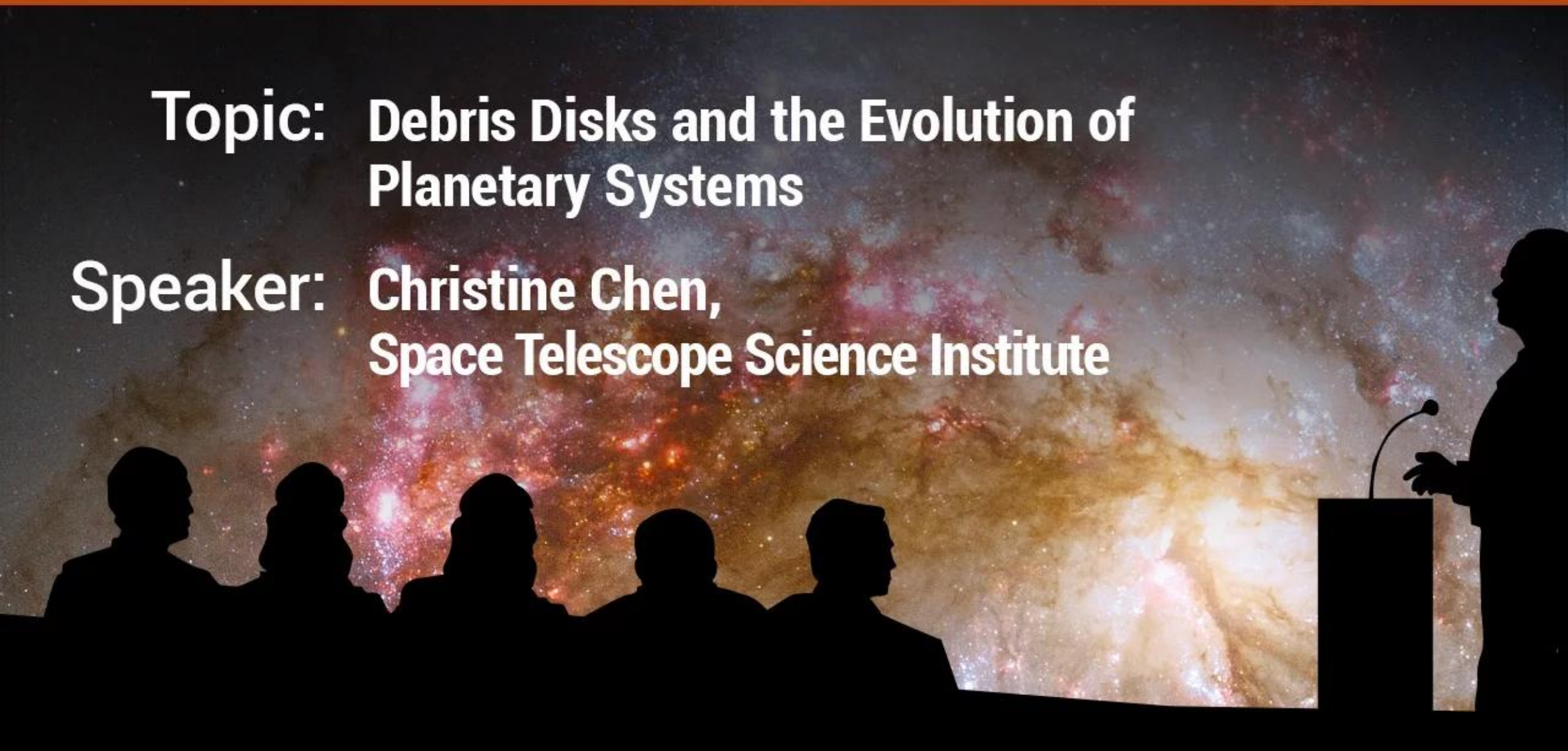
Hubble Public Lecture Series



Topic: Debris Disks and the Evolution of Planetary Systems

Speaker: Christine Chen,
Space Telescope Science Institute

1
00:00:05,539 --> 00:00:03,560
all right welcome everyone to the

2
00:00:08,990 --> 00:00:05,549
December edition of the public lecture

3
00:00:11,240 --> 00:00:09,000
series i'm joel green i'm playing dr.

4
00:00:12,560 --> 00:00:11,250
frank summers for the evening I'm the

5
00:00:13,850 --> 00:00:12,570
project scientist in the office of

6
00:00:16,430 --> 00:00:13,860
public outreach so I work with Frank

7
00:00:18,170 --> 00:00:16,440
quite a bit he is actually currently on

8
00:00:20,630 --> 00:00:18,180
a flight back from I believe San

9
00:00:22,820 --> 00:00:20,640
Francisco as we speak so he will be back

10
00:00:25,429 --> 00:00:22,830
tomorrow but that's too late for tonight

11
00:00:28,630 --> 00:00:25,439
so you're stuck with me please take a

12
00:00:30,890 --> 00:00:28,640
example of our holiday greeting cards

13
00:00:35,060 --> 00:00:30,900

one per person and there might be a few

14
00:00:36,799 --> 00:00:35,070
extras left at the end our speaker

15
00:00:40,160 --> 00:00:36,809
tonight who will be speaking I'll give a

16
00:00:41,600 --> 00:00:40,170
short introduction prior to that and our

17
00:00:44,150 --> 00:00:41,610
speaker tonight will be Chris dr.

18
00:00:46,639 --> 00:00:44,160
Christine Chen I'll introduce you in a

19
00:00:49,430 --> 00:00:46,649
moment as we get through and she will be

20
00:00:52,180 --> 00:00:49,440
talking about debris disks and other the

21
00:00:54,529 --> 00:00:52,190
formation of young planetary systems

22
00:00:56,779 --> 00:00:54,539
upcoming talks upcoming public lecture

23
00:00:59,060 --> 00:00:56,789
series talks our January 3rd or 10th

24
00:01:00,500 --> 00:00:59,070
I guess it's TB I think that's why Frank

25
00:01:03,139 --> 00:01:00,510
has Frank gave me these slides so you

26
00:01:04,429 --> 00:01:03,149
can blame him I think I think he

27
00:01:07,850 --> 00:01:04,439
basically hasn't decided what today it

28
00:01:10,370 --> 00:01:07,860
is the 3rd of the 10th the February date

29
00:01:13,340 --> 00:01:10,380
is set that is the 7th the talk there

30
00:01:17,149 --> 00:01:13,350
will be mapping the heavens and on March

31
00:01:19,850 --> 00:01:17,159
7th will be another talk bye-bye lauren

32
00:01:25,370 --> 00:01:19,860
Corley's from johns hopkins with a TBA

33
00:01:27,770 --> 00:01:25,380
title you've probably already noticed

34
00:01:30,530 --> 00:01:27,780
this but there's still construction on

35
00:01:32,990 --> 00:01:30,540
San Martin Drive so if you are coming

36
00:01:33,880 --> 00:01:33,000
from the South it's pretty easy but if

37
00:01:36,200 --> 00:01:33,890
you're coming from the north you've

38
00:01:37,700 --> 00:01:36,210

either got a park on University Parkway

39
00:01:39,469 --> 00:01:37,710
or drive all the way around so hopefully

40
00:01:41,420 --> 00:01:39,479
everyone found their way here easy used

41
00:01:42,950 --> 00:01:41,430
to approach from the south but the good

42
00:01:44,990 --> 00:01:42,960
news is this will all stop in the new

43
00:01:46,039 --> 00:01:45,000
year so hopefully this won't be the last

44
00:01:49,429 --> 00:01:46,049
one of these where you have to worry

45
00:01:51,590 --> 00:01:49,439
about this and this is the schedule see

46
00:01:54,649 --> 00:01:51,600
it says through December 2016 so

47
00:01:56,899 --> 00:01:54,659
hopefully the writ so currently the red

48
00:02:00,740 --> 00:01:56,909
part and the yellow are the closed parts

49
00:02:02,569 --> 00:02:00,750
the blue part is done so anyway the key

50
00:02:04,760 --> 00:02:02,579
is to approach from the south on San

51
00:02:08,990 --> 00:02:04,770
Martin Drive

52
00:02:11,270 --> 00:02:09,000
keep keep turning I think weather does

53
00:02:13,190 --> 00:02:11,280
not permit us to go to the observatory

54
00:02:15,699 --> 00:02:13,200
but that usually is something that

55
00:02:21,949 --> 00:02:15,709
happens afterward I I assume relevant

56
00:02:22,970 --> 00:02:21,959
people know what to do there and I'm

57
00:02:25,880 --> 00:02:22,980
just gonna give a quick introduction

58
00:02:27,410 --> 00:02:25,890
talk about a funny experience I had

59
00:02:29,420 --> 00:02:27,420
rather than I know Frank sometimes does

60
00:02:31,610 --> 00:02:29,430
news and updates I thought it might be

61
00:02:33,080 --> 00:02:31,620
fun to kind of tell you a tale of one of

62
00:02:35,210 --> 00:02:33,090
the most unusual observing runs I've

63
00:02:40,699 --> 00:02:35,220

been on and it's called why I had a

64
00:02:42,470 --> 00:02:40,709
Boeing 747 almost to myself so when I'm

65
00:02:43,970 --> 00:02:42,480
when people find out I'm an astronomer

66
00:02:46,490 --> 00:02:43,980
the first question I invariably get

67
00:02:49,339 --> 00:02:46,500
asked in a kind of angry aggressive tone

68
00:02:52,660 --> 00:02:49,349
is why is Pluto not a planet anymore I

69
00:02:55,460 --> 00:02:52,670
people really outraged by this right so

70
00:02:58,069 --> 00:02:55,470
you know the correct the question you

71
00:02:59,330 --> 00:02:58,079
should be asking and I'm sure that that

72
00:03:02,300 --> 00:02:59,340
everyone here has thought about this the

73
00:03:05,030 --> 00:03:02,310
real question is what is a planet right

74
00:03:06,319 --> 00:03:05,040
why is Pluto not one or is it one why

75
00:03:09,830 --> 00:03:06,329
should we even be concerned about that

76
00:03:11,180 --> 00:03:09,840
and there are many answers to this

77
00:03:12,650 --> 00:03:11,190
question about what does the planet it

78
00:03:14,330 --> 00:03:12,660
could be you could call it a round thing

79
00:03:17,420 --> 00:03:14,340
above a certain size it could be

80
00:03:19,129 --> 00:03:17,430
something that orbits a star that

81
00:03:20,750 --> 00:03:19,139
doesn't you know have a larger object

82
00:03:23,449 --> 00:03:20,760
orbiting it or something and there are

83
00:03:24,860 --> 00:03:23,459
lots of semantic definitions but both

84
00:03:27,650 --> 00:03:24,870
Christine and I work in the field of

85
00:03:29,780 --> 00:03:27,660
formation of planets and that's the way

86
00:03:33,559 --> 00:03:29,790
I think about planets is a planet is

87
00:03:36,199 --> 00:03:33,569
something that formed around a star in

88
00:03:37,699 --> 00:03:36,209

its disk so I mean these are the

89
00:03:39,379 --> 00:03:37,709
traditional planets right these are this

90
00:03:41,479 --> 00:03:39,389
is planet was the definition of planet

91
00:03:42,890 --> 00:03:41,489
until 2006 was just something the

92
00:03:48,080 --> 00:03:42,900
ancient Greeks thought wandered in the

93
00:03:50,270 --> 00:03:48,090
sky but the real thing to think about is

94
00:03:51,680 --> 00:03:50,280
when you approach a planetary system I

95
00:03:54,710 --> 00:03:51,690
was having a fun discussion at lunch a

96
00:03:55,819 --> 00:03:54,720
few days ago about this when you if you

97
00:03:57,110 --> 00:03:55,829
let's say you were on the bridge of the

98
00:03:58,460 --> 00:03:57,120
Starship Enterprise or something like

99
00:04:00,559 --> 00:03:58,470
that and you were flying it to your star

100
00:04:02,270 --> 00:04:00,569
system and you wanted to say something

101
00:04:04,129 --> 00:04:02,280
useful about it you were surveying it

102
00:04:05,479 --> 00:04:04,139
what would you want to know you want to

103
00:04:07,159 --> 00:04:05,489
know what are the objects in orbit

104
00:04:09,259 --> 00:04:07,169
around the star what are they made out

105
00:04:10,970 --> 00:04:09,269
of what are they like how many of each

106
00:04:12,170 --> 00:04:10,980
are there and what temperature are they

107
00:04:14,990 --> 00:04:12,180
what are their gases

108
00:04:17,150 --> 00:04:15,000
do they have surfaces and what this is

109
00:04:18,170 --> 00:04:17,160
really a question about is how did we

110
00:04:19,759 --> 00:04:18,180
what we want to understand is

111
00:04:25,270 --> 00:04:19,769
how do you form all of these different

112
00:04:27,680 --> 00:04:25,280
kinds of objects our solar system is a

113
00:04:29,749 --> 00:04:27,690

morass of different kinds of objects

114
00:04:33,620 --> 00:04:29,759
ranging from planetary bodies down to

115
00:04:35,120 --> 00:04:33,630
dust particles and the solar system as

116
00:04:38,270 --> 00:04:35,130
it looks today is this kind of neatly

117
00:04:40,370 --> 00:04:38,280
organized mostly neatly organized system

118
00:04:42,020 --> 00:04:40,380
with the rocky inner planets sort of an

119
00:04:43,969 --> 00:04:42,030
asteroid belt that's not the only place

120
00:04:46,129 --> 00:04:43,979
where asteroids are but that's one of

121
00:04:47,920 --> 00:04:46,139
the most common places to find them the

122
00:04:50,719 --> 00:04:47,930
gas giant outer planets

123
00:04:54,680 --> 00:04:50,729
objects in the Kuiper belt with the ski

124
00:04:56,839 --> 00:04:54,690
orbits ice Dwarfs and what's interesting

125
00:04:59,300 --> 00:04:56,849
is if you were to rewind the clock 4.5

126
00:05:00,920 --> 00:04:59,310
billion years to when the solar system

127
00:05:02,120 --> 00:05:00,930
was less than a million years old you

128
00:05:06,260 --> 00:05:02,130
probably would see it looking something

129
00:05:08,900 --> 00:05:06,270
like this a swirling disk of gas with

130
00:05:10,879 --> 00:05:08,910
tiny dust particles hanging suspended in

131
00:05:13,969 --> 00:05:10,889
that gas about a hundred times as much

132
00:05:16,249 --> 00:05:13,979
gas as dust and that is a planet making

133
00:05:18,020 --> 00:05:16,259
factory that's where solar systems come

134
00:05:18,589 --> 00:05:18,030
from and we know this because we look at

135
00:05:21,170 --> 00:05:18,599
other ones

136
00:05:23,060 --> 00:05:21,180
all of these are ingredients of things

137
00:05:27,500 --> 00:05:23,070
that have been found in space using

138
00:05:29,810 --> 00:05:27,510

space telescopes actually can skip this

139
00:05:33,469 --> 00:05:29,820
one so how do we know that planets form

140
00:05:35,689 --> 00:05:33,479
in these discs if you take a meteorite

141
00:05:38,480 --> 00:05:35,699
and you carve it open as this actual

142
00:05:40,730 --> 00:05:38,490
meteorite shows they are matchups of

143
00:05:42,980 --> 00:05:40,740
little pebbles that have been plastered

144
00:05:45,529 --> 00:05:42,990
together to build into bigger and bigger

145
00:05:47,930 --> 00:05:45,539
objects this is the building blocks of

146
00:05:49,279 --> 00:05:47,940
planets it starts it may start big or it

147
00:05:51,920 --> 00:05:49,289
starts small but whatever it is you

148
00:05:52,820 --> 00:05:51,930
generate into these massive objects that

149
00:05:54,589 --> 00:05:52,830
we know today so these are

150
00:05:57,770 --> 00:05:54,599
collaborations and Christine is gonna

151
00:06:00,350 --> 00:05:57,780
talk I suspect quite a bit about this so

152
00:06:02,510 --> 00:06:00,360
in order to study the infrared the most

153
00:06:04,700 --> 00:06:02,520
powerful instrument ever developed for

154
00:06:06,920 --> 00:06:04,710
infrared study is the James Webb Space

155
00:06:09,680 --> 00:06:06,930
Telescope which it will be controlled

156
00:06:11,360 --> 00:06:09,690
upstairs just one floor above us after

157
00:06:13,399 --> 00:06:11,370
it launches in 2018 about 2 minutes

158
00:06:15,350 --> 00:06:13,409
after that control will shift to this

159
00:06:17,480 --> 00:06:15,360
building and we're all very excited and

160
00:06:21,439 --> 00:06:17,490
it's a great tool for studying dusty

161
00:06:24,770 --> 00:06:21,449
infrared bright young stars and here's a

162
00:06:26,390 --> 00:06:24,780
picture of me in front of the mirrors of

163
00:06:27,800 --> 00:06:26,400

the James Webb so that's that's gonna be

164
00:06:30,409 --> 00:06:27,810
in space what's sitting behind me right

165
00:06:32,000 --> 00:06:30,419
there so that's pretty amazing now when

166
00:06:33,650 --> 00:06:32,010
I wanted to study young stars

167
00:06:35,240 --> 00:06:33,660
there's one problem which is that the

168
00:06:36,440 --> 00:06:35,250
telescope that I want to use is sitting

169
00:06:39,560 --> 00:06:36,450
in a clean room in Goddard Space Flight

170
00:06:41,900 --> 00:06:39,570
Center and not in space so I had to use

171
00:06:45,530 --> 00:06:41,910
the current state of the art in the

172
00:06:47,120 --> 00:06:45,540
infrared which is airborne astronomy so

173
00:06:48,830 --> 00:06:47,130
I'm going to talk not at all about the

174
00:06:50,270 --> 00:06:48,840
James Webb Space Telescope and tell you

175
00:06:54,770 --> 00:06:50,280
about another tale of a very unusual

176
00:06:56,780 --> 00:06:54,780
observatory in Palmdale California with

177
00:06:58,010 --> 00:06:56,790
its many residents and you don't look

178
00:07:01,810 --> 00:06:58,020
too closely the picture you might see

179
00:07:04,880 --> 00:07:01,820
some that you recognize from other shows

180
00:07:07,310 --> 00:07:04,890
is a an area called Armstrong Flight

181
00:07:09,470 --> 00:07:07,320
Research Center or Dryden Air Force Base

182
00:07:13,610 --> 00:07:09,480
and in that Air Force Base is an

183
00:07:14,540 --> 00:07:13,620
airplane that NASA bought it's not the

184
00:07:16,820 --> 00:07:14,550
vomit comet

185
00:07:18,230 --> 00:07:16,830
so when people think of NASA airplanes

186
00:07:19,730 --> 00:07:18,240
they ask me oh did you fly in the vomit

187
00:07:22,040 --> 00:07:19,740
combat nights that's exactly the

188
00:07:23,900 --> 00:07:22,050

opposite of what I wanted to do flying

189
00:07:26,660 --> 00:07:23,910
up and down like you know that's a we

190
00:07:29,690 --> 00:07:26,670
want super stable this is this is why I

191
00:07:31,760 --> 00:07:29,700
would never do well in space I just I

192
00:07:34,340 --> 00:07:31,770
would lose lose my contents of my

193
00:07:34,700 --> 00:07:34,350
stomach very quickly so not the Vomit

194
00:07:36,770 --> 00:07:34,710
Comet

195
00:07:39,710 --> 00:07:36,780
it's the stratospheric Observatory for

196
00:07:41,720 --> 00:07:39,720
infrared astronomy Sofia and what they

197
00:07:45,020 --> 00:07:41,730
did was they took a 747 and actually an

198
00:07:48,100 --> 00:07:45,030
old-style 747 from the 70s bought it and

199
00:07:53,210 --> 00:07:48,110
they cut a hole in the side of the plane

200
00:07:55,280 --> 00:07:53,220
and in that hole is a telescope so

201
00:07:57,530 --> 00:07:55,290
there's a telescope about 2.4 meters in

202
00:07:59,660 --> 00:07:57,540
diameter James Webb is 6.5 meters for

203
00:08:00,710 --> 00:07:59,670
comparison so this is small but it's

204
00:08:03,620 --> 00:08:00,720
larger than most of our ground-based

205
00:08:05,420 --> 00:08:03,630
telescopes and they carry it to 42,000

206
00:08:07,370 --> 00:08:05,430
feet because the atmosphere of our earth

207
00:08:08,870 --> 00:08:07,380
is one of the things that you know

208
00:08:10,730 --> 00:08:08,880
shields us from a lot of things but it

209
00:08:12,650 --> 00:08:10,740
also makes infrared astronomy very

210
00:08:14,450 --> 00:08:12,660
tricky so that less air that you have to

211
00:08:16,100 --> 00:08:14,460
go through the better it is that's why

212
00:08:17,810 --> 00:08:16,110
we usually put these things into space

213
00:08:18,860 --> 00:08:17,820

the nice thing about an airplane is you

214
00:08:21,050 --> 00:08:18,870
can bring it down to the end of the day

215
00:08:22,340 --> 00:08:21,060
and do repairs and change out the

216
00:08:24,470 --> 00:08:22,350
instruments and things like that and

217
00:08:26,510 --> 00:08:24,480
what's really neat is I can't go to

218
00:08:29,240 --> 00:08:26,520
James Webb or Hubble and use them

219
00:08:33,110 --> 00:08:29,250
directly I couldn't fly with Sophia and

220
00:08:34,790 --> 00:08:33,120
in fact I did it takes a lot of people

221
00:08:40,660 --> 00:08:34,800
to flip plan one of these flights I have

222
00:08:45,550 --> 00:08:44,209
two flight planners the two pilot or

223
00:08:48,730 --> 00:08:45,560
pilot and co-pilot

224
00:08:51,820 --> 00:08:48,740
sort of a amidships person to safety

225
00:08:54,430 --> 00:08:51,830
officers to telescope operators and to

226
00:08:57,100 --> 00:08:54,440
instrument scientists and an outreach

227
00:08:58,360 --> 00:08:57,110
and education specialist and then six

228
00:09:00,040 --> 00:08:58,370
teachers in the California Science

229
00:09:02,950 --> 00:09:00,050
Center who come along to check out how

230
00:09:04,420 --> 00:09:02,960
science worked so it was about 20 people

231
00:09:05,620 --> 00:09:04,430
on the flight and that's only a small

232
00:09:08,530 --> 00:09:05,630
fraction when we went through the

233
00:09:10,150 --> 00:09:08,540
initial briefing we had to come up with

234
00:09:12,430 --> 00:09:10,160
a flight plan and so they came up with a

235
00:09:14,320 --> 00:09:12,440
plan now they have now this this map

236
00:09:16,930 --> 00:09:14,330
right so it takes off from Southern

237
00:09:20,710 --> 00:09:16,940
California we can't fly over Mexico for

238
00:09:22,090 --> 00:09:20,720

various obscure legal reasons so we you

239
00:09:24,910 --> 00:09:22,100
have to avoid Mexico you have to avoid

240
00:09:27,760 --> 00:09:24,920
military no-fly zones and you have to

241
00:09:29,260 --> 00:09:27,770
fly in such a direction that you can

242
00:09:30,910 --> 00:09:29,270
observe your target so think about this

243
00:09:33,160 --> 00:09:30,920
all right let me go back to for a second

244
00:09:35,560 --> 00:09:33,170
if you look at this airplane so the

245
00:09:38,320 --> 00:09:35,570
telescope can only point out the left

246
00:09:40,990 --> 00:09:38,330
side of the plane so you have to fly the

247
00:09:43,450 --> 00:09:41,000
plane such that the direction it's

248
00:09:45,010 --> 00:09:43,460
facing has the telescope pointed toward

249
00:09:47,670 --> 00:09:45,020
the star you want to look at or the

250
00:09:50,650 --> 00:09:47,680
galaxy you want to look at so you fly it

251
00:09:51,640 --> 00:09:50,660
in a straight line as long as you

252
00:09:53,800 --> 00:09:51,650
possibly can

253
00:09:56,620 --> 00:09:53,810
pointing toward your target with no

254
00:10:01,090 --> 00:09:56,630
particular destination in mind this

255
00:10:02,500 --> 00:10:01,100
drives air traffic controllers crazy and

256
00:10:04,300 --> 00:10:02,510
what's one of the neat things is you

257
00:10:05,140 --> 00:10:04,310
have a headset because it I'll show you

258
00:10:07,090 --> 00:10:05,150
later they ripped out all the

259
00:10:08,230 --> 00:10:07,100
installations so it's quite loud inside

260
00:10:12,070 --> 00:10:08,240
this plane it's kind of like being in a

261
00:10:13,329 --> 00:10:12,080
noisy bar and but you could get to

262
00:10:14,800 --> 00:10:13,339
listen to the pilot chatter with the

263
00:10:17,530 --> 00:10:14,810

very confused air traffic controllers

264
00:10:19,260 --> 00:10:17,540
the callsign of the plane is NASA 747

265
00:10:21,670 --> 00:10:19,270
you could follow it on flight aware

266
00:10:27,940 --> 00:10:21,680
every one of its flights and they're all

267
00:10:29,440 --> 00:10:27,950
posted and the so the the trajectory you

268
00:10:31,329 --> 00:10:29,450
make ask you have to end up back where

269
00:10:33,670 --> 00:10:31,339
you started so you fly for 10 hours and

270
00:10:35,170 --> 00:10:33,680
end up nowhere when you're gone nowhere

271
00:10:37,120 --> 00:10:35,180
ultimately but you've done it's been

272
00:10:38,949 --> 00:10:37,130
quite a journey on the way so each of

273
00:10:41,560 --> 00:10:38,959
these legs of this flight was a

274
00:10:43,210 --> 00:10:41,570
different target and my two targets were

275
00:10:45,760 --> 00:10:43,220
when we were out over the Pacific so we

276
00:10:48,130 --> 00:10:45,770
flew around into the Pacific just

277
00:10:51,160 --> 00:10:48,140
skirting Mexico kind of halfway out to

278
00:10:53,980 --> 00:10:51,170
Hawaii up over Juneau Alaska and back

279
00:10:56,410 --> 00:10:53,990
down the entire west coast of the US so

280
00:10:58,860 --> 00:10:56,420
we had to have contingency plans in case

281
00:11:02,550 --> 00:10:58,870
we had to land at Mexico City Hana

282
00:11:04,950 --> 00:11:02,560
Lulu Fairbanks this was February and I

283
00:11:07,260 --> 00:11:04,960
said they're Fairbanks are you insane I

284
00:11:09,120 --> 00:11:07,270
have a like a light jacket on for Los

285
00:11:10,769 --> 00:11:09,130
Angeles weather like we had to land in

286
00:11:14,579 --> 00:11:10,779
Fairbanks in February I think I would

287
00:11:17,640 --> 00:11:14,589
have you know jumped out with anyway so

288
00:11:19,440 --> 00:11:17,650

we didn't you all went great this is me

289
00:11:21,030 --> 00:11:19,450
before we're getting ready to take off I

290
00:11:22,019 --> 00:11:21,040
have a little protective reflector so

291
00:11:24,510 --> 00:11:22,029
that I don't get run over

292
00:11:26,010 --> 00:11:24,520
you cannot point the camera this way it

293
00:11:29,730 --> 00:11:26,020
turns out there's some other plane and

294
00:11:31,530 --> 00:11:29,740
hangar that they don't wanna show no I

295
00:11:35,070 --> 00:11:31,540
think it's some work they do for someone

296
00:11:36,540 --> 00:11:35,080
else the that was my seat for takeoff

297
00:11:39,300 --> 00:11:36,550
and landing those chairs at that table

298
00:11:40,320 --> 00:11:39,310
and those are our headsets so you you

299
00:11:42,540 --> 00:11:40,330
know when you fly on this thing you

300
00:11:44,460 --> 00:11:42,550
basically you kind of wait and then they

301
00:11:46,050 --> 00:11:44,470
announce they're taking off and they go

302
00:11:48,660 --> 00:11:46,060
and you basically just go you know

303
00:11:50,579 --> 00:11:48,670
they're pretty sharply upward to get to

304
00:11:53,610 --> 00:11:50,589
forty to that or at least 39,000 feet as

305
00:11:55,980 --> 00:11:53,620
quickly as possible and once you're up

306
00:11:57,690 --> 00:11:55,990
there it is about five minutes in they

307
00:11:58,860 --> 00:11:57,700
open the door for the telescope they

308
00:12:00,150 --> 00:11:58,870
don't even tell you they're doing it you

309
00:12:01,860 --> 00:12:00,160
would have no idea it's perfectly

310
00:12:03,990 --> 00:12:01,870
pressurized they open a hole in the side

311
00:12:06,420 --> 00:12:04,000
of the plane and the telescope sticks

312
00:12:08,490 --> 00:12:06,430
out and it's little harness where it is

313
00:12:10,519 --> 00:12:08,500

capped you know incredibly carefully in

314
00:12:12,780 --> 00:12:10,529
place it's kind of an amazing technology

315
00:12:14,430 --> 00:12:12,790
so it's not worried about we're not

316
00:12:17,790 --> 00:12:14,440
worried about wobble and stuff like that

317
00:12:19,079 --> 00:12:17,800
it's basically under control the safety

318
00:12:21,510 --> 00:12:19,089
briefing is a bit more extensive than

319
00:12:23,430 --> 00:12:21,520
you hit out for a commercial flight but

320
00:12:26,550 --> 00:12:23,440
it's a lot more comfortable so you

321
00:12:28,670 --> 00:12:26,560
imagine 20 people in a plane a 747 where

322
00:12:31,019 --> 00:12:28,680
they ripped out most of the seats and

323
00:12:34,050 --> 00:12:31,029
put in some computer desks but it's a

324
00:12:35,850 --> 00:12:34,060
cavernous space actually this is a

325
00:12:37,440 --> 00:12:35,860
pretty nice flight it's a little cold

326
00:12:39,660 --> 00:12:37,450
because the insulation is kind of gone

327
00:12:42,090 --> 00:12:39,670
from a lot of the sides and the back

328
00:12:44,699 --> 00:12:42,100
third of the plane is a telescope but

329
00:12:47,610 --> 00:12:44,709
it's a pretty neat situation this is

330
00:12:49,320 --> 00:12:47,620
actually this this picture may be

331
00:12:50,430 --> 00:12:49,330
nostalgic because the very first project

332
00:12:52,470 --> 00:12:50,440
I ever did as an undergraduate

333
00:12:56,850 --> 00:12:52,480
astronomer was to work with dr. Terry

334
00:12:58,740 --> 00:12:56,860
herder on the forecast camera which is

335
00:13:02,460 --> 00:12:58,750
the red instrument with the Cornell Red

336
00:13:04,860 --> 00:13:02,470
Bear on it so when I was about 20 years

337
00:13:06,600 --> 00:13:04,870
ago almost but I was there I was working

338
00:13:08,699 --> 00:13:06,610

on that I can't say well I say working

339
00:13:10,290 --> 00:13:08,709
on it I was doing a little bit of

340
00:13:11,550 --> 00:13:10,300
programming anyway it was fun it was

341
00:13:12,480 --> 00:13:11,560
really nice to be able to use the

342
00:13:13,950 --> 00:13:12,490
instrument that I remem

343
00:13:16,320 --> 00:13:13,960
being there for some of the testing of

344
00:13:20,700 --> 00:13:16,330
when it was first proposed it's a long

345
00:13:22,140 --> 00:13:20,710
life cycle so it's it's so the the

346
00:13:23,940 --> 00:13:22,150
instrument is out here on the side that

347
00:13:25,350 --> 00:13:23,950
I'm on but it's anchored to the

348
00:13:29,280 --> 00:13:25,360
telescope which is on the far side of

349
00:13:30,960 --> 00:13:29,290
that sort of circular safe looking thing

350
00:13:36,090 --> 00:13:30,970
so the telescope is inside on the other

351
00:13:37,470 --> 00:13:36,100
side in a shock frame and from this side

352
00:13:38,820 --> 00:13:37,480
you could just sort of see it adjusting

353
00:13:40,200 --> 00:13:38,830
it back and forth now the key essentials

354
00:13:42,090 --> 00:13:40,210
on the flight are that they have a

355
00:13:44,160 --> 00:13:42,100
built-in coffee maker with like a bolt

356
00:13:46,740 --> 00:13:44,170
that holds the coffee I don't know I

357
00:13:48,180 --> 00:13:46,750
just imagined hot coffee whipping across

358
00:13:50,060 --> 00:13:48,190
the plane at hundreds of miles an hour

359
00:13:54,090 --> 00:13:50,070
or something but nothing happened

360
00:13:55,230 --> 00:13:54,100
there's a microwave oven and so you

361
00:13:56,730 --> 00:13:55,240
bring your snacks on board and you can

362
00:13:58,230 --> 00:13:56,740
have dinner and it's nice because they

363
00:13:59,850 --> 00:13:58,240

left some of the first-class cabin seats

364
00:14:03,330 --> 00:13:59,860
so after your observations done you can

365
00:14:05,010 --> 00:14:03,340
kind of take a nap and you can go check

366
00:14:06,390 --> 00:14:05,020
out what we're looking at so you can

367
00:14:08,340 --> 00:14:06,400
look at the Stars you can see what our

368
00:14:11,070 --> 00:14:08,350
targets are our amazing science that was

369
00:14:13,320 --> 00:14:11,080
ongoing and the best picture I got of

370
00:14:16,320 --> 00:14:13,330
the entire flight they let I got to fly

371
00:14:20,130 --> 00:14:16,330
in the cockpit for a little bit at the

372
00:14:21,630 --> 00:14:20,140
top you know the jump seat and the you

373
00:14:23,100 --> 00:14:21,640
know so that's a pretty open section of

374
00:14:25,320 --> 00:14:23,110
the plane and the nice thing was when we

375
00:14:26,670 --> 00:14:25,330
were over Juno there were the northern

376
00:14:28,290 --> 00:14:26,680
this is a terrible picture but the

377
00:14:30,120 --> 00:14:28,300
northern lights occupied the entire left

378
00:14:31,320 --> 00:14:30,130
side of the plane so it's the most

379
00:14:33,450 --> 00:14:31,330
stunning view of the Northern Lights I'm

380
00:14:34,710 --> 00:14:33,460
ever gonna get so that was really

381
00:14:36,660 --> 00:14:34,720
probably the best picture in the flight

382
00:14:39,810 --> 00:14:36,670
but we did get some data and some

383
00:14:41,490 --> 00:14:39,820
science happened and this fun press

384
00:14:43,440 --> 00:14:41,500
release on gluttonous stars that you can

385
00:14:46,230 --> 00:14:43,450
read and I'm happy to explain some other

386
00:14:47,700 --> 00:14:46,240
time and you know my press briefing

387
00:14:50,160 --> 00:14:47,710
happened and I was really excited about

388
00:14:52,980 --> 00:14:50,170

the big news and you know I hope to go

389
00:14:54,240 --> 00:14:52,990
back again soon and in terms of the

390
00:14:55,620 --> 00:14:54,250
actual science that we discovered I

391
00:14:59,310 --> 00:14:55,630
think I'm gonna leave that to our main

392
00:15:03,080 --> 00:14:59,320
speaker let me introduce dr. Christine

393
00:15:09,500 --> 00:15:05,860
[Applause]

394
00:15:11,570 --> 00:15:09,510
so Christine got did her undergraduate

395
00:15:15,740 --> 00:15:11,580
at Caltech she's from California

396
00:15:19,400 --> 00:15:15,750
originally she got her PhD from UCLA yes

397
00:15:20,720 --> 00:15:19,410
and became a Spitzer fellow so she was

398
00:15:22,220 --> 00:15:20,730
working on the spitzer space telescope

399
00:15:25,130 --> 00:15:22,230
she was actually funded directly by

400
00:15:26,030 --> 00:15:25,140
their grants program and she worked on

401
00:15:28,190 --> 00:15:26,040
that for a number of years where we

402
00:15:31,280 --> 00:15:28,200
collaborated on projects when I was a

403
00:15:33,440 --> 00:15:31,290
little wee graduate student and then she

404
00:15:34,850 --> 00:15:33,450
became the miry one of the miry

405
00:15:37,330 --> 00:15:34,860
instrument scientists here at the Space

406
00:15:39,530 --> 00:15:37,340
Telescope Science Institute in 2008 and

407
00:15:41,450 --> 00:15:39,540
she remained in that position until this

408
00:15:42,950 --> 00:15:41,460
year where she when she became the

409
00:15:45,320 --> 00:15:42,960
deputy project scientist for the entire

410
00:15:47,150 --> 00:15:45,330
James Webb Space Telescope so she knows

411
00:15:48,710 --> 00:15:47,160
a lot about that and she can tell you a

412
00:15:51,200 --> 00:15:48,720
lot about young stars and really cool

413
00:15:54,530 --> 00:15:51,210

stuff about planets and take it away

414
00:15:56,300 --> 00:15:54,540
Christine thanks for the introduction

415
00:15:59,270 --> 00:15:56,310
Joel I'm gonna talk about things that

416
00:16:01,430 --> 00:15:59,280
are very related to what Joel just kind

417
00:16:03,710 --> 00:16:01,440
of told you about so in particular

418
00:16:06,320 --> 00:16:03,720
electoral I'm an infrared astronomer and

419
00:16:10,810 --> 00:16:06,330
I'm also interested in how planetary

420
00:16:12,860 --> 00:16:10,820
systems form and evolve so Joel the

421
00:16:16,160 --> 00:16:12,870
targets that Joel was looking at were

422
00:16:18,410 --> 00:16:16,170
fairly young stars that still have these

423
00:16:21,680 --> 00:16:18,420
nascent clouds of gas and dust and are

424
00:16:23,480 --> 00:16:21,690
still forming giant planets the targets

425
00:16:25,700 --> 00:16:23,490
that I tend to look at our planetary

426
00:16:28,670 --> 00:16:25,710
systems that are somewhat older and that

427
00:16:30,740 --> 00:16:28,680
are perhaps more analogous to our own

428
00:16:33,020 --> 00:16:30,750
solar system although some of these

429
00:16:35,150 --> 00:16:33,030
systems can be young too the defining

430
00:16:36,500 --> 00:16:35,160
difference between the systems that I

431
00:16:38,360 --> 00:16:36,510
look at and some of the ones that Joel

432
00:16:41,960 --> 00:16:38,370
showed you some nice observations from

433
00:16:44,540 --> 00:16:41,970
is the presence or absence of molecular

434
00:16:47,300 --> 00:16:44,550
gas so if you think about the

435
00:16:50,360 --> 00:16:47,310
interstellar medium and what's contained

436
00:16:54,230 --> 00:16:50,370
in the region between stars we know that

437
00:16:57,650 --> 00:16:54,240
it's largely gas and dust and with about

438
00:16:59,420 --> 00:16:57,660

a hundred times more gas by mass than

439
00:17:02,330 --> 00:16:59,430
dust and predominantly a lot of this is

440
00:17:04,689 --> 00:17:02,340
contained in molecular hydrogen for the

441
00:17:07,069 --> 00:17:04,699
the systems that I'm going to talk about

442
00:17:09,590 --> 00:17:07,079
we think that in the majority of them

443
00:17:12,470 --> 00:17:09,600
the giant planets have already formed

444
00:17:14,929 --> 00:17:12,480
and so in that process all of the gas

445
00:17:15,590 --> 00:17:14,939
that was in the disk has accreted on to

446
00:17:17,720 --> 00:17:15,600
the star

447
00:17:20,270 --> 00:17:17,730
or created onto the atmospheres of

448
00:17:22,850 --> 00:17:20,280
jovian planets or been expelled out of

449
00:17:25,100 --> 00:17:22,860
the planetary system so these are much

450
00:17:29,690 --> 00:17:25,110
more analogous to our own solar system

451
00:17:31,640 --> 00:17:29,700
than protoplanetary discs so if you were

452
00:17:33,590 --> 00:17:31,650
to try to take a high-resolution image

453
00:17:35,960 --> 00:17:33,600
of some of the systems that I study

454
00:17:37,580 --> 00:17:35,970
these so-called debris disks this is

455
00:17:38,990 --> 00:17:37,590
actually a picture that you might see

456
00:17:40,880 --> 00:17:39,000
this is a picture that was obtained with

457
00:17:43,039 --> 00:17:40,890
the Hubble Space Telescope the advanced

458
00:17:45,700 --> 00:17:43,049
camera for surveys it has what's known

459
00:17:47,960 --> 00:17:45,710
as a corona graphic instrument so

460
00:17:50,330 --> 00:17:47,970
coronagraphs were developed to study the

461
00:17:53,470 --> 00:17:50,340
corona of the Sun and essentially what

462
00:17:56,149 --> 00:17:53,480
they contain is a physical mechanism

463
00:17:58,850 --> 00:17:56,159

something mechanical for blocking out

464
00:18:00,950 --> 00:17:58,860
the bright disk of the Sun and allowing

465
00:18:03,560 --> 00:18:00,960
you to study the faint Corona of the

466
00:18:06,409 --> 00:18:03,570
star or the Sun and in this particular

467
00:18:08,149 --> 00:18:06,419
case what we're doing instead is we're

468
00:18:10,940 --> 00:18:08,159
blocking out the light from the central

469
00:18:14,270 --> 00:18:10,950
star in the planetary system and by

470
00:18:16,310 --> 00:18:14,280
doing so having the possibility then of

471
00:18:16,850 --> 00:18:16,320
detecting fainter material around the

472
00:18:20,720 --> 00:18:16,860
star

473
00:18:23,539 --> 00:18:20,730
whether that is faint planets Jovian

474
00:18:25,460 --> 00:18:23,549
mass planets or lower mass planets or in

475
00:18:28,039 --> 00:18:25,470
this particular case what you see is a

476
00:18:31,370 --> 00:18:28,049
ring of dust which is around this star

477
00:18:34,250 --> 00:18:31,380
so this is the star Fomalhaut it's a one

478
00:18:36,380 --> 00:18:34,260
of the nearest stars to our Sun it's

479
00:18:38,600 --> 00:18:36,390
about 10 parsecs away and this is a

480
00:18:42,350 --> 00:18:38,610
intermediate-mass star so it's mass is

481
00:18:44,419 --> 00:18:42,360
about twice the mass of our Sun so when

482
00:18:46,039 --> 00:18:44,429
I think of these systems this is kind of

483
00:18:49,130 --> 00:18:46,049
the typical kind of picture that I have

484
00:18:51,169 --> 00:18:49,140
in my head although many of the systems

485
00:18:53,500 --> 00:18:51,179
that we observe and try to learn about

486
00:18:56,510 --> 00:18:53,510
we don't have such pretty pictures for

487
00:18:59,690 --> 00:18:56,520
so this is just a quick outline of my

488
00:19:02,149 --> 00:18:59,700

talk so again many of these systems are

489
00:19:03,860 --> 00:19:02,159
very analogous to our solar system so

490
00:19:07,909 --> 00:19:03,870
it's useful to stand back and to think

491
00:19:09,620 --> 00:19:07,919
about our solar system and the the

492
00:19:11,810 --> 00:19:09,630
demographics of bodies in our solar

493
00:19:13,190 --> 00:19:11,820
system so there are the giant planets

494
00:19:14,659 --> 00:19:13,200
the terrestrial planets there's

495
00:19:17,090 --> 00:19:14,669
asteroids and comets and there's

496
00:19:18,799 --> 00:19:17,100
actually dust as well so I'll tell you a

497
00:19:21,320 --> 00:19:18,809
little bit about the solar system dust

498
00:19:23,720 --> 00:19:21,330
and then there's actually forces that

499
00:19:25,970 --> 00:19:23,730
act on the dust that rearrange the dust

500
00:19:28,159 --> 00:19:25,980
in our solar system so for example

501
00:19:29,450 --> 00:19:28,169
there's radiation pressure which can

502
00:19:31,669 --> 00:19:29,460
blow dust out

503
00:19:33,919 --> 00:19:31,679
and there's also something called

504
00:19:36,440 --> 00:19:33,929
pointing robertson drag which is a

505
00:19:38,000 --> 00:19:36,450
relativistic effect which causes larger

506
00:19:39,289 --> 00:19:38,010
dust grains to spiral into the central

507
00:19:41,149 --> 00:19:39,299
star so I'll tell you about some of

508
00:19:43,159 --> 00:19:41,159
these forces that rearrange dust in our

509
00:19:45,740 --> 00:19:43,169
own solar system

510
00:19:47,529 --> 00:19:45,750
so these populations this population of

511
00:19:50,810 --> 00:19:47,539
dust that we see in our own solar system

512
00:19:53,029 --> 00:19:50,820
has now been analogous populations have

513
00:19:56,690 --> 00:19:53,039

been seen around other stars other

514
00:19:57,830 --> 00:19:56,700
main-sequence other midlife stars and

515
00:20:00,350 --> 00:19:57,840
I'll tell you about some of the

516
00:20:02,810 --> 00:20:00,360
demographics from the early iris

517
00:20:04,840 --> 00:20:02,820
discoveries and then Spitzer was a

518
00:20:07,460 --> 00:20:04,850
tremendous boon to this area of study

519
00:20:09,799 --> 00:20:07,470
where iris discovered maybe about a

520
00:20:11,570 --> 00:20:09,809
hundred targets Spitzer told us about

521
00:20:13,760 --> 00:20:11,580
maybe a thousand so an order of

522
00:20:16,490 --> 00:20:13,770
magnitude more and gave us much more

523
00:20:19,010 --> 00:20:16,500
detailed spectroscopic information about

524
00:20:20,539 --> 00:20:19,020
these targets and then because as dole

525
00:20:22,730 --> 00:20:20,549
mentioned I worked on JB St I'm

526
00:20:25,610 --> 00:20:22,740
tremendously excited about the gains

527
00:20:26,990 --> 00:20:25,620
that jade was T will make especially in

528
00:20:29,289 --> 00:20:27,000
this area of science and I'll try to

529
00:20:32,419 --> 00:20:29,299
give you a hint of what that looks like

530
00:20:33,919 --> 00:20:32,429
so I put this outline on top of this

531
00:20:36,830 --> 00:20:33,929
really beautiful picture of the night

532
00:20:39,890 --> 00:20:36,840
sky and this is just to remind you of

533
00:20:42,529 --> 00:20:39,900
what the dust in our solar system looks

534
00:20:45,230 --> 00:20:42,539
like so there is the zodiacal dust in

535
00:20:47,000 --> 00:20:45,240
our solar system which is produced it's

536
00:20:49,669 --> 00:20:47,010
in the region of the asteroid belt and

537
00:20:52,669 --> 00:20:49,679
you can see it here at a time that's

538
00:20:54,110 --> 00:20:52,679

pretty much close to sunset so that

539
00:20:56,240 --> 00:20:54,120
you're not looking very far away from

540
00:20:58,430 --> 00:20:56,250
the Sun but you can see from the dark

541
00:20:59,899 --> 00:20:58,440
site here this is the Milky Way and then

542
00:21:03,169 --> 00:20:59,909
you can see this sort of linear feature

543
00:21:04,850 --> 00:21:03,179
here in sort of reflected light this is

544
00:21:06,860 --> 00:21:04,860
light that's reflected off of dust

545
00:21:09,140 --> 00:21:06,870
grains in our solar system again this is

546
00:21:11,360 --> 00:21:09,150
called zodiacal light and it's produced

547
00:21:16,070 --> 00:21:11,370
by sunlight scattered off of what's

548
00:21:18,740 --> 00:21:16,080
called as a dial dust so this is just a

549
00:21:21,049 --> 00:21:18,750
reminder agile already spoke about this

550
00:21:23,330 --> 00:21:21,059
a little bit about the bodies that we

551
00:21:24,529 --> 00:21:23,340
find in our own solar system of course

552
00:21:27,049 --> 00:21:24,539
we're the most familiar with the

553
00:21:28,880 --> 00:21:27,059
terrestrial planets and there are so

554
00:21:31,010 --> 00:21:28,890
many really beautiful images of the

555
00:21:34,430 --> 00:21:31,020
jovian planets and we've learned so much

556
00:21:36,409 --> 00:21:34,440
about them but in addition to the

557
00:21:39,799 --> 00:21:36,419
planets there's also a number of

558
00:21:41,510 --> 00:21:39,809
populations of minor bodies so the ones

559
00:21:43,720 --> 00:21:41,520
that most people are familiar with are

560
00:21:49,149 --> 00:21:43,730
the asteroid belt

561
00:21:51,970 --> 00:21:49,159
these are a kilometer up to tens of

562
00:21:56,259 --> 00:21:51,980
kilometers sighs bodies that live

563
00:21:58,960 --> 00:21:56,269

between Mars and Jupiter and then in the

564
00:22:00,789 --> 00:21:58,970
outer reaches of the solar system beyond

565
00:22:05,019 --> 00:22:00,799
the orbit of Neptune there is the Kuiper

566
00:22:08,200 --> 00:22:05,029
belt and the largest objects and the

567
00:22:10,720 --> 00:22:08,210
Kuiper belts have been named I store

568
00:22:12,789 --> 00:22:10,730
planets so adul also mentioned this

569
00:22:13,389 --> 00:22:12,799
controversy about what is the status of

570
00:22:15,220 --> 00:22:13,399
Pluto

571
00:22:18,039 --> 00:22:15,230
so as you call it was originally a

572
00:22:20,710 --> 00:22:18,049
planet that has been reclassified as an

573
00:22:23,019 --> 00:22:20,720
ice storm planet so for the most part

574
00:22:26,860 --> 00:22:23,029
all of these objects play and the

575
00:22:31,060 --> 00:22:26,870
zodiacal in those a vehicle plane in the

576
00:22:33,220 --> 00:22:31,070
plane of the solar system and but the

577
00:22:36,730 --> 00:22:33,230
last population which is called the Oort

578
00:22:39,700 --> 00:22:36,740
cloud actually lies in a spherical

579
00:22:41,980 --> 00:22:39,710
distribution around the Sun and these

580
00:22:44,139 --> 00:22:41,990
are small bodies that are sort of

581
00:22:45,669 --> 00:22:44,149
analogous to Kuiper belt objects obses

582
00:22:47,499 --> 00:22:45,679
furred they've been scattered out to

583
00:22:49,659 --> 00:22:47,509
very large distances in all different

584
00:22:53,080 --> 00:22:49,669
directions from the Sun and this happens

585
00:22:55,360 --> 00:22:53,090
because the small bodies for example in

586
00:22:56,889 --> 00:22:55,370
the Kuiper belt might have migrated into

587
00:22:58,539 --> 00:22:56,899
the inner solar system and then

588
00:23:01,570 --> 00:22:58,549

gravitationally encountered Jupiter

589
00:23:04,539 --> 00:23:01,580
Saturn and then slung into the outer

590
00:23:07,570 --> 00:23:04,549
part of the solar system so when I think

591
00:23:09,850 --> 00:23:07,580
about the solar system this is what I

592
00:23:11,169 --> 00:23:09,860
think about this is the part of the

593
00:23:13,269 --> 00:23:11,179
solar system that were most familiar

594
00:23:15,340 --> 00:23:13,279
with the inner 5au with the terrestrial

595
00:23:18,789 --> 00:23:15,350
planets and the asteroid belts and then

596
00:23:22,869 --> 00:23:18,799
moving out to the outer solar system you

597
00:23:25,269 --> 00:23:22,879
can see the orbits here for the giant

598
00:23:28,680 --> 00:23:25,279
planets the gas giants and then this

599
00:23:30,909 --> 00:23:28,690
population of Kuiper belt objects and

600
00:23:33,039 --> 00:23:30,919
both in the Kuiper belt in the asteroid

601
00:23:36,100 --> 00:23:33,049
belt those small bodies collide ground

602
00:23:38,710 --> 00:23:36,110
down and produce dust strains and then

603
00:23:41,230 --> 00:23:38,720
on larger scales the spherical

604
00:23:45,909 --> 00:23:41,240
distribution of small bodies that makes

605
00:23:49,090 --> 00:23:45,919
up that were cloud so I showed you a

606
00:23:52,750 --> 00:23:49,100
nice scattered light image of dust in

607
00:23:54,280 --> 00:23:52,760
our solar system that beautiful panorama

608
00:23:57,190 --> 00:23:54,290
of the Milky Way and then

609
00:23:59,830 --> 00:23:57,200
the zodiacal light this is another way

610
00:24:01,330 --> 00:23:59,840
to look at the sky and this is an image

611
00:24:03,810 --> 00:24:01,340
that was taken from the infrared

612
00:24:07,690 --> 00:24:03,820
astronomical satellite so this was a

613
00:24:09,610 --> 00:24:07,700

satellite that launched in 1983 and it

614
00:24:13,690 --> 00:24:09,620
surveyed the entire sky in the infrared

615
00:24:16,960 --> 00:24:13,700
so it mapped the sky at 1225 60 and 100

616
00:24:19,300 --> 00:24:16,970
microns when you look at this map it

617
00:24:21,970 --> 00:24:19,310
doesn't look like most maps that you're

618
00:24:25,720 --> 00:24:21,980
familiar with because you're seeing the

619
00:24:27,820 --> 00:24:25,730
heat signature from bodies both in the

620
00:24:31,420 --> 00:24:27,830
Milky Way so this is the Galactic plane

621
00:24:33,520 --> 00:24:31,430
here so this is the our galaxy and then

622
00:24:36,610 --> 00:24:33,530
also the heat signature for foreground

623
00:24:39,400 --> 00:24:36,620
closer objects so this thing tilted here

624
00:24:41,530 --> 00:24:39,410
this is dust this is a dial dust in our

625
00:24:43,870 --> 00:24:41,540
solar system so you can see the plane of

626
00:24:47,500 --> 00:24:43,880
our solar system is canted compared to

627
00:24:49,660 --> 00:24:47,510
the plane of the Milky Way so this is to

628
00:24:53,020 --> 00:24:49,670
illustrate that when you look at these

629
00:24:54,490 --> 00:24:53,030
maps of heat you're seeing in the far

630
00:24:57,250 --> 00:24:54,500
infrared you're looking at maps of heat

631
00:25:00,970 --> 00:24:57,260
and this is an incredibly efficient way

632
00:25:02,620 --> 00:25:00,980
to find dust because the dust for

633
00:25:06,280 --> 00:25:02,630
example that's in our solar system it

634
00:25:07,990 --> 00:25:06,290
absorbs sunlight from our Sun and that

635
00:25:11,020 --> 00:25:08,000
causes the dust grains to heat up to

636
00:25:14,440 --> 00:25:11,030
about 230 K and then those dust grains

637
00:25:17,490 --> 00:25:14,450
are irradiate temperature heat which is

638
00:25:19,900 --> 00:25:17,500

detectable in the far infrared is light

639
00:25:22,150 --> 00:25:19,910
what's particularly powerful is that

640
00:25:25,510 --> 00:25:22,160
with the dust grains is that if you

641
00:25:27,910 --> 00:25:25,520
think of a particular mass of stuff and

642
00:25:31,090 --> 00:25:27,920
small dust grains you have a lot of

643
00:25:33,820 --> 00:25:31,100
surface area for those small dust grains

644
00:25:35,890 --> 00:25:33,830
compared to like a planet so for example

645
00:25:37,960 --> 00:25:35,900
if you were to imagine Jupiter broken up

646
00:25:40,210 --> 00:25:37,970
into micron sized dust grains there's

647
00:25:41,920 --> 00:25:40,220
much more surface area in those micron

648
00:25:44,080 --> 00:25:41,930
sized dust grains compared to the planet

649
00:25:46,650 --> 00:25:44,090
Jupiter and this is what makes it so

650
00:25:51,270 --> 00:25:46,660
easy to detect those dust grains then

651
00:25:54,640 --> 00:25:51,280
through the infrared thermal emission so

652
00:25:57,760 --> 00:25:54,650
so if this is the is a die of coal it--

653
00:26:01,300 --> 00:25:57,770
which was maps so beautifully here by

654
00:26:03,730 --> 00:26:01,310
the IR s satellite you know it's

655
00:26:06,700 --> 00:26:03,740
interesting to try to understand what is

656
00:26:08,110 --> 00:26:06,710
the connection between this dust and for

657
00:26:11,230 --> 00:26:08,120
example the miner bodies

658
00:26:13,830 --> 00:26:11,240
our solar system so this is a plot

659
00:26:16,360 --> 00:26:13,840
showing you the orbital parameters of

660
00:26:19,030 --> 00:26:16,370
asteroids in the main asteroid belt in

661
00:26:21,160 --> 00:26:19,040
particular the y-axis here shows you the

662
00:26:23,380 --> 00:26:21,170
inclination of their orbits plot as a

663
00:26:25,660 --> 00:26:23,390

function of their semi-major axis and

664
00:26:29,050 --> 00:26:25,670
every little dot on this plot represents

665
00:26:30,520 --> 00:26:29,060
a single asteroid a plot like this was

666
00:26:33,460 --> 00:26:30,530
first made by an astronomer named

667
00:26:36,550 --> 00:26:33,470
Hariyama in 1918 and one of the stunning

668
00:26:37,840 --> 00:26:36,560
things that he discovered was that and

669
00:26:40,060 --> 00:26:37,850
you can see this when you look at this

670
00:26:42,390 --> 00:26:40,070
more modern plot today is that there is

671
00:26:45,790 --> 00:26:42,400
structure in this plot so for example

672
00:26:48,280 --> 00:26:45,800
there's a gap here an absence of

673
00:26:53,050 --> 00:26:48,290
asteroids this is the Kirkwood gap and

674
00:26:54,820 --> 00:26:53,060
so this is a location where if a body

675
00:26:57,280 --> 00:26:54,830
was here it would be in resonance with

676
00:26:59,410 --> 00:26:57,290
Jupiter and that resonance then makes

677
00:27:02,200 --> 00:26:59,420
the object unstable gravitationally

678
00:27:04,000 --> 00:27:02,210
unstable so it gets ejected out of that

679
00:27:06,670 --> 00:27:04,010
orbit so that's why this whole region is

680
00:27:09,250 --> 00:27:06,680
clear but in addition to structures like

681
00:27:12,460 --> 00:27:09,260
that you can actually also see clumping

682
00:27:14,890 --> 00:27:12,470
of objects in this plot and when this

683
00:27:17,080 --> 00:27:14,900
was first noticed it was hypothesized

684
00:27:19,960 --> 00:27:17,090
that the reason why you have so many

685
00:27:21,280 --> 00:27:19,970
objects that are in these clumps is that

686
00:27:24,310 --> 00:27:21,290
they were originally part of a larger

687
00:27:27,220 --> 00:27:24,320
object that broke apart into smaller

688
00:27:31,060 --> 00:27:27,230

pieces and so they still retained the

689
00:27:34,930 --> 00:27:31,070
overall same orbital parameters that you

690
00:27:37,240 --> 00:27:34,940
see you know on this plot but there's

691
00:27:41,520 --> 00:27:37,250
now a little bit of dispersion from

692
00:27:45,400 --> 00:27:41,530
having broken up you can imagine that

693
00:27:47,800 --> 00:27:45,410
when you have the breakup of an asteroid

694
00:27:49,540 --> 00:27:47,810
you create not just large objects but

695
00:27:51,910 --> 00:27:49,550
actually a whole size distribution of

696
00:27:54,250 --> 00:27:51,920
particles so not just things that have

697
00:27:56,440 --> 00:27:54,260
sizes of a kilometer or ten kilometers

698
00:27:58,690 --> 00:27:56,450
but things all the way down to fine

699
00:28:00,970 --> 00:27:58,700
grain dust things with the size of a

700
00:28:04,120 --> 00:28:00,980
micron or so and those are things that

701
00:28:07,570 --> 00:28:04,130
again have a lot of surface area for

702
00:28:09,490 --> 00:28:07,580
their mass and so they're very

703
00:28:12,040 --> 00:28:09,500
efficiently warmed up and they very

704
00:28:15,340 --> 00:28:12,050
efficiently radiate that the heat the

705
00:28:17,380 --> 00:28:15,350
energy that they absorb and so one of

706
00:28:20,560 --> 00:28:17,390
the really interesting discoveries of

707
00:28:21,940 --> 00:28:20,570
the i-rath satellite was structures in

708
00:28:24,909 --> 00:28:21,950
the zodiacal light in

709
00:28:28,840 --> 00:28:24,919
vehicle dust and in particular so these

710
00:28:30,730 --> 00:28:28,850
are sort of zoomed in pictures of the

711
00:28:34,180 --> 00:28:30,740
sadaqa light in which you can see that

712
00:28:36,519 --> 00:28:34,190
there's actually these bands where you

713
00:28:39,009 --> 00:28:36,529

have an enhancement of small particles

714
00:28:42,279 --> 00:28:39,019
and the dust and the inner part of the

715
00:28:44,320 --> 00:28:42,289
solar system you can go through and

716
00:28:46,389 --> 00:28:44,330
model in better detail what the orbital

717
00:28:48,250 --> 00:28:46,399
parameters are associated with these

718
00:28:52,090 --> 00:28:48,260
dust bands and you find that they're

719
00:28:53,830 --> 00:28:52,100
actually coincident with for the

720
00:28:55,750 --> 00:28:53,840
particular case of these dust bands so

721
00:28:58,470 --> 00:28:55,760
alpha beta and gamma dust bands they're

722
00:29:02,919 --> 00:28:58,480
orbital parameters are coincident with

723
00:29:04,750 --> 00:29:02,929
the famous es and Cronus families and so

724
00:29:07,180 --> 00:29:04,760
this tells you that this these are the

725
00:29:09,159 --> 00:29:07,190
small particles that were formed when

726
00:29:10,629 --> 00:29:09,169
the larger body broke up so not only do

727
00:29:13,389 --> 00:29:10,639
you see the large bodies in this

728
00:29:16,960 --> 00:29:13,399
asteroid plot orbital parameter plot but

729
00:29:18,549 --> 00:29:16,970
then you also see in maps the sky the

730
00:29:22,269 --> 00:29:18,559
fine dust grains that are created and

731
00:29:24,430 --> 00:29:22,279
when they break up so so infrared a lot

732
00:29:27,490 --> 00:29:24,440
of infrared astronomy is about detecting

733
00:29:29,399 --> 00:29:27,500
the heat signature from dust and so I

734
00:29:33,129 --> 00:29:29,409
just wanted to remind you about

735
00:29:36,700 --> 00:29:33,139
blackbody emission and how it works so

736
00:29:39,850 --> 00:29:36,710
this particular plot shows you intensity

737
00:29:43,149 --> 00:29:39,860
as a function of wavelength so this side

738
00:29:44,980 --> 00:29:43,159

is blue and this side is red for in this

739
00:29:48,039 --> 00:29:44,990
particular case it would be stars of

740
00:29:51,460 --> 00:29:48,049
various temperatures so 3,000 4,000

741
00:29:53,649 --> 00:29:51,470
5,000 6,000 Kelvin so our Sun has a

742
00:29:55,480 --> 00:29:53,659
temperature of about 5800 Kelvin so it's

743
00:29:58,539 --> 00:29:55,490
approximately like this 6,000 Kelvin

744
00:30:02,560 --> 00:29:58,549
star so in the particular case of our

745
00:30:04,570 --> 00:30:02,570
sign you can see that the peak of the

746
00:30:07,180 --> 00:30:04,580
light that comes out is about 5500

747
00:30:10,750 --> 00:30:07,190
angstroms it sort of corresponds to

748
00:30:13,629 --> 00:30:10,760
yellow-green but if you imagine stars

749
00:30:16,419 --> 00:30:13,639
that have decreasing temperatures the

750
00:30:19,240 --> 00:30:16,429
peak in this blackbody function actually

751
00:30:21,009 --> 00:30:19,250
shifts to the right and so the energy

752
00:30:22,930 --> 00:30:21,019
that comes out for lower and lower

753
00:30:24,580 --> 00:30:22,940
temperature stars is redder and redder

754
00:30:26,500 --> 00:30:24,590
so they have redder and redder colors

755
00:30:28,389 --> 00:30:26,510
the other thing that you notice is that

756
00:30:29,950 --> 00:30:28,399
as you lower the temperature the

757
00:30:32,500 --> 00:30:29,960
brightness or the intensity of the

758
00:30:34,839 --> 00:30:32,510
object also decreases so when you lower

759
00:30:37,839 --> 00:30:34,849
the temperatures for things

760
00:30:40,629 --> 00:30:37,849
radiation becomes longer and wavelength

761
00:30:42,969 --> 00:30:40,639
more red and it also diminishes lowers

762
00:30:45,789 --> 00:30:42,979
and intensity so that's one of the major

763
00:30:48,249 --> 00:30:45,799

tools that we look at is detecting the

764
00:30:51,609 --> 00:30:48,259
heat and I'll tell you more about the

765
00:30:53,560 --> 00:30:51,619
observations for the dust in our

766
00:30:55,930 --> 00:30:53,570
particular solar system it turns out

767
00:30:58,719 --> 00:30:55,940
that it doesn't really stay put from

768
00:31:01,899 --> 00:30:58,729
where it's generated so you can imagine

769
00:31:04,599 --> 00:31:01,909
for example asteroids that collide

770
00:31:06,369 --> 00:31:04,609
together and as they do so they grind

771
00:31:08,739 --> 00:31:06,379
down and produce little tiny dust grains

772
00:31:10,749 --> 00:31:08,749
it turns out that for the smallest

773
00:31:12,519 --> 00:31:10,759
screens and the size distribution they

774
00:31:14,529 --> 00:31:12,529
have a lot of surface area for their

775
00:31:17,079 --> 00:31:14,539
volume so they have a lot of surface

776
00:31:18,549 --> 00:31:17,089
area for their mass and so that actually

777
00:31:20,469 --> 00:31:18,559
means that they're not gravitationally

778
00:31:23,229 --> 00:31:20,479
bound to the star and so they act like

779
00:31:25,959 --> 00:31:23,239
tiny sails and so the radiation pressure

780
00:31:27,909 --> 00:31:25,969
just drives them blows them out of our

781
00:31:30,099 --> 00:31:27,919
solar system and so in some sense

782
00:31:31,809 --> 00:31:30,109
there's a minimum size to the dust

783
00:31:35,859 --> 00:31:31,819
grains that are in our in our solar

784
00:31:38,409 --> 00:31:35,869
system for dust grains that are larger

785
00:31:41,349 --> 00:31:38,419
there are no longer sensitive to

786
00:31:43,209 --> 00:31:41,359
radiation pressure in this way but what

787
00:31:45,009 --> 00:31:43,219
happens to them instead is they feel a

788
00:31:47,109 --> 00:31:45,019

relativistic effects called pointing

789
00:31:49,180 --> 00:31:47,119
robertson drag and in that particular

790
00:31:51,669 --> 00:31:49,190
case you can imagine that you're a dust

791
00:31:54,189 --> 00:31:51,679
grain orbiting around the star and as

792
00:31:56,949 --> 00:31:54,199
you do so you feel a headwind of photons

793
00:31:59,019 --> 00:31:56,959
from the star and that causes you to

794
00:32:00,759 --> 00:31:59,029
slow down and so you lose angular

795
00:32:01,329 --> 00:32:00,769
momentum and you slowly spiral into the

796
00:32:03,609 --> 00:32:01,339
star

797
00:32:05,469 --> 00:32:03,619
so the basic takeaway message is the

798
00:32:07,539 --> 00:32:05,479
expectation or what happens in our solar

799
00:32:09,399 --> 00:32:07,549
system is that the small variance get

800
00:32:12,339 --> 00:32:09,409
radiatively blown out and the large

801
00:32:18,719 --> 00:32:12,349
larger ones spiral into the into the

802
00:32:21,999 --> 00:32:18,729
star so it turns out that for our Sun

803
00:32:24,069 --> 00:32:22,009
there's another effect that brings large

804
00:32:26,199 --> 00:32:24,079
dust for instance to the star it's

805
00:32:28,359 --> 00:32:26,209
called solar wind drag and this happens

806
00:32:30,369 --> 00:32:28,369
around active stars too and in this

807
00:32:32,019 --> 00:32:30,379
particular case it's very analogous to

808
00:32:34,180 --> 00:32:32,029
pointing robertson drag i've suffered

809
00:32:37,239 --> 00:32:34,190
the difference is that the star is

810
00:32:41,319 --> 00:32:37,249
emitting not only photons light but it's

811
00:32:42,909 --> 00:32:41,329
also emitting particles protons so and

812
00:32:45,549 --> 00:32:42,919
you can imagine now that what happens

813
00:32:46,640 --> 00:32:45,559

instead is that that orbiting dust grain

814
00:32:49,250 --> 00:32:46,650
feels a headway

815
00:32:51,800 --> 00:32:49,260
and of these protons of particles which

816
00:32:53,270 --> 00:32:51,810
then cause them to slow down lose

817
00:32:55,910 --> 00:32:53,280
angular momentum and spiral into the

818
00:32:58,160 --> 00:32:55,920
star so the just the the main point is

819
00:33:01,760 --> 00:32:58,170
just that dust in the solar system gets

820
00:33:04,150 --> 00:33:01,770
rearranged in these different ways so

821
00:33:07,220 --> 00:33:04,160
the part that really interests me is

822
00:33:12,230 --> 00:33:07,230
what do we know about planetary systems

823
00:33:14,330 --> 00:33:12,240
around other stars do we do we think

824
00:33:16,970 --> 00:33:14,340
that there are lots of other planetary

825
00:33:22,100 --> 00:33:16,980
systems that have analogous belts of

826
00:33:24,320 --> 00:33:22,110
small bodies and you know are they do

827
00:33:26,930 --> 00:33:24,330
they play some sort of role and how

828
00:33:30,500 --> 00:33:26,940
planetary systems form and evolve so for

829
00:33:33,020 --> 00:33:30,510
example if you think about our solar

830
00:33:35,030 --> 00:33:33,030
system and the earth one of the

831
00:33:36,650 --> 00:33:35,040
outstanding questions today is how was

832
00:33:38,150 --> 00:33:36,660
water delivered to the earth how did the

833
00:33:38,990 --> 00:33:38,160
oceans get here and that's that's

834
00:33:42,200 --> 00:33:39,000
actually something that we don't

835
00:33:45,110 --> 00:33:42,210
understand well and one of the ideas for

836
00:33:47,030 --> 00:33:45,120
the origin of the oceans was essentially

837
00:33:49,850 --> 00:33:47,040
they were delivered by comets from the

838
00:33:51,320 --> 00:33:49,860

outer solar system so these minor bodies

839
00:33:54,020 --> 00:33:51,330
might actually be a very important

840
00:33:56,600 --> 00:33:54,030
source of water in extrasolar planetary

841
00:33:59,210 --> 00:33:56,610
systems so the answer is that we've been

842
00:34:01,220 --> 00:33:59,220
able to discover minor bodies so

843
00:34:04,070 --> 00:34:01,230
asteroid and Kuiper belt populations

844
00:34:07,100 --> 00:34:04,080
around other stars and we do this in the

845
00:34:09,080 --> 00:34:07,110
infrared and particularly this started

846
00:34:10,820 --> 00:34:09,090
with the irath satellite so I showed you

847
00:34:13,340 --> 00:34:10,830
the beautiful off sky image and then

848
00:34:15,260 --> 00:34:13,350
showed you the zodiacal dust bands this

849
00:34:18,610 --> 00:34:15,270
was another one of the key contributions

850
00:34:21,860 --> 00:34:18,620
from the i-rath satellite so basically

851
00:34:24,260 --> 00:34:21,870
when IRS was launched they the

852
00:34:26,990 --> 00:34:24,270
astronomers envisioned that they would

853
00:34:29,210 --> 00:34:27,000
use nearby a type stars as calibrators

854
00:34:32,149 --> 00:34:29,220
and they felt that they understood very

855
00:34:34,760 --> 00:34:32,159
well what the flux from those stars

856
00:34:37,790 --> 00:34:34,770
should look like based on how they look

857
00:34:39,169 --> 00:34:37,800
at visual wavelengths and so basically

858
00:34:41,389 --> 00:34:39,179
if you look at these pots their

859
00:34:44,540 --> 00:34:41,399
brightness flux as a function of

860
00:34:45,740 --> 00:34:44,550
wavelength and you can see 12 25 60 100

861
00:34:47,810 --> 00:34:45,750
microns so these are far infrared

862
00:34:50,690 --> 00:34:47,820
wavelengths and these straight lines

863
00:34:52,850 --> 00:34:50,700

show you the expectations that people

864
00:34:55,399 --> 00:34:52,860
had for how bright those stars would be

865
00:34:57,410 --> 00:34:55,409
and you can see these error bars show

866
00:34:59,540 --> 00:34:57,420
you the actual data and what's really

867
00:35:00,410 --> 00:34:59,550
stunning is that these predictions for

868
00:35:03,349 --> 00:35:00,420
how bright the star

869
00:35:05,960 --> 00:35:03,359
should be was a factor of a hundred or

870
00:35:09,470 --> 00:35:05,970
so wrong for these four particular stars

871
00:35:12,500 --> 00:35:09,480
and so when this was discovered it was

872
00:35:15,380 --> 00:35:12,510
immediately hypothesized that the reason

873
00:35:16,819 --> 00:35:15,390
why they're so bright at 60 and 100

874
00:35:18,980 --> 00:35:16,829
microns is because you have

875
00:35:21,230 --> 00:35:18,990
circumstellar dust so dust around the

876
00:35:23,870 --> 00:35:21,240
star which is absorbing light from the

877
00:35:27,079 --> 00:35:23,880
star warming up and reradiating that

878
00:35:29,569 --> 00:35:27,089
energy is thermal emission and so that's

879
00:35:33,259 --> 00:35:29,579
the current understanding and indeed

880
00:35:35,539 --> 00:35:33,269
when astronomers were able to once they

881
00:35:38,390 --> 00:35:35,549
identified these interesting candidate

882
00:35:40,759 --> 00:35:38,400
targets so in this particular case this

883
00:35:44,059 --> 00:35:40,769
is like Vega Fomalhaut beta Pictoris and

884
00:35:45,769 --> 00:35:44,069
Epsilon Eridani they would go to other

885
00:35:49,029 --> 00:35:45,779
facilities and then try to take a

886
00:35:51,410 --> 00:35:49,039
picture of the planetary system and so

887
00:35:53,150 --> 00:35:51,420
when the first ones that they were able

888
00:35:55,609 --> 00:35:53,160

to do this successfully for was beta

889
00:35:57,200 --> 00:35:55,619
Pictoris this is a more modern image

890
00:36:00,589 --> 00:35:57,210
taken with the Hubble Space Telescope

891
00:36:03,559 --> 00:36:00,599
with this disk coronagraph in which the

892
00:36:05,420 --> 00:36:03,569
star has been placed behind an occulting

893
00:36:07,519 --> 00:36:05,430
wedge and you can see that there's this

894
00:36:10,370 --> 00:36:07,529
bright linear feature this is a disc

895
00:36:13,460 --> 00:36:10,380
that's being seen edge on and then you

896
00:36:16,249 --> 00:36:13,470
can see a different stretch here which

897
00:36:18,230 --> 00:36:16,259
shows you more clearly this edge on disc

898
00:36:20,660 --> 00:36:18,240
so this again is what you're seeing is

899
00:36:23,509 --> 00:36:20,670
heat from small dust grains in this

900
00:36:25,549 --> 00:36:23,519
particular system the really interesting

901
00:36:28,009 --> 00:36:25,559
thing about whenever people go out and

902
00:36:30,440 --> 00:36:28,019
take images of the system at higher and

903
00:36:32,990 --> 00:36:30,450
higher angular resolution is they find

904
00:36:34,970 --> 00:36:33,000
detailed structures that imply the

905
00:36:36,470 --> 00:36:34,980
presence of planets so in this

906
00:36:38,480 --> 00:36:36,480
particular case in the case of beta

907
00:36:40,190 --> 00:36:38,490
Pictoris what you can see is that the

908
00:36:41,599 --> 00:36:40,200
inner part of the disc is warped with

909
00:36:45,650 --> 00:36:41,609
respect to the outer part of the disc

910
00:36:48,140 --> 00:36:45,660
and the one of the hypotheses for why

911
00:36:50,120 --> 00:36:48,150
this is true is essentially that there

912
00:36:52,880 --> 00:36:50,130
is a companion that is a planetary mask

913
00:36:56,599 --> 00:36:52,890

size thing in this planetary system

914
00:36:59,180 --> 00:36:56,609
which disrupts the dust and forces the

915
00:37:01,759 --> 00:36:59,190
dust onto these inclined orbits if you

916
00:37:04,549 --> 00:37:01,769
look at the distance of this warp

917
00:37:06,589 --> 00:37:04,559
compared to the star you can then place

918
00:37:09,200 --> 00:37:06,599
constraints on the product of the mass

919
00:37:10,560 --> 00:37:09,210
of the planet and its distance from the

920
00:37:12,570 --> 00:37:10,570
central star

921
00:37:15,540 --> 00:37:12,580
and one of the really exciting things is

922
00:37:18,000 --> 00:37:15,550
in the 20 or 30 years of studying these

923
00:37:20,070 --> 00:37:18,010
particular objects people have been able

924
00:37:23,690 --> 00:37:20,080
to refine their understandings of these

925
00:37:27,330 --> 00:37:23,700
planetary systems and so this is now a

926
00:37:29,580 --> 00:37:27,340
even more recent image of the exact same

927
00:37:32,820 --> 00:37:29,590
system this is now ground-based data

928
00:37:35,550 --> 00:37:32,830
taken with a very large telescope so the

929
00:37:37,890 --> 00:37:35,560
European facility in Chile and it's a

930
00:37:41,280 --> 00:37:37,900
composite image showing you the disk but

931
00:37:42,950 --> 00:37:41,290
now you also see so the disk is taken

932
00:37:45,300 --> 00:37:42,960
with a coronagraph but now you also see

933
00:37:48,210 --> 00:37:45,310
images of a point source that were

934
00:37:51,320 --> 00:37:48,220
discovered very close to the star at

935
00:37:54,090 --> 00:37:51,330
about 10a you from the star this

936
00:37:55,710 --> 00:37:54,100
position on the sort of left side here

937
00:37:57,390 --> 00:37:55,720
was the discovery epoch and then it

938
00:37:59,070 --> 00:37:57,400

appeared to disappear for a while and

939
00:38:01,200 --> 00:37:59,080
then it reappeared so it first was

940
00:38:04,950 --> 00:38:01,210
detected in 2003 and then was reappeared

941
00:38:07,110 --> 00:38:04,960
in 2009 and so it is you're actually

942
00:38:09,630 --> 00:38:07,120
seeing then the orbital motion of a

943
00:38:11,730 --> 00:38:09,640
giant planet in this particular disk

944
00:38:14,640 --> 00:38:11,740
which is consistent with the structures

945
00:38:18,510 --> 00:38:14,650
that were seen in the dust from the

946
00:38:21,210 --> 00:38:18,520
older Hubble Space Telescope images so

947
00:38:23,550 --> 00:38:21,220
why do we want to go out and try to

948
00:38:25,920 --> 00:38:23,560
study these particular planetary systems

949
00:38:27,600 --> 00:38:25,930
we already learned so much from Kepler

950
00:38:29,100 --> 00:38:27,610
and looking at the demographics of

951
00:38:30,960 --> 00:38:29,110
planets that are detected through

952
00:38:33,120 --> 00:38:30,970
transit or radio velocity or other

953
00:38:35,640 --> 00:38:33,130
things and the answer is that it gives

954
00:38:37,860 --> 00:38:35,650
us complimentary information it's very

955
00:38:39,630 --> 00:38:37,870
hard with planets to understand what the

956
00:38:42,630 --> 00:38:39,640
detailed composition of the planet is

957
00:38:45,060 --> 00:38:42,640
because really all you ever met measure

958
00:38:46,770 --> 00:38:45,070
for like the transiting planets is the

959
00:38:49,140 --> 00:38:46,780
mass and the radius and so you get the

960
00:38:50,520 --> 00:38:49,150
density of the planet but in the case of

961
00:38:53,070 --> 00:38:50,530
these particular systems you have the

962
00:38:55,410 --> 00:38:53,080
opportunity to actually measure the

963
00:38:57,720 --> 00:38:55,420

detailed composition of the material and

964
00:39:00,750 --> 00:38:57,730
understand what's really made of and it

965
00:39:02,910 --> 00:39:00,760
also provides insight into particular

966
00:39:05,990 --> 00:39:02,920
epochs that were very violent in the

967
00:39:09,390 --> 00:39:06,000
formation of our own solar system and so

968
00:39:11,040 --> 00:39:09,400
early on in the trend terrestrial planet

969
00:39:12,510 --> 00:39:11,050
formation within the first 30 million

970
00:39:15,510 --> 00:39:12,520
years there are a lot of violent

971
00:39:17,550 --> 00:39:15,520
collisions in which you know things

972
00:39:20,940 --> 00:39:17,560
collided together to build up larger and

973
00:39:23,160 --> 00:39:20,950
larger things to form earth and then at

974
00:39:24,390 --> 00:39:23,170
ages of 30 100 million years we know

975
00:39:27,150 --> 00:39:24,400
that there were giant :

976
00:39:30,020 --> 00:39:27,160
in our solar system so for example we

977
00:39:33,600 --> 00:39:30,030
knew that mars-sized object called Theia

978
00:39:36,420 --> 00:39:33,610
impacted the earth and form the moon and

979
00:39:38,580 --> 00:39:36,430
so you know by studying these other

980
00:39:40,440 --> 00:39:38,590
systems we can understand whether or not

981
00:39:43,320 --> 00:39:40,450
these events in the history of our solar

982
00:39:46,920 --> 00:39:43,330
system are common or rare so this is

983
00:39:51,750 --> 00:39:46,930
just meant to be a nice simulation of I

984
00:39:53,700 --> 00:39:51,760
mentioned to you how giant impacts or

985
00:40:00,030 --> 00:39:53,710
important in the history of our solar

986
00:40:03,150 --> 00:40:00,040
system there goes and so this is just a

987
00:40:06,000 --> 00:40:03,160
simulation of the the moon-forming

988
00:40:09,090 --> 00:40:06,010

impact and in which the Thea sized body

989
00:40:10,830 --> 00:40:09,100
ran into the earth on a glancing sort of

990
00:40:14,070 --> 00:40:10,840
collision course and what you see here

991
00:40:17,190 --> 00:40:14,080
is basically the mantles of the two

992
00:40:18,780 --> 00:40:17,200
objects mixed together spin off and

993
00:40:21,780 --> 00:40:18,790
condense and eventually forming to the

994
00:40:27,270 --> 00:40:21,790
moon and then the core of the impactor

995
00:40:30,180 --> 00:40:27,280
actually sunk into the forming earth and

996
00:40:33,540 --> 00:40:30,190
so this explains a lot of what we know

997
00:40:35,850 --> 00:40:33,550
about the the properties of the moon so

998
00:40:38,190 --> 00:40:35,860
for example the Apollo astronauts went

999
00:40:40,740 --> 00:40:38,200
and collected lunar samples and analyzed

1000
00:40:42,240 --> 00:40:40,750
the composition of those and it turns

1001
00:40:46,440 --> 00:40:42,250
out they're very similar to the the

1002
00:40:47,670 --> 00:40:46,450
mantle of our own earth so we can try

1003
00:40:49,580 --> 00:40:47,680
and learn about these violent things

1004
00:40:51,810 --> 00:40:49,590
that happened in our solar system

1005
00:40:55,110 --> 00:40:51,820
whether they're giant collisions early

1006
00:40:56,850 --> 00:40:55,120
on or we also think that there is a an

1007
00:40:58,380 --> 00:40:56,860
interesting period in the evolution of

1008
00:41:00,510 --> 00:40:58,390
our solar system called the period of

1009
00:41:02,250 --> 00:41:00,520
late heavy bombardment but this happens

1010
00:41:04,470 --> 00:41:02,260
when our solar system had an age of

1011
00:41:06,630 --> 00:41:04,480
about 700 million years this is

1012
00:41:10,080 --> 00:41:06,640
preserved in the crater record of old

1013
00:41:13,170 --> 00:41:10,090

terrestrial surfaces such as the moon

1014
00:41:15,840 --> 00:41:13,180
and so these are maps showing you

1015
00:41:17,880 --> 00:41:15,850
highlighted craters I'm left over from

1016
00:41:19,740 --> 00:41:17,890
the period of late heavy bombardment at

1017
00:41:21,420 --> 00:41:19,750
about 700 million years so the

1018
00:41:23,820 --> 00:41:21,430
prevailing idea for how these craters

1019
00:41:25,800 --> 00:41:23,830
got to be there is essentially that the

1020
00:41:28,740 --> 00:41:25,810
giant planets the locations that we see

1021
00:41:30,900 --> 00:41:28,750
them at today are not the locations at

1022
00:41:33,210 --> 00:41:30,910
which those giant planets formed the

1023
00:41:34,620 --> 00:41:33,220
giant planets actually migrated from a

1024
00:41:34,980 --> 00:41:34,630
different location to where they are

1025
00:41:37,090 --> 00:41:34,990
today

1026
00:41:39,850 --> 00:41:37,100
and as they did so do

1027
00:41:43,260 --> 00:41:39,860
Saturn crossed the two Diwan residents

1028
00:41:45,610 --> 00:41:43,270
and basically the resonance crossing

1029
00:41:47,380 --> 00:41:45,620
destabilized all of the minor bodies and

1030
00:41:50,470 --> 00:41:47,390
our solar systems such as the asteroids

1031
00:41:54,250 --> 00:41:50,480
in the Kuiper belt and so basically all

1032
00:41:55,840 --> 00:41:54,260
of the minor bodies became chaotic for a

1033
00:41:57,730 --> 00:41:55,850
brief period and they went all

1034
00:41:59,980 --> 00:41:57,740
throughout the solar system and this is

1035
00:42:03,340 --> 00:41:59,990
sort of you can sort of visualize that

1036
00:42:05,560 --> 00:42:03,350
in this simulation here where the Rings

1037
00:42:07,900 --> 00:42:05,570
show you the orbits of the four

1038
00:42:10,060 --> 00:42:07,910

outermost planets and initially you saw

1039
00:42:12,010 --> 00:42:10,070
those green dots which were each one

1040
00:42:13,510 --> 00:42:12,020
represents the Kuiper belt and then you

1041
00:42:15,100 --> 00:42:13,520
can see the moment when you cross the

1042
00:42:16,780 --> 00:42:15,110
two-to-one resonance and all of those

1043
00:42:20,890 --> 00:42:16,790
things get to stabilize and they go

1044
00:42:23,080 --> 00:42:20,900
everywhere in the solar system so these

1045
00:42:25,420 --> 00:42:23,090
are the kinds of periods in the history

1046
00:42:28,540 --> 00:42:25,430
that we're trying to study so the tool

1047
00:42:30,190 --> 00:42:28,550
that I used and Joel used as well was

1048
00:42:32,590 --> 00:42:30,200
the Spitzer Space Telescope Spitzer

1049
00:42:35,470 --> 00:42:32,600
launched in 2003 it was cryogenic or

1050
00:42:38,080 --> 00:42:35,480
2004 it was cryogenic it was liquid

1051
00:42:39,880 --> 00:42:38,090
helium cooled to about four Kelvin but

1052
00:42:44,110 --> 00:42:39,890
it was a relatively small telescope it

1053
00:42:48,430 --> 00:42:44,120
was only 85 centimeters in diameter but

1054
00:42:50,680 --> 00:42:48,440
because it was so cold and in space it

1055
00:42:52,270 --> 00:42:50,690
had tremendous sensitivity compared to

1056
00:42:54,850 --> 00:42:52,280
any other facility at working at those

1057
00:42:58,450 --> 00:42:54,860
wavelengths prior so wavelengths of you

1058
00:43:00,420 --> 00:42:58,460
know a couple microns 260 microns and it

1059
00:43:03,220 --> 00:43:00,430
really enabled for the first time

1060
00:43:07,960 --> 00:43:03,230
solid-state infrared spectroscopy of

1061
00:43:11,200 --> 00:43:07,970
large samples of young discs and so the

1062
00:43:13,350 --> 00:43:11,210
this is whoops that's an excerpt from a

1063
00:43:16,090 --> 00:43:13,360

paper basically trying to illustrate

1064
00:43:18,490 --> 00:43:16,100
what these solid-state features from

1065
00:43:21,520 --> 00:43:18,500
silicates like olivine look like in the

1066
00:43:23,350 --> 00:43:21,530
infrared so basically you get a peak

1067
00:43:25,690 --> 00:43:23,360
this is like an emission feature around

1068
00:43:28,120 --> 00:43:25,700
10 microns and another one at 20 microns

1069
00:43:30,610 --> 00:43:28,130
it's really fascinating because just

1070
00:43:32,950 --> 00:43:30,620
like atoms when you you can tell the

1071
00:43:35,260 --> 00:43:32,960
composition of a gas by looking at the

1072
00:43:38,500 --> 00:43:35,270
spectrum from it you can tell the

1073
00:43:41,620 --> 00:43:38,510
composition of the dust material by

1074
00:43:44,080 --> 00:43:41,630
looking at the peak position of for

1075
00:43:45,910 --> 00:43:44,090
example of the material that you see the

1076
00:43:47,560 --> 00:43:45,920
spectrum before and the infrared but

1077
00:43:49,090 --> 00:43:47,570
more than that not only can tell you

1078
00:43:50,810 --> 00:43:49,100
tell what it's made of but you can

1079
00:43:53,840 --> 00:43:50,820
actually also tell how large the

1080
00:43:56,930 --> 00:43:53,850
strains are so it turns out that the

1081
00:43:58,430 --> 00:43:56,940
feature actually changes shape so

1082
00:44:00,110 --> 00:43:58,440
against this is brightness as a function

1083
00:44:01,790 --> 00:44:00,120
of wavelength but the feature changes

1084
00:44:04,960 --> 00:44:01,800
shape depending on how large the grains

1085
00:44:07,940 --> 00:44:04,970
are so for small grains the feature is

1086
00:44:11,300 --> 00:44:07,950
sort of triangular so it's tall and

1087
00:44:14,060 --> 00:44:11,310
pointy and if as the grains grow the

1088
00:44:17,300 --> 00:44:14,070

feature actually becomes more broad and

1089
00:44:19,760 --> 00:44:17,310
trapezoidal in shape and so by fitting

1090
00:44:22,250 --> 00:44:19,770
the shapes of these features you can

1091
00:44:24,790 --> 00:44:22,260
tell the composition of the dust and you

1092
00:44:29,560 --> 00:44:24,800
can also say how big the dust grains are

1093
00:44:32,830 --> 00:44:29,570
so these are some examples of spectra

1094
00:44:36,140 --> 00:44:32,840
from targets that I was interested in

1095
00:44:38,510 --> 00:44:36,150
which actually helped to constrain the

1096
00:44:41,150 --> 00:44:38,520
evolutionary phase of these particular

1097
00:44:43,010 --> 00:44:41,160
objects so again this is flux as a

1098
00:44:45,650 --> 00:44:43,020
function of wavelength and then this is

1099
00:44:47,240 --> 00:44:45,660
again that 10 micron feature and then

1100
00:44:48,680 --> 00:44:47,250
here it's harder to see the 20 micron

1101
00:44:50,900 --> 00:44:48,690
feature but again the 10 micron feature

1102
00:44:52,550 --> 00:44:50,910
in the 20 micron feature you can see in

1103
00:44:54,890 --> 00:44:52,560
this particular case it's not purely

1104
00:44:56,900 --> 00:44:54,900
just simple olivines or proxy and simple

1105
00:44:59,180 --> 00:44:56,910
silicates there's actually a number of

1106
00:45:01,120 --> 00:44:59,190
different materials that go into

1107
00:45:03,950 --> 00:45:01,130
modeling this particular feature

1108
00:45:06,020 --> 00:45:03,960
including materials that are altered at

1109
00:45:08,000 --> 00:45:06,030
high pressures and temperatures so

1110
00:45:10,960 --> 00:45:08,010
things like obsidian that you find on

1111
00:45:15,440 --> 00:45:10,970
earth or tektite that you find in the

1112
00:45:19,100 --> 00:45:15,450
eject envelopes of craters and possibly

1113
00:45:20,750 --> 00:45:19,110

sio silicon monoxide gas this is the

1114
00:45:23,840 --> 00:45:20,760
sort of feature that might be indicative

1115
00:45:26,030 --> 00:45:23,850
of a giant hypervelocity collision so a

1116
00:45:28,460 --> 00:45:26,040
collision in which you have a moon

1117
00:45:30,740 --> 00:45:28,470
forming events because you produce all

1118
00:45:32,630 --> 00:45:30,750
this material it's altered at high

1119
00:45:34,970 --> 00:45:32,640
pressures and temperatures in the

1120
00:45:36,830 --> 00:45:34,980
terrestrial planet zone this is in

1121
00:45:38,960 --> 00:45:36,840
contrast to something that has a feature

1122
00:45:40,400 --> 00:45:38,970
like this where you can see the 10

1123
00:45:42,710 --> 00:45:40,410
micron feature the shape of it looks

1124
00:45:44,930 --> 00:45:42,720
really really different and this is

1125
00:45:45,680 --> 00:45:44,940
because when you decompose it it's made

1126
00:45:47,750 --> 00:45:45,690
out of

1127
00:45:50,180 --> 00:45:47,760
instead things more like water and

1128
00:45:52,100 --> 00:45:50,190
amorphous carbon and so these are very

1129
00:45:54,320 --> 00:45:52,110
pristine things that you might expect to

1130
00:45:57,470 --> 00:45:54,330
find in the outer solar system so this

1131
00:45:58,940 --> 00:45:57,480
might then tell you about a Kuiper belt

1132
00:46:01,010 --> 00:45:58,950
objects from the outer solar system

1133
00:46:02,070 --> 00:46:01,020
coming into the terrestrial planet zone

1134
00:46:04,020 --> 00:46:02,080
and

1135
00:46:07,140 --> 00:46:04,030
you know disintegrating or colliding

1136
00:46:09,300 --> 00:46:07,150
with a terrestrial planet producing the

1137
00:46:11,760 --> 00:46:09,310
sort of spectral feature so spectroscopy

1138
00:46:14,040 --> 00:46:11,770

although you know it's not as pretty to

1139
00:46:15,390 --> 00:46:14,050
look at as nice pictures can actually

1140
00:46:17,970 --> 00:46:15,400
tell you a lot of really detailed

1141
00:46:20,220 --> 00:46:17,980
diagnostic information about the

1142
00:46:23,460 --> 00:46:20,230
composition and the evolutionary phase

1143
00:46:25,380 --> 00:46:23,470
of the target but you can learn not only

1144
00:46:28,950 --> 00:46:25,390
about the composition of the targets but

1145
00:46:31,020 --> 00:46:28,960
also about the spatial distribution of

1146
00:46:33,270 --> 00:46:31,030
the dust and this is really relying on

1147
00:46:35,460 --> 00:46:33,280
the fact that when you look at dust in

1148
00:46:38,190 --> 00:46:35,470
these systems the dust that's closest to

1149
00:46:39,990 --> 00:46:38,200
the star is actually warmest and the

1150
00:46:42,810 --> 00:46:40,000
dust that's further away is actually

1151
00:46:45,690 --> 00:46:42,820
coolest so this just kind of gives you a

1152
00:46:48,120 --> 00:46:45,700
broad idea so if you're looking at

1153
00:46:50,630 --> 00:46:48,130
material that's at point 1 au this

1154
00:46:53,400 --> 00:46:50,640
radiates most strongly at 1 micron

1155
00:46:55,500 --> 00:46:53,410
whereas this material here that's at

1156
00:46:58,290 --> 00:46:55,510
maybe about a hundred au from a solar

1157
00:47:01,020 --> 00:46:58,300
like star radiates more strongly at a

1158
00:47:03,480 --> 00:47:01,030
thousand microns so basically in the

1159
00:47:05,670 --> 00:47:03,490
absence of having a picture that shows

1160
00:47:08,250 --> 00:47:05,680
you where all the dust is located you

1161
00:47:10,020 --> 00:47:08,260
can take measurements of the brightness

1162
00:47:13,020 --> 00:47:10,030
as a function of wavelength and try to

1163
00:47:17,490 --> 00:47:13,030

invert them to figure out where the dust

1164
00:47:18,870 --> 00:47:17,500
is located so that was a project that I

1165
00:47:21,180 --> 00:47:18,880
carried out with an undergraduate

1166
00:47:24,690 --> 00:47:21,190
student here at Johns Hopkins we looked

1167
00:47:28,020 --> 00:47:24,700
at the spectra of some 500 stars and

1168
00:47:29,700 --> 00:47:28,030
each one of these postage stamps is the

1169
00:47:32,850 --> 00:47:29,710
brightness as a function of wavelength

1170
00:47:36,450 --> 00:47:32,860
for a bunch of stars and you can see

1171
00:47:38,640 --> 00:47:36,460
there's these strong sources on the blue

1172
00:47:41,190 --> 00:47:38,650
side this is the emission from the star

1173
00:47:45,330 --> 00:47:41,200
and then the gray things are the

1174
00:47:48,440 --> 00:47:45,340
emission from the dust and so you can

1175
00:47:50,700 --> 00:47:48,450
see that in a lot of cases there are

1176
00:47:52,320 --> 00:47:50,710
sources for which there's not dust very

1177
00:47:55,140 --> 00:47:52,330
close to the star but there is dust

1178
00:47:59,790 --> 00:47:55,150
pretty far away and this tells us

1179
00:48:01,860 --> 00:47:59,800
basically that there is an inner region

1180
00:48:03,360 --> 00:48:01,870
that's devoid of dust and one of the

1181
00:48:05,040 --> 00:48:03,370
possibilities for why there's no dust

1182
00:48:06,810 --> 00:48:05,050
there is that there's a giant planet

1183
00:48:08,910 --> 00:48:06,820
which is basically clearing the inner

1184
00:48:12,330 --> 00:48:08,920
part of the planetary system from dust

1185
00:48:15,360 --> 00:48:12,340
so just to look at a

1186
00:48:17,040 --> 00:48:15,370
more detailed example this is again one

1187
00:48:18,630 --> 00:48:17,050
of these spectral energy distributions

1188
00:48:21,210 --> 00:48:18,640

brightness as a function of wavelength

1189
00:48:23,960 --> 00:48:21,220
for a particular star which is HR 8799

1190
00:48:27,180 --> 00:48:23,970
and you see here's the big bump from the

1191
00:48:29,010 --> 00:48:27,190
emission from the star and then the red

1192
00:48:30,180 --> 00:48:29,020
stuff here these are data points and

1193
00:48:32,820 --> 00:48:30,190
it's hard to see but there's some blue

1194
00:48:35,160 --> 00:48:32,830
data points here too but you can see

1195
00:48:37,560 --> 00:48:35,170
that at the long wavelengths here at 30

1196
00:48:40,590 --> 00:48:37,570
microns or so that you get a mission

1197
00:48:42,390 --> 00:48:40,600
that's an excess of what you expect from

1198
00:48:44,040 --> 00:48:42,400
the star and then it actually turns

1199
00:48:46,710 --> 00:48:44,050
upward a little bit and then there's

1200
00:48:48,720 --> 00:48:46,720
these bright points here essentially

1201
00:48:51,690 --> 00:48:48,730
when you try to do the analysis of the

1202
00:48:54,210 --> 00:48:51,700
the heat from this system

1203
00:48:56,010 --> 00:48:54,220
you require having two components a

1204
00:48:58,230 --> 00:48:56,020
warmish component and a coldish

1205
00:49:00,480 --> 00:48:58,240
component and this is very analogous to

1206
00:49:02,490 --> 00:49:00,490
like what you might expect our solar

1207
00:49:05,250 --> 00:49:02,500
system to look like to an observer far

1208
00:49:07,350 --> 00:49:05,260
away we have the asteroid belt and the

1209
00:49:09,390 --> 00:49:07,360
Kuiper belt and then a family of jovian

1210
00:49:10,920 --> 00:49:09,400
planets that live in between and in this

1211
00:49:13,200 --> 00:49:10,930
particular system you're seeing kind of

1212
00:49:14,790 --> 00:49:13,210
the same thing an asteroid belt and a

1213
00:49:16,860 --> 00:49:14,800

Kuiper belt and some space in between

1214
00:49:19,910 --> 00:49:16,870
and so that seems like a really good

1215
00:49:22,110 --> 00:49:19,920
place to go look for planets and indeed

1216
00:49:25,230 --> 00:49:22,120
there are some astronomers using the

1217
00:49:27,270 --> 00:49:25,240
Keck telescope in Hawaii and they were

1218
00:49:30,570 --> 00:49:27,280
they weren't using a coronagraph but

1219
00:49:31,950 --> 00:49:30,580
essentially they were having to subtract

1220
00:49:33,750 --> 00:49:31,960
out the emission from the star so you

1221
00:49:35,220 --> 00:49:33,760
could see faint things so that's why

1222
00:49:37,320 --> 00:49:35,230
there should be a bright star in here

1223
00:49:39,980 --> 00:49:37,330
but it's been subtracted out but they

1224
00:49:42,450 --> 00:49:39,990
actually discovered the presence of four

1225
00:49:45,420 --> 00:49:42,460
Jovian mass planets so planets with

1226
00:49:47,550 --> 00:49:45,430
masses about ten Juber masses in orbit

1227
00:49:49,830 --> 00:49:47,560
around this particular star and those

1228
00:49:52,140 --> 00:49:49,840
planets happen to fall right in between

1229
00:49:54,750 --> 00:49:52,150
where the asteroid and Kuiper belts are

1230
00:49:58,230 --> 00:49:54,760
for this planetary system so we know

1231
00:50:00,960 --> 00:49:58,240
that there are planetary systems with

1232
00:50:03,300 --> 00:50:00,970
architectures like our own but we don't

1233
00:50:06,270 --> 00:50:03,310
really understand maybe what the context

1234
00:50:09,630 --> 00:50:06,280
is for our solar system how common is it

1235
00:50:10,650 --> 00:50:09,640
or how common or how rare is it so one

1236
00:50:12,570 --> 00:50:10,660
of the reasons why I'm tremendously

1237
00:50:15,150 --> 00:50:12,580
excited about the James Webb Space

1238
00:50:17,100 --> 00:50:15,160

Telescope is you can just tell by

1239
00:50:19,110 --> 00:50:17,110
looking at this particular graphic right

1240
00:50:20,730 --> 00:50:19,120
this shows you to scale the difference

1241
00:50:22,170 --> 00:50:20,740
between the Spitzer Space Telescope and

1242
00:50:24,060 --> 00:50:22,180
the James Webb Space Telescope

1243
00:50:26,099 --> 00:50:24,070
so Spitzer was an 85 centimeter

1244
00:50:28,259 --> 00:50:26,109
telescope jdbc is gonna be a

1245
00:50:30,269 --> 00:50:28,269
and a half meter telescope Spitzer was

1246
00:50:32,519 --> 00:50:30,279
phenomenal for this area of study in

1247
00:50:36,420 --> 00:50:32,529
being able to serve a large number of

1248
00:50:38,880 --> 00:50:36,430
stars to be able to discover more than a

1249
00:50:41,099 --> 00:50:38,890
thousand planetary systems with asteroid

1250
00:50:42,809 --> 00:50:41,109
allure Kuiper belt dust in them but what

1251
00:50:45,150 --> 00:50:42,819
JT beasty is really going to bring to

1252
00:50:47,519 --> 00:50:45,160
the table is because it has such a much

1253
00:50:50,069 --> 00:50:47,529
bigger mirror it has much better angular

1254
00:50:52,140 --> 00:50:50,079
resolution and so now instead of seeing

1255
00:50:54,299 --> 00:50:52,150
an unresolved point you'll actually be

1256
00:50:56,489 --> 00:50:54,309
able to look at where the dust is as a

1257
00:50:58,680 --> 00:50:56,499
function of position map out the dust in

1258
00:51:03,089 --> 00:50:58,690
these planetary systems and it'll do

1259
00:51:05,009 --> 00:51:03,099
this for hundreds of nearby stars so

1260
00:51:08,069 --> 00:51:05,019
this is just a direct comparison of what

1261
00:51:10,859 --> 00:51:08,079
our expectations are so this top panel

1262
00:51:12,569 --> 00:51:10,869
here this is actually data from the

1263
00:51:13,890 --> 00:51:12,579

Spitzer Space Telescope this was

1264
00:51:17,880 --> 00:51:13,900
obtained by Kate sue and her

1265
00:51:21,210 --> 00:51:17,890
collaborators this is data for the Vega

1266
00:51:23,249 --> 00:51:21,220
system which was observed at 24 microns

1267
00:51:25,430 --> 00:51:23,259
and you can see here because the

1268
00:51:28,109 --> 00:51:25,440
resolution for Spitzer is so poor

1269
00:51:29,970 --> 00:51:28,119
essentially you take that poor

1270
00:51:31,769 --> 00:51:29,980
resolution and convolve it with this

1271
00:51:35,700 --> 00:51:31,779
planetary system and you just get a big

1272
00:51:38,069 --> 00:51:35,710
blob but JWST we expect to have much

1273
00:51:41,009 --> 00:51:38,079
better angular resolution and so this

1274
00:51:43,200 --> 00:51:41,019
panel here shows you simulations of what

1275
00:51:45,120 --> 00:51:43,210
the possibilities might actually be for

1276
00:51:48,289 --> 00:51:45,130
the configuration of the dust in this

1277
00:51:50,999 --> 00:51:48,299
system this is taking advantage of

1278
00:51:52,739 --> 00:51:51,009
coronagraphs onboard JD was t to block

1279
00:51:55,920 --> 00:51:52,749
out the central light from the star and

1280
00:51:58,229 --> 00:51:55,930
so on the left-hand side you see a top

1281
00:51:59,910 --> 00:51:58,239
model in a bottom model and this is

1282
00:52:02,400 --> 00:51:59,920
without what's called point spread

1283
00:52:04,019 --> 00:52:02,410
function PSF subtraction so this is if

1284
00:52:05,400 --> 00:52:04,029
you were just to use the coronagraph and

1285
00:52:05,910 --> 00:52:05,410
put the star behind the center of the

1286
00:52:09,390 --> 00:52:05,920
coronagraph

1287
00:52:11,849 --> 00:52:09,400
and then what people do to improve their

1288
00:52:13,499 --> 00:52:11,859

images it's essentially they observe

1289
00:52:15,450 --> 00:52:13,509
their target star with a coronagraph and

1290
00:52:16,589 --> 00:52:15,460
they observe another star but their

1291
00:52:18,420 --> 00:52:16,599
cronograph one that doesn't have

1292
00:52:20,819 --> 00:52:18,430
anything around it and they subtract

1293
00:52:23,579 --> 00:52:20,829
those two images so that they can remove

1294
00:52:25,710 --> 00:52:23,589
the residual stellar light and then dig

1295
00:52:28,049 --> 00:52:25,720
in deeper close to the star looking for

1296
00:52:31,079 --> 00:52:28,059
additional material so this is a these

1297
00:52:33,239 --> 00:52:31,089
are PSF subtracted images simulations

1298
00:52:34,950 --> 00:52:33,249
instead and then you can see there's two

1299
00:52:37,650 --> 00:52:34,960
flavors of models here one where the

1300
00:52:39,080 --> 00:52:37,660
dust is symmetric and here it's not I

1301
00:52:40,490 --> 00:52:39,090
mean the

1302
00:52:42,830 --> 00:52:40,500
the key things that you notice here are

1303
00:52:44,780 --> 00:52:42,840
here you don't see this inner hole in

1304
00:52:46,130 --> 00:52:44,790
the disk that's expected to be seen

1305
00:52:48,320 --> 00:52:46,140
based on what the spectral energy

1306
00:52:50,270 --> 00:52:48,330
distribution looks like and then also we

1307
00:52:52,880 --> 00:52:50,280
have questions about what is the

1308
00:52:55,850 --> 00:52:52,890
detailed distribution of the dust is it

1309
00:52:57,560 --> 00:52:55,860
symmetric or is it asymmetric there's a

1310
00:53:00,130 --> 00:52:57,570
possibility that there's a planet in

1311
00:53:03,050 --> 00:53:00,140
this particular system and it traps

1312
00:53:06,050 --> 00:53:03,060
asteroids or Kuiper belt objects into

1313
00:53:08,240 --> 00:53:06,060

exterior mean motion resonances and that

1314
00:53:09,740 --> 00:53:08,250
those bodies collide and grind down and

1315
00:53:11,360 --> 00:53:09,750
produce dust grains which are

1316
00:53:13,520 --> 00:53:11,370
radiatively drunk driven out by

1317
00:53:15,740 --> 00:53:13,530
radiation pressure and blown into these

1318
00:53:17,360 --> 00:53:15,750
spiral structures that then you might be

1319
00:53:18,260 --> 00:53:17,370
able to actually see with the James Webb

1320
00:53:21,080 --> 00:53:18,270
Space Telescope

1321
00:53:22,790 --> 00:53:21,090
so we're tremendously excited about what

1322
00:53:25,850 --> 00:53:22,800
we can do the other thing that's really

1323
00:53:28,640 --> 00:53:25,860
exciting is before I showed you some

1324
00:53:30,350 --> 00:53:28,650
spectra obtained with Spitzer and it was

1325
00:53:32,780 --> 00:53:30,360
just a spectrum of the whole planetary

1326
00:53:34,730 --> 00:53:32,790
system but because James Webb Space

1327
00:53:36,950 --> 00:53:34,740
Telescope has this phenomenal angular

1328
00:53:39,320 --> 00:53:36,960
resolution you'll actually be able to

1329
00:53:40,940 --> 00:53:39,330
take spectra of all the different points

1330
00:53:42,860 --> 00:53:40,950
in the field because you'll spatially

1331
00:53:45,080 --> 00:53:42,870
resolve the whole planetary system and

1332
00:53:47,360 --> 00:53:45,090
so you'll be able to look it for

1333
00:53:50,300 --> 00:53:47,370
gradients in the composition of the dust

1334
00:53:51,980 --> 00:53:50,310
grains as a function of position so this

1335
00:53:54,590 --> 00:53:51,990
has actually been carried out for one

1336
00:53:56,780 --> 00:53:54,600
planetary system beta Pictoris the first

1337
00:53:59,270 --> 00:53:56,790
one that I showed you that we had that

1338
00:54:01,790 --> 00:53:59,280

edge on disk this has been done from the

1339
00:54:04,760 --> 00:54:01,800
Subaru telescope in Hawaii and

1340
00:54:07,040 --> 00:54:04,770
essentially these are spectra from

1341
00:54:08,900 --> 00:54:07,050
different little positions in the disk

1342
00:54:10,940 --> 00:54:08,910
right around 10 microns where that

1343
00:54:12,950 --> 00:54:10,950
silicate feature is and if you squint

1344
00:54:14,660 --> 00:54:12,960
really hard you can see that the shape

1345
00:54:17,210 --> 00:54:14,670
of this 10 micron feature actually

1346
00:54:20,360 --> 00:54:17,220
changes as a function of position along

1347
00:54:23,390 --> 00:54:20,370
the disk and it tells you where the

1348
00:54:25,670 --> 00:54:23,400
small grains are located in this disk it

1349
00:54:28,460 --> 00:54:25,680
turns out that they tend to be it looks

1350
00:54:31,130 --> 00:54:28,470
like that they're predominantly in three

1351
00:54:33,260 --> 00:54:31,140
large rings it also tells you where the

1352
00:54:35,750 --> 00:54:33,270
crystalline material is so we're the

1353
00:54:38,030 --> 00:54:35,760
dust grains that have been annealed by

1354
00:54:40,160 --> 00:54:38,040
interactions with the star are located

1355
00:54:43,970 --> 00:54:40,170
and then they tend to be located near

1356
00:54:46,610 --> 00:54:43,980
the orbit Center so so I just think the

1357
00:54:49,370 --> 00:54:46,620
the spectroscopic power of James T is

1358
00:54:52,420 --> 00:54:49,380
absolutely amazing so not only will we

1359
00:54:54,580 --> 00:54:52,430
be able to take this these kind of space

1360
00:54:56,580 --> 00:54:54,590
resolve thermal emission spectra but

1361
00:54:58,690 --> 00:54:56,590
we're also be able to take hopefully

1362
00:55:00,850 --> 00:54:58,700
spatially resolved scattered light

1363
00:55:02,860 --> 00:55:00,860

spectra so now instead of looking at the

1364
00:55:04,900 --> 00:55:02,870
spectrum from the heat generated by

1365
00:55:06,790 --> 00:55:04,910
these dust grains you'll be able to look

1366
00:55:08,950 --> 00:55:06,800
at the spectrum of the reflected light

1367
00:55:11,610 --> 00:55:08,960
from these dust grains and this just

1368
00:55:13,660 --> 00:55:11,620
shows you there's an instrument on board

1369
00:55:17,950 --> 00:55:13,670
called the near infrared spectrograph

1370
00:55:20,200 --> 00:55:17,960
nurse back and essentially it has an

1371
00:55:22,480 --> 00:55:20,210
image slicer so it divides the field up

1372
00:55:25,090 --> 00:55:22,490
the field of view up into all these

1373
00:55:26,620 --> 00:55:25,100
little tiny rectangles these and then it

1374
00:55:28,690 --> 00:55:26,630
basically it disperses the light from

1375
00:55:30,310 --> 00:55:28,700
each rectangle so in this way you'll be

1376
00:55:33,580 --> 00:55:30,320
able to take spectra at different

1377
00:55:35,410 --> 00:55:33,590
positions for for in particular this

1378
00:55:37,240 --> 00:55:35,420
particular disc and this is really

1379
00:55:39,310 --> 00:55:37,250
interesting in the near infrared because

1380
00:55:41,800 --> 00:55:39,320
in the near-infrared you have access to

1381
00:55:45,280 --> 00:55:41,810
solid-state features now not from

1382
00:55:46,810 --> 00:55:45,290
silicates but from ices and I think ices

1383
00:55:48,580 --> 00:55:46,820
are tremendously exciting because I

1384
00:55:50,560 --> 00:55:48,590
meant as I mentioned before we don't

1385
00:55:53,320 --> 00:55:50,570
understand what the origin of water is

1386
00:55:55,030 --> 00:55:53,330
in our solar system and it would be very

1387
00:55:57,250 --> 00:55:55,040
interesting to understand what the

1388
00:55:58,930 --> 00:55:57,260

reservoirs of water around other

1389
00:56:00,370 --> 00:55:58,940
planetary systems look like and whether

1390
00:56:02,200 --> 00:56:00,380
or not they have the potential to

1391
00:56:07,060 --> 00:56:02,210
deliver oceans to terrestrial planets

1392
00:56:08,740 --> 00:56:07,070
there so this is just my last slide just

1393
00:56:10,960 --> 00:56:08,750
the key points that I wanted to say

1394
00:56:12,190 --> 00:56:10,970
we're these debris disc systems that

1395
00:56:14,470 --> 00:56:12,200
I've been showing you the data from

1396
00:56:17,110 --> 00:56:14,480
their analogs of our solar system when

1397
00:56:20,200 --> 00:56:17,120
it was young or middle-aged and they're

1398
00:56:21,850 --> 00:56:20,210
common around young stars Mitterrand

1399
00:56:23,860 --> 00:56:21,860
fred spectra that we saw these discs

1400
00:56:25,270 --> 00:56:23,870
reveal these solid state features that

1401
00:56:26,650 --> 00:56:25,280
indicate that the dust is composed of

1402
00:56:28,720 --> 00:56:26,660
silicates so these are things like

1403
00:56:31,720 --> 00:56:28,730
olivines like real materials that we're

1404
00:56:33,280 --> 00:56:31,730
familiar with on our own planets so for

1405
00:56:35,140 --> 00:56:33,290
example if you go to South Point and

1406
00:56:37,090 --> 00:56:35,150
y-you can see that all of you in the

1407
00:56:39,940 --> 00:56:37,100
green sand beach there and it's the same

1408
00:56:41,470 --> 00:56:39,950
materials spectrally just energy

1409
00:56:42,610 --> 00:56:41,480
distribution analysis so that was that

1410
00:56:45,100 --> 00:56:42,620
flux as a function of wavelength

1411
00:56:47,560 --> 00:56:45,110
analysis indicates the majority of these

1412
00:56:49,750 --> 00:56:47,570
debris disk systems possess structure

1413
00:56:51,250 --> 00:56:49,760

that means that they have these central

1414
00:56:53,290 --> 00:56:51,260
clearings these regions close to the

1415
00:56:55,030 --> 00:56:53,300
star that are devoid of dust and it

1416
00:56:57,220 --> 00:56:55,040
tells us that there's probably something

1417
00:56:59,280 --> 00:56:57,230
in those cleared out regions

1418
00:57:01,930 --> 00:56:59,290
that's clearing them out such as a

1419
00:57:02,470 --> 00:57:01,940
jovian planets Oh planets may be forming

1420
00:57:05,740 --> 00:57:02,480
or may

1421
00:57:07,720 --> 00:57:05,750
already formed in these systems so thank

1422
00:57:16,410 --> 00:57:07,730
you for your attention and I'm happy to

1423
00:57:42,220 --> 00:57:39,280
questions for dr. Chen yeah so it

1424
00:57:43,810 --> 00:57:42,230
basically the key thing that's important

1425
00:57:45,640 --> 00:57:43,820
is the dispersion velocity so the

1426
00:57:47,859 --> 00:57:45,650
relative velocity between the particles

1427
00:57:50,230 --> 00:57:47,869
so if the relative velocity is

1428
00:57:52,420 --> 00:57:50,240
relatively low then things tend to stick

1429
00:57:54,790 --> 00:57:52,430
but if the relative velocity is very

1430
00:57:56,260 --> 00:57:54,800
high then things tend to shatter so if

1431
00:57:58,090 --> 00:57:56,270
you think about the early phases of our

1432
00:57:59,470 --> 00:57:58,100
solar system the phases that Joel told

1433
00:58:00,280 --> 00:57:59,480
you about when there's a lot of gas in

1434
00:58:02,260 --> 00:58:00,290
the disk

1435
00:58:04,359 --> 00:58:02,270
everything is sort of entrained in the

1436
00:58:05,830 --> 00:58:04,369
gas and so it moves at approximately the

1437
00:58:08,440 --> 00:58:05,840
same velocity and the relative

1438
00:58:09,849 --> 00:58:08,450

velocities are very low and so during

1439
00:58:11,740 --> 00:58:09,859
that phase especially when you have a

1440
00:58:14,080 --> 00:58:11,750
lot of gas in the disc you're in a

1441
00:58:17,050 --> 00:58:14,090
really strong building phase but once

1442
00:58:20,020 --> 00:58:17,060
the gas is dissipated it you don't

1443
00:58:21,520 --> 00:58:20,030
longer maintain similar relative similar

1444
00:58:23,740 --> 00:58:21,530
velocities and the material going around

1445
00:58:26,200 --> 00:58:23,750
the star and so you can get fairly high

1446
00:58:28,690 --> 00:58:26,210
relative velocity so things can be going

1447
00:58:30,520 --> 00:58:28,700
in different directions at fairly good

1448
00:58:33,240 --> 00:58:30,530
speeds so that when they actually hit

1449
00:58:37,290 --> 00:58:33,250
its destructive rather than constructive

1450
00:58:41,650 --> 00:58:39,910
right but there's a little bit of a I

1451
00:58:43,540 --> 00:58:41,660
mean it's not just so you're thinking

1452
00:58:46,330 --> 00:58:43,550
about Kepler's law but I mean in

1453
00:58:47,770 --> 00:58:46,340
addition to you know it's not just the

1454
00:58:49,780 --> 00:58:47,780
orbital velocity because everything

1455
00:58:53,230 --> 00:58:49,790
doesn't orbit in a perfect plane right

1456
00:58:56,530 --> 00:58:53,240
and so there's different semi-major axes

1457
00:58:58,000 --> 00:58:56,540
inclination eccentricity z-- I mean

1458
00:59:00,070 --> 00:58:58,010
you're in a pile of goo right you're

1459
00:59:02,140 --> 00:59:00,080
this gas and you're traveling through

1460
00:59:04,359 --> 00:59:02,150
molasses that is gonna let things sort

1461
00:59:07,359 --> 00:59:04,369
of gently roll into each other whereas

1462
00:59:09,820 --> 00:59:07,369
if you take the gas oh the gas away it's

1463
00:59:13,200 --> 00:59:09,830

open season it's like firing a bullet

1464
00:59:28,210 --> 00:59:24,339
yes oh that's really interesting so I

1465
00:59:30,370 --> 00:59:28,220
think you're oh okay I'll repeat the

1466
00:59:32,620 --> 00:59:30,380
question sorry am i right the question

1467
00:59:35,380 --> 00:59:32,630
was is is there's any of you research

1468
00:59:37,180 --> 00:59:35,390
focus on potentially large planets in

1469
00:59:38,680 --> 00:59:37,190
our own solar system that we haven't

1470
00:59:41,020 --> 00:59:38,690
found yet like planet nine that could be

1471
00:59:43,480 --> 00:59:41,030
way out in these debris disks yeah so

1472
00:59:45,970 --> 00:59:43,490
planet nine is is really fascinating and

1473
00:59:48,190 --> 00:59:45,980
unfortunately so I tend to focus on

1474
00:59:50,049 --> 00:59:48,200
extrasolar planetary system so planetary

1475
00:59:52,630 --> 00:59:50,059
systems outside of her own but your what

1476
00:59:54,789 --> 00:59:52,640
you're referring to of course is there's

1477
00:59:58,299 --> 00:59:54,799
been this really fascinating work partly

1478
01:00:00,099 --> 00:59:58,309
out of Caltech by Mike Brown and I'm

1479
01:00:02,380 --> 01:00:00,109
blanking on the other fellows name Brad

1480
01:00:06,430 --> 01:00:02,390
the Pluto killer the Pluto killer yes

1481
01:00:08,289 --> 01:00:06,440
exactly where essentially he was so he

1482
01:00:11,049 --> 01:00:08,299
was so you may know him as the

1483
01:00:12,730 --> 01:00:11,059
discoverer of a lot of these ice dwarf

1484
01:00:15,250 --> 01:00:12,740
planets in the outer solar system and

1485
01:00:17,380 --> 01:00:15,260
when he was looking at the orbital

1486
01:00:18,970 --> 01:00:17,390
properties of those ice Dwarfs planets

1487
01:00:22,270 --> 01:00:18,980
he noticed that there is sort of this

1488
01:00:23,980 --> 01:00:22,280

coincidence in their orbital parameters

1489
01:00:25,420 --> 01:00:23,990
that is they were all sort of grouped

1490
01:00:28,030 --> 01:00:25,430
together in one place and you would sort

1491
01:00:29,770 --> 01:00:28,040
of expect you might not even expect that

1492
01:00:33,130 --> 01:00:29,780
they should be they should have sort of

1493
01:00:35,890 --> 01:00:33,140
more random orbital parameters and so

1494
01:00:37,900 --> 01:00:35,900
one of the hypotheses essentially that

1495
01:00:41,190 --> 01:00:37,910
he's been advocating is that there is an

1496
01:00:43,890 --> 01:00:41,200
additional planet that is heretofore

1497
01:00:46,210 --> 01:00:43,900
undetected which is essentially

1498
01:00:49,809 --> 01:00:46,220
interacting gravitationally with these

1499
01:00:54,670 --> 01:00:49,819
ice giants and forcing them into these

1500
01:00:58,049 --> 01:00:54,680
sort of aligned orbits there's actually

1501
01:01:00,819 --> 01:00:58,059
a fabulous I should advertise this Mike

1502
01:01:01,960 --> 01:01:00,829
has this fabulous Coursera course I

1503
01:01:05,799 --> 01:01:01,970
don't know if you've ever seen Coursera

1504
01:01:07,780 --> 01:01:05,809
it's an online learning thing but he has

1505
01:01:10,000 --> 01:01:07,790
a class called physics of the solar

1506
01:01:12,099 --> 01:01:10,010
system or something like that and he

1507
01:01:13,900 --> 01:01:12,109
actually spends two weeks talking about

1508
01:01:17,770 --> 01:01:13,910
small bodies in the outer solar system

1509
01:01:19,720 --> 01:01:17,780
of our solar system it's a great class

1510
01:01:21,069 --> 01:01:19,730
he's a really engaging lecturer I think

1511
01:01:23,030 --> 01:01:21,079
he spends the first four weeks talking

1512
01:01:24,350 --> 01:01:23,040
about Mars

1513
01:01:26,810 --> 01:01:24,360

and then I think he talks about life in

1514
01:01:28,910 --> 01:01:26,820
the university that hypothesized planet

1515
01:01:30,710 --> 01:01:28,920
would be quite large right I think it's

1516
01:01:32,000 --> 01:01:30,720
not like a Pluto is it no no it's like a

1517
01:01:34,070 --> 01:01:32,010
terrestrial planet it's like an

1518
01:01:47,690 --> 01:01:34,080
earth-sized I think it's the or size

1519
01:01:50,240 --> 01:01:47,700
thing yes yeah well these are these are

1520
01:01:52,280 --> 01:01:50,250
debris disks they're debris disks so

1521
01:01:54,170 --> 01:01:52,290
they're older so they're this fate so an

1522
01:01:56,150 --> 01:01:54,180
accretion disk means that you have stuff

1523
01:01:58,010 --> 01:01:56,160
accreting onto the star so that in

1524
01:02:00,890 --> 01:01:58,020
inherently it means that there's gas in

1525
01:02:03,860 --> 01:02:00,900
the disk and so all that motes materials

1526
01:02:20,420 --> 01:02:03,870
entrained and going on to the star it's

1527
01:02:21,950 --> 01:02:20,430
more like a solar system yeah how does

1528
01:02:23,720 --> 01:02:21,960
the modelling work yeah

1529
01:02:25,850 --> 01:02:23,730
so basically this is work that was

1530
01:02:29,690 --> 01:02:25,860
carried out by my friend Casey Lee's at

1531
01:02:32,060 --> 01:02:29,700
APL and he has this huge library of

1532
01:02:33,680 --> 01:02:32,070
emissivities of different materials and

1533
01:02:36,050 --> 01:02:33,690
basically he does like a minimum

1534
01:02:38,570 --> 01:02:36,060
chi-squared analysis so he takes all of

1535
01:02:40,520 --> 01:02:38,580
these components and tries to add them

1536
01:02:42,140 --> 01:02:40,530
up in some sensible way in order to

1537
01:02:44,450 --> 01:02:42,150
reproduce the feature as best as you can

1538
01:02:46,340 --> 01:02:44,460

so you can see in some cases that this

1539
01:02:48,500 --> 01:02:46,350
might be successful if like there are

1540
01:02:50,090 --> 01:02:48,510
features that are distinct wavelengths

1541
01:02:52,100 --> 01:02:50,100
so that they can't be created by

1542
01:02:54,140 --> 01:02:52,110
anything else but you can see that there

1543
01:02:55,280 --> 01:02:54,150
are a lot of things where you know you

1544
01:02:57,590 --> 01:02:55,290
might have spectral features that are

1545
01:02:59,300 --> 01:02:57,600
overlapping and so one of the

1546
01:03:01,340 --> 01:02:59,310
frustrations with this kind of analysis

1547
01:03:04,040 --> 01:03:01,350
is actually it's somewhat degenerate and

1548
01:03:06,590 --> 01:03:04,050
so you can imagine different mixtures of

1549
01:03:09,290 --> 01:03:06,600
materials giving rise to the same

1550
01:03:11,210 --> 01:03:09,300
feature yeah and so when people do this

1551
01:03:12,710 --> 01:03:11,220
kind of analysis basically they have to

1552
01:03:14,210 --> 01:03:12,720
you know if they're being very rigorous

1553
01:03:16,460 --> 01:03:14,220
about it they'll go through and do a

1554
01:03:17,990 --> 01:03:16,470
Monte Carlo analysis and then basically

1555
01:03:19,820 --> 01:03:18,000
they'll show you like a probability

1556
01:03:22,820 --> 01:03:19,830
distribution function so the likelihood

1557
01:03:25,490 --> 01:03:22,830
that you have any given material so it's

1558
01:03:28,640 --> 01:03:25,500
it's not just like oh it's like 50% is

1559
01:03:30,710 --> 01:03:28,650
this it's like you know the most likely

1560
01:03:32,240 --> 01:03:30,720
model is that 50% of it is that but you

1561
01:03:34,820 --> 01:03:32,250
like you know there's also some

1562
01:03:37,940 --> 01:03:34,830
probability that it's like you know 30

1563
01:03:41,330 --> 01:03:37,950

instead so so just to clarify the

1564
01:03:43,640 --> 01:03:41,340
audience so that the the non-experts the

1565
01:03:45,560 --> 01:03:43,650
- the lines at the bottom these olivines

1566
01:03:46,940 --> 01:03:45,570
obsidians etc would you say there a

1567
01:03:50,240 --> 01:03:46,950
library there that means that they were

1568
01:03:52,130 --> 01:03:50,250
measured by in a laboratory so with on

1569
01:03:55,160 --> 01:03:52,140
earth someone took one of these rocks

1570
01:03:57,890 --> 01:03:55,170
used a spectrograph to create an actual

1571
01:04:01,570 --> 01:03:57,900
lab spectrum of that rock and then we're

1572
01:04:16,820 --> 01:04:01,580
using it to as a fingerprint for yeah

1573
01:04:18,230 --> 01:04:16,830
for space-based ones yes yeah actually

1574
01:04:20,090 --> 01:04:18,240
what's about comets and the source of

1575
01:04:23,150 --> 01:04:20,100
the oceans yes that's actually a really

1576
01:04:26,540 --> 01:04:23,160
fascinating field of research

1577
01:04:27,740 --> 01:04:26,550
so basically when one of the things

1578
01:04:30,020 --> 01:04:27,750
about the earth that we don't really

1579
01:04:32,840 --> 01:04:30,030
understand well is like how much water

1580
01:04:34,670 --> 01:04:32,850
is on earth because you know water is

1581
01:04:36,470 --> 01:04:34,680
incorporated in the earth that many

1582
01:04:38,600 --> 01:04:36,480
different locations including in the

1583
01:04:41,180 --> 01:04:38,610
deep interior and so the exact amount of

1584
01:04:43,370 --> 01:04:41,190
water is not known one of the ways that

1585
01:04:45,560 --> 01:04:43,380
people have tried to diagnose what so

1586
01:04:47,210 --> 01:04:45,570
the the fundamental problem is if you

1587
01:04:47,930 --> 01:04:47,220
look at the location of the earth where

1588
01:04:49,370 --> 01:04:47,940

it is today

1589
01:04:53,120 --> 01:04:49,380
and assume that it formed there

1590
01:04:55,970 --> 01:04:53,130
essentially the earth the proto-earth is

1591
01:04:59,600 --> 01:04:55,980
too hot to basically retain water vapour

1592
01:05:01,340 --> 01:04:59,610
and so the going in hypothesis for

1593
01:05:04,130 --> 01:05:01,350
people for decades has been that the

1594
01:05:06,050 --> 01:05:04,140
earth is warm dry because of this and so

1595
01:05:08,960 --> 01:05:06,060
that means that like the water had to

1596
01:05:12,230 --> 01:05:08,970
come from somewhere else and so for a

1597
01:05:15,800 --> 01:05:12,240
long time people had considered comets

1598
01:05:18,830 --> 01:05:15,810
as the source source of water in an

1599
01:05:20,000 --> 01:05:18,840
ocean and one of the diagnostic ways

1600
01:05:21,920 --> 01:05:20,010
that they would try to figure out

1601
01:05:24,020 --> 01:05:21,930
whether or not this was true was looking

1602
01:05:27,260 --> 01:05:24,030
at the deuterium to hydrogen ratio in

1603
01:05:30,290 --> 01:05:27,270
mean ocean seawater and compare that to

1604
01:05:32,380 --> 01:05:30,300
the deuterium to hydrogen ratio in

1605
01:05:36,260 --> 01:05:32,390
comets to see if at all they were common

1606
01:05:37,640 --> 01:05:36,270
it turned out for a long time the the

1607
01:05:41,210 --> 01:05:37,650
distribution of comets that people were

1608
01:05:42,950 --> 01:05:41,220
probing which I think were from fairly

1609
01:05:45,710 --> 01:05:42,960
far out in the solar system they

1610
01:05:46,390 --> 01:05:45,720
actually had a higher deuterium fraction

1611
01:05:48,430 --> 01:05:46,400
I think

1612
01:05:50,080 --> 01:05:48,440
compared to mean ocean seawater so

1613
01:05:51,460 --> 01:05:50,090

people were really uncertain you know

1614
01:05:53,620 --> 01:05:51,470
that was not the most favorite

1615
01:05:57,250 --> 01:05:53,630
explanation for the origin of water on

1616
01:06:00,010 --> 01:05:57,260
earth there was there has it is still a

1617
01:06:02,200 --> 01:06:00,020
really active field of research so there

1618
01:06:04,930 --> 01:06:02,210
was more recent data taken by the

1619
01:06:08,440 --> 01:06:04,940
Herschel Space Telescope around 2010 or

1620
01:06:11,260 --> 01:06:08,450
so of some of these Trojan objects

1621
01:06:13,450 --> 01:06:11,270
instead and those actually tended to

1622
01:06:15,430 --> 01:06:13,460
have d2h ratios that were more similar

1623
01:06:18,220 --> 01:06:15,440
to mean ocean sea water so people are

1624
01:06:19,870 --> 01:06:18,230
not sure what the origin of water on

1625
01:06:22,420 --> 01:06:19,880
Earth is so that's one possibility

1626
01:06:25,450 --> 01:06:22,430
another possibility that's I think

1627
01:06:27,760 --> 01:06:25,460
become more in vogue is the idea that

1628
01:06:30,250 --> 01:06:27,770
the water is actually delivered by water

1629
01:06:33,100 --> 01:06:30,260
rich asteroids so you remember that

1630
01:06:34,990 --> 01:06:33,110
scenario that I told you about the

1631
01:06:36,280 --> 01:06:35,000
period of late heavy bombardment and how

1632
01:06:38,080 --> 01:06:36,290
the migration of the planets

1633
01:06:40,990 --> 01:06:38,090
destabilized the minor bodies in our

1634
01:06:43,930 --> 01:06:41,000
solar system it de stabilized all of

1635
01:06:46,510 --> 01:06:43,940
them including we think the asteroids in

1636
01:06:49,150 --> 01:06:46,520
the main asteroid belt the asteroids

1637
01:06:52,330 --> 01:06:49,160
that are a little bit further out in

1638
01:06:54,610 --> 01:06:52,340

outer parts of the asteroid belt are

1639
01:06:58,540 --> 01:06:54,620
expected to be somewhat volatile rich

1640
01:07:01,600 --> 01:06:58,550
and so they have been hypothesized as

1641
01:07:05,380 --> 01:07:01,610
another source of water for the oceans

1642
01:07:07,840 --> 01:07:05,390
on earth we think we have evidence for

1643
01:07:09,850 --> 01:07:07,850
collisions between those objects and the

1644
01:07:11,830 --> 01:07:09,860
inner solar system when you look at the

1645
01:07:13,600 --> 01:07:11,840
cratering record on like the Moon or

1646
01:07:15,610 --> 01:07:13,610
Mars so you can look at the size

1647
01:07:17,950 --> 01:07:15,620
distribution so how many big craters

1648
01:07:20,200 --> 01:07:17,960
versus how many little craters on the

1649
01:07:22,030 --> 01:07:20,210
moon or Mars or something like that and

1650
01:07:23,950 --> 01:07:22,040
look at the size distribution of

1651
01:07:25,780 --> 01:07:23,960
asteroids how many big asteroids versus

1652
01:07:28,240 --> 01:07:25,790
little asteroids and it turns out the

1653
01:07:29,740 --> 01:07:28,250
size distribution of asteroids in the

1654
01:07:33,250 --> 01:07:29,750
main asteroid belt lines up with the

1655
01:07:34,840 --> 01:07:33,260
size distribution of craters on on old

1656
01:07:36,520 --> 01:07:34,850
terrestrial surfaces so we know those

1657
01:07:39,490 --> 01:07:36,530
things got slung in during the period of

1658
01:07:41,020 --> 01:07:39,500
late heavy bombardment and based on some

1659
01:07:43,120 --> 01:07:41,030
of the spectroscopic analysis we think

1660
01:07:44,110 --> 01:07:43,130
they're water rich - so there another I

1661
01:07:46,650 --> 01:07:44,120
think right now they're actually

1662
01:07:53,220 --> 01:07:46,660
probably the more favorite source of

1663
01:08:07,090 --> 01:07:58,570

right but that's a small yeah yes back

1664
01:08:09,130 --> 01:08:07,100
there more question about more

1665
01:08:14,020 --> 01:08:09,140
clarification for icy planets and Planet

1666
01:08:15,460 --> 01:08:14,030
nine yeah that's correct and so so when

1667
01:08:17,950 --> 01:08:15,470
this whole whole controversy was going

1668
01:08:20,830 --> 01:08:17,960
on about Pluto essentially what happened

1669
01:08:23,110 --> 01:08:20,840
was so you know Pluto was discovered

1670
01:08:25,600 --> 01:08:23,120
shoot I think like in 1930 or so at

1671
01:08:27,190 --> 01:08:25,610
Lowell Observatory and you know it would

1672
01:08:28,900 --> 01:08:27,200
for a long time it was the only thing

1673
01:08:33,400 --> 01:08:28,910
kind of known in the outer solar system

1674
01:08:37,060 --> 01:08:33,410
and basically in the 1990s Dave Jewett

1675
01:08:39,070 --> 01:08:37,070
and Jane Lew went out and you know

1676
01:08:41,770 --> 01:08:39,080
basically carried out these deep surveys

1677
01:08:45,400 --> 01:08:41,780
of the sky of the ecliptic plane looking

1678
01:08:48,070 --> 01:08:45,410
for you know additional minor bodies out

1679
01:08:51,130 --> 01:08:48,080
there and so this led to the discovery

1680
01:08:53,290 --> 01:08:51,140
of you know the whole population of

1681
01:08:55,540 --> 01:08:53,300
Kuiper belt objects and so when the

1682
01:08:57,130 --> 01:08:55,550
Kuiper belt objects were discovered you

1683
01:08:59,170 --> 01:08:57,140
know you know and this is again some of

1684
01:09:00,850 --> 01:08:59,180
my Browns really beautiful work they

1685
01:09:03,010 --> 01:09:00,860
discovered that some of the largest

1686
01:09:05,350 --> 01:09:03,020
copper belt objects were even bigger

1687
01:09:07,330 --> 01:09:05,360
than Pluto right and so then there

1688
01:09:10,990 --> 01:09:07,340

became a sort of thing well do you

1689
01:09:13,030 --> 01:09:11,000
consider them planets too and the thing

1690
01:09:15,640 --> 01:09:13,040
that made them very similar to Pluto was

1691
01:09:17,710 --> 01:09:15,650
so Pluto is in a three-to-two resonance

1692
01:09:19,600 --> 01:09:17,720
with Neptune and it turns out there's a

1693
01:09:21,160 --> 01:09:19,610
whole family of other Kuiper belt

1694
01:09:23,140 --> 01:09:21,170
objects that are also in the

1695
01:09:26,950 --> 01:09:23,150
three-to-two resonance so Pluto doesn't

1696
01:09:29,020 --> 01:09:26,960
have a particularly you know unique mass

1697
01:09:30,370 --> 01:09:29,030
or size compared to things in the Kuiper

1698
01:09:33,430 --> 01:09:30,380
belt region and it doesn't have a

1699
01:09:35,800 --> 01:09:33,440
particularly unique orbit and so that

1700
01:09:39,250 --> 01:09:35,810
that was part of the reasoning that the

1701
01:09:41,290 --> 01:09:39,260
IAU used to demote its status from a

1702
01:09:42,730 --> 01:09:41,300
planet to a Kuiper belt objects because

1703
01:09:43,960 --> 01:09:42,740
they said hey there's so many more of

1704
01:09:46,690 --> 01:09:43,970
these other objects that are out there

1705
01:09:48,040 --> 01:09:46,700
it's really not that special and you

1706
01:09:50,290 --> 01:09:48,050
know maybe it's really one of these

1707
01:09:52,270 --> 01:09:50,300
other Kuiper belt objects and you know

1708
01:09:54,070 --> 01:09:52,280
there's a whole like half a dozen of

1709
01:09:56,750 --> 01:09:54,080
them that instead we're gonna designate

1710
01:10:03,200 --> 01:09:56,760
as ice Dwarfs so things like

1711
01:10:07,070 --> 01:10:03,210
and other stuff okay so this is not my

1712
01:10:08,960 --> 01:10:07,080
field of expertise but essentially what

1713
01:10:10,280 --> 01:10:08,970

I recall of Mike Brown's analysis is

1714
01:10:12,890 --> 01:10:10,290
essentially he was looking at the

1715
01:10:15,680 --> 01:10:12,900
orbital parameters for all of those

1716
01:10:17,930 --> 01:10:15,690
large objects you know maybe like the

1717
01:10:20,750 --> 01:10:17,940
largest nine or twelve of them or

1718
01:10:24,680 --> 01:10:20,760
something like that and basically he

1719
01:10:26,540 --> 01:10:24,690
noticed that again if you expect them to

1720
01:10:28,730 --> 01:10:26,550
be randomly scattered out or something

1721
01:10:31,430 --> 01:10:28,740
this should be all over the place

1722
01:10:33,680 --> 01:10:31,440
but he noticed when he made this orbital

1723
01:10:36,800 --> 01:10:33,690
parameter plot that they were all sort

1724
01:10:38,960 --> 01:10:36,810
of clumped in one area or at least

1725
01:10:42,860 --> 01:10:38,970
avoided a particular area of the phase

1726
01:10:44,690 --> 01:10:42,870
space and so based on the dynamical

1727
01:10:47,720 --> 01:10:44,700
evidence like what the orbits look like

1728
01:10:50,600 --> 01:10:47,730
you know essentially that's where the

1729
01:10:53,720 --> 01:10:50,610
hypothesis for this planet 9 came from

1730
01:10:56,330 --> 01:10:53,730
that basically it's exerting a

1731
01:10:59,630 --> 01:10:56,340
gravitational influence on these large

1732
01:11:01,880 --> 01:10:59,640
objects we don't see it directly we just

1733
01:11:05,000 --> 01:11:01,890
see how the other objects feel its

1734
01:11:08,090 --> 01:11:05,010
presence so I really recommend to you I

1735
01:11:10,940 --> 01:11:08,100
think part of that Coursera class that

1736
01:11:12,500 --> 01:11:10,950
Mike Brown has I think it starts up

1737
01:11:16,010 --> 01:11:12,510
every three months or something like

1738
01:11:18,980 --> 01:11:16,020

that because he he and his colleagues

1739
01:11:21,680 --> 01:11:18,990
are the lead proponents for this sort of

1740
01:11:23,300 --> 01:11:21,690
theory I think he has a lecture in in

1741
01:11:24,620 --> 01:11:23,310
this course about it and it's actually a

1742
01:11:26,210 --> 01:11:24,630
really excellent class so if you're

1743
01:11:27,680 --> 01:11:26,220
interested in the solar system

1744
01:11:29,630 --> 01:11:27,690
generically there's a there's a

1745
01:11:32,720 --> 01:11:29,640
beautiful the first four weeks are about

1746
01:11:35,300 --> 01:11:32,730
Mars I hadn't seen the detailed radar

1747
01:11:37,340 --> 01:11:35,310
maps for for Mars and you know seeing

1748
01:11:39,380 --> 01:11:37,350
how much geology people now know from

1749
01:11:42,670 --> 01:11:39,390
our it's it's it's really spectacular I

1750
01:11:51,990 --> 01:11:42,680
highly recommend it

1751
01:11:52,000 --> 01:12:00,570
[Music]

1752
01:12:07,950 --> 01:12:04,080
so in the particular case of Jupiter

1753
01:12:11,649 --> 01:12:07,960
Jupiter is so massive that essentially

1754
01:12:13,899 --> 01:12:11,659
it tends to it's gravity affects things

1755
01:12:17,080 --> 01:12:13,909
that try to come in to where it's

1756
01:12:19,120 --> 01:12:17,090
located and most of the time if an

1757
01:12:21,070 --> 01:12:19,130
object comes in from the outer solar

1758
01:12:23,140 --> 01:12:21,080
system toward Jupiter it encounters

1759
01:12:24,970 --> 01:12:23,150
Jupiter and it is actually it's a little

1760
01:12:26,830 --> 01:12:24,980
bit counterintuitive but it's actually

1761
01:12:29,919 --> 01:12:26,840
gravitationally slung out of the system

1762
01:12:32,250 --> 01:12:29,929
so most the time Jupiter doesn't you

1763
01:12:36,609 --> 01:12:32,260

know it doesn't either gain or lose mass

1764
01:12:39,879 --> 01:12:36,619
but for smaller objects for some objects

1765
01:12:42,359 --> 01:12:39,889
so comment linear several years ago or

1766
01:12:45,280 --> 01:12:42,369
even shoot what was it though the one

1767
01:12:49,180 --> 01:12:45,290
shoemaker levy that impacted Jupiter and

1768
01:12:54,280 --> 01:12:49,190
they yeah that was a clear case of

1769
01:13:00,189 --> 01:12:54,290
material being a created a ringside T -

1770
01:13:02,080 --> 01:13:00,199
that's right so I mean that I think

1771
01:13:04,390 --> 01:13:02,090
that's an active area of research where

1772
01:13:06,100 --> 01:13:04,400
people actually do real dynamical

1773
01:13:08,979 --> 01:13:06,110
simulations right because they're

1774
01:13:11,439 --> 01:13:08,989
curious what happens when you imagine

1775
01:13:13,330 --> 01:13:11,449
implant a planet in a planetary system

1776
01:13:15,430 --> 01:13:13,340
and watched us come in and how does it

1777
01:13:17,109 --> 01:13:15,440
affect it because if it's if it's a

1778
01:13:18,910 --> 01:13:17,119
small planet you can imagine the gravity

1779
01:13:21,399 --> 01:13:18,920
is not so great and so it doesn't affect

1780
01:13:35,179 --> 01:13:21,409
it as strongly as like a big planet like

1781
01:13:42,100 --> 01:13:37,189
sure question about the late heavy

1782
01:13:44,359 --> 01:13:42,110
bombardment what was it so this is this

1783
01:13:47,060 --> 01:13:44,369
yeah so this is something that's been

1784
01:13:50,689 --> 01:13:47,070
talked about in planetary science for a

1785
01:13:52,459 --> 01:13:50,699
while essentially people noticed a long

1786
01:13:54,140 --> 01:13:52,469
time ago that when you looked at old

1787
01:13:56,629 --> 01:13:54,150
terrestrial planet surfaces so the

1788
01:13:58,609 --> 01:13:56,639

surfaces of Mercury Mars and the moon

1789
01:14:01,520 --> 01:13:58,619
that they had a lot of craters on them

1790
01:14:03,259 --> 01:14:01,530
so this is just a map of the near side

1791
01:14:04,609 --> 01:14:03,269
and the far side of the Moon and you can

1792
01:14:07,399 --> 01:14:04,619
see the craters are picked out so you

1793
01:14:08,899 --> 01:14:07,409
can see them more easily on the moon you

1794
01:14:11,719 --> 01:14:08,909
can see there are periods where there's

1795
01:14:13,759 --> 01:14:11,729
been geologic resurfacing where lava has

1796
01:14:15,469 --> 01:14:13,769
come up to the surface and formed Marya

1797
01:14:18,319 --> 01:14:15,479
the seas that you see on the surface of

1798
01:14:20,629 --> 01:14:18,329
the Moon right and so it was you know

1799
01:14:22,669 --> 01:14:20,639
based on observations like that you knew

1800
01:14:24,409 --> 01:14:22,679
that there was a violent period in the

1801
01:14:26,719 --> 01:14:24,419
early part of the solar system where you

1802
01:14:28,040 --> 01:14:26,729
had a lot of collisions and you could

1803
01:14:30,259 --> 01:14:28,050
kind of constrain when that happened

1804
01:14:34,359 --> 01:14:30,269
based on looking at where the more like

1805
01:14:38,270 --> 01:14:34,369
the properties of the Maurya right so

1806
01:14:39,770 --> 01:14:38,280
one of the things that people have been

1807
01:14:42,859 --> 01:14:39,780
struggling to understand for a long time

1808
01:14:45,350 --> 01:14:42,869
is when those observations were first

1809
01:14:48,080 --> 01:14:45,360
made and noticed people sort of thought

1810
01:14:49,429 --> 01:14:48,090
that all of these collisions happened at

1811
01:14:51,649 --> 01:14:49,439
the same time like it was kind of like a

1812
01:14:53,569 --> 01:14:51,659
delta function when all the cratering

1813
01:14:55,009 --> 01:14:53,579

like all the collisions went up you know

1814
01:14:56,419 --> 01:14:55,019
the collision rate went up really high

1815
01:14:59,509 --> 01:14:56,429
just went up really high and came down

1816
01:15:02,779 --> 01:14:59,519
really fast there's been a lot of really

1817
01:15:06,199 --> 01:15:02,789
nice work by a researcher named Bill

1818
01:15:09,009 --> 01:15:06,209
baki particularly you know studying

1819
01:15:13,969 --> 01:15:09,019
these surfaces and trying to understand

1820
01:15:16,669 --> 01:15:13,979
this cratering period and I honestly I

1821
01:15:19,580 --> 01:15:16,679
don't remember the exact details but my

1822
01:15:22,279 --> 01:15:19,590
impression has been that over time our

1823
01:15:24,049 --> 01:15:22,289
thinking of the cratering record is that

1824
01:15:26,979 --> 01:15:24,059
you know essentially these craters were

1825
01:15:30,199 --> 01:15:26,989
actually formed over time and

1826
01:15:31,879 --> 01:15:30,209
essentially you know people then are of

1827
01:15:36,310 --> 01:15:31,889
course very interested in what are the

1828
01:15:39,939 --> 01:15:36,320
mechanisms to create the creators and so

1829
01:15:42,399 --> 01:15:39,949
this idea that I was describing for you

1830
01:15:46,009 --> 01:15:42,409
this is actually called the nice model

1831
01:15:47,550 --> 01:15:46,019
because it was first hypothesized by a

1832
01:15:51,930 --> 01:15:47,560
number of astronomers in

1833
01:15:55,530 --> 01:15:51,940
in Nice and France and essentially it it

1834
01:15:57,870 --> 01:15:55,540
basically tried to account for a number

1835
01:15:59,340 --> 01:15:57,880
of things observations that people made

1836
01:16:02,040 --> 01:15:59,350
of the solar system that seems sort of

1837
01:16:03,690 --> 01:16:02,050
startling so one of them was for example

1838
01:16:05,790 --> 01:16:03,700

when you look at the mass of the

1839
01:16:07,050 --> 01:16:05,800
asteroid belt and compare it to the mass

1840
01:16:09,420 --> 01:16:07,060
and the terrestrial planets and the

1841
01:16:11,700 --> 01:16:09,430
jovian planets around it if you were to

1842
01:16:13,140 --> 01:16:11,710
smooth out all of that mass you actually

1843
01:16:15,270 --> 01:16:13,150
get a divot in the amount of stuff

1844
01:16:17,400 --> 01:16:15,280
around the asteroid belt and so people

1845
01:16:20,010 --> 01:16:17,410
knew essentially that the asteroid belt

1846
01:16:22,110 --> 01:16:20,020
the premortal asteroid belt was actually

1847
01:16:24,210 --> 01:16:22,120
a lot more massive than the asteroid

1848
01:16:25,980 --> 01:16:24,220
belt that we see today then this sort of

1849
01:16:28,290 --> 01:16:25,990
leads to the question of life well what

1850
01:16:31,890 --> 01:16:28,300
happened to all those objects right and

1851
01:16:33,930 --> 01:16:31,900
so you know you know it was noticed that

1852
01:16:36,810 --> 01:16:33,940
there were these Kirkwood gaps that I

1853
01:16:39,630 --> 01:16:36,820
talked about where you have mean motion

1854
01:16:44,430 --> 01:16:39,640
resonances where you you you lose

1855
01:16:46,050 --> 01:16:44,440
material but the nice model which has

1856
01:16:48,210 --> 01:16:46,060
really come into fashion in the past few

1857
01:16:49,770 --> 01:16:48,220
years and described a lot of reasons why

1858
01:16:51,900 --> 01:16:49,780
you see certain properties of the solar

1859
01:16:54,840 --> 01:16:51,910
system such as the diminished asteroid

1860
01:16:57,420 --> 01:16:54,850
belt is has become the leading

1861
01:16:59,340 --> 01:16:57,430
explanation so again this is that the

1862
01:17:01,290 --> 01:16:59,350
location of Jupiter and Saturn in our

1863
01:17:03,570 --> 01:17:01,300

solar system today are not the locations

1864
01:17:06,120 --> 01:17:03,580
where Jupiter and Saturn formed and that

1865
01:17:08,070 --> 01:17:06,130
Jupiter and Saturn migrated from their

1866
01:17:10,230 --> 01:17:08,080
formation locations to their present day

1867
01:17:12,030 --> 01:17:10,240
locations and as they did so they cost

1868
01:17:14,520 --> 01:17:12,040
across the two-to-one resonance so this

1869
01:17:16,800 --> 01:17:14,530
means that for every two times Jupiter

1870
01:17:20,510 --> 01:17:16,810
goes around the Sun Saturn goes around

1871
01:17:22,590 --> 01:17:20,520
once and when you do that it actually

1872
01:17:28,080 --> 01:17:22,600
destabilizes the orbits of the minor

1873
01:17:30,170 --> 01:17:28,090
bodies because they get a you know you

1874
01:17:32,220 --> 01:17:30,180
know this gravitational pull that's

1875
01:17:33,960 --> 01:17:32,230
exacerbated by the two planets because

1876
01:17:35,910 --> 01:17:33,970
they're both in the same positions like

1877
01:17:38,790 --> 01:17:35,920
they they both come around to being at

1878
01:17:40,950 --> 01:17:38,800
the same place around the Sun right so

1879
01:17:46,290 --> 01:17:40,960
that that's what destabilizes the Minor

1880
01:17:49,560 --> 01:17:46,300
bodies so so basically I spoke a little

1881
01:17:53,490 --> 01:17:49,570
bit of some of the sort of planetary

1882
01:17:55,770 --> 01:17:53,500
science evidence for this so for example

1883
01:17:57,960 --> 01:17:55,780
so one we think the asteroid belt had to

1884
01:18:00,119 --> 01:17:57,970
be more massive to when you look at the

1885
01:18:02,520 --> 01:18:00,129
size distribution of craters on

1886
01:18:04,560 --> 01:18:02,530
the moon it matches with the size

1887
01:18:05,369 --> 01:18:04,570
distribution of bodies in the mean

1888
01:18:07,349 --> 01:18:05,379

asteroid belt

1889
01:18:09,719 --> 01:18:07,359
so that tells you that the projectiles

1890
01:18:14,909 --> 01:18:09,729
are consistent with coming from the main

1891
01:18:18,060 --> 01:18:14,919
asteroid belt so so it's really become

1892
01:18:19,679 --> 01:18:18,070
like the accepted sort of mechanism

1893
01:18:23,759 --> 01:18:19,689
describing the period of late heavy

1894
01:18:28,939 --> 01:18:23,769
bombardment today I think we have time

1895
01:18:37,520 --> 01:18:32,009
think maybe we've we've done it alright