53,978
we know this because we look at other

121
00:04:51,250 --> 00:04:55,870
ones all of these are ingredients of

122
00:04:53,978 --> 00:05:00,370
things that have been found in space

123
00:04:55,870 --> 00:05:02,019
using space telescopes actually going to

124
00:05:00,370 --> 00:05:04,718
get this one so how do we know that

125
00:05:02,019 --> 00:05:08,019
planets form in these disks if you take

126
00:05:04,718 --> 00:05:10,288
a meteorite and you carve it open as

127
00:05:08,019 --> 00:05:13,180
this actual meteorite shows they are

128
00:05:10,288 --> 00:05:15,818
mashups of little pebbles that have been

129
00:05:13,180 --> 00:05:18,129
much together to building bigger and

130
00:05:15,819 --> 00:05:20,408
bigger objects this is the building

131
00:05:18,129 --> 00:05:22,090
blocks of planets it starts it may start

132
00:05:20,408 --> 00:05:23,529
big or it starts small but whatever it

133
00:05:22,089 --> 00:05:25,899
is you generate into these massive

134
00:05:23,529 --> 00:05:27,728
objects that we know today so these are

135
00:05:25,899 --> 00:05:30,848
glom erations and Christine is going to

136
00:05:27,728 --> 00:05:33,459
talk I suspect quite a bit about this so

137
00:05:30,848 --> 00:05:35,500
in order to study the infrared the most

138
00:05:33,459 --> 00:05:37,718
powerful instrument ever developed for

139
00:05:35,500 --> 00:05:40,028
if bread study is the James Webb Space

140
00:05:37,718 --> 00:05:42,788
Telescope which it will be controlled

141
00:05:40,028 --> 00:05:44,740
upstairs just one floor above us at dirt

142
00:05:42,788 --> 00:05:47,228
launches in 2018 about two minutes after

143

00:05:44,740 --> 00:05:49,360
that control shift to this building and

144
00:05:47,228 --> 00:05:52,089
we're all very excited and it's a great

145
00:05:49,360 --> 00:05:56,050
tool for study infrared bright young

146
00:05:52,089 --> 00:05:58,478
songs and here's a picture of me in

147
00:05:56,050 --> 00:06:00,038
front of the mirrors of the James so

148
00:05:58,478 --> 00:06:03,519
that's that's gonna be in space what's

149
00:06:00,038 --> 00:06:05,348
sitting with their be amazing yeah but I

150
00:06:03,519 --> 00:06:07,120
want to study young stars there's one

151
00:06:05,348 --> 00:06:08,620
problem which is that the telescope that

152
00:06:07,120 --> 00:06:10,180
I want to use is sitting in a clean room

153
00:06:08,620 --> 00:06:13,959
and Goddard Space Flight Center and not

154
00:06:10,180 --> 00:06:16,199
in space so I had use the current state

155
00:06:13,959 --> 00:06:18,779
of the art in the infrared

156
00:06:16,199 --> 00:06:20,399
which is airborne astronomy so I'm going

157
00:06:18,779 --> 00:06:22,019

to talk not at all about the James Webb

158

00:06:20,399 --> 00:06:23,339

Space Telescope and tell you about

159

00:06:22,019 --> 00:06:27,839

another tale of a very unusual

160

00:06:23,339 --> 00:06:29,939

Observatory in palmdale california with

161

00:06:27,839 --> 00:06:31,289

its many residents you don't look too

162

00:06:29,939 --> 00:06:35,910

closely the picture you might see some

163

00:06:31,290 --> 00:06:38,100

of you recognize from other shows is a

164

00:06:35,910 --> 00:06:40,980

an area called Armstrong Flight Research

165

00:06:38,100 --> 00:06:43,400

Center or dried an Air Force Base and in

166

00:06:40,980 --> 00:06:48,540

that air force base is an airplane that

167

00:06:43,399 --> 00:06:50,099

NASA bought it's not the Vomit Comet so

168

00:06:48,540 --> 00:06:51,480

when people think of NASA airplanes they

169

00:06:50,100 --> 00:06:53,580

ask me oh did you fly in the vomit

170

00:06:51,480 --> 00:06:55,590

comments that's exactly the opposite of

171

00:06:53,579 --> 00:06:57,359

what I wanted to do flying up and down

172
00:06:55,589 --> 00:07:00,179
like you know that's we want super

173
00:06:57,360 --> 00:07:03,030
stable this is this is why I would never

174
00:07:00,180 --> 00:07:05,250
do well in space I just I would lose

175
00:07:03,029 --> 00:07:08,459
lose my contents of my stomach very

176
00:07:05,250 --> 00:07:09,930
quickly so not the vomit comet it's the

177
00:07:08,459 --> 00:07:13,019
stratospheric Observatory for infrared

178
00:07:09,930 --> 00:07:15,480
astronomy Sofia and what they did was

179
00:07:13,019 --> 00:07:19,409
they took a 747 and actually an old I'm

180
00:07:15,480 --> 00:07:22,319
47 from the 70s bought it and they cut a

181
00:07:19,410 --> 00:07:26,520
hole in the side of the plane and in

182
00:07:22,319 --> 00:07:28,439
that hole is a telescope so there's a

183
00:07:26,519 --> 00:07:30,569
telescope about 2.4 meters in diameter

184
00:07:28,439 --> 00:07:32,699
James Webb is six point five meters for

185
00:07:30,569 --> 00:07:33,779
comparison so this is small but it's

186
00:07:32,699 --> 00:07:36,659
larger than most of our ground-based

187
00:07:33,779 --> 00:07:38,399
telescopes and they carry it to 42,000

188
00:07:36,660 --> 00:07:40,470
feet because the atmosphere of our earth

189
00:07:38,399 --> 00:07:41,909
is one of the things that you know

190
00:07:40,470 --> 00:07:43,830
shields us from a lot of things but it

191
00:07:41,910 --> 00:07:45,750
also makes infrared astronomy very

192
00:07:43,829 --> 00:07:47,550
tricky so that less air that you have to

193
00:07:45,750 --> 00:07:48,980
go through the better it is that's why

194
00:07:47,550 --> 00:07:50,939
we usually put these things into space

195
00:07:48,980 --> 00:07:52,530
nice thing about an airplane is you can

196
00:07:50,939 --> 00:07:54,569
bring it down the end of day and do

197
00:07:52,529 --> 00:07:56,129
repairs and change out the instruments

198
00:07:54,569 --> 00:07:58,439
and things like that and what's really

199
00:07:56,129 --> 00:08:01,469
neat is I can't go to James Webb or

200

00:07:58,439 --> 00:08:05,639
Hubble and use them directly I can fly

201
00:08:01,470 --> 00:08:07,260
with Sofia and in fact I did it takes a

202
00:08:05,639 --> 00:08:09,599
lot of people to flip plan one of these

203
00:08:07,259 --> 00:08:15,480
flights I have to tell you that on my

204
00:08:09,600 --> 00:08:18,540
flight there were two flight planners

205
00:08:15,480 --> 00:08:21,810
the two pilot or pilot and co-pilot is

206
00:08:18,540 --> 00:08:24,900
sort of a midships person to safety

207
00:08:21,810 --> 00:08:27,509
officers to telescope operators and to

208
00:08:24,899 --> 00:08:29,339
instrument scientists and an outreach

209
00:08:27,509 --> 00:08:31,319
and education specialist

210
00:08:29,339 --> 00:08:32,788
and then six teachers in the California

211
00:08:31,319 --> 00:08:35,490
Science Center who come along to check

212
00:08:32,788 --> 00:08:37,259
out how science worked so it was about

213
00:08:35,490 --> 00:08:38,639
20 people on the flight and that's only

214
00:08:37,259 --> 00:08:41,610

a small fraction we went through the

215

00:08:38,639 --> 00:08:43,229

initial briefing we had to come up with

216

00:08:41,610 --> 00:08:45,509

a flight plan and so they came up with a

217

00:08:43,229 --> 00:08:47,430

plan now they have now this this map

218

00:08:45,509 --> 00:08:50,009

right so it takes off from Southern

219

00:08:47,429 --> 00:08:53,699

California we can't fly over Mexico for

220

00:08:50,009 --> 00:08:54,990

various obscure legal reasons so we you

221

00:08:53,700 --> 00:08:57,900

have to avoid Mexico you have to avoid

222

00:08:54,990 --> 00:09:00,750

military no-fly zones and you have to

223

00:08:57,899 --> 00:09:02,129

fly in such a direction that you can

224

00:09:00,750 --> 00:09:03,990

observe your target so think about this

225

00:09:02,129 --> 00:09:06,149

all right let me go back for a second if

226

00:09:03,990 --> 00:09:08,580

you look at this airplane so the

227

00:09:06,149 --> 00:09:11,370

telescope can only point out the left

228

00:09:08,580 --> 00:09:14,009

side of the plane so you have to fly the

229
00:09:11,370 --> 00:09:16,470
plane such that the direction it's

230
00:09:14,009 --> 00:09:18,028
facing has the telescope pointed toward

231
00:09:16,470 --> 00:09:20,399
the star you want to look at or the

232
00:09:18,028 --> 00:09:23,669
galaxy you want to look at so you fly it

233
00:09:20,399 --> 00:09:26,189
in a straight line as long as you

234
00:09:23,669 --> 00:09:28,669
possibly can pointing toward your target

235
00:09:26,190 --> 00:09:31,500
with no particular destination in mind

236
00:09:28,669 --> 00:09:34,949
this drives air traffic controllers

237
00:09:31,500 --> 00:09:37,080
crazy and what's one of the neat things

238
00:09:34,950 --> 00:09:38,250
is you have a headset because it I'll

239
00:09:37,080 --> 00:09:40,110
show you later they ripped out all the

240
00:09:38,250 --> 00:09:41,278
installation so it's quite loud inside

241
00:09:40,110 --> 00:09:45,120
this plane it's kind of like being in a

242
00:09:41,278 --> 00:09:46,379
lousy bar and but you could get to

243
00:09:45,120 --> 00:09:47,850
listen to the pilot chatter with the

244
00:09:46,379 --> 00:09:50,580
very confused air traffic controllers

245
00:09:47,850 --> 00:09:53,459
the call sign of the plane is NASA 747

246
00:09:50,580 --> 00:09:55,139
you can follow it on flightaware every

247
00:09:53,458 --> 00:10:01,199
one of its flight and they're all posted

248
00:09:55,139 --> 00:10:03,059
and the so the the trajectory you may

249
00:10:01,200 --> 00:10:05,310
cast you have to end up back started see

250
00:10:03,059 --> 00:10:07,559
fly for ten hours and end up nowhere

251
00:10:05,309 --> 00:10:09,119
you've gone nowhere ultimately but

252
00:10:07,559 --> 00:10:11,969
you've been quite a journey on the way

253
00:10:09,120 --> 00:10:14,399
so each of these legs of this flight was

254
00:10:11,970 --> 00:10:15,660
a different target and my two targets

255
00:10:14,399 --> 00:10:18,809
were when we were out over the Pacific

256
00:10:15,659 --> 00:10:21,088
so we flew around into the Pacific just

257

00:10:18,809 --> 00:10:24,299
skirting Mexico kind of halfway out to

258
00:10:21,089 --> 00:10:26,480
Hawaii up over Juneau Alaska and back

259
00:10:24,299 --> 00:10:29,759
down the entire west coast of the u.s.

260
00:10:26,480 --> 00:10:33,509
we had contingency in case we had to

261
00:10:29,759 --> 00:10:36,000
blend Mexico City Honolulu Fairbanks

262
00:10:33,509 --> 00:10:38,970
this is februari and I said there

263
00:10:36,000 --> 00:10:40,980
Fairbanks are you insane I have a like a

264
00:10:38,970 --> 00:10:42,870
light jacket on for Los Angeles weather

265
00:10:40,980 --> 00:10:43,209
like we had to land in Fairbanks and

266
00:10:42,870 --> 00:10:45,459
febrile

267
00:10:43,208 --> 00:10:49,378
I think I would have you know jumped out

268
00:10:45,458 --> 00:10:51,609
of anyway so we didn't it all went great

269
00:10:49,379 --> 00:10:53,319
this is me before we're getting ready to

270
00:10:51,610 --> 00:10:54,669
take off I have a little protective

271
00:10:53,318 --> 00:10:57,610

reflector so that I don't get run over

272

00:10:54,669 --> 00:10:59,078

you cannot point the camera this way it

273

00:10:57,610 --> 00:11:02,829

turns out there's some other plane and

274

00:10:59,078 --> 00:11:04,628

hangar that they don't want to show no I

275

00:11:02,828 --> 00:11:08,138

think it's some work they do for someone

276

00:11:04,629 --> 00:11:09,550

else the that was my seat for take on

277

00:11:08,139 --> 00:11:12,549

attending those chairs at that table

278

00:11:09,549 --> 00:11:14,258

those are headset so you you know when

279

00:11:12,549 --> 00:11:16,508

you fly in this thing you basically you

280

00:11:14,259 --> 00:11:18,039

kind of wait and then they announced

281

00:11:16,509 --> 00:11:19,720

they're taking off and they go and you

282

00:11:18,039 --> 00:11:22,269

basically just go you know pretty

283

00:11:19,720 --> 00:11:23,980

sharply upward to get to 42 that at

284

00:11:22,269 --> 00:11:27,369

least 39,000 feet as quickly as possible

285

00:11:23,980 --> 00:11:30,100

and once you're up there it is about

286
00:11:27,369 --> 00:11:31,178
five minutes in they open the door for

287
00:11:30,100 --> 00:11:32,319
the telescope they don't even tell you

288
00:11:31,178 --> 00:11:34,659
they're doing it you would have no idea

289
00:11:32,318 --> 00:11:36,818
it's perfectly pressurized they hold

290
00:11:34,659 --> 00:11:39,219
side of the plane and the telescope

291
00:11:36,818 --> 00:11:41,438
sticks out and it's little harness where

292
00:11:39,220 --> 00:11:43,240
it is kept you know incredibly carefully

293
00:11:41,438 --> 00:11:45,399
in place it's kind of an amazing

294
00:11:43,240 --> 00:11:47,169
technology so it's not worried about

295
00:11:45,399 --> 00:11:49,470
we're not worried about wobble and stuff

296
00:11:47,169 --> 00:11:51,610
like that it's basically under control

297
00:11:49,470 --> 00:11:52,778
the safety briefing is a bit more

298
00:11:51,610 --> 00:11:54,879
extensive than you hit em for a

299
00:11:52,778 --> 00:11:57,578
commercial flight but it's a lot more

300
00:11:54,879 --> 00:12:00,610
comfortable so you imagine 20 people in

301
00:11:57,578 --> 00:12:03,338
a plane a 747 where they ripped out most

302
00:12:00,610 --> 00:12:04,990
of the seats and put in some computer

303
00:12:03,339 --> 00:12:08,499
desks but it's a cavernous space

304
00:12:04,990 --> 00:12:10,028
actually this is pretty nice flight it's

305
00:12:08,499 --> 00:12:11,860
a little cold because the insulation is

306
00:12:10,028 --> 00:12:13,600
kind of gone from a lot of the sides and

307
00:12:11,860 --> 00:12:15,999
the back third of the plane is a

308
00:12:13,600 --> 00:12:19,269
telescope but it's a pretty neat

309
00:12:15,999 --> 00:12:21,639
situation this is actually this this

310
00:12:19,269 --> 00:12:23,139
picture made me nostalgic because the

311
00:12:21,639 --> 00:12:24,909
very first project I ever did as an

312
00:12:23,139 --> 00:12:27,568
undergraduate astronomer was to work

313
00:12:24,909 --> 00:12:31,058
with dr. Terry herder on the forecast

314

00:12:27,568 --> 00:12:34,599
camera which is the red instrument with

315
00:12:31,058 --> 00:12:36,519
the cornell red bear on it so when I was

316
00:12:34,600 --> 00:12:38,769
a about 20 years ago almost when I was

317
00:12:36,519 --> 00:12:41,438
there I was working on that I can't say

318
00:12:38,769 --> 00:12:43,028
well I say working on it i was doing a

319
00:12:41,438 --> 00:12:44,438
little bit of programming anyway it was

320
00:12:43,028 --> 00:12:45,759
fun it was really nice to be able to use

321
00:12:44,438 --> 00:12:47,289
the instrument that i remember being

322
00:12:45,759 --> 00:12:49,629
there for some of the testing of when it

323
00:12:47,289 --> 00:12:54,338
was first proposed it's a long life

324
00:12:49,629 --> 00:12:56,139
cycle so it's it's so the instrument is

325
00:12:54,339 --> 00:12:56,950
out here on the side that i'm on but

326
00:12:56,139 --> 00:12:58,389
it's anchored

327
00:12:56,950 --> 00:13:01,840
the telescope which is on the far side

328
00:12:58,389 --> 00:13:03,819

of that sort of circular safe flying

329

00:13:01,840 --> 00:13:08,830

thing so the telescope is inside on the

330

00:13:03,820 --> 00:13:09,910

other side in a shock frame and from

331

00:13:08,830 --> 00:13:11,500

this side you could just sort of see an

332

00:13:09,909 --> 00:13:13,089

adjusting it back and forth now the key

333

00:13:11,500 --> 00:13:14,799

essentials on the flight are that they

334

00:13:13,090 --> 00:13:17,230

have a built-in coffee maker with like a

335

00:13:14,799 --> 00:13:19,719

bolt that holds the coffee I don't I

336

00:13:17,230 --> 00:13:21,490

just imagined hot coffee whipping across

337

00:13:19,720 --> 00:13:24,250

playing at hundreds of miles an hour or

338

00:13:21,490 --> 00:13:27,669

something but nothing happened there's a

339

00:13:24,250 --> 00:13:29,320

microwave oven and you bring your snacks

340

00:13:27,669 --> 00:13:30,370

on board you can have dinner and it's

341

00:13:29,320 --> 00:13:32,620

nice because they left some of the per

342

00:13:30,370 --> 00:13:36,340

class cabin seats so two missions drive

343
00:13:32,620 --> 00:13:38,139
you've gotta take a nap and you can go

344
00:13:36,340 --> 00:13:39,370
check out what / looking at so you can

345
00:13:38,139 --> 00:13:41,409
look at the stars you can see what our

346
00:13:39,370 --> 00:13:44,110
targets are our amazing science that was

347
00:13:41,409 --> 00:13:46,360
ongoing and the best picture I got at

348
00:13:44,110 --> 00:13:49,269
the entire flight they let I got to fly

349
00:13:46,360 --> 00:13:53,169
in the cockpit for a little bit at the

350
00:13:49,269 --> 00:13:55,809
top you know the jump seat and the you

351
00:13:53,169 --> 00:13:58,569
know so that pretty open and nice things

352
00:13:55,809 --> 00:13:59,949
when we were over Juneau the know this

353
00:13:58,570 --> 00:14:01,540
is a terrible picture but Northern

354
00:13:59,950 --> 00:14:03,550
Lights occupy the entire left side of

355
00:14:01,539 --> 00:14:04,509
the plane so there's a most stunning

356
00:14:03,549 --> 00:14:06,819
view of the Northern Lights I'm ever

357
00:14:04,509 --> 00:14:08,889
going to get so that was really probably

358
00:14:06,820 --> 00:14:10,600
the best picture the flight but we did

359
00:14:08,889 --> 00:14:13,720
get some data and some science happened

360
00:14:10,600 --> 00:14:15,909
and this fun press release on gluttonous

361
00:14:13,720 --> 00:14:19,899
stars that you can read and I'm happy to

362
00:14:15,909 --> 00:14:21,250
explain some other and yeah and then I

363
00:14:19,899 --> 00:14:23,590
was really excited about the big news

364
00:14:21,250 --> 00:14:26,740
and you know I hope to go back again

365
00:14:23,590 --> 00:14:27,910
soon and in terms of the actual science

366
00:14:26,740 --> 00:14:31,690
we discovered i think i'm going to leave

367
00:14:27,909 --> 00:14:36,089
that to our main speaker so let me

368
00:14:31,690 --> 00:14:36,090
introduce dr. christine jen

369
00:14:37,490 --> 00:14:43,509
[Applause]

370
00:14:40,259 --> 00:14:45,850
so Christine got it would did her

371

00:14:43,509 --> 00:14:47,620
undergraduate at Caltech she's from

372
00:14:45,850 --> 00:14:52,540
California originally she got her PhD

373
00:14:47,620 --> 00:14:54,519
from UCLA yes and became a Spitzer

374
00:14:52,539 --> 00:14:56,259
fellow so she was working on the Spitzer

375
00:14:54,519 --> 00:14:59,319
Space Telescope she was actually funded

376
00:14:56,259 --> 00:15:00,069
directly by their grants program and she

377
00:14:59,320 --> 00:15:02,470
worked on that for a number of years

378
00:15:00,070 --> 00:15:04,440
where we collaborated on projects when I

379
00:15:02,470 --> 00:15:07,660
was a little we graduate student and

380
00:15:04,440 --> 00:15:09,070
then she became the miry one of the

381
00:15:07,659 --> 00:15:10,600
Murie instrument scientists here at the

382
00:15:09,070 --> 00:15:13,360
Space Telescope Science Institute in

383
00:15:10,600 --> 00:15:15,370
2008 and she remained in that position

384
00:15:13,360 --> 00:15:16,990
until this year where she when she

385
00:15:15,370 --> 00:15:19,060

became the deputy project scientist for

386

00:15:16,990 --> 00:15:21,340

the entire James Webb Space Telescope so

387

00:15:19,059 --> 00:15:22,479

she knows a lot about that and she can

388

00:15:21,340 --> 00:15:25,450

tell you a lot about young stars and

389

00:15:22,480 --> 00:15:28,539

really cool stuff about planets and take

390

00:15:25,450 --> 00:15:30,100

it away Christine thanks for the

391

00:15:28,539 --> 00:15:32,169

introduction Joel I'm going to talk

392

00:15:30,100 --> 00:15:35,500

about things that are very related to

393

00:15:32,169 --> 00:15:37,360

what Joel just kind of told you about so

394

00:15:35,500 --> 00:15:39,370

in particular lecture alignment infrared

395

00:15:37,360 --> 00:15:45,480

astronomer and I'm also interested in

396

00:15:39,370 --> 00:15:48,370

how planetary systems normal so Joel the

397

00:15:45,480 --> 00:15:51,100

module was looking at were fairly young

398

00:15:48,370 --> 00:15:53,049

stars that still have these nice and

399

00:15:51,100 --> 00:15:56,290

clouds of gas and dust and are still

400
00:15:53,049 --> 00:15:58,299
forming giant planets the targets that I

401
00:15:56,289 --> 00:16:00,189
tend to look at our planetary systems

402
00:15:58,299 --> 00:16:03,339
that are somewhat older and that are

403
00:16:00,190 --> 00:16:05,770
perhaps more analogous to our own solar

404
00:16:03,340 --> 00:16:08,800
system although the systems can be young

405
00:16:05,769 --> 00:16:10,329
to do the defining difference between

406
00:16:08,799 --> 00:16:11,949
the systems that I look at and some of

407
00:16:10,330 --> 00:16:14,170
the ones that Joel showed you some nice

408
00:16:11,950 --> 00:16:18,580
observations from is the presence or

409
00:16:14,169 --> 00:16:20,889
absence of molecular gas so if you think

410
00:16:18,580 --> 00:16:24,310
about the interstellar medium and what's

411
00:16:20,889 --> 00:16:28,029
contained in the region between stars we

412
00:16:24,309 --> 00:16:30,789
know that it's largely gas and dust and

413
00:16:28,029 --> 00:16:33,370
with about a hundred times more gas by

414
00:16:30,789 --> 00:16:34,629
mass than dust and predominantly a lot

415
00:16:33,370 --> 00:16:38,379
of this is contained in molecular

416
00:16:34,629 --> 00:16:40,689
hydrogen for the the systems that I'm

417
00:16:38,379 --> 00:16:43,149
going to talk about we think that in the

418
00:16:40,690 --> 00:16:45,790
majority of them the giant planets have

419
00:16:43,149 --> 00:16:49,329
already formed and so in that process

420
00:16:45,789 --> 00:16:50,199
all the gaps that whisk has agreed on to

421
00:16:49,330 --> 00:16:52,509
the saw

422
00:16:50,200 --> 00:16:54,910
recruited onto the atmospheres of jovian

423
00:16:52,509 --> 00:16:57,460
planets or been expelled out of the

424
00:16:54,909 --> 00:17:00,569
planetary system so these are much more

425
00:16:57,460 --> 00:17:04,180
analogous to our own solar system than

426
00:17:00,570 --> 00:17:06,190
protoplanetary disks so if you were to

427
00:17:04,180 --> 00:17:08,049
try to take a high-resolution image of

428

00:17:06,190 --> 00:17:10,720
some of the systems that I study the

429
00:17:08,049 --> 00:17:12,279
so-called debris disks this is actually

430
00:17:10,720 --> 00:17:13,390
a picture that you might see this is a

431
00:17:12,279 --> 00:17:15,160
picture that was obtained with the

432
00:17:13,390 --> 00:17:17,380
Hubble Space Telescope the advanced

433
00:17:15,160 --> 00:17:20,230
camera for surveys it has what's known

434
00:17:17,380 --> 00:17:22,360
as a corona graphic instrument a

435
00:17:20,230 --> 00:17:24,250
coronagraphs were developed to study the

436
00:17:22,359 --> 00:17:27,909
corona of the Sun and essentially what

437
00:17:24,250 --> 00:17:30,579
they contain is a physical mechanism

438
00:17:27,910 --> 00:17:33,279
something mechanical for blocking out

439
00:17:30,579 --> 00:17:35,649
the bright disc of the Sun and allowing

440
00:17:33,279 --> 00:17:38,470
you to study the faint corona the star

441
00:17:35,650 --> 00:17:40,840
or the Sun and in this particular case

442
00:17:38,470 --> 00:17:42,549

what we're doing instead is we're

443

00:17:40,839 --> 00:17:45,369
blocking out the light from the central

444

00:17:42,549 --> 00:17:48,669
star in the planetary system and by

445

00:17:45,369 --> 00:17:50,709
doing so having the possibility then of

446

00:17:48,670 --> 00:17:54,490
detecting feature material around the

447

00:17:50,710 --> 00:17:58,930
star whether that is faint planets

448

00:17:54,490 --> 00:18:01,720
Jovian mass planet or mass is a ring of

449

00:17:58,930 --> 00:18:04,450
dust I'm just around a star so this is a

450

00:18:01,720 --> 00:18:07,539
the star Fomalhaut it's a one of the

451

00:18:04,450 --> 00:18:10,120
nearest stars to our Sun it's about 10

452

00:18:07,539 --> 00:18:15,059
parsecs away and this is a intermediate

453

00:18:10,119 --> 00:18:17,709
mass star its mass is about twice so

454

00:18:15,059 --> 00:18:21,849
these items this is kind of the typical

455

00:18:17,710 --> 00:18:24,190
go ahead although many of the systems

456

00:18:21,849 --> 00:18:26,429
that we observe and try to learn about

457
00:18:24,190 --> 00:18:29,410
we don't have such pretty pictures for

458
00:18:26,430 --> 00:18:32,560
so this is just a quick outline of my

459
00:18:29,410 --> 00:18:35,050
top so again many of these systems are

460
00:18:32,559 --> 00:18:36,759
very analogous to our solar system so

461
00:18:35,049 --> 00:18:40,559
it's useful to stand back and to think

462
00:18:36,759 --> 00:18:42,519
about our solar system and the

463
00:18:40,559 --> 00:18:44,470
demographics of bodies in our solar

464
00:18:42,519 --> 00:18:46,119
system so there are the giant planets

465
00:18:44,470 --> 00:18:47,589
the terrestrial planets there's

466
00:18:46,119 --> 00:18:49,989
asteroids and comets and there's

467
00:18:47,589 --> 00:18:51,699
actually dust as well so I'll tell you a

468
00:18:49,990 --> 00:18:54,279
little bit about the solar system dust

469
00:18:51,700 --> 00:18:56,620
and then there's actually forces that

470
00:18:54,279 --> 00:18:58,509
act on the dust that rearrange the dust

471
00:18:56,619 --> 00:19:01,089
in our solar system so for example

472
00:18:58,509 --> 00:19:03,420
there's radiation pressure which can

473
00:19:01,089 --> 00:19:05,919
blow dust outward and there's also

474
00:19:03,420 --> 00:19:08,440
something called pointing robertson drag

475
00:19:05,920 --> 00:19:10,330
which is a relativistic effect which

476
00:19:08,440 --> 00:19:11,860
causes larger dust grains to spiral into

477
00:19:10,329 --> 00:19:13,689
the central star so i'll tell you about

478
00:19:11,859 --> 00:19:16,929
some of these forces that rearrange dust

479
00:19:13,690 --> 00:19:19,000
in our own solar system so these

480
00:19:16,930 --> 00:19:21,610
populations this population of dust that

481
00:19:19,000 --> 00:19:23,710
we see in our own solar system has now

482
00:19:21,609 --> 00:19:26,349
been analogous populations have been

483
00:19:23,710 --> 00:19:29,620
seen around other stars other main

484
00:19:26,349 --> 00:19:31,419
sequence other midlife stars and I'll

485

00:19:29,619 --> 00:19:34,719
tell you about some of the demographics

486
00:19:31,420 --> 00:19:37,120
from the early I rasta memories and then

487
00:19:34,720 --> 00:19:40,299
spits was tremendous boon this area of

488
00:19:37,119 --> 00:19:42,639
study were IRS discovered maybe about a

489
00:19:40,299 --> 00:19:44,409
hundred targets Spitzer told us about

490
00:19:42,640 --> 00:19:46,600
maybe a thousand so an order of

491
00:19:44,410 --> 00:19:49,269
magnitude more and gave us much more

492
00:19:46,599 --> 00:19:51,759
detailed spectroscopic information about

493
00:19:49,269 --> 00:19:53,379
these targets and then because as Joe

494
00:19:51,759 --> 00:19:55,539
mentioned I worked on jvst I'm

495
00:19:53,380 --> 00:19:58,510
tremendously excited about the gains

496
00:19:55,539 --> 00:19:59,920
that jade was t will make especially in

497
00:19:58,509 --> 00:20:02,220
this area of science and I'll try to

498
00:19:59,920 --> 00:20:05,350
give you a hint of what that looks like

499
00:20:02,220 --> 00:20:06,819

so I put this outline on top of this

500

00:20:05,349 --> 00:20:09,730

really beautiful picture of the night

501

00:20:06,819 --> 00:20:12,789

sky and this is just to remind you of

502

00:20:09,730 --> 00:20:15,579

what the dust in our solar system looks

503

00:20:12,789 --> 00:20:18,849

like so there is the cycle dust in our

504

00:20:15,579 --> 00:20:22,000

solar system which is produced in the

505

00:20:18,849 --> 00:20:23,769

asteroid belt and you can see it here at

506

00:20:22,000 --> 00:20:26,230

a time that's pretty much close to

507

00:20:23,769 --> 00:20:28,690

sunset so that you're not looking very

508

00:20:26,230 --> 00:20:30,009

far away from the Sun but you can see

509

00:20:28,690 --> 00:20:32,170

from the dark site here this is the

510

00:20:30,009 --> 00:20:32,440

Milky Way and then you can see this sort

511

00:20:32,170 --> 00:20:35,200

of

512

00:20:32,440 --> 00:20:37,360

your future here in sort of reflected

513

00:20:35,200 --> 00:20:39,160

light this is light that's reflected off

514
00:20:37,359 --> 00:20:41,619
of dust grains in our solar system again

515
00:20:39,160 --> 00:20:43,900
this is called zodiacal light and it's

516
00:20:41,619 --> 00:20:48,609
produced by sunlight scattered off of

517
00:20:43,900 --> 00:20:51,340
what's called the zodiacal dust so this

518
00:20:48,609 --> 00:20:53,619
is just a reminder I Joel already spoke

519
00:20:51,339 --> 00:20:55,480
about this a little bit about the bodies

520
00:20:53,619 --> 00:20:57,459
that we find in our own solar system of

521
00:20:55,480 --> 00:20:59,980
course we're the most familiar with the

522
00:20:57,460 --> 00:21:01,809
terrestrial planets and there are so

523
00:20:59,980 --> 00:21:03,910
many really beautiful images of the

524
00:21:01,809 --> 00:21:07,329
jovian planets and we've learned so much

525
00:21:03,910 --> 00:21:09,340
about them but in addition to the

526
00:21:07,329 --> 00:21:12,699
planets there's also a number of

527
00:21:09,339 --> 00:21:14,409
populations of minor bodies so the ones

528
00:21:12,700 --> 00:21:19,200
that most people are familiar with our

529
00:21:14,410 --> 00:21:23,460
the asteroid belt so these are a

530
00:21:19,200 --> 00:21:25,960
kilometer up to tens of kilometers size

531
00:21:23,460 --> 00:21:30,279
bodies that live between Mars and

532
00:21:25,960 --> 00:21:32,350
Jupiter and then in the outer reaches of

533
00:21:30,279 --> 00:21:36,309
the solar system beyond the orbit of

534
00:21:32,349 --> 00:21:38,889
Neptune there is the Kuiper belt and the

535
00:21:36,309 --> 00:21:42,759
largest objects and the Kuiper belts

536
00:21:38,890 --> 00:21:44,890
have been named I store planets so agile

537
00:21:42,759 --> 00:21:47,470
awesome and this controversy about what

538
00:21:44,890 --> 00:21:49,600
is the status of Pluto so as you call it

539
00:21:47,470 --> 00:21:53,259
was originally a planet it has been

540
00:21:49,599 --> 00:21:55,059
reclassified as an iced or planet so for

541
00:21:53,259 --> 00:21:58,900
the most part all of these objects play

542

00:21:55,059 --> 00:22:03,700
in the zodiacal in those a vehicle plane

543
00:21:58,900 --> 00:22:05,890
in the plane of the solar system and but

544
00:22:03,700 --> 00:22:09,610
the last population which is called the

545
00:22:05,890 --> 00:22:12,580
Oort cloud actually lies in a spherical

546
00:22:09,609 --> 00:22:14,859
distribution around the Sun and these

547
00:22:12,579 --> 00:22:17,019
are small bodies that are sort of

548
00:22:14,859 --> 00:22:18,729
analogous to Kuiper belt objects obses

549
00:22:17,019 --> 00:22:20,230
where they've been scattered out to very

550
00:22:18,730 --> 00:22:22,539
large distances in all different

551
00:22:20,230 --> 00:22:25,930
directions from the Sun and this happens

552
00:22:22,539 --> 00:22:28,240
because the small bodies for example in

553
00:22:25,930 --> 00:22:29,769
the Kuiper belt might have migrated into

554
00:22:28,240 --> 00:22:31,660
the inner solar system and then

555
00:22:29,769 --> 00:22:35,049
gravitationally encounter Jupiter Saturn

556
00:22:31,660 --> 00:22:37,480

and then flung into the outer part of

557

00:22:35,049 --> 00:22:40,720

the solar system so when I think about

558

00:22:37,480 --> 00:22:42,910

the solar system this is what I think

559

00:22:40,720 --> 00:22:44,620

about this is the part of the solar

560

00:22:42,910 --> 00:22:45,080

system that were most familiar with the

561

00:22:44,619 --> 00:22:46,699

inner

562

00:22:45,079 --> 00:22:49,699

a you at the terrestrial planets and the

563

00:22:46,700 --> 00:22:52,539

asteroid belt and then moving out to the

564

00:22:49,700 --> 00:22:56,420

outer solar system you can see the

565

00:22:52,539 --> 00:22:59,149

orbits here for the giant planets the

566

00:22:56,420 --> 00:23:02,900

gas giants and then this population of

567

00:22:59,150 --> 00:23:04,400

Kuiper belt objects and both in the

568

00:23:02,900 --> 00:23:06,470

Kuiper belt in the asteroid belt those

569

00:23:04,400 --> 00:23:10,340

small bodies collide ground down and

570

00:23:06,470 --> 00:23:12,589

produce dust grains and then on larger

571
00:23:10,339 --> 00:23:14,569
scales this spherical distribution of

572
00:23:12,589 --> 00:23:19,459
small bodies that makes up that work

573
00:23:14,569 --> 00:23:23,439
cloud so I showed you a nice scattered

574
00:23:19,460 --> 00:23:26,480
light image of dust in our solar system

575
00:23:23,440 --> 00:23:29,809
that beautiful pan on a milky way and

576
00:23:26,480 --> 00:23:32,029
then the zodiacal light this is another

577
00:23:29,809 --> 00:23:34,309
way to look at the sky and this is an

578
00:23:32,029 --> 00:23:36,710
image that was taken from the infrared

579
00:23:34,309 --> 00:23:40,609
astronomical satellite so this was a

580
00:23:36,710 --> 00:23:42,529
satellite that launched in 1983 and it

581
00:23:40,609 --> 00:23:46,609
surveyed the entire sky in the infrared

582
00:23:42,529 --> 00:23:49,910
so it mapped the sky at 12 25 60 and 100

583
00:23:46,609 --> 00:23:52,189
microns when you look at this map it

584
00:23:49,910 --> 00:23:54,860
doesn't look like most maps that you're

585
00:23:52,190 --> 00:23:58,580
familiar with because you're seeing the

586
00:23:54,859 --> 00:24:00,799
heat signature from bodies both in the

587
00:23:58,579 --> 00:24:04,279
Milky Way so this is the Galactic plane

588
00:24:00,799 --> 00:24:06,409
here so this is the our galaxy and then

589
00:24:04,279 --> 00:24:09,440
also the heat signature for foreground

590
00:24:06,410 --> 00:24:12,320
closer objects so this thing tilted here

591
00:24:09,440 --> 00:24:14,390
this is a dust as a vehicle dust in our

592
00:24:12,319 --> 00:24:16,819
solar system so you can see the plane of

593
00:24:14,390 --> 00:24:20,420
our solar system is canted compared to

594
00:24:16,819 --> 00:24:22,549
the plane of the Milky Way so this is to

595
00:24:20,420 --> 00:24:25,759
illustrate that when you look at these

596
00:24:22,549 --> 00:24:27,139
maps of heat you're seeing in the

597
00:24:25,759 --> 00:24:29,900
foreign Fred you're looking at maps of

598
00:24:27,140 --> 00:24:33,890
heat and this is an incredibly efficient

599

00:24:29,900 --> 00:24:35,509
way to find dust because the dust for

600
00:24:33,890 --> 00:24:39,200
example that's in our solar system it

601
00:24:35,509 --> 00:24:40,789
absorbs sunlight from our Sun and that

602
00:24:39,200 --> 00:24:44,080
causes the dust grains to heat up to

603
00:24:40,789 --> 00:24:47,210
about 230 k and then those dust grains

604
00:24:44,079 --> 00:24:50,409
re-radiate temperature heat which is

605
00:24:47,210 --> 00:24:53,180
detectable in the far infrared is light

606
00:24:50,410 --> 00:24:55,040
what's particularly powerful is that

607
00:24:53,180 --> 00:24:57,110
with the dust grains is that if you

608
00:24:55,039 --> 00:25:00,379
think of a particular mass of

609
00:24:57,109 --> 00:25:03,709
stuff and small dust grains you have a

610
00:25:00,380 --> 00:25:06,410
lot of surface area for those small dust

611
00:25:03,710 --> 00:25:07,819
grains compared to like a planet so for

612
00:25:06,410 --> 00:25:10,308
example if you were to imagine Jupiter

613
00:25:07,819 --> 00:25:12,589

broken up into micron sized dust grains

614

00:25:10,308 --> 00:25:14,569

there's much more surface area in those

615

00:25:12,589 --> 00:25:16,699

micron sized dust grains compared to the

616

00:25:14,569 --> 00:25:19,480

planet Jupiter and this is what makes it

617

00:25:16,700 --> 00:25:24,100

so easy to detect those dust grains then

618

00:25:19,480 --> 00:25:28,370

through the infrared thermal emission so

619

00:25:24,099 --> 00:25:33,668

so if this is the sadaqa light which was

620

00:25:28,369 --> 00:25:33,668

a map so beautiful here by Rask

621

00:25:35,548 --> 00:25:42,778

but is the kitchen became this dust and

622

00:25:39,058 --> 00:25:45,678

for example your bottom so this is a

623

00:25:42,778 --> 00:25:48,269

plot showing you the world parameters of

624

00:25:45,679 --> 00:25:50,970

asteroids in the main asteroid belt in

625

00:25:48,269 --> 00:25:53,069

particular the y-axis here shows you the

626

00:25:50,970 --> 00:25:55,679

inclination of their orbits plotted as a

627

00:25:53,069 --> 00:25:57,778

function of their semi major axis every

628
00:25:55,679 --> 00:26:01,379
little dot on a top represents a single

629
00:25:57,778 --> 00:26:04,048
asteroid a plot like this was first made

630
00:26:01,378 --> 00:26:05,969
by an astronomer named Hariyama in 1918

631
00:26:04,048 --> 00:26:09,089
and one of the stunning things that he

632
00:26:05,970 --> 00:26:10,409
discovered was that and you can see this

633
00:26:09,089 --> 00:26:13,019
when you look at this more modern plot

634
00:26:10,409 --> 00:26:15,960
today is that there is structure in this

635
00:26:13,019 --> 00:26:22,519
plot so for example there's a gap here

636
00:26:15,960 --> 00:26:25,590
an absence of Africa so this is a

637
00:26:22,519 --> 00:26:27,989
location where if a body was here it

638
00:26:25,589 --> 00:26:29,849
would be in residence with Jupiter and

639
00:26:27,989 --> 00:26:32,009
that resonance then makes the object

640
00:26:29,849 --> 00:26:34,949
unstable gravitationally unstable so it

641
00:26:32,009 --> 00:26:37,230
gets ejected out of that orbit so that's

642
00:26:34,950 --> 00:26:39,840
why this whole region is clear but in

643
00:26:37,230 --> 00:26:42,210
addition to structures like that you can

644
00:26:39,839 --> 00:26:44,788
actually also see clumping of objects in

645
00:26:42,210 --> 00:26:48,179
this plot and when this was first

646
00:26:44,788 --> 00:26:50,579
noticed it was hypothesized that like

647
00:26:48,179 --> 00:26:52,080
you have so many objects that are in

648
00:26:50,579 --> 00:26:54,928
these clumps is that they were

649
00:26:52,079 --> 00:26:57,628
originally part of a larger object that

650
00:26:54,929 --> 00:26:59,970
broke apart into smaller pieces and so

651
00:26:57,628 --> 00:27:04,858
they still retained the overall same

652
00:26:59,970 --> 00:27:07,169
orbital parameters that you see a you

653
00:27:04,858 --> 00:27:09,569
know on this plot but there's now a

654
00:27:07,169 --> 00:27:15,239
little bit of dispersion from having

655
00:27:09,569 --> 00:27:17,548
broken up you can imagine that and you

656

00:27:15,239 --> 00:27:19,679
have the breakup of an asteroid you

657
00:27:17,548 --> 00:27:21,450
create not just large objects but

658
00:27:19,679 --> 00:27:23,519
actually a whole size distribution of

659
00:27:21,450 --> 00:27:26,190
particles it's not just sayings that

660
00:27:23,519 --> 00:27:28,349
have sizes of a kilometer ten kilometers

661
00:27:26,190 --> 00:27:30,629
but things all the way down to fine

662
00:27:28,349 --> 00:27:32,908
grain dust things with the size of a

663
00:27:30,628 --> 00:27:36,028
micron or so and those are things that

664
00:27:32,909 --> 00:27:39,259
again have a lot of surface area for

665
00:27:36,028 --> 00:27:41,339
their mass and so they're very

666
00:27:39,259 --> 00:27:43,980
efficiently warmed up and they very

667
00:27:41,339 --> 00:27:47,369
efficiently radiate that the heat the

668
00:27:43,980 --> 00:27:49,079
energy that they absorb and so one

669
00:27:47,369 --> 00:27:52,469
they're really interesting discoveries

670
00:27:49,079 --> 00:27:54,389

of the IRS satellite was structures in

671

00:27:52,470 --> 00:27:57,720

the zodiacal light in the zoo daya coal

672

00:27:54,390 --> 00:28:01,259

dust and in particular so these are sort

673

00:27:57,720 --> 00:28:02,819

of zoomed in pictures of the zodiacal

674

00:28:01,259 --> 00:28:06,660

light in which you can see that there's

675

00:28:02,819 --> 00:28:09,750

actually these bands where you have an

676

00:28:06,660 --> 00:28:10,980

enhancement of small particles in the

677

00:28:09,750 --> 00:28:14,640

dust in the inner part of the solar

678

00:28:10,980 --> 00:28:16,259

system you can go through and model in

679

00:28:14,640 --> 00:28:18,270

better detail what the orbital

680

00:28:16,259 --> 00:28:20,160

parameters are associated with these

681

00:28:18,269 --> 00:28:24,000

dust bands and you find that they're

682

00:28:20,160 --> 00:28:25,558

actually coincident with for the

683

00:28:24,000 --> 00:28:27,660

particular case of these dust bands

684

00:28:25,558 --> 00:28:30,379

alpha beta and gamma dust bands their

685
00:28:27,660 --> 00:28:34,350
orbital parameters are coincident with

686
00:28:30,380 --> 00:28:36,540
the famous EOS and Cronus families and

687
00:28:34,349 --> 00:28:38,819
so this tells you that this these are

688
00:28:36,539 --> 00:28:40,678
the small particles that were formed

689
00:28:38,819 --> 00:28:42,539
when the larger body broke up so not

690
00:28:40,679 --> 00:28:47,580
only do you see the large bodies in this

691
00:28:42,539 --> 00:28:49,799
asteroid plot an orbital parameters the

692
00:28:47,579 --> 00:28:53,428
sky the fine dust grains that are

693
00:28:49,799 --> 00:28:55,409
created and when they break up so so

694
00:28:53,429 --> 00:28:58,380
infrared a lot of infrared astronomy is

695
00:28:55,410 --> 00:29:00,570
about detecting the heat signature from

696
00:28:58,380 --> 00:29:03,420
dust and so I just wanted to remind you

697
00:29:00,569 --> 00:29:07,700
about blackbody emission and how it

698
00:29:03,420 --> 00:29:11,039
works so this particular plot shows you

699
00:29:07,700 --> 00:29:13,259
intensity as a function of wavelength so

700
00:29:11,039 --> 00:29:15,808
this side is blue and the side is red

701
00:29:13,259 --> 00:29:17,670
for from in this particular case it

702
00:29:15,808 --> 00:29:22,829
would be stars of various temperatures

703
00:29:17,670 --> 00:29:24,870
so 3,000 4,000 5,000 6,000 Kelvin so our

704
00:29:22,829 --> 00:29:26,490
sun has a temperature of about 5800

705
00:29:24,869 --> 00:29:29,399
Kelvin so it's approximately like this

706
00:29:26,490 --> 00:29:32,039
six thousand Kelvin star so in the

707
00:29:29,400 --> 00:29:35,100
particular case of our sign you can see

708
00:29:32,039 --> 00:29:38,279
that the peak of the light that comes

709
00:29:35,099 --> 00:29:41,789
out is about 5500 angstroms it sort of

710
00:29:38,279 --> 00:29:43,740
corresponds to yellow green but if you

711
00:29:41,789 --> 00:29:46,789
imagine stars that have decreasing

712
00:29:43,740 --> 00:29:49,140
temperatures the peak in this black body

713

00:29:46,789 --> 00:29:52,230
function actually shifts to the right

714
00:29:49,140 --> 00:29:54,090
and so the energy that comes out for

715
00:29:52,230 --> 00:29:55,679
lower and lower temperature stars is

716
00:29:54,089 --> 00:29:57,659
redder and redder so they have redder

717
00:29:55,679 --> 00:29:59,340
and redder colors the other thing that

718
00:29:57,660 --> 00:30:00,509
you notice is that as you lower the

719
00:29:59,339 --> 00:30:02,278
temperature the

720
00:30:00,509 --> 00:30:04,588
rightness or the intensity of the object

721
00:30:02,278 --> 00:30:07,440
also decreases so when you lower the

722
00:30:04,588 --> 00:30:10,378
temperatures for things the radiation

723
00:30:07,440 --> 00:30:12,719
becomes longer and wavelengths more red

724
00:30:10,378 --> 00:30:14,819
and it also diminishes lowers and

725
00:30:12,719 --> 00:30:17,669
intensity so that's one of the major

726
00:30:14,819 --> 00:30:20,069
tools that we look at is detecting the

727
00:30:17,669 --> 00:30:23,459

heat and I'll tell you more about the

728

00:30:20,069 --> 00:30:25,408
observations for the dust in our

729

00:30:23,459 --> 00:30:27,808
particular solar system it turns out

730

00:30:25,409 --> 00:30:30,509
that it doesn't really stay put from

731

00:30:27,808 --> 00:30:35,608
where it's generated so you can imagine

732

00:30:30,509 --> 00:30:37,709
for example that I'd better and as they

733

00:30:35,608 --> 00:30:39,898
do so they grind down and produce little

734

00:30:37,709 --> 00:30:41,609
tiny dust grains it turns out that for

735

00:30:39,898 --> 00:30:43,588
the smallest screens in the size

736

00:30:41,608 --> 00:30:46,048
distribution they have a lot of surface

737

00:30:43,588 --> 00:30:48,178
area for their volume so they have a lot

738

00:30:46,048 --> 00:30:51,298
of surface area for their mass and so

739

00:30:48,179 --> 00:30:54,059
that gravitationally bound to the star

740

00:30:51,298 --> 00:30:56,519
and so they act like tiny sales and so

741

00:30:54,058 --> 00:30:58,469
the radiation pressure just drives them

742
00:30:56,519 --> 00:31:01,919
below them out of our solar system

743
00:30:58,469 --> 00:31:05,419
instead inserted I'm sorry to the dust

744
00:31:01,919 --> 00:31:08,399
grains that are in our solar system for

745
00:31:05,419 --> 00:31:11,129
dust grains that are larger they're no

746
00:31:08,398 --> 00:31:13,948
longer sensitive to radiation pressure

747
00:31:11,128 --> 00:31:15,838
in this way but what happens to them

748
00:31:13,949 --> 00:31:17,669
instead is they feel a relativistic

749
00:31:15,838 --> 00:31:19,708
effect called pointing robertson drag

750
00:31:17,669 --> 00:31:21,389
and in that particular case you can

751
00:31:19,709 --> 00:31:24,719
imagine that you're a dust grain

752
00:31:21,388 --> 00:31:27,689
orbiting around the star and so you feel

753
00:31:24,719 --> 00:31:30,179
like head with photons from the star and

754
00:31:27,690 --> 00:31:31,919
that causes you to slow down and so you

755
00:31:30,179 --> 00:31:34,469
lose angular momentum and you slowly

756
00:31:31,919 --> 00:31:36,359
spiral into the star so the basic

757
00:31:34,469 --> 00:31:38,338
takeaway message is the expectation or

758
00:31:36,358 --> 00:31:40,259
what happens in our solar system is that

759
00:31:38,338 --> 00:31:42,690
the small variance get radiatively blown

760
00:31:40,259 --> 00:31:48,690
out and the large larger ones spiral

761
00:31:42,690 --> 00:31:52,318
into the into the star so it turns out

762
00:31:48,690 --> 00:31:54,869
that for our son there's another effect

763
00:31:52,318 --> 00:31:57,568
that brings large desk brains into the

764
00:31:54,868 --> 00:31:59,698
star it's called solar wind drag and

765
00:31:57,568 --> 00:32:01,318
this happens around active stars too and

766
00:31:59,699 --> 00:32:03,690
in this particular case it's very

767
00:32:01,318 --> 00:32:06,239
analogous to point in Roberts a drag as

768
00:32:03,690 --> 00:32:09,149
a difference is that the star is

769
00:32:06,239 --> 00:32:13,259
emitting not only photons light but it's

770

00:32:09,148 --> 00:32:14,278
also emitting particles protons so and

771
00:32:13,259 --> 00:32:16,409
you can imagine now

772
00:32:14,278 --> 00:32:18,808
what happens instead is that that

773
00:32:16,409 --> 00:32:21,749
orbiting dust grain feels a headwind of

774
00:32:18,808 --> 00:32:24,418
these protons of particles we can cause

775
00:32:21,749 --> 00:32:27,028
them to slow down whose angular momentum

776
00:32:24,419 --> 00:32:29,219
as Ireland to the scar so that just the

777
00:32:27,028 --> 00:32:31,169
main point is just that dust in the

778
00:32:29,219 --> 00:32:34,649
solar system gets rearranged in these

779
00:32:31,169 --> 00:32:37,559
different ways so the part that really

780
00:32:34,648 --> 00:32:41,608
interests me is what do we know about

781
00:32:37,558 --> 00:32:45,450
planetary systems around other stars do

782
00:32:41,608 --> 00:32:47,249
we do we think that there are lots of

783
00:32:45,450 --> 00:32:52,080
other planetary systems that have

784
00:32:47,249 --> 00:32:55,649

analogous belts of small bodies and you

785

00:32:52,079 --> 00:32:58,468

know a do they play some sort of role in

786

00:32:55,648 --> 00:33:02,338

how planetary systems form and evolve so

787

00:32:58,469 --> 00:33:04,889

for example if you think about our solar

788

00:33:02,338 --> 00:33:06,868

system and the earth one of the

789

00:33:04,888 --> 00:33:08,488

outstanding questions today is how was

790

00:33:06,868 --> 00:33:09,928

water delivered to the earth how did the

791

00:33:08,489 --> 00:33:10,829

oceans get here and that's that's

792

00:33:09,929 --> 00:33:14,009

actually something that we don't

793

00:33:10,829 --> 00:33:16,949

understand well and one of the ideas for

794

00:33:14,009 --> 00:33:18,868

the origin of the oceans was essentially

795

00:33:16,950 --> 00:33:21,690

they were delivered by comets from the

796

00:33:18,868 --> 00:33:23,158

outer solar system so these minor bodies

797

00:33:21,690 --> 00:33:25,859

might actually be a very important

798

00:33:23,159 --> 00:33:28,440

source of water in extrasolar planetary

799
00:33:25,858 --> 00:33:31,048
systems so the answer is that we've been

800
00:33:28,440 --> 00:33:33,058
able to discover minor bodies so

801
00:33:31,048 --> 00:33:35,729
asteroid and Kuiper belt populations

802
00:33:33,058 --> 00:33:39,148
around our stars and we do this in the

803
00:33:35,729 --> 00:33:41,069
infrared particularly this started with

804
00:33:39,148 --> 00:33:42,928
the IRS satellite so I showed you the

805
00:33:41,069 --> 00:33:45,358
beautiful off sky image and then showed

806
00:33:42,929 --> 00:33:47,099
you the survival dust bands this was

807
00:33:45,358 --> 00:33:51,449
another one of the key contributions

808
00:33:47,098 --> 00:33:54,569
from the IRA satellite so basically when

809
00:33:51,450 --> 00:33:57,179
I r s was launched they the astronomers

810
00:33:54,569 --> 00:33:59,968
envisioned that they would use nearby a

811
00:33:57,179 --> 00:34:02,548
type stars as calibrators and they felt

812
00:33:59,969 --> 00:34:04,710
that they understood very well what the

813
00:34:02,548 --> 00:34:07,499
flux from those stars should look like

814
00:34:04,710 --> 00:34:10,079
based on how they look at visual

815
00:34:07,499 --> 00:34:12,568
wavelengths and so basically if you look

816
00:34:10,079 --> 00:34:14,940
at these plots their brightness flux as

817
00:34:12,568 --> 00:34:17,338
a function of wavelength and you can see

818
00:34:14,940 --> 00:34:19,349
1225 60 100 microns so these are far

819
00:34:17,338 --> 00:34:22,139
infrared wavelengths and these straight

820
00:34:19,349 --> 00:34:24,450
lines show you the expectations that

821
00:34:22,139 --> 00:34:26,519
people had for how bright those stars

822
00:34:24,449 --> 00:34:28,259
would be and you can see these error

823
00:34:26,519 --> 00:34:30,780
bars show you the actual day

824
00:34:28,260 --> 00:34:32,550
and what's really stunning at these

825
00:34:30,780 --> 00:34:35,250
predictions for how about the stars were

826
00:34:32,550 --> 00:34:37,889
should be was a factor of a hundred or

827

00:34:35,250 --> 00:34:41,340
so wrong for these four particular stars

828
00:34:37,889 --> 00:34:44,429
and so when this was discovered it was

829
00:34:41,340 --> 00:34:47,309
immediately hypothesized that the reason

830
00:34:44,429 --> 00:34:48,539
why they're so bright at sixteen 100

831
00:34:47,309 --> 00:34:50,880
microns is because you have

832
00:34:48,539 --> 00:34:54,199
circumstellar dust so dust around the

833
00:34:50,880 --> 00:34:58,500
star which is absorbing the warming I'm

834
00:34:54,199 --> 00:35:03,239
radiated energy thermal mission and

835
00:34:58,500 --> 00:35:06,000
that's a dress today indeed Tron wars

836
00:35:03,239 --> 00:35:09,419
were able to once they identified these

837
00:35:06,000 --> 00:35:11,010
interesting candidate targets so in this

838
00:35:09,420 --> 00:35:12,990
particular case this is like Vega

839
00:35:11,010 --> 00:35:15,870
Fomalhaut beta Pictoris and epsilon

840
00:35:12,989 --> 00:35:17,669
eridani they would go to other

841
00:35:15,869 --> 00:35:20,929

facilities and then try to take a

842

00:35:17,670 --> 00:35:23,280

picture of the planetary system and so

843

00:35:20,929 --> 00:35:25,049

when the first ones that they were able

844

00:35:23,280 --> 00:35:27,440

to do this successfully for was beta

845

00:35:25,050 --> 00:35:29,210

Pictoris this is a more modern in it

846

00:35:27,440 --> 00:35:32,789

taken with the Hubble Space Telescope

847

00:35:29,210 --> 00:35:35,490

this disc coronagraph in which the star

848

00:35:32,789 --> 00:35:37,349

has been placed behind an occulting

849

00:35:35,489 --> 00:35:39,449

wedge and you think that there's this

850

00:35:37,349 --> 00:35:42,299

bright linear feature this is a disc

851

00:35:39,449 --> 00:35:45,389

that's being seen edge on and then you

852

00:35:42,300 --> 00:35:48,180

can see a different stretch here which

853

00:35:45,389 --> 00:35:50,159

shows you more clearly this edge on disc

854

00:35:48,179 --> 00:35:52,589

so this again is what you're seeing is

855

00:35:50,159 --> 00:35:54,869

heat from small dust grains in this

856
00:35:52,590 --> 00:35:57,480
particular system the really interesting

857
00:35:54,869 --> 00:35:59,699
thing about whenever people go out and

858
00:35:57,480 --> 00:36:02,070
take images of the system at a higher

859
00:35:59,699 --> 00:36:04,919
and higher angular resolution as they

860
00:36:02,070 --> 00:36:06,870
find detailed structures that imply the

861
00:36:04,920 --> 00:36:08,400
presence of planets so in this

862
00:36:06,869 --> 00:36:10,409
particular case in the case of beta

863
00:36:08,400 --> 00:36:12,119
Pictoris what you can see is that the

864
00:36:10,409 --> 00:36:15,109
inner part of the disc is warped with

865
00:36:12,119 --> 00:36:18,449
respect to the outer part of the disc

866
00:36:15,110 --> 00:36:20,220
one of the hypotheses or why this is

867
00:36:18,449 --> 00:36:22,349
true is essentially that there is a

868
00:36:20,219 --> 00:36:25,319
companion that is a planetary mass size

869
00:36:22,349 --> 00:36:28,920
thing in this planetary system which

870
00:36:25,320 --> 00:36:32,190
disrupts the dust and forces the dust on

871
00:36:28,920 --> 00:36:34,230
to these inclined orbits if you look at

872
00:36:32,190 --> 00:36:37,440
the distance of this warp compared to

873
00:36:34,230 --> 00:36:38,880
the star you can then place strengths on

874
00:36:37,440 --> 00:36:40,960
the product of the mass of the planet

875
00:36:38,880 --> 00:36:43,510
and its distance

876
00:36:40,960 --> 00:36:46,720
the central star and one of the really

877
00:36:43,510 --> 00:36:49,390
exciting things is in the 23 years of

878
00:36:46,719 --> 00:36:51,009
studying these particular objects people

879
00:36:49,389 --> 00:36:52,420
have been able to refine their

880
00:36:51,010 --> 00:36:57,040
understandings of these planetary

881
00:36:52,420 --> 00:36:59,889
systems and so this is now a even more

882
00:36:57,039 --> 00:37:02,230
recent image of the exact same system

883
00:36:59,889 --> 00:37:04,509
this is now ground-based data taken with

884

00:37:02,230 --> 00:37:07,480
The Very Large Telescope ESO the

885
00:37:04,510 --> 00:37:09,820
European facility and GA and it's a

886
00:37:07,480 --> 00:37:13,210
composite image showing you the disk but

887
00:37:09,820 --> 00:37:14,880
now you also see so the disk is taken

888
00:37:13,210 --> 00:37:17,230
with a coronagraph but now you also see

889
00:37:14,880 --> 00:37:20,140
images of a point source that were

890
00:37:17,230 --> 00:37:23,250
discovered very close to the star at

891
00:37:20,139 --> 00:37:25,989
about 10 a you from the star this

892
00:37:23,250 --> 00:37:27,639
position on the sort of left side here

893
00:37:25,989 --> 00:37:29,289
was the discovery epic and then it

894
00:37:27,639 --> 00:37:31,420
appeared to disappear for a while and

895
00:37:29,289 --> 00:37:34,000
then it reappeared so first was detected

896
00:37:31,420 --> 00:37:37,599
in 2003 and then was reappeared in 2009

897
00:37:34,000 --> 00:37:40,659
and so it is you're actually seeing them

898
00:37:37,599 --> 00:37:42,430

the orbital motion of a giant planet in

899

00:37:40,659 --> 00:37:44,409

this particular disk which is consistent

900

00:37:42,429 --> 00:37:48,159

with the structures that were seen in

901

00:37:44,409 --> 00:37:51,969

the dust from the older hubble space

902

00:37:48,159 --> 00:37:54,549

telescope images so why do we want to go

903

00:37:51,969 --> 00:37:56,529

out and try to study these particular

904

00:37:54,550 --> 00:37:58,599

planetary systems we already learned so

905

00:37:56,530 --> 00:38:00,220

much from Kepler and looking at the

906

00:37:58,599 --> 00:38:02,200

demographics of planets that are

907

00:38:00,219 --> 00:38:04,389

detected through transit or radial

908

00:38:02,199 --> 00:38:05,919

velocity or other things and the answer

909

00:38:04,389 --> 00:38:08,618

is that it gives us complementary

910

00:38:05,920 --> 00:38:10,210

information it's very hard with planets

911

00:38:08,619 --> 00:38:12,430

to understand what the detailed

912

00:38:10,210 --> 00:38:15,369

composition of the planet is because

913
00:38:12,429 --> 00:38:17,559
really all you ever met measure for like

914
00:38:15,369 --> 00:38:19,210
the transiting planets is the mass and

915
00:38:17,559 --> 00:38:21,190
the radius and so you get the density of

916
00:38:19,210 --> 00:38:22,449
the planet but in the case of these

917
00:38:21,190 --> 00:38:24,940
particular systems you have the

918
00:38:22,449 --> 00:38:28,029
opportunity to actually measure the

919
00:38:24,940 --> 00:38:31,000
detail of the Mariners and with really

920
00:38:28,030 --> 00:38:33,670
need of and it also provides insight

921
00:38:31,000 --> 00:38:35,679
into particular epochs that were very

922
00:38:33,670 --> 00:38:39,940
violent in the formation of our own

923
00:38:35,679 --> 00:38:41,919
solar system and so early on in the

924
00:38:39,940 --> 00:38:43,720
trend trustful planet formation within

925
00:38:41,920 --> 00:38:47,050
the first 30 million years there are a

926
00:38:43,719 --> 00:38:48,549
lot of violent collisions in which you

927
00:38:47,050 --> 00:38:50,589
know things collided together to build

928
00:38:48,550 --> 00:38:54,260
up larger and larger things to form

929
00:38:50,588 --> 00:38:55,460
earth and then at ages of 30 100

930
00:38:54,260 --> 00:38:57,590
million years we know that there were

931
00:38:55,460 --> 00:39:00,440
giant collisions in our solar system so

932
00:38:57,590 --> 00:39:03,380
for example we knew that mars-sized

933
00:39:00,440 --> 00:39:07,579
object called Theia impacted the earth

934
00:39:03,380 --> 00:39:09,530
and form the moon and so you know by

935
00:39:07,579 --> 00:39:12,349
studying these other systems understand

936
00:39:09,530 --> 00:39:15,050
their ease about they serve our solar

937
00:39:12,349 --> 00:39:18,710
system our common or rare so this is

938
00:39:15,050 --> 00:39:23,720
just meant to be a nice simulation of I

939
00:39:18,710 --> 00:39:25,579
mentioned to you how giant impacts are

940
00:39:23,719 --> 00:39:29,409
important in the history of our solar

941

00:39:25,579 --> 00:39:32,599
system a little bit of trouble there

942
00:39:29,409 --> 00:39:36,710
goes and so this is just a simulation of

943
00:39:32,599 --> 00:39:39,469
the the moon-forming impact and in which

944
00:39:36,710 --> 00:39:41,659
the Thea sighs body ran into the earth

945
00:39:39,469 --> 00:39:44,809
on a glancing sort of collision course

946
00:39:41,659 --> 00:39:46,940
in what you see here is basically the

947
00:39:44,809 --> 00:39:49,699
mantles of the two objects mixed

948
00:39:46,940 --> 00:39:51,650
together spin off and condense and

949
00:39:49,699 --> 00:39:54,529
eventually forming to the moon and then

950
00:39:51,650 --> 00:39:59,809
the core of the impactor actually sunk

951
00:39:54,530 --> 00:40:03,280
into the the forming earth and so this

952
00:39:59,809 --> 00:40:05,929
explains a lot of what we know about the

953
00:40:03,280 --> 00:40:08,030
the properties of the moon so for

954
00:40:05,929 --> 00:40:10,659
example the Apollo astronauts went and

955
00:40:08,030 --> 00:40:12,860

collected lunar samples and analyzed

956

00:40:10,659 --> 00:40:16,869

position of those and it turns out that

957

00:40:12,860 --> 00:40:19,010

very similar to the the mantle on earth

958

00:40:16,869 --> 00:40:20,420

so we can try and learn about these

959

00:40:19,010 --> 00:40:23,090

violent things that happened in our

960

00:40:20,420 --> 00:40:25,579

solar system and whether they're giant

961

00:40:23,090 --> 00:40:28,190

collisions early on or we also think

962

00:40:25,579 --> 00:40:29,750

that there is a interesting period in

963

00:40:28,190 --> 00:40:30,909

the evolution of our solar system called

964

00:40:29,750 --> 00:40:33,320

the period of late heavy bombardment

965

00:40:30,909 --> 00:40:35,449

that this happened when our solar system

966

00:40:33,320 --> 00:40:38,150

had an age of about 700 million years

967

00:40:35,449 --> 00:40:41,779

this is preserved in the crater record

968

00:40:38,150 --> 00:40:45,079

of old terrestrial surfaces such as the

969

00:40:41,780 --> 00:40:47,690

moon and so these are maps showing you

970
00:40:45,079 --> 00:40:49,699
highlighted craters I'm left over from

971
00:40:47,690 --> 00:40:51,590
the period of late heavy bombardment at

972
00:40:49,699 --> 00:40:53,269
about 700 million years so the

973
00:40:51,590 --> 00:40:55,670
prevailing idea for how these craters

974
00:40:53,269 --> 00:40:57,619
got to be there is essentially that the

975
00:40:55,670 --> 00:41:00,590
giant planets the locations that we see

976
00:40:57,619 --> 00:41:02,750
them at today are not the locations at

977
00:41:00,590 --> 00:41:05,059
which those giant planets formed the

978
00:41:02,750 --> 00:41:06,380
giant planets actually migrated from a

979
00:41:05,059 --> 00:41:07,429
different location to where they are

980
00:41:06,380 --> 00:41:09,530
today

981
00:41:07,429 --> 00:41:12,669
and as they did so Jupiter and Saturn

982
00:41:09,530 --> 00:41:15,099
crossed on the two dhawan residents and

983
00:41:12,670 --> 00:41:17,420
basically the resonance crossing

984
00:41:15,099 --> 00:41:19,220
destabilized all of the minor bodies in

985
00:41:17,420 --> 00:41:22,818
our solar systems such as the asteroids

986
00:41:19,219 --> 00:41:26,088
in the Kuiper belt and so basically all

987
00:41:22,818 --> 00:41:27,679
of the minor bodies became chaotic for a

988
00:41:26,088 --> 00:41:29,690
brief period and they went all

989
00:41:27,679 --> 00:41:31,909
throughout the solar system and this is

990
00:41:29,690 --> 00:41:35,240
sort of you can sort of visualize that

991
00:41:31,909 --> 00:41:37,489
in this simulation here where the Rings

992
00:41:35,239 --> 00:41:39,828
show you the orbits of the four

993
00:41:37,489 --> 00:41:41,989
outermost planets and initially saw

994
00:41:39,829 --> 00:41:43,940
those green dots which were each one

995
00:41:41,989 --> 00:41:45,439
represents the Kuiper belt and then you

996
00:41:43,940 --> 00:41:47,030
can see the moment when you cross the

997
00:41:45,440 --> 00:41:48,710
two-to-one resonance and all of those

998

00:41:47,030 --> 00:41:52,819
things get to stabilize and they go

999
00:41:48,710 --> 00:41:55,010
everywhere in the solar system so these

1000
00:41:52,818 --> 00:41:57,318
are the kinds of periods in the history

1001
00:41:55,010 --> 00:42:00,589
that we're trying to study so the tool

1002
00:41:57,318 --> 00:42:02,539
that I used in Joel used as well was the

1003
00:42:00,588 --> 00:42:05,210
Spitzer Space Telescope Spitzer launched

1004
00:42:02,539 --> 00:42:09,139
in 2003 it was cryogenic or 2000 for

1005
00:42:05,210 --> 00:42:10,760
cryogenic it was pulled to about 4

1006
00:42:09,139 --> 00:42:13,759
Kelvin but it was a relatively small

1007
00:42:10,760 --> 00:42:18,410
telescope it was only 85 centimeters in

1008
00:42:13,760 --> 00:42:21,950
diameter but because it was so cold and

1009
00:42:18,409 --> 00:42:23,598
in space it had tremendous sensitivity

1010
00:42:21,949 --> 00:42:25,279
compared to any other facility at

1011
00:42:23,599 --> 00:42:27,650
working at those wavelengths prior so

1012
00:42:25,280 --> 00:42:31,280

wavelengths of you know a couple microns

1013

00:42:27,650 --> 00:42:33,950

260 microns and it really enabled for

1014

00:42:31,280 --> 00:42:37,519

the first time solid-state infrared

1015

00:42:33,949 --> 00:42:41,960

spectroscopy of large samples of young

1016

00:42:37,519 --> 00:42:44,989

discs and so the lips that's an excerpt

1017

00:42:41,960 --> 00:42:47,210

from a paper basically trying to

1018

00:42:44,989 --> 00:42:49,159

illustrate what these solid-state

1019

00:42:47,210 --> 00:42:51,460

features from silicates like all of

1020

00:42:49,159 --> 00:42:54,078

being look like in the infrared so

1021

00:42:51,460 --> 00:42:56,389

basically you get a peak this is like an

1022

00:42:54,079 --> 00:42:58,400

emission feature or microns and then

1023

00:42:56,389 --> 00:43:01,368

there were 120 microns it's really

1024

00:42:58,400 --> 00:43:03,440

fascinating because just like atoms when

1025

00:43:01,369 --> 00:43:05,838

you you can tell the composition of a

1026

00:43:03,440 --> 00:43:09,470

gas by looking at the spectrum from it

1027
00:43:05,838 --> 00:43:12,108
you can tell the composition of the dust

1028
00:43:09,469 --> 00:43:15,379
material by looking at the peak position

1029
00:43:12,108 --> 00:43:17,179
of for example of the material that you

1030
00:43:15,380 --> 00:43:19,490
see the spectrum for and the infrared

1031
00:43:17,179 --> 00:43:20,809
but more than that not only can tell you

1032
00:43:19,489 --> 00:43:22,549
tell what it's made of but

1033
00:43:20,809 --> 00:43:25,759
you can actually also tell how large the

1034
00:43:22,550 --> 00:43:28,820
dust grains are so it turns out that the

1035
00:43:25,760 --> 00:43:30,320
feature actually changes shape so

1036
00:43:28,820 --> 00:43:32,210
against this is brightness as a function

1037
00:43:30,320 --> 00:43:33,680
of wavelength but the feature changes

1038
00:43:32,210 --> 00:43:36,849
shape depending on how large the grains

1039
00:43:33,679 --> 00:43:39,829
are so for small grains the feature is a

1040
00:43:36,849 --> 00:43:43,549
sort of triangular so it's tall and

1041
00:43:39,829 --> 00:43:46,219
pointy and it was great the feature

1042
00:43:43,550 --> 00:43:49,130
actually becomes more broad and

1043
00:43:46,219 --> 00:43:51,619
trapezoidal in shape and so by fitting

1044
00:43:49,130 --> 00:43:54,079
the shapes of these features you can

1045
00:43:51,619 --> 00:43:56,619
tell the composition of the dust and you

1046
00:43:54,079 --> 00:44:01,389
can also say how big the dust grains are

1047
00:43:56,619 --> 00:44:04,690
so these are some examples of spectra

1048
00:44:01,389 --> 00:44:08,210
from targets that I was interested in

1049
00:44:04,690 --> 00:44:10,369
which actually helped to constrain the

1050
00:44:08,210 --> 00:44:12,980
evolutionary phase of these particular

1051
00:44:10,369 --> 00:44:14,719
objects so again this is flux as a

1052
00:44:12,980 --> 00:44:17,480
function of wavelength and then this is

1053
00:44:14,719 --> 00:44:19,069
again that 10 micron feature and then

1054
00:44:17,480 --> 00:44:20,570
here it's harder to see the 20 micron

1055

00:44:19,070 --> 00:44:22,730
feature but again the 10 micron feature

1056
00:44:20,570 --> 00:44:24,289
in the 20 micron feature you can see in

1057
00:44:22,730 --> 00:44:29,179
this particular case it's not purely

1058
00:44:24,289 --> 00:44:32,179
just simple the number of different

1059
00:44:29,179 --> 00:44:34,759
materials that go into modeling this

1060
00:44:32,179 --> 00:44:36,769
particular feature including materials

1061
00:44:34,760 --> 00:44:38,810
that are altered at high pressures and

1062
00:44:36,769 --> 00:44:41,420
temperatures so things like obsidian

1063
00:44:38,809 --> 00:44:45,019
that you find on earth or tektite that

1064
00:44:41,420 --> 00:44:48,530
you find in the ejecta envelopes of

1065
00:44:45,019 --> 00:44:51,739
craters and possibly SiO silicon

1066
00:44:48,530 --> 00:44:53,480
monoxide gas this is the sort of feature

1067
00:44:51,739 --> 00:44:56,449
that might be indicative of a giant

1068
00:44:53,480 --> 00:44:58,670
hypervelocity collision so a collision

1069
00:44:56,449 --> 00:45:00,829

in which you have a moon forming event

1070

00:44:58,670 --> 00:45:03,230

because you produce all this material

1071

00:45:00,829 --> 00:45:06,679

its altered at high pressures and

1072

00:45:03,230 --> 00:45:08,360

temperatures terrestrial plants this is

1073

00:45:06,679 --> 00:45:10,639

in contrast to something that has a

1074

00:45:08,360 --> 00:45:12,320

feature like this where you can see the

1075

00:45:10,639 --> 00:45:14,900

10 micron feature the shape of it looks

1076

00:45:12,320 --> 00:45:17,000

really different and this is because

1077

00:45:14,900 --> 00:45:19,579

when you decompose it it's made out of

1078

00:45:17,000 --> 00:45:22,010

instead things more like water and

1079

00:45:19,579 --> 00:45:23,929

amorphous carbon and so these are very

1080

00:45:22,010 --> 00:45:26,240

pristine things that you might expect to

1081

00:45:23,929 --> 00:45:29,359

find in the outer solar system so this

1082

00:45:26,239 --> 00:45:31,909

fight then tell you about a Kyber battle

1083

00:45:29,360 --> 00:45:33,500

object our solar system coming into

1084
00:45:31,909 --> 00:45:36,949
trust

1085
00:45:33,500 --> 00:45:39,530
um yes in your lighting with much rest

1086
00:45:36,949 --> 00:45:42,289
rope net producing the source spectral

1087
00:45:39,530 --> 00:45:44,269
fear spectroscopy all that you know it's

1088
00:45:42,289 --> 00:45:46,550
not as pretty to look at as nice

1089
00:45:44,269 --> 00:45:48,320
pictures can actually tell you a lot of

1090
00:45:46,550 --> 00:45:51,050
really detailed diagnostic information

1091
00:45:48,320 --> 00:45:54,650
about the composition and the

1092
00:45:51,050 --> 00:45:56,360
evolutionary phase of the target but you

1093
00:45:54,650 --> 00:45:58,360
can learn not only about the composition

1094
00:45:56,360 --> 00:46:01,579
of the targets but also about the

1095
00:45:58,360 --> 00:46:03,380
spatial distribution of the dust and

1096
00:46:01,579 --> 00:46:05,509
this is really relying on the fact that

1097
00:46:03,380 --> 00:46:08,119
when you look at dust in these systems

1098
00:46:05,510 --> 00:46:10,460
the dust that's closest to the star is

1099
00:46:08,119 --> 00:46:13,339
actually warmest and the dust that's

1100
00:46:10,460 --> 00:46:15,470
further away is actually coolest so this

1101
00:46:13,340 --> 00:46:20,030
I just current it gives you a broad idea

1102
00:46:15,469 --> 00:46:22,509
so if looking at point why do this

1103
00:46:20,030 --> 00:46:25,280
radiates most strongly at one micron

1104
00:46:22,510 --> 00:46:27,320
whereas this material here that's at

1105
00:46:25,280 --> 00:46:30,230
maybe about a hundred AU from a solar

1106
00:46:27,320 --> 00:46:32,960
like star radiates more strongly at a

1107
00:46:30,230 --> 00:46:35,389
thousand microns so basically in the

1108
00:46:32,960 --> 00:46:37,849
absence of having a picture that shows

1109
00:46:35,389 --> 00:46:40,489
you where all the dust is located you

1110
00:46:37,849 --> 00:46:41,960
can take measurements of the brightness

1111
00:46:40,489 --> 00:46:44,989
as a function of wavelength and try to

1112

00:46:41,960 --> 00:46:49,070
invert them to figure out where the dust

1113
00:46:44,989 --> 00:46:50,809
is located so that was a project that I

1114
00:46:49,070 --> 00:46:53,120
carried out with an undergraduate

1115
00:46:50,809 --> 00:46:56,599
student here at Johns Hopkins we looked

1116
00:46:53,119 --> 00:46:59,960
at the spectra of some 500 stars and

1117
00:46:56,599 --> 00:47:01,639
each one of these postage stamps is the

1118
00:46:59,960 --> 00:47:04,789
brightness as a function of wavelength

1119
00:47:01,639 --> 00:47:08,359
for a bunch of stars and you can see

1120
00:47:04,789 --> 00:47:10,550
there's these strong sources on the blue

1121
00:47:08,360 --> 00:47:13,070
side this is the emission from the star

1122
00:47:10,550 --> 00:47:17,210
and then the gray things are the

1123
00:47:13,070 --> 00:47:20,210
emission from the dust and so you can

1124
00:47:17,210 --> 00:47:23,840
see that in a lot of cases there are

1125
00:47:20,210 --> 00:47:26,780
sources for which there's not but there

1126
00:47:23,840 --> 00:47:31,309

is dust pretty far away and this tells

1127

00:47:26,780 --> 00:47:33,800

us basically that there is an inner

1128

00:47:31,309 --> 00:47:35,299

region that's devoid dust and one of the

1129

00:47:33,800 --> 00:47:36,980

possibilities for why there's no dust

1130

00:47:35,300 --> 00:47:38,750

there is that there's a giant planet

1131

00:47:36,980 --> 00:47:40,820

which is basically clearing the inner

1132

00:47:38,750 --> 00:47:45,170

part of the planetary system from dust

1133

00:47:40,820 --> 00:47:47,420

so just to look at a more detailed

1134

00:47:45,170 --> 00:47:49,639

example this is again one of these

1135

00:47:47,420 --> 00:47:51,170

spectral energy distributions brightness

1136

00:47:49,639 --> 00:47:54,139

as a function of wavelength for a

1137

00:47:51,170 --> 00:47:55,900

particular star which is HR 8799 and you

1138

00:47:54,139 --> 00:47:59,089

see here's the big bump from the

1139

00:47:55,900 --> 00:48:00,889

emission from the star and then the red

1140

00:47:59,090 --> 00:48:02,120

stuff here these are data points and

1141
00:48:00,889 --> 00:48:05,449
it's hard to see but there's some blue

1142
00:48:02,119 --> 00:48:07,909
data point too but you can see that at

1143
00:48:05,449 --> 00:48:10,219
the long wavelengths here at 30 microns

1144
00:48:07,909 --> 00:48:12,920
or so that you get a mission that's in

1145
00:48:10,219 --> 00:48:14,779
excess of what you expect from the star

1146
00:48:12,920 --> 00:48:16,340
and then it actually turns upward a

1147
00:48:14,780 --> 00:48:19,130
little bit and then there's these bright

1148
00:48:16,340 --> 00:48:22,250
points here essentially when you try to

1149
00:48:19,130 --> 00:48:25,340
do the analysis of the the heat from

1150
00:48:22,250 --> 00:48:27,559
this system you require having two

1151
00:48:25,340 --> 00:48:29,360
components a warmish component and a

1152
00:48:27,559 --> 00:48:31,519
coldish component and this is very

1153
00:48:29,360 --> 00:48:33,740
analogous to like what you might expect

1154
00:48:31,519 --> 00:48:36,590
our solar system to look like tuned

1155
00:48:33,739 --> 00:48:38,209
observer far away we have the asteroid

1156
00:48:36,590 --> 00:48:40,100
belt and the Kuiper belt and then a

1157
00:48:38,210 --> 00:48:41,990
family of jovian planets that live in

1158
00:48:40,099 --> 00:48:43,699
between and in this particular system

1159
00:48:41,989 --> 00:48:46,189
you're seeing kind of the same thing an

1160
00:48:43,699 --> 00:48:48,319
asteroid belt and a Kuiper belt and some

1161
00:48:46,190 --> 00:48:49,670
space in between and so that seems like

1162
00:48:48,320 --> 00:48:53,150
a really good place to go look for

1163
00:48:49,670 --> 00:48:55,070
planets and indeed there are some

1164
00:48:53,150 --> 00:48:58,099
astronomers using the keck telescope in

1165
00:48:55,070 --> 00:49:00,970
hawaii and they were they weren't using

1166
00:48:58,099 --> 00:49:03,289
a coronagraph but essentially they were

1167
00:49:00,969 --> 00:49:04,699
having to subtract out the emission from

1168
00:49:03,289 --> 00:49:06,529
the star so you could see faint things

1169

00:49:04,699 --> 00:49:07,909
so that's why there should be a bright

1170
00:49:06,530 --> 00:49:10,910
star in here but it's been subtracted

1171
00:49:07,909 --> 00:49:13,730
out but they actually discovered the

1172
00:49:10,909 --> 00:49:15,440
presence of four Jovian mass planets so

1173
00:49:13,730 --> 00:49:18,139
planets with masses about ten Juber

1174
00:49:15,440 --> 00:49:20,720
masses in orbit around this particular

1175
00:49:18,139 --> 00:49:23,150
star and those planets happen to fall

1176
00:49:20,719 --> 00:49:25,099
right in between where the asteroid and

1177
00:49:23,150 --> 00:49:28,420
Kuiper belts are for this planetary

1178
00:49:25,099 --> 00:49:30,889
system so we know that there are

1179
00:49:28,420 --> 00:49:32,960
planetary systems with architectures

1180
00:49:30,889 --> 00:49:35,629
like our own but we don't really

1181
00:49:32,960 --> 00:49:38,659
understand maybe with the context is for

1182
00:49:35,630 --> 00:49:41,660
our solar system how common is it or how

1183
00:49:38,659 --> 00:49:43,399

common or how rare is it so one of the

1184

00:49:41,659 --> 00:49:45,379

reasons why I'm tremendously excited

1185

00:49:43,400 --> 00:49:47,599

about the James Webb Space Telescope is

1186

00:49:45,380 --> 00:49:49,970

you can just tell by looking at this

1187

00:49:47,599 --> 00:49:51,380

particular graphic right this shows you

1188

00:49:49,969 --> 00:49:52,909

to scale the difference between the

1189

00:49:51,380 --> 00:49:55,130

Spitzer Space Telescope and the James

1190

00:49:52,909 --> 00:49:57,779

Webb Space Telescope so Spitzer was an

1191

00:49:55,130 --> 00:50:00,119

85 centimeters telescope GBT is going to

1192

00:49:57,780 --> 00:50:01,710

six and a half meter telescope Spitzer

1193

00:50:00,119 --> 00:50:04,409

was phenomenal for this area of study

1194

00:50:01,710 --> 00:50:08,159

and being able to serve a large number

1195

00:50:04,409 --> 00:50:10,230

of stars to be able to discover more

1196

00:50:08,159 --> 00:50:12,119

than a thousand planetary systems with

1197

00:50:10,230 --> 00:50:14,429

asteroidal or Kuiper belt dust in them

1198
00:50:12,119 --> 00:50:16,049
but what JT boosty is really going to

1199
00:50:14,429 --> 00:50:18,779
bring to the table is because it has

1200
00:50:16,050 --> 00:50:21,269
such a much bigger mirror it has much

1201
00:50:18,780 --> 00:50:23,130
better angular resolution and so now

1202
00:50:21,269 --> 00:50:25,230
instead of seeing an unresolved point

1203
00:50:23,130 --> 00:50:27,030
you'll actually be able to look at where

1204
00:50:25,230 --> 00:50:29,070
the dust is as a function of position

1205
00:50:27,030 --> 00:50:31,590
map out the dust in these planetary

1206
00:50:29,070 --> 00:50:35,760
systems and it'll do this for hundreds

1207
00:50:31,590 --> 00:50:37,829
of nearby stars so it's just a wreck

1208
00:50:35,760 --> 00:50:42,300
comparison of what our expectations are

1209
00:50:37,829 --> 00:50:44,340
so this top here this is actually data

1210
00:50:42,300 --> 00:50:45,810
from this fits or space telescope this

1211
00:50:44,340 --> 00:50:49,950
was obtained by que su and her

1212
00:50:45,809 --> 00:50:53,130
collaborators this is a data for Vegas

1213
00:50:49,949 --> 00:50:55,829
system which was observed at 24 microns

1214
00:50:53,130 --> 00:50:58,800
and you can see here because Aleutian

1215
00:50:55,829 --> 00:51:01,440
for spares so for essentially you take

1216
00:50:58,800 --> 00:51:03,240
that poor resolution and convolve it

1217
00:51:01,440 --> 00:51:07,260
with this planetary system and you just

1218
00:51:03,239 --> 00:51:09,149
get a big blob but jwst we expect to

1219
00:51:07,260 --> 00:51:12,060
have much better angular resolution and

1220
00:51:09,150 --> 00:51:14,130
so this panel here shows you simulations

1221
00:51:12,059 --> 00:51:16,860
of what the possibilities might actually

1222
00:51:14,130 --> 00:51:20,150
be for the configuration of the dust and

1223
00:51:16,860 --> 00:51:22,890
the system this is taking advantage of

1224
00:51:20,150 --> 00:51:24,570
coronagraphs onboard JT was t to block

1225
00:51:22,889 --> 00:51:27,779
out the central light from the star and

1226

00:51:24,570 --> 00:51:30,090
so on the left-hand side you see a top

1227
00:51:27,780 --> 00:51:31,740
model of a bottom model and this is

1228
00:51:30,090 --> 00:51:34,230
without what's called point spread

1229
00:51:31,739 --> 00:51:35,879
function psf subtraction so this is if

1230
00:51:34,230 --> 00:51:37,230
you were just to use the coronagraph and

1231
00:51:35,880 --> 00:51:39,769
put the star behind the center of the

1232
00:51:37,230 --> 00:51:42,420
coronagraph and then what people do to

1233
00:51:39,769 --> 00:51:44,610
improve their images it's essentially

1234
00:51:42,420 --> 00:51:46,619
they observe their target star with a

1235
00:51:44,610 --> 00:51:48,210
coronagraph and they observe another

1236
00:51:46,619 --> 00:51:49,739
star but their coronagraph one that

1237
00:51:48,210 --> 00:51:52,110
doesn't have anything around it and they

1238
00:51:49,739 --> 00:51:54,119
subtract those two images so that they

1239
00:51:52,110 --> 00:51:56,970
can remove the residual stellar light

1240
00:51:54,119 --> 00:51:59,219

and then dig in deeper close to the star

1241

00:51:56,969 --> 00:52:02,939

looking for additional material so this

1242

00:51:59,219 --> 00:52:05,069

is a psf subtracted images simulations

1243

00:52:02,940 --> 00:52:06,809

instead and then you can see there's two

1244

00:52:05,070 --> 00:52:10,630

flavors of models here one where the

1245

00:52:06,809 --> 00:52:13,328

dust is symmetric and here it's not

1246

00:52:10,630 --> 00:52:15,579

things they notice here here you don't

1247

00:52:13,329 --> 00:52:17,559

see its inner hole in the disk that's

1248

00:52:15,579 --> 00:52:19,059

expected to be seen based on what the

1249

00:52:17,559 --> 00:52:21,880

spectral energy distribution looks like

1250

00:52:19,059 --> 00:52:24,519

and also we have questions about what is

1251

00:52:21,880 --> 00:52:27,608

the detailed distribution of the dust is

1252

00:52:24,518 --> 00:52:29,379

it symmetric or is it asymmetric there's

1253

00:52:27,608 --> 00:52:31,980

a possibility that there's a planet in

1254

00:52:29,380 --> 00:52:34,869

this particular system and it traps

1255
00:52:31,980 --> 00:52:37,869
asteroids or Kuiper belt objects into

1256
00:52:34,869 --> 00:52:40,450
exterior mean motion resonances and that

1257
00:52:37,869 --> 00:52:43,150
those bodies collide and grind produce

1258
00:52:40,449 --> 00:52:45,159
dust grains which are radiatively driven

1259
00:52:43,150 --> 00:52:47,318
out by radiation pressure and blown into

1260
00:52:45,159 --> 00:52:48,848
these spiral structures that then you

1261
00:52:47,318 --> 00:52:51,579
might be able to actually see with the

1262
00:52:48,849 --> 00:52:53,230
James Webb Space Telescope so we're

1263
00:52:51,579 --> 00:52:54,730
tremendously excited about what we can

1264
00:52:53,230 --> 00:52:57,789
do the other thing that's really

1265
00:52:54,730 --> 00:53:00,579
exciting is before I showed you some

1266
00:52:57,789 --> 00:53:02,200
spectra obtained with Spitzer and it was

1267
00:53:00,579 --> 00:53:04,568
just a spectrum of the whole planetary

1268
00:53:02,199 --> 00:53:06,639
system but because James Webb Space

1269
00:53:04,568 --> 00:53:08,858
Telescope has this phenomenal angular

1270
00:53:06,639 --> 00:53:11,230
resolution you'll actually be able to

1271
00:53:08,858 --> 00:53:12,880
take spectra of all the different points

1272
00:53:11,230 --> 00:53:14,798
in the field because you'll spatially

1273
00:53:12,880 --> 00:53:17,019
resolve the whole planetary system and

1274
00:53:14,798 --> 00:53:19,268
so you'll be able to look at four

1275
00:53:17,018 --> 00:53:22,239
gradients in the composition of the dust

1276
00:53:19,268 --> 00:53:23,889
grains as a function of position so this

1277
00:53:22,239 --> 00:53:26,500
has actually been carried out for one

1278
00:53:23,889 --> 00:53:28,750
planetary system beta Pictoris the first

1279
00:53:26,500 --> 00:53:31,150
one that I showed you that we had that

1280
00:53:28,750 --> 00:53:33,670
edge on disk this has been done from the

1281
00:53:31,150 --> 00:53:36,670
Subaru telescope in Hawaii and

1282
00:53:33,670 --> 00:53:38,950
essentially these are spectra from

1283

00:53:36,670 --> 00:53:40,838
different little positions in the disk

1284
00:53:38,949 --> 00:53:42,879
right around 10 microns where that

1285
00:53:40,838 --> 00:53:45,099
silicate feature is and if you squint

1286
00:53:42,880 --> 00:53:46,599
really hard you can see that the shape

1287
00:53:45,099 --> 00:53:49,150
of this 10 micron feature actually

1288
00:53:46,599 --> 00:53:52,028
changes as a function of position along

1289
00:53:49,150 --> 00:53:55,269
the disk and it tells you where the

1290
00:53:52,028 --> 00:53:57,639
small grains are located amidst discs it

1291
00:53:55,268 --> 00:54:00,308
turns out that they tend to be it looks

1292
00:53:57,639 --> 00:54:02,858
like that they're predominantly in three

1293
00:54:00,309 --> 00:54:05,079
large rings it also tells you where the

1294
00:54:02,858 --> 00:54:07,598
crystalline material is so we're the

1295
00:54:05,079 --> 00:54:09,910
dust grains that have been annealed by

1296
00:54:07,599 --> 00:54:12,009
interactions with the star are located

1297
00:54:09,909 --> 00:54:15,670

then they tend to be located near the

1298

00:54:12,009 --> 00:54:18,338

orbit Center so it's how I just think

1299

00:54:15,670 --> 00:54:20,920

the the spectroscopic power of James T

1300

00:54:18,338 --> 00:54:24,159

is absolutely amazing so not only will

1301

00:54:20,920 --> 00:54:25,539

we be able to take this these kind of

1302

00:54:24,159 --> 00:54:27,699

spatially resolved thermal emission

1303

00:54:25,539 --> 00:54:30,430

spectra that will also be able to take

1304

00:54:27,699 --> 00:54:32,348

hopefully spatially resolved scattered

1305

00:54:30,429 --> 00:54:34,750

light spectra so now instead of looking

1306

00:54:32,349 --> 00:54:36,730

at the spectrum from the heat generated

1307

00:54:34,750 --> 00:54:38,289

by these dust grains you'll be able to

1308

00:54:36,730 --> 00:54:40,630

look at the spectrum of the reflected

1309

00:54:38,289 --> 00:54:43,240

light from these dust grains and this

1310

00:54:40,630 --> 00:54:44,950

just shows you there's an instrument on

1311

00:54:43,239 --> 00:54:48,038

board called the near infrared

1312
00:54:44,949 --> 00:54:51,669
spectrograph nurse back and essentially

1313
00:54:48,039 --> 00:54:54,250
it has an image slicer so it divides the

1314
00:54:51,670 --> 00:54:56,559
field up the field of view up into all

1315
00:54:54,250 --> 00:54:58,389
these little tiny rectangles these and

1316
00:54:56,559 --> 00:55:00,190
then it basically it disperses the light

1317
00:54:58,389 --> 00:55:01,900
from each rectangle so in this way

1318
00:55:00,190 --> 00:55:04,869
you'll be able to take spectra at

1319
00:55:01,900 --> 00:55:06,940
different positions for four in

1320
00:55:04,869 --> 00:55:08,280
particular this particular disc and this

1321
00:55:06,940 --> 00:55:10,420
really interesting in the near-infrared

1322
00:55:08,280 --> 00:55:13,450
because in the near and Fred you have

1323
00:55:10,420 --> 00:55:16,750
access to solid state features now not

1324
00:55:13,449 --> 00:55:18,699
from silicates but from Isis and I think

1325
00:55:16,750 --> 00:55:20,500
Isis are tremendously exciting because I

1326
00:55:18,699 --> 00:55:22,449
meant as I mentioned before we don't

1327
00:55:20,500 --> 00:55:25,210
understand what the origin of water is

1328
00:55:22,449 --> 00:55:26,919
in our solar system and it would be very

1329
00:55:25,210 --> 00:55:29,170
interesting to understand what the

1330
00:55:26,920 --> 00:55:30,818
reservoirs of water around other

1331
00:55:29,170 --> 00:55:32,139
planetary systems look like and whether

1332
00:55:30,818 --> 00:55:34,119
or not they have the potential to

1333
00:55:32,139 --> 00:55:39,009
deliver oceans to terrestrial planets

1334
00:55:34,119 --> 00:55:40,660
there so this is just my last slide just

1335
00:55:39,010 --> 00:55:42,880
the key points that I wanted to say

1336
00:55:40,659 --> 00:55:44,078
we're these debris disk systems that

1337
00:55:42,880 --> 00:55:46,358
I've been showing you the data from

1338
00:55:44,079 --> 00:55:49,690
their analogs of our solar system when

1339
00:55:46,358 --> 00:55:52,900
it was young or middle-aged and around

1340

00:55:49,690 --> 00:55:54,278
young stars Mitterrand Fred spectra that

1341
00:55:52,900 --> 00:55:56,230
we saw these disks reveal these

1342
00:55:54,278 --> 00:55:58,028
solid-state features that indicate that

1343
00:55:56,230 --> 00:55:59,528
the dust is composed of silicates so

1344
00:55:58,028 --> 00:56:01,088
these are things like olive eons like

1345
00:55:59,528 --> 00:56:04,210
real materials that we're familiar with

1346
00:56:01,088 --> 00:56:06,400
on our own planet so for example if you

1347
00:56:04,210 --> 00:56:07,778
go to South Point and why you can see

1348
00:56:06,400 --> 00:56:10,170
that all of you in the green sand beach

1349
00:56:07,778 --> 00:56:13,000
there and it's the same materials

1350
00:56:10,170 --> 00:56:15,519
spectral distribution analysis so that

1351
00:56:13,000 --> 00:56:17,588
was that flux of functional analysis in

1352
00:56:15,519 --> 00:56:20,230
case the majority of these debris disk

1353
00:56:17,588 --> 00:56:22,000
systems possess structure that means

1354
00:56:20,230 --> 00:56:23,679

that they have these central clearings

1355

00:56:22,000 --> 00:56:25,989

these regions close the star that are

1356

00:56:23,679 --> 00:56:27,879

devoid of dust and it tells us that

1357

00:56:25,989 --> 00:56:30,038

there's probably something in those

1358

00:56:27,880 --> 00:56:33,068

cleared out regions that's clearing them

1359

00:56:30,039 --> 00:56:34,630

out such as jovian planets oh planets

1360

00:56:33,068 --> 00:56:35,730

may be forming or may have already

1361

00:56:34,630 --> 00:56:38,010

performed in these

1362

00:56:35,730 --> 00:56:40,230

stuff so I'm thank you for your

1363

00:56:38,010 --> 00:57:10,800

attention and I'm happy to say question

1364

00:56:40,230 --> 00:57:13,590

might have questions for dr. Chen yeah

1365

00:57:10,800 --> 00:57:15,630

so it basically and the key thing that's

1366

00:57:13,590 --> 00:57:17,100

important is the dispersion velocity so

1367

00:57:15,630 --> 00:57:19,710

the relative velocity between the

1368

00:57:17,099 --> 00:57:22,139

particles so if the relative velocity is

1369
00:57:19,710 --> 00:57:24,358
relatively low then things tend to stick

1370
00:57:22,139 --> 00:57:26,730
but if the relative velocity is very

1371
00:57:24,358 --> 00:57:28,199
high then things tend to shatter so if

1372
00:57:26,730 --> 00:57:30,000
you think about the early phases of our

1373
00:57:28,199 --> 00:57:31,710
solar system the phase that jolts will

1374
00:57:30,000 --> 00:57:33,780
do about when there's a lot of gas in

1375
00:57:31,710 --> 00:57:35,460
the disk everything is sort of entrained

1376
00:57:33,780 --> 00:57:37,380
in the gas and so it moves at

1377
00:57:35,460 --> 00:57:39,840
approximately the same velocity and the

1378
00:57:37,380 --> 00:57:41,579
relative velocities are very low and so

1379
00:57:39,840 --> 00:57:43,530
during that phase especially when you

1380
00:57:41,579 --> 00:57:46,019
have a lot of gas in the disk you're in

1381
00:57:43,530 --> 00:57:49,230
a really strong building phase but once

1382
00:57:46,019 --> 00:57:51,960
the gas is dissipated it you no longer

1383
00:57:49,230 --> 00:57:53,400
maintain similar relative similar

1384
00:57:51,960 --> 00:57:55,650
velocities of the material going around

1385
00:57:53,400 --> 00:57:58,019
the star and so you can get fairly high

1386
00:57:55,650 --> 00:58:00,599
relative velocity so things can be going

1387
00:57:58,019 --> 00:58:02,699
in different directions at fairly good

1388
00:58:00,599 --> 00:58:06,589
speed that when they actually hit its

1389
00:58:02,699 --> 00:58:06,589
destructive rather than constructive

1390
00:58:09,199 --> 00:58:13,589
right but there's a little bit of I mean

1391
00:58:12,000 --> 00:58:16,130
it's not just so you're thinking about

1392
00:58:13,590 --> 00:58:18,600
Kepler's law but I mean in addition to

1393
00:58:16,130 --> 00:58:19,858
you know it's not just the orbital

1394
00:58:18,599 --> 00:58:22,049
velocity because everything doesn't

1395
00:58:19,858 --> 00:58:24,779
orbit in a perfect plane right and so

1396
00:58:22,050 --> 00:58:28,500
there's different semi-major axis

1397

00:58:24,780 --> 00:58:30,450
inclinations eccentricity I mean you're

1398
00:58:28,500 --> 00:58:32,519
in a pile of goo right you're this gas

1399
00:58:30,449 --> 00:58:34,169
and you're traveling through molasses

1400
00:58:32,519 --> 00:58:36,269
that is going to let things sort of

1401
00:58:34,170 --> 00:58:38,730
gently roll into each other whereas if

1402
00:58:36,269 --> 00:58:41,639
you take the gas oh that's away

1403
00:58:38,730 --> 00:58:48,409
it's open season it's like firing a

1404
00:58:41,639 --> 00:58:48,409
bullet underwater versus air yes oh

1405
00:58:53,599 --> 00:59:00,118
that's really interesting so I think

1406
00:58:56,429 --> 00:59:02,608
you're rich oh okay I'll repeat the

1407
00:59:00,119 --> 00:59:07,710
question sorry am I quick question was

1408
00:59:02,608 --> 00:59:09,358
is it does any resource on planets Ronan

1409
00:59:07,710 --> 00:59:10,769
solar system that we haven't found yet

1410
00:59:09,358 --> 00:59:13,920
like planning on that could be way out

1411
00:59:10,769 --> 00:59:16,259

any debris disk Rajesh so Planet nine is

1412
00:59:13,920 --> 00:59:18,539
is really fascinating and unfortunately

1413
00:59:16,260 --> 00:59:20,430
I'm so I tend to focus on extrasolar

1414
00:59:18,539 --> 00:59:21,960
planetary system so planetary systems

1415
00:59:20,429 --> 00:59:24,569
outside of her own but you're what

1416
00:59:21,960 --> 00:59:26,730
you're referring to of course is there's

1417
00:59:24,570 --> 00:59:30,180
been this really fascinating work partly

1418
00:59:26,730 --> 00:59:31,740
out of Caltech by Mike Brown and I'm

1419
00:59:30,179 --> 00:59:34,259
blanking on the other fellows like

1420
00:59:31,739 --> 00:59:38,969
Brandi Pluto killer the Pluto killer yes

1421
00:59:34,260 --> 00:59:41,850
exactly where he was so he was so you

1422
00:59:38,969 --> 00:59:43,529
may know him as the discoverer of a lot

1423
00:59:41,849 --> 00:59:46,289
of these I support planets in the outer

1424
00:59:43,530 --> 00:59:48,900
solar system and when he was looking at

1425
00:59:46,289 --> 00:59:50,759
the world properties of those iced Wharf

1426
00:59:48,900 --> 00:59:53,639
planets he noticed that there was sort

1427
00:59:50,760 --> 00:59:55,590
of this coincidence in their orbital

1428
00:59:53,639 --> 00:59:57,059
parameters that is they were all sort of

1429
00:59:55,590 --> 00:59:59,160
grouped together in one place and you

1430
00:59:57,059 --> 01:00:01,049
would sort of expect you might naively

1431
00:59:59,159 --> 01:00:03,089
expect that they should be they should

1432
01:00:01,050 --> 01:00:06,720
have sort of more random orbital

1433
01:00:03,090 --> 01:00:09,300
parameters and so one of the hypotheses

1434
01:00:06,719 --> 01:00:13,529
essentially he's advocating is that

1435
01:00:09,300 --> 01:00:16,740
there is dislike that is here 24 I'm

1436
01:00:13,530 --> 01:00:18,960
tected which is essentially interacting

1437
01:00:16,739 --> 01:00:22,379
gravitationally with these ice giants

1438
01:00:18,960 --> 01:00:27,108
and forcing them into these sort of

1439
01:00:22,380 --> 01:00:29,990
aligned orbits there's actually a

1440
01:00:27,108 --> 01:00:32,759
fabulous I should advertise this mike

1441
01:00:29,989 --> 01:00:33,868
has this fabulous Coursera course I

1442
01:00:32,760 --> 01:00:37,710
don't know if you've ever seen Coursera

1443
01:00:33,869 --> 01:00:39,720
it's an online learning thing but he has

1444
01:00:37,710 --> 01:00:41,940
a class called physics of the solar

1445
01:00:39,719 --> 01:00:44,039
system or something like that and he

1446
01:00:41,940 --> 01:00:45,840
actually spends two weeks talking about

1447
01:00:44,039 --> 01:00:49,739
small bodies in the outer solar system

1448
01:00:45,840 --> 01:00:51,630
of our solar system it's a great class

1449
01:00:49,739 --> 01:00:52,379
he's a really engaging lecturer I think

1450
01:00:51,630 --> 01:00:55,349
he spends the

1451
01:00:52,380 --> 01:00:56,309
four weeks talking about Mars and then I

1452
01:00:55,349 --> 01:00:58,740
think he talks about life in the

1453
01:00:56,309 --> 01:01:00,778
universe to that hypothesize planet

1454

01:00:58,739 --> 01:01:02,669
would be quite large right I think it

1455
01:01:00,778 --> 01:01:04,469
stopped videos no no it's like at

1456
01:01:02,670 --> 01:01:11,358
terrestrial planets like an earth-sized

1457
01:01:04,469 --> 01:01:11,358
I think it's an earth-sized thing yes

1458
01:01:14,568 --> 01:01:22,318
yeah well these are these are debris

1459
01:01:19,858 --> 01:01:24,150
disks they're debris disk so they're

1460
01:01:22,318 --> 01:01:25,949
older so they're this face so an

1461
01:01:24,150 --> 01:01:27,809
accretion disk means that you have stuff

1462
01:01:25,949 --> 01:01:30,000
accreting onto the star so that

1463
01:01:27,809 --> 01:01:32,730
inherently means that there's gas in the

1464
01:01:30,000 --> 01:01:34,699
disk and so all that moats materials

1465
01:01:32,730 --> 01:01:52,289
been trained and going on to the star

1466
01:01:34,699 --> 01:01:54,509
it's more like a solar system yeah how

1467
01:01:52,289 --> 01:01:56,309
does the modeling work yeah specifically

1468
01:01:54,509 --> 01:01:59,369

this is work that was carried out by my

1469

01:01:56,309 --> 01:02:02,849

friend Casey Lee's at APL and he has

1470

01:01:59,369 --> 01:02:04,890

this a huge library of emissivity zuv

1471

01:02:02,849 --> 01:02:06,568

different materials and basically he

1472

01:02:04,889 --> 01:02:09,088

does like a minimum chi-squared analysis

1473

01:02:06,568 --> 01:02:11,190

so he takes all of these components and

1474

01:02:09,088 --> 01:02:14,130

tries to add them up in some sensible

1475

01:02:11,190 --> 01:02:16,380

way or to reproduce the features but not

1476

01:02:14,130 --> 01:02:18,269

so you can see in some cases that this

1477

01:02:16,380 --> 01:02:20,430

might be swell if like there are

1478

01:02:18,268 --> 01:02:22,018

features that are distinct wavelengths

1479

01:02:20,429 --> 01:02:24,028

so that they can't be created by

1480

01:02:22,018 --> 01:02:26,038

anything else but you can see that there

1481

01:02:24,028 --> 01:02:27,210

are a lot of things where you know you

1482

01:02:26,039 --> 01:02:29,579

might have special features that are

1483
01:02:27,210 --> 01:02:31,230
overlapping and so one of the

1484
01:02:29,579 --> 01:02:33,150
frustrations with this kind of analysis

1485
01:02:31,230 --> 01:02:35,699
is actually it's somewhat degenerate and

1486
01:02:33,150 --> 01:02:38,430
so you can imagine different mixtures of

1487
01:02:35,699 --> 01:02:41,159
materials giving rise to the same

1488
01:02:38,429 --> 01:02:43,048
feature yeah and so when people do this

1489
01:02:41,159 --> 01:02:44,699
kind of analysis basically they have to

1490
01:02:43,048 --> 01:02:46,048
you know if they're being very rigorous

1491
01:02:44,699 --> 01:02:48,058
about it they'll go through and do a

1492
01:02:46,048 --> 01:02:49,949
Monte Carlo analysis and then basically

1493
01:02:48,059 --> 01:02:51,599
they'll show you like a probability

1494
01:02:49,949 --> 01:02:54,659
distribution function so the likelihood

1495
01:02:51,599 --> 01:02:56,880
that you have any given material so it's

1496
01:02:54,659 --> 01:02:59,909
it's not just like oh it's like fifty

1497
01:02:56,880 --> 01:03:01,680
percent is this it's like you know the

1498
01:02:59,909 --> 01:03:03,449
most likely model is that fifty percent

1499
01:03:01,679 --> 01:03:05,719
of it is that but like you know there's

1500
01:03:03,449 --> 01:03:08,899
also some probability that it's

1501
01:03:05,719 --> 01:03:12,039
you know thirty percent instead so so

1502
01:03:08,900 --> 01:03:14,269
just to clarify the audience so that the

1503
01:03:12,039 --> 01:03:16,550
non-experts the dash the lines at the

1504
01:03:14,269 --> 01:03:18,259
bottom these olivion's obsidians etc

1505
01:03:16,550 --> 01:03:20,510
when you say there a library there that

1506
01:03:18,260 --> 01:03:23,270
means that they were measured by in the

1507
01:03:20,510 --> 01:03:25,250
laboratory so with on earth someone took

1508
01:03:23,269 --> 01:03:28,070
one of these rocks used a spectrograph

1509
01:03:25,250 --> 01:03:34,489
to create an actual lab spectrum of that

1510
01:03:28,070 --> 01:03:37,000
rock and then we're using where yeah for

1511

01:03:34,489 --> 01:03:37,000
space basement

1512
01:03:37,940 --> 01:03:51,200
oh yes yes actually was about comets and

1513
01:03:49,699 --> 01:03:54,348
the source of the oceans yes that's

1514
01:03:51,199 --> 01:03:58,098
actually a really fascinating field of

1515
01:03:54,349 --> 01:03:59,300
research so basically when Wow one of

1516
01:03:58,099 --> 01:04:01,670
the things about the earth that we don't

1517
01:03:59,300 --> 01:04:04,670
really understand well is like how much

1518
01:04:01,670 --> 01:04:06,588
water is on earth because you know water

1519
01:04:04,670 --> 01:04:08,539
is incorporated in or that many

1520
01:04:06,588 --> 01:04:10,519
different location including in the deep

1521
01:04:08,539 --> 01:04:13,250
interior and so the exact amount of

1522
01:04:10,519 --> 01:04:15,289
water is not known one of the ways that

1523
01:04:13,250 --> 01:04:17,690
people have tried to diagnose what so

1524
01:04:15,289 --> 01:04:19,309
the fundamental problem is if you look

1525
01:04:17,690 --> 01:04:21,338

at the location of the earth where it is

1526

01:04:19,309 --> 01:04:25,039

today and assume that it formed they're

1527

01:04:21,338 --> 01:04:27,889

essentially the earth the proto-earth is

1528

01:04:25,039 --> 01:04:31,489

too hot to basically retain water vapor

1529

01:04:27,889 --> 01:04:33,379

and so the going in hypothesis for

1530

01:04:31,489 --> 01:04:36,559

people for decades has in other words

1531

01:04:33,380 --> 01:04:38,150

warm dry because of this and so that

1532

01:04:36,559 --> 01:04:41,029

means that like the water had to come

1533

01:04:38,150 --> 01:04:44,720

from somewhere else and so for a long

1534

01:04:41,030 --> 01:04:49,460

time people had considered comets as the

1535

01:04:44,719 --> 01:04:51,108

source source of water in the ocean and

1536

01:04:49,460 --> 01:04:52,250

one of the diagnostic ways that they

1537

01:04:51,108 --> 01:04:54,049

would try to figure out whether or not

1538

01:04:52,250 --> 01:04:56,179

this was true was looking at the

1539

01:04:54,050 --> 01:04:59,539

deuterium to hydrogen ratio in mean

1540
01:04:56,179 --> 01:05:02,629
ocean sea water and compare that to the

1541
01:04:59,539 --> 01:05:05,269
deuterium to hydrogen ratio and comets

1542
01:05:02,630 --> 01:05:08,180
to see if at all they were common it

1543
01:05:05,269 --> 01:05:09,530
turned out for a long time the the

1544
01:05:08,179 --> 01:05:13,129
distribution of comets that people were

1545
01:05:09,530 --> 01:05:14,869
probing which I think we're from fairly

1546
01:05:13,130 --> 01:05:17,599
far out in the solar system they

1547
01:05:14,869 --> 01:05:20,480
actually had a higher deuterium fraction

1548
01:05:17,599 --> 01:05:23,769
I think I'm compared to meanest people

1549
01:05:20,480 --> 01:05:23,769
were certain oh

1550
01:05:27,159 --> 01:05:33,319
has it is still early active field of

1551
01:05:30,230 --> 01:05:35,329
research so there was more recent data

1552
01:05:33,320 --> 01:05:37,910
taken by the Herschel Space Telescope

1553
01:05:35,329 --> 01:05:41,750
around two thousand and ten or so of

1554
01:05:37,909 --> 01:05:44,329
some of these Trojan objects instead and

1555
01:05:41,750 --> 01:05:46,219
those actually happy day trade shows

1556
01:05:44,329 --> 01:05:48,469
that were more similar to mean ocean sea

1557
01:05:46,219 --> 01:05:50,929
water so people are not sure what the

1558
01:05:48,469 --> 01:05:52,909
origin of water on Earth is so that's

1559
01:05:50,929 --> 01:05:56,690
one possibility another possibility

1560
01:05:52,909 --> 01:05:58,239
that's I think become more invoke is the

1561
01:05:56,690 --> 01:06:02,019
idea that the water is actually

1562
01:05:58,239 --> 01:06:06,169
delivered by water rich asteroids so

1563
01:06:02,019 --> 01:06:08,179
that told you about the period of lebard

1564
01:06:06,170 --> 01:06:10,010
montano migration of the planets

1565
01:06:08,179 --> 01:06:12,679
destabilize the minor bodies in our

1566
01:06:10,010 --> 01:06:15,770
solar system and it disturb realized all

1567
01:06:12,679 --> 01:06:18,440
of them including we think the asteroids

1568

01:06:15,769 --> 01:06:21,050
in the main asteroid belt the asteroids

1569
01:06:18,440 --> 01:06:26,389
that are a little bit further out in

1570
01:06:21,050 --> 01:06:30,470
order to belt are expected to be alright

1571
01:06:26,389 --> 01:06:33,500
and so they have been hypothesized as

1572
01:06:30,469 --> 01:06:37,339
another source of water for the oceans

1573
01:06:33,500 --> 01:06:39,769
on earth we think we have evidence for

1574
01:06:37,340 --> 01:06:42,350
collisions between those objects and the

1575
01:06:39,769 --> 01:06:47,119
inner solar system when you look on like

1576
01:06:42,349 --> 01:06:50,449
the Moon or Mars is versus how many

1577
01:06:47,119 --> 01:06:52,159
workers on the Moon or Mars or something

1578
01:06:50,449 --> 01:06:54,049
like that and look at the size

1579
01:06:52,159 --> 01:06:56,210
distribution of asteroids how many big

1580
01:06:54,050 --> 01:06:58,060
asteroids vs. little asteroids and it

1581
01:06:56,210 --> 01:06:59,900
turns out the size distribution of

1582
01:06:58,059 --> 01:07:01,639

asteroids in the main asteroid belt

1583

01:06:59,900 --> 01:07:05,480

lines up with the size distribution of

1584

01:07:01,639 --> 01:07:07,460

craters on on ultra services so we know

1585

01:07:05,480 --> 01:07:10,490

things got slung in during the period of

1586

01:07:07,460 --> 01:07:12,019

late heavy bombardment and based on some

1587

01:07:10,489 --> 01:07:13,489

of the spectroscopic analysis we think

1588

01:07:12,019 --> 01:07:14,929

their water Ridge to so there are

1589

01:07:13,489 --> 01:07:16,729

another I think right now they're

1590

01:07:14,929 --> 01:07:20,710

actually probably the more favorite

1591

01:07:16,730 --> 01:07:20,710

source of butter

1592

01:07:24,179 --> 01:07:38,049

right but that's a small yeah it's back

1593

01:07:29,559 --> 01:07:42,489

there and what question that work

1594

01:07:38,050 --> 01:07:45,430

variations rice planets and fine that's

1595

01:07:42,489 --> 01:07:47,349

correct and so when this a whole

1596

01:07:45,429 --> 01:07:50,500

controversy is going on about Pluto

1597
01:07:47,349 --> 01:07:52,569
essentially what happened was so you

1598
01:07:50,500 --> 01:07:54,219
know pluto was discovered shoot i think

1599
01:07:52,570 --> 01:07:57,910
like in nineteen thirty or so at lowell

1600
01:07:54,219 --> 01:08:02,019
observatory and you know it was the only

1601
01:07:57,909 --> 01:08:05,349
thing kind of note system and basically

1602
01:08:02,019 --> 01:08:08,829
in the 1990s Dave do it and jane lew

1603
01:08:05,349 --> 01:08:11,170
went out and you know basically carried

1604
01:08:08,829 --> 01:08:14,349
out these deep surveys of the sky of the

1605
01:08:11,170 --> 01:08:17,409
ecliptic plane looking for you no

1606
01:08:14,349 --> 01:08:20,739
additional minor bodies out there and so

1607
01:08:17,409 --> 01:08:22,599
this led to the discovery of you know

1608
01:08:20,739 --> 01:08:24,639
the whole population of Kuiper belt

1609
01:08:22,600 --> 01:08:26,980
objects and so when the pepper belt

1610
01:08:24,640 --> 01:08:28,810
objects were discovered you know you

1611
01:08:26,979 --> 01:08:30,579
know and this is again some of my Browns

1612
01:08:28,810 --> 01:08:32,500
really beautiful work they discovered

1613
01:08:30,579 --> 01:08:34,630
that some of the largest Kuiper belt

1614
01:08:32,500 --> 01:08:37,000
objects were even bigger than Pluto

1615
01:08:34,630 --> 01:08:40,329
right and so then there became a sort of

1616
01:08:37,000 --> 01:08:42,548
thing well do you consider them planets

1617
01:08:40,329 --> 01:08:45,548
too and the thing that made them very

1618
01:08:42,548 --> 01:08:47,680
similar to Pluto was so Pluto is in a

1619
01:08:45,548 --> 01:08:49,630
three-to-two resonance with Neptune and

1620
01:08:47,680 --> 01:08:51,850
it turns out there's a whole family of

1621
01:08:49,630 --> 01:08:54,310
other Kuiper belt objects that are also

1622
01:08:51,850 --> 01:08:59,200
in the 322 residents so please have a

1623
01:08:54,310 --> 01:09:00,819
particularly unique mass eyes compared

1624
01:08:59,199 --> 01:09:02,039
to things in the Kuiper belt region and

1625

01:09:00,819 --> 01:09:05,289
it doesn't have a particularly unique

1626
01:09:02,039 --> 01:09:08,528
orbit and so that that was part of the

1627
01:09:05,289 --> 01:09:11,409
reasoning that the IAU used to demote

1628
01:09:08,529 --> 01:09:12,759
its status from a planet to a Kuiper

1629
01:09:11,409 --> 01:09:13,960
belt objects because they said hey

1630
01:09:12,759 --> 01:09:15,939
there's so many more of these other

1631
01:09:13,960 --> 01:09:18,338
objects that are out there it's really

1632
01:09:15,939 --> 01:09:20,439
not that special and you know maybe it's

1633
01:09:18,338 --> 01:09:22,869
really one of these other belt objects

1634
01:09:20,439 --> 01:09:24,129
and you know there's a whole like half a

1635
01:09:22,869 --> 01:09:26,710
dozen of them that instead we're going

1636
01:09:24,130 --> 01:09:27,770
to designate as ice Dwarfs so things

1637
01:09:26,710 --> 01:09:34,220
like

1638
01:09:27,770 --> 01:09:38,029
none either still okay so this is not my

1639
01:09:34,220 --> 01:09:39,980

field of expertise but essentially what

1640

01:09:38,029 --> 01:09:41,450

i recall of mike brown's analysis is

1641

01:09:39,979 --> 01:09:43,789

essentially he was looking at the

1642

01:09:41,449 --> 01:09:46,608

orbital parameters for all of those

1643

01:09:43,789 --> 01:09:49,278

large objects you know maybe like the

1644

01:09:46,609 --> 01:09:54,260

largest mind told them or something like

1645

01:09:49,279 --> 01:09:56,300

that and basically he noticed that again

1646

01:09:54,260 --> 01:09:58,100

if you expect them to be randomly

1647

01:09:56,300 --> 01:10:00,650

saturday out or something this should be

1648

01:09:58,100 --> 01:10:03,710

all over the place but he noticed when

1649

01:10:00,649 --> 01:10:06,649

he made this orbital parameter plot that

1650

01:10:03,710 --> 01:10:09,770

they were all sort of caught in one area

1651

01:10:06,649 --> 01:10:13,099

or at least avoid particular area the

1652

01:10:09,770 --> 01:10:15,230

phase space and so based on the

1653

01:10:13,100 --> 01:10:18,650

dynamical evidence like what the orbits

1654
01:10:15,229 --> 01:10:21,559
look like essentially that's where the

1655
01:10:18,649 --> 01:10:24,679
hypothesis for this planet 9 came from

1656
01:10:21,560 --> 01:10:27,289
that basically it's exerting a

1657
01:10:24,680 --> 01:10:30,590
gravitational influence on these large

1658
01:10:27,289 --> 01:10:34,609
objects we don't see it directly we just

1659
01:10:30,590 --> 01:10:37,579
see how the other audience so I really

1660
01:10:34,609 --> 01:10:40,880
recommend to you I think part of that

1661
01:10:37,579 --> 01:10:43,039
Coursera class that Mike Brown has I

1662
01:10:40,880 --> 01:10:46,100
think it starts up every three months or

1663
01:10:43,039 --> 01:10:50,960
something like that because he he and

1664
01:10:46,100 --> 01:10:53,450
his colleagues are the he has a lecture

1665
01:10:50,960 --> 01:10:55,789
in this course about so you're really

1666
01:10:53,449 --> 01:10:57,229
excellent classes are interested in the

1667
01:10:55,789 --> 01:10:59,210
solar system phonetically there's a

1668
01:10:57,229 --> 01:11:01,879
there's a beautiful the first four weeks

1669
01:10:59,210 --> 01:11:04,340
are about Mars I hadn't seen the

1670
01:11:01,880 --> 01:11:06,590
detailed radar maps for from ours and

1671
01:11:04,340 --> 01:11:08,569
you know seeing how much geology people

1672
01:11:06,590 --> 01:11:13,640
now know from our it's it's it's really

1673
01:11:08,569 --> 01:11:17,170
spectacular i highly recommend it other

1674
01:11:13,640 --> 01:11:17,170
questions yes

1675
01:11:22,010 --> 01:11:25,859
[Music]

1676
01:11:30,630 --> 01:11:38,489
so in the particular case of Jupiter

1677
01:11:34,170 --> 01:11:42,399
Jupiter is so massive that essentially

1678
01:11:38,488 --> 01:11:45,899
attendants to gravity things that try to

1679
01:11:42,399 --> 01:11:49,269
come in to where it's okay it was like

1680
01:11:45,899 --> 01:11:51,069
if an object to come in outer solar

1681
01:11:49,270 --> 01:11:53,290
system towards Jupiter it encounters

1682

01:11:51,069 --> 01:11:54,868
Jupiter and it is actually it's a little

1683
01:11:53,289 --> 01:11:56,710
bit counterintuitive but it's actually

1684
01:11:54,868 --> 01:11:59,979
gravitationally slung out of the system

1685
01:11:56,710 --> 01:12:02,310
so most of the time Jupiter doesn't you

1686
01:11:59,979 --> 01:12:06,189
know it doesn't either gain or lose mass

1687
01:12:02,310 --> 01:12:09,340
but for a smaller objects for some

1688
01:12:06,189 --> 01:12:12,419
objects so comment Lear several years

1689
01:12:09,340 --> 01:12:15,310
ago or even she was it though the one

1690
01:12:12,420 --> 01:12:19,239
shoemaker-levy that impacted Jupiter in

1691
01:12:15,310 --> 01:12:22,289
the night yeah that was a clear case of

1692
01:12:19,238 --> 01:12:24,549
material being a created on planet

1693
01:12:22,289 --> 01:12:30,399
depends will had a ringside t2 that's

1694
01:12:24,550 --> 01:12:32,440
right sit so I mean that I think that's

1695
01:12:30,399 --> 01:12:35,019
an active area of research where people

1696
01:12:32,439 --> 01:12:36,819

actually do real dynamical simulations

1697

01:12:35,020 --> 01:12:40,030

right because they're curious what

1698

01:12:36,819 --> 01:12:41,859

happens when you imagine implant a

1699

01:12:40,029 --> 01:12:43,899

planet in a planetary system and watched

1700

01:12:41,859 --> 01:12:46,299

us come in and how does it affect it

1701

01:12:43,899 --> 01:12:48,009

because it's it's a small planet you can

1702

01:12:46,300 --> 01:12:50,139

imagine the gravity's not so great and

1703

01:12:48,010 --> 01:12:55,600

so it doesn't affect it as strongly as

1704

01:12:50,139 --> 01:12:59,429

like a big planet like Jupiter any other

1705

01:12:55,600 --> 01:12:59,429

questions yes

1706

01:13:05,078 --> 01:13:09,518

sure question about the late heavy

1707

01:13:07,149 --> 01:13:15,959

bombardment what would so this is um

1708

01:13:09,519 --> 01:13:20,708

listen yeah so this is that's been up

1709

01:13:15,958 --> 01:13:22,510

for a while sadly people noticed a long

1710

01:13:20,708 --> 01:13:24,188

time ago that when you looked at old

1711
01:13:22,510 --> 01:13:26,679
terrestrial planet surfaces to the

1712
01:13:24,189 --> 01:13:28,659
surfaces of Mercury Mars and the moon

1713
01:13:26,679 --> 01:13:31,538
that they had a lot of craters on them

1714
01:13:28,658 --> 01:13:33,308
so this is just a map of the near side

1715
01:13:31,538 --> 01:13:34,628
and the far side of the Moon and you can

1716
01:13:33,309 --> 01:13:37,389
see the craters are picked out so you

1717
01:13:34,628 --> 01:13:38,918
can see them more easily on the moon you

1718
01:13:37,389 --> 01:13:41,800
can see there are periods where there's

1719
01:13:38,918 --> 01:13:43,779
been geologic resurfacing where lava has

1720
01:13:41,800 --> 01:13:45,399
come up to the surface and formed Marya

1721
01:13:43,779 --> 01:13:48,338
the Seas that you see on the surface of

1722
01:13:45,399 --> 01:13:50,979
the Moon right and so it was you know

1723
01:13:48,338 --> 01:13:53,800
based on observations like that there's

1724
01:13:50,979 --> 01:13:55,439
a violent in the early part of the solar

1725
01:13:53,800 --> 01:13:57,550
system where you had a lot of collisions

1726
01:13:55,439 --> 01:13:59,559
and you could kind of constrain when

1727
01:13:57,550 --> 01:14:02,668
that happened based on looking at where

1728
01:13:59,559 --> 01:14:08,260
them like the properties of Marya right

1729
01:14:02,668 --> 01:14:09,608
so one of the things that people have

1730
01:14:08,260 --> 01:14:12,699
been struggling to understand for a long

1731
01:14:09,609 --> 01:14:15,219
time is when those observations were

1732
01:14:12,698 --> 01:14:17,319
first made and noticed people sort of

1733
01:14:15,219 --> 01:14:19,118
thought that all of these collisions

1734
01:14:17,319 --> 01:14:20,978
happened at the same time like it was

1735
01:14:19,118 --> 01:14:22,779
kind of like a delta function when all

1736
01:14:20,979 --> 01:14:24,609
the cratering like all the collisions

1737
01:14:22,779 --> 01:14:25,958
went up you know the collision rate went

1738
01:14:24,609 --> 01:14:28,899
up really high just went up really high

1739

01:14:25,958 --> 01:14:31,958
and came down really fast and there's a

1740
01:14:28,899 --> 01:14:35,709
lot of really uh nice work by in a

1741
01:14:31,958 --> 01:14:38,198
research and Bill baki particularly you

1742
01:14:35,708 --> 01:14:42,908
know studying these surfaces and trying

1743
01:14:38,198 --> 01:14:45,698
to understand this cratering period and

1744
01:14:42,908 --> 01:14:48,128
I honestly I don't remember the exact

1745
01:14:45,698 --> 01:14:51,428
details but my impression has been that

1746
01:14:48,128 --> 01:14:53,078
over time our thinking of the cratering

1747
01:14:51,429 --> 01:14:54,788
record is that you know essentially

1748
01:14:53,078 --> 01:14:59,889
these craters are actually formed over

1749
01:14:54,788 --> 01:15:01,418
time and essentially you know people

1750
01:14:59,889 --> 01:15:04,809
then are of course very interested in

1751
01:15:01,418 --> 01:15:08,108
what are the mechanisms to create the

1752
01:15:04,809 --> 01:15:11,679
creators and so this idea that I was

1753
01:15:08,109 --> 01:15:14,469

describing for you this is called the

1754

01:15:11,679 --> 01:15:16,989

nice model because it was first

1755

01:15:14,469 --> 01:15:17,890

hypothesized by a number of astronomers

1756

01:15:16,988 --> 01:15:22,209

in

1757

01:15:17,890 --> 01:15:26,160

France and essentially it it basically

1758

01:15:22,210 --> 01:15:28,180

tried to account for a number of things

1759

01:15:26,159 --> 01:15:29,319

observations that people made of the

1760

01:15:28,180 --> 01:15:32,110

solar system that seems sort of

1761

01:15:29,319 --> 01:15:33,609

startling so one of them was for example

1762

01:15:32,109 --> 01:15:35,829

when you look at the mass of the

1763

01:15:33,609 --> 01:15:37,179

asteroid belt and compare it to the mass

1764

01:15:35,829 --> 01:15:39,399

and the terrestrial planets and the dog

1765

01:15:37,180 --> 01:15:41,740

alien planets around it if you were to

1766

01:15:39,399 --> 01:15:43,239

smooth out all of that mass you actually

1767

01:15:41,739 --> 01:15:45,279

get a divot in the amount of stuff

1768
01:15:43,239 --> 01:15:47,399
around the asteroid belt and so people

1769
01:15:45,279 --> 01:15:49,599
knew essentially that the asteroid belt

1770
01:15:47,399 --> 01:15:51,549
the primordial asteroid belt was

1771
01:15:49,600 --> 01:15:53,800
actually a lot more massive than the

1772
01:15:51,550 --> 01:15:55,239
asteroid belt that we see today then

1773
01:15:53,800 --> 01:15:56,980
this sort of leads to the question of

1774
01:15:55,239 --> 01:16:01,210
like well what happened to all those

1775
01:15:56,979 --> 01:16:02,500
objects right and so you know you know

1776
01:16:01,210 --> 01:16:05,500
it was noticed that there were these

1777
01:16:02,500 --> 01:16:08,079
kirkwood gaps that I talked about where

1778
01:16:05,500 --> 01:16:14,229
you have mean motion resonances where

1779
01:16:08,079 --> 01:16:15,430
you you lose material but the nice model

1780
01:16:14,229 --> 01:16:19,089
which is really come into fashion

1781
01:16:15,430 --> 01:16:21,970
there's a lot of reasons maybe certain

1782
01:16:19,090 --> 01:16:24,850
properties of the system just destroyed

1783
01:16:21,970 --> 01:16:27,400
belt is has become the leading

1784
01:16:24,850 --> 01:16:29,320
explanation so again this is that the

1785
01:16:27,399 --> 01:16:31,269
location of Jupiter and Saturn in our

1786
01:16:29,319 --> 01:16:33,549
solar system today are not the locations

1787
01:16:31,270 --> 01:16:36,100
where Jupiter and Saturn forms and that

1788
01:16:33,550 --> 01:16:37,989
Jupiter and Saturn migrated from their

1789
01:16:36,100 --> 01:16:40,210
formation locations to their present-day

1790
01:16:37,989 --> 01:16:42,010
locations and as they did say they cost

1791
01:16:40,210 --> 01:16:44,529
across the two-to-one resonance so this

1792
01:16:42,010 --> 01:16:46,780
means that for every two times Jupiter

1793
01:16:44,529 --> 01:16:50,489
goes around the Sun Saturn goes around

1794
01:16:46,779 --> 01:16:52,569
once and when you do that it actually

1795
01:16:50,489 --> 01:16:58,059
destabilizes the orbits of the minor

1796

01:16:52,569 --> 01:16:59,670
bodies because they get you know you

1797
01:16:58,060 --> 01:17:02,200
know this gravitational pull that's

1798
01:16:59,670 --> 01:17:04,029
exacerbated by the two planets because

1799
01:17:02,199 --> 01:17:05,949
they're both in the same pitches like

1800
01:17:04,029 --> 01:17:08,859
they they both come around to being at

1801
01:17:05,949 --> 01:17:11,019
the same place around the song right so

1802
01:17:08,859 --> 01:17:16,359
that that's what destabilizes the minor

1803
01:17:11,020 --> 01:17:19,630
bodies so so basically I spoke a little

1804
01:17:16,359 --> 01:17:23,130
bit of some of the sort of planetary

1805
01:17:19,630 --> 01:17:25,750
science evidence for this so for example

1806
01:17:23,130 --> 01:17:27,940
so one we think the asteroid belt had to

1807
01:17:25,750 --> 01:17:31,038
be more massive too when you look at the

1808
01:17:27,939 --> 01:17:33,529
size distribution on like the moon it

1809
01:17:31,038 --> 01:17:35,719
it matters with a size distribution of

1810
01:17:33,529 --> 01:17:37,698

bodies in the main asteroid belt so that

1811

01:17:35,719 --> 01:17:39,679

tells you that their projectiles are

1812

01:17:37,698 --> 01:17:44,868

consistent with coming from the main

1813

01:17:39,679 --> 01:17:48,109

asteroid belt so so it's really become

1814

01:17:44,868 --> 01:17:49,728

like the accepted but of mechanism

1815

01:17:48,109 --> 01:17:53,809

describing the period of late heavy

1816

01:17:49,729 --> 01:17:58,539

bombardment today I think we have time

1817

01:17:53,809 --> 01:17:58,538

for one final question if there's one I

1818

01:17:59,019 --> 01:18:05,139

think maybe we've we've done it all

1819

01:18:01,908 --> 01:18:05,138

right well thank you everyone for coming

1820

01:18:07,569 --> 01:18:19,609

thanks again to dr. Christine Chen and

1821

01:18:10,479 --> 01:18:25,280

see you in a month if it's the 10th yes

1822

01:18:19,609 --> 01:18:29,959

if it's the third know if it's the third

1823

01:18:25,279 --> 01:18:32,139

i'll be in texas in fact we'll all be

1824

01:18:29,958 --> 01:18:32,139

toast

