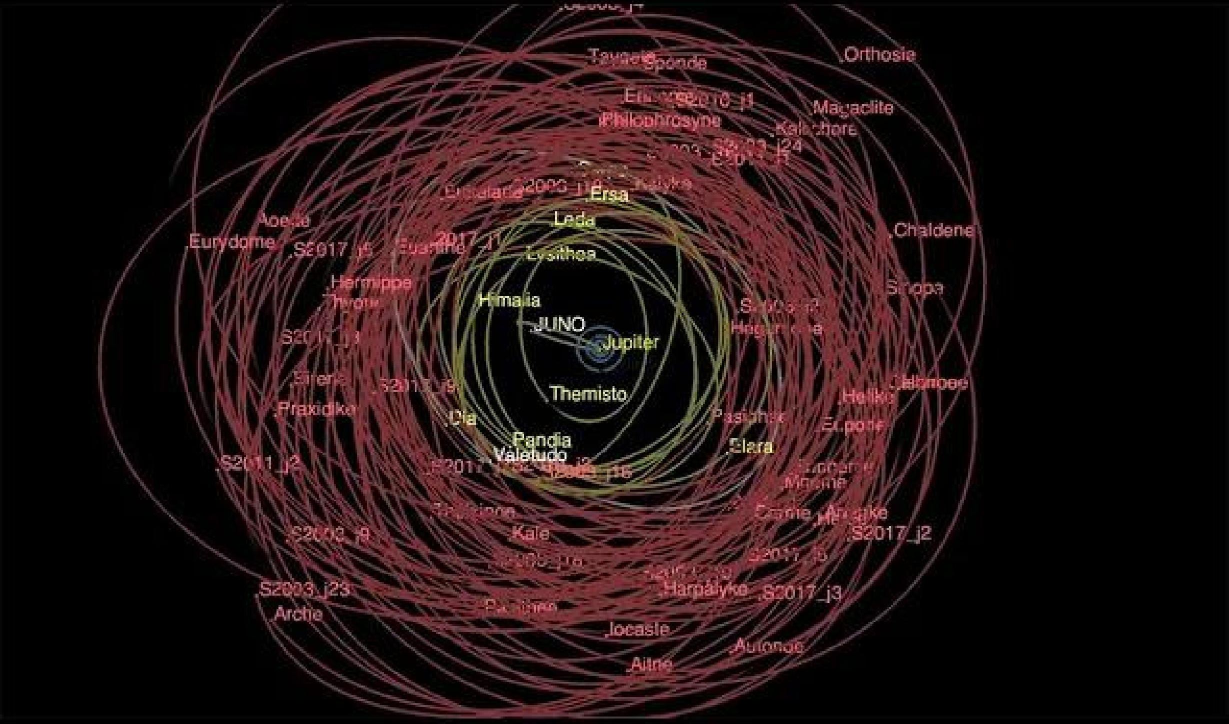

Orthosie
Sponde
Philophrosyne
Megaclite
Ersa
Leda
Aoede
Eurydome
Chaldene
S2017_j5
Lysithea
Hermippe
Sinope
Himalia
JUNO
Jupiter
Themisto
Praxidike
Helike
Dia
Pandia
Valetudo
Elara
S2011_j2
Kale
S2017_j2
S2003_j23
Harpalyke
S2017_j3
Arche
Iocaste
Autonoe
Aitne

1
00:00:05,670 --> 00:00:04,070
nasa's jet propulsion laboratory

2
00:00:08,310 --> 00:00:05,680
presents

3
00:00:10,390 --> 00:00:08,320
the von carmen lecture a series of talks

4
00:00:13,669 --> 00:00:10,400
by scientists and engineers who are

5
00:00:21,029 --> 00:00:13,679
exploring our planet our solar system

6
00:00:25,750 --> 00:00:23,670
good evening folks wherever you may be i

7
00:00:28,150 --> 00:00:25,760
am brian white from jpl's office of

8
00:00:30,470 --> 00:00:28,160
communications and education and welcome

9
00:00:32,229 --> 00:00:30,480
to the von carmen series the von carmen

10
00:00:34,870 --> 00:00:32,239
talks are a monthly opportunity to

11
00:00:37,350 --> 00:00:34,880
engage with you the public this is your

12
00:00:38,950 --> 00:00:37,360
space program now as a reminder as we're

13
00:00:40,630 --> 00:00:38,960

going through tonight if we have any

14
00:00:43,030 --> 00:00:40,640
technical difficulties we ask your

15
00:00:45,110 --> 00:00:43,040
patients as we get them sorted out

16
00:00:46,869 --> 00:00:45,120
tonight we'll be exploring the outer

17
00:00:48,790 --> 00:00:46,879
moons what they're doing out there and

18
00:00:50,310 --> 00:00:48,800
what their orbits have to do with us

19
00:00:52,069 --> 00:00:50,320
here at home

20
00:00:53,590 --> 00:00:52,079
as always you are a big part of these

21
00:00:55,590 --> 00:00:53,600
discussions and joining us as our

22
00:00:58,470 --> 00:00:55,600
questions co-host tonight is lindsay

23
00:01:01,270 --> 00:00:58,480
mclaurin hi lindsay

24
00:01:03,590 --> 00:01:01,280
hello brian and welcome everybody as a

25
00:01:04,789 --> 00:01:03,600
reminder this is your space program and

26
00:01:06,870 --> 00:01:04,799
we want you to be involved with

27
00:01:08,550 --> 00:01:06,880
tonight's discussion so for wherever

28
00:01:10,630 --> 00:01:08,560
you're joining us please use our chat

29
00:01:12,710 --> 00:01:10,640
feature to ask questions and members

30
00:01:14,310 --> 00:01:12,720
from our amazing social media team will

31
00:01:15,830 --> 00:01:14,320
pass them along to us

32
00:01:17,990 --> 00:01:15,840
if for some reason you don't see the

33
00:01:19,910 --> 00:01:18,000
chat feature please refresh your page

34
00:01:21,510 --> 00:01:19,920
and it should be there shortly let's get

35
00:01:23,030 --> 00:01:21,520
started brian

36
00:01:24,070 --> 00:01:23,040
thank you very much lindsey i'm looking

37
00:01:26,550 --> 00:01:24,080
forward to hearing those audience

38
00:01:28,550 --> 00:01:26,560

questions here in a bit now our speaker

39
00:01:30,390 --> 00:01:28,560
tonight is a radar scientist and an

40
00:01:32,230 --> 00:01:30,400
orbital dynamicist from nasa's jet

41
00:01:34,710 --> 00:01:32,240
propulsion laboratory in pasadena

42
00:01:36,390 --> 00:01:34,720
california dr brozovich observed

43
00:01:38,630 --> 00:01:36,400
hundreds of near-earth asteroids with

44
00:01:40,310 --> 00:01:38,640
the gold stone and arecibo planetary

45
00:01:42,389 --> 00:01:40,320
radars she was involved in the

46
00:01:45,270 --> 00:01:42,399
discoveries of binary and triple

47
00:01:48,550 --> 00:01:45,280
asteroid systems 14 moons of jupiter and

48
00:01:52,469 --> 00:01:48,560
several trans-neptunian objects a main

49
00:01:54,469 --> 00:01:52,479
belt asteroid 7295 brozovich is named

50
00:01:56,870 --> 00:01:54,479
after her her research also involves

51
00:01:59,350 --> 00:01:56,880
tonight's subject orbital dynamics of

52
00:02:01,830 --> 00:01:59,360
the moons of the outer planets and she

53
00:02:04,149 --> 00:02:01,840
worked on nasa's new horizons mission to

54
00:02:05,429 --> 00:02:04,159
the dwarf planet pluto as a part of the

55
00:02:07,590 --> 00:02:05,439
hazards team

56
00:02:09,510 --> 00:02:07,600
she received her undergrad undergraduate

57
00:02:12,710 --> 00:02:09,520
degree in physics at the university of

58
00:02:14,869 --> 00:02:12,720
zagreb in croatia and her phd in physics

59
00:02:16,790 --> 00:02:14,879
from duke university she spent several

60
00:02:18,229 --> 00:02:16,800
years at caltech as a postdoc before

61
00:02:21,750 --> 00:02:18,239
joining jpl

62
00:02:23,510 --> 00:02:21,760
please welcome dr marina brozovich hiya

63
00:02:25,750 --> 00:02:23,520

marina

64
00:02:27,750 --> 00:02:25,760
hi lindsay hi brian thank you for

65
00:02:28,630 --> 00:02:27,760
inviting me it's really pleasure to be

66
00:02:32,229 --> 00:02:28,640
here

67
00:02:34,630 --> 00:02:32,239
going to start with the basics

68
00:02:36,229 --> 00:02:34,640
what is it that we consider satellites

69
00:02:37,589 --> 00:02:36,239
of the older system how do we find them

70
00:02:39,509 --> 00:02:37,599
where do we find them what is their

71
00:02:41,509 --> 00:02:39,519
origin

72
00:02:43,750 --> 00:02:41,519
well the most basic definition of a

73
00:02:45,430 --> 00:02:43,760
satellite is just a small body orbiting

74
00:02:47,190 --> 00:02:45,440
a large body

75
00:02:49,990 --> 00:02:47,200
and the small bodies that i want to talk

76
00:02:52,150 --> 00:02:50,000
about are actual natural planet natural

77
00:02:54,150 --> 00:02:52,160
satellites of planets

78
00:02:56,390 --> 00:02:54,160
and we find these objects within

79
00:02:58,949 --> 00:02:56,400
planetary hill sphere and planet's hill

80
00:03:01,830 --> 00:02:58,959
sphere is just basically region of space

81
00:03:02,790 --> 00:03:01,840
where planet gravity dominates the sun

82
00:03:04,710 --> 00:03:02,800
gravity

83
00:03:07,750 --> 00:03:04,720
and the size of these hill sphere it

84
00:03:09,990 --> 00:03:07,760
depends on how massive the planet is and

85
00:03:11,589 --> 00:03:10,000
actually let's go to our first slide

86
00:03:13,750 --> 00:03:11,599
and so it depends how large the planet

87
00:03:15,430 --> 00:03:13,760
how massive the planet is and how far

88
00:03:18,229 --> 00:03:15,440

away it is from the sun

89
00:03:20,149 --> 00:03:18,239
so here we see kind of visual comparison

90
00:03:22,070 --> 00:03:20,159
of the heel spheres of the planet

91
00:03:23,990 --> 00:03:22,080
jupiter despite being the most massive

92
00:03:25,110 --> 00:03:24,000
planet does not have the largest heal

93
00:03:27,509 --> 00:03:25,120
sphere

94
00:03:29,589 --> 00:03:27,519
that goes to neptune which is still a

95
00:03:31,589 --> 00:03:29,599
fairly large planet

96
00:03:33,670 --> 00:03:31,599
and it's very far away from the sun and

97
00:03:34,710 --> 00:03:33,680
so it has this really large region of

98
00:03:36,710 --> 00:03:34,720
space

99
00:03:39,509 --> 00:03:36,720
where it could potentially have its

100
00:03:42,070 --> 00:03:39,519
satellites and you see that the size of

101
00:03:45,030 --> 00:03:42,080
its hill sphere is almost three-quarter

102
00:03:47,190 --> 00:03:45,040
distance from earth to the sun

103
00:03:49,190 --> 00:03:47,200
so really really large space

104
00:03:52,309 --> 00:03:49,200
um and going back to your question about

105
00:03:54,550 --> 00:03:52,319
origins well um their orbits and the

106
00:03:56,229 --> 00:03:54,560
sizes of satellites they tell us they

107
00:03:59,670 --> 00:03:56,239
kind of give us a hint

108
00:04:01,429 --> 00:03:59,680
um so let's go to perhaps next slide

109
00:04:04,070 --> 00:04:01,439
where i'm just going to go

110
00:04:06,229 --> 00:04:04,080
over three basic groups of what of the

111
00:04:08,149 --> 00:04:06,239
planetary satellites so we have the

112
00:04:10,550 --> 00:04:08,159
regular satellites we have the inner

113
00:04:13,270 --> 00:04:10,560

satellites and we have the outer moons

114
00:04:15,190 --> 00:04:13,280
or sometimes called the regular moons

115
00:04:17,509 --> 00:04:15,200
and i'm going to start with basic we are

116
00:04:18,789 --> 00:04:17,519
all familiar with the regular satellites

117
00:04:21,030 --> 00:04:18,799
this would be like

118
00:04:24,070 --> 00:04:21,040
the galen satellites of jupiter so these

119
00:04:26,550 --> 00:04:24,080
are kind of massive spherical bodies

120
00:04:28,390 --> 00:04:26,560
that are orbiting the planets in almost

121
00:04:30,469 --> 00:04:28,400
perfect circles and they are along the

122
00:04:32,950 --> 00:04:30,479
equator of the planet and they orbit in

123
00:04:35,189 --> 00:04:32,960
the same direction as the planet spins

124
00:04:37,749 --> 00:04:35,199
and they form with the planet itself

125
00:04:39,749 --> 00:04:37,759
from the circumplanetary nebula

126
00:04:42,230 --> 00:04:39,759
and then inner to these uh regular

127
00:04:44,469 --> 00:04:42,240
satellites uh we have the inner

128
00:04:47,830 --> 00:04:44,479
satellites and we sometimes call them

129
00:04:49,670 --> 00:04:47,840
the collisional shards because um they

130
00:04:52,070 --> 00:04:49,680
probably used to be regular satellites

131
00:04:53,590 --> 00:04:52,080
that ground down to smaller pieces but

132
00:04:55,030 --> 00:04:53,600
they still have these nice circular

133
00:04:57,749 --> 00:04:55,040
orbits

134
00:05:00,629 --> 00:04:57,759
and then uh when you see these weird

135
00:05:03,350 --> 00:05:00,639
orbits marked in red these are the

136
00:05:06,070 --> 00:05:03,360
irregular satellites uh they orbit from

137
00:05:08,950 --> 00:05:06,080
huge distances from the planets their

138
00:05:10,870 --> 00:05:08,960

orbits are anything but circular they

139
00:05:12,310 --> 00:05:10,880
are you know very elongated they're not

140
00:05:13,510 --> 00:05:12,320
anymore aligned with the planet's

141
00:05:15,670 --> 00:05:13,520
equator

142
00:05:17,510 --> 00:05:15,680
and they know to orbit the planets in

143
00:05:19,590 --> 00:05:17,520
the opposite direction that the planet

144
00:05:21,749 --> 00:05:19,600
is revolving around the sun

145
00:05:24,550 --> 00:05:21,759
which kind of gives us a strong hint

146
00:05:27,670 --> 00:05:24,560
that these are not native to the system

147
00:05:29,430 --> 00:05:27,680
these are actually captured objects um

148
00:05:31,830 --> 00:05:29,440
presumably you know they used to orbit

149
00:05:34,070 --> 00:05:31,840
the sun and at some point they came too

150
00:05:36,390 --> 00:05:34,080
close to the planet and it's just

151
00:05:37,990 --> 00:05:36,400
basically planet gravity caught it

152
00:05:40,790 --> 00:05:38,000
and the dynamicists are still kind of

153
00:05:43,430 --> 00:05:40,800
debating exactly on which mechanism is

154
00:05:45,110 --> 00:05:43,440
the best to capture an object

155
00:05:47,430 --> 00:05:45,120
and also we are there are a lot of

156
00:05:48,790 --> 00:05:47,440
puzzles about their their kind of source

157
00:05:50,629 --> 00:05:48,800
region you know we don't know whether

158
00:05:53,189 --> 00:05:50,639
these are captured asteroids from the

159
00:05:55,670 --> 00:05:53,199
main belt or these are perhaps kuiper

160
00:05:57,510 --> 00:05:55,680
belt objects or or you know there's

161
00:05:59,350 --> 00:05:57,520
something in between and and i and i

162
00:06:02,309 --> 00:05:59,360
really hope to kind of tell you a little

163
00:06:05,029 --> 00:06:02,319

bit more stories um about the irregular

164
00:06:07,270 --> 00:06:05,039
satellites as we as we go through our

165
00:06:09,189 --> 00:06:07,280
kind of chat today

166
00:06:10,550 --> 00:06:09,199
yeah well as you talk about how there's

167
00:06:12,469 --> 00:06:10,560
still some uncertainty with how they get

168
00:06:13,990 --> 00:06:12,479
captured have we found

169
00:06:15,990 --> 00:06:14,000
all of the planetary satellites in our

170
00:06:17,909 --> 00:06:16,000
solar system so far

171
00:06:20,390 --> 00:06:17,919
uh well it's safe to say we definitely

172
00:06:22,629 --> 00:06:20,400
find all those big regular satellites

173
00:06:24,550 --> 00:06:22,639
but we're probably missing a

174
00:06:26,150 --> 00:06:24,560
some number of the inner satellites and

175
00:06:29,270 --> 00:06:26,160
we're missing a lot

176
00:06:33,510 --> 00:06:29,280
of the outer satellites so the current

177
00:06:35,189 --> 00:06:33,520
head count is we have 213 moons

178
00:06:36,550 --> 00:06:35,199
these are acknowledged by the

179
00:06:39,350 --> 00:06:36,560
international

180
00:06:42,309 --> 00:06:39,360
astronomical union and our job here at

181
00:06:44,309 --> 00:06:42,319
the solar system dynamics at jpl is to

182
00:06:45,909 --> 00:06:44,319
keep track of their orbits so to

183
00:06:47,590 --> 00:06:45,919
calculate their orbits so we're a little

184
00:06:48,950 --> 00:06:47,600
bit like you know flight control for the

185
00:06:51,990 --> 00:06:48,960
solar system

186
00:06:53,990 --> 00:06:52,000
and we depend on astronomers to observe

187
00:06:55,510 --> 00:06:54,000
them and so let's let's take a look at

188
00:06:58,070 --> 00:06:55,520

the next slide

189
00:07:00,790 --> 00:06:58,080
these are images uh from where we get

190
00:07:02,390 --> 00:07:00,800
our data so uh to your left you're

191
00:07:04,550 --> 00:07:02,400
seeing this is example these are inner

192
00:07:06,950 --> 00:07:04,560
moons of neptune

193
00:07:09,189 --> 00:07:06,960
and so what astronomers do they have to

194
00:07:11,270 --> 00:07:09,199
kind of block this bright glare of the

195
00:07:12,469 --> 00:07:11,280
planet and then they work really hard to

196
00:07:14,469 --> 00:07:12,479
dig out these

197
00:07:16,550 --> 00:07:14,479
really you know tiny specks of light

198
00:07:18,550 --> 00:07:16,560
from the background and they report to

199
00:07:20,950 --> 00:07:18,560
us measurements of their position with

200
00:07:22,469 --> 00:07:20,960
respect to central planets in time

201
00:07:24,790 --> 00:07:22,479
and they have a little bit easier time

202
00:07:27,670 --> 00:07:24,800
with the outer satellites uh you see

203
00:07:30,469 --> 00:07:27,680
here to your right this is an outer moon

204
00:07:33,990 --> 00:07:30,479
of jupiter and you see this little

205
00:07:36,870 --> 00:07:34,000
bright glint as it's darting off uh

206
00:07:38,070 --> 00:07:36,880
across the the the stellar background

207
00:07:39,029 --> 00:07:38,080
and in this case you know they don't

208
00:07:40,390 --> 00:07:39,039
have to deal

209
00:07:41,830 --> 00:07:40,400
with the bright glare of the planet they

210
00:07:44,950 --> 00:07:41,840
just kind of measure its position in

211
00:07:46,629 --> 00:07:44,960
time with respect to the stars

212
00:07:48,469 --> 00:07:46,639
and now we have kind of you know

213
00:07:50,230 --> 00:07:48,479

beginning of you know we have all the

214
00:07:53,510 --> 00:07:50,240
data all the ingredients that we can we

215
00:07:55,990 --> 00:07:53,520
can start doing our orbit fit

216
00:07:57,830 --> 00:07:56,000
you started to hint at your group and

217
00:07:59,270 --> 00:07:57,840
and the people you work with so let's

218
00:08:01,270 --> 00:07:59,280
talk a little bit about you in the solar

219
00:08:04,150 --> 00:08:01,280
system dynamics group

220
00:08:05,990 --> 00:08:04,160
how do you calculate these orbits

221
00:08:08,790 --> 00:08:06,000
yeah so um

222
00:08:10,309 --> 00:08:08,800
basically it's just physics um so i try

223
00:08:12,629 --> 00:08:10,319
to let's go to the next slide because

224
00:08:15,029 --> 00:08:12,639
this is where i kind of try to visualize

225
00:08:17,110 --> 00:08:15,039
the the the our orbit fitting

226
00:08:19,189 --> 00:08:17,120
what orbit fit really is

227
00:08:21,589 --> 00:08:19,199
so so so basically you start with a

228
00:08:23,510 --> 00:08:21,599
dynamical model so this would be an

229
00:08:25,270 --> 00:08:23,520
equation of motion

230
00:08:27,430 --> 00:08:25,280
that takes into account

231
00:08:29,350 --> 00:08:27,440
all the forces that are acting on the

232
00:08:30,710 --> 00:08:29,360
satellite so this blue circle that

233
00:08:32,630 --> 00:08:30,720
you're seeing here this is your

234
00:08:34,550 --> 00:08:32,640
dynamical model

235
00:08:36,469 --> 00:08:34,560
and then what we also have are you know

236
00:08:38,469 --> 00:08:36,479
look at these little balloons these are

237
00:08:42,389 --> 00:08:38,479
our free parameters

238
00:08:44,470 --> 00:08:42,399

and objective of the orbit fit is to

239
00:08:45,829 --> 00:08:44,480
adjust these free parameters so that

240
00:08:48,230 --> 00:08:45,839
your starting

241
00:08:50,150 --> 00:08:48,240
position and velocity of a satellite

242
00:08:52,710 --> 00:08:50,160
that this blue dynamical model can

243
00:08:55,269 --> 00:08:52,720
correctly propagated in time so that you

244
00:08:57,430 --> 00:08:55,279
can reproduce your measurements

245
00:09:00,310 --> 00:08:57,440
and um you know we go through iterations

246
00:09:02,870 --> 00:09:00,320
and we have these algorithms that are

247
00:09:06,070 --> 00:09:02,880
minimizing the difference between our

248
00:09:07,829 --> 00:09:06,080
orbits and the measurements at hand by

249
00:09:09,190 --> 00:09:07,839
adjusting these parameters and you'll

250
00:09:11,110 --> 00:09:09,200
notice that some of the balloons are

251
00:09:13,269 --> 00:09:11,120
larger than the others because

252
00:09:14,150 --> 00:09:13,279
some of these parameters end up being

253
00:09:17,350 --> 00:09:14,160
more

254
00:09:19,509 --> 00:09:17,360
important than the others and so

255
00:09:21,990 --> 00:09:19,519
once when all this is done

256
00:09:23,590 --> 00:09:22,000
i'll show you how

257
00:09:24,470 --> 00:09:23,600
you know the the on the next slide

258
00:09:27,110 --> 00:09:24,480
please

259
00:09:29,509 --> 00:09:27,120
uh this is kind of how we evaluate the

260
00:09:32,470 --> 00:09:29,519
the quality of our orbit fit we are

261
00:09:35,670 --> 00:09:32,480
looking at the differences between our

262
00:09:37,269 --> 00:09:35,680
uh simulated data and the real data and

263
00:09:40,710 --> 00:09:37,279

this is something we call residuals and

264
00:09:43,990 --> 00:09:40,720
as an orbit fitter we love our plots um

265
00:09:45,990 --> 00:09:44,000
with residuals um and um

266
00:09:47,829 --> 00:09:46,000
you know they there's no better way to

267
00:09:49,590 --> 00:09:47,839
to to show this and and i know when i

268
00:09:51,590 --> 00:09:49,600
give my you know technical talks if i

269
00:09:53,829 --> 00:09:51,600
show more than three of these i i know i

270
00:09:56,310 --> 00:09:53,839
can put half of my audience to sleep so

271
00:09:58,550 --> 00:09:56,320
i'm not going to do that um but i just

272
00:10:01,190 --> 00:09:58,560
want to mention that um you know the

273
00:10:04,150 --> 00:10:01,200
orbit fitting is important because

274
00:10:06,710 --> 00:10:04,160
um you need to know orbits in order to

275
00:10:10,150 --> 00:10:06,720
tell a story and to understand the

276
00:10:13,509 --> 00:10:11,829
you mentioned to me before we did this

277
00:10:16,550 --> 00:10:13,519
tonight that you've got some great

278
00:10:17,590 --> 00:10:16,560
animations of planetary systems

279
00:10:18,470 --> 00:10:17,600
they show they're showing the real

280
00:10:20,389 --> 00:10:18,480
position

281
00:10:22,630 --> 00:10:20,399
of these satellites in time which one do

282
00:10:24,150 --> 00:10:22,640
you want to start with tonight

283
00:10:26,630 --> 00:10:24,160
yeah so what you're going to be seeing i

284
00:10:28,949 --> 00:10:26,640
made some i made some visualization and

285
00:10:30,069 --> 00:10:28,959
and these are real orbits so so you

286
00:10:32,389 --> 00:10:30,079
could be you know pointing your

287
00:10:34,470 --> 00:10:32,399
telescope or flying a mission based on

288
00:10:35,750 --> 00:10:34,480

orbits that you're going to see

289
00:10:37,750 --> 00:10:35,760
we have to start with the system of

290
00:10:39,350 --> 00:10:37,760
jupiter so let's go to the to the next

291
00:10:41,829 --> 00:10:39,360
slide

292
00:10:45,590 --> 00:10:41,839
and so here's jupiter and it really has

293
00:10:46,790 --> 00:10:45,600
it has 80 natural satellites

294
00:10:48,870 --> 00:10:46,800
and

295
00:10:51,670 --> 00:10:48,880
what you're seeing here first you have

296
00:10:52,870 --> 00:10:51,680
four galen satellites io europa ganymede

297
00:10:54,710 --> 00:10:52,880
and callisto

298
00:10:57,190 --> 00:10:54,720
and then inner to these you have these

299
00:10:59,829 --> 00:10:57,200
four inner satellites and they're also

300
00:11:01,430 --> 00:10:59,839
connected with the system of faint rings

301
00:11:03,590 --> 00:11:01,440
that jupiter has

302
00:11:05,110 --> 00:11:03,600
and they're they're strange objects you

303
00:11:07,750 --> 00:11:05,120
know some of them kind of resemble

304
00:11:09,509 --> 00:11:07,760
asteroids um and there are even some

305
00:11:11,590 --> 00:11:09,519
theories that they could be captured but

306
00:11:13,910 --> 00:11:11,600
it's very difficult to explain how

307
00:11:16,630 --> 00:11:13,920
something captured could end up in this

308
00:11:18,790 --> 00:11:16,640
well-behaved circular orbit along the

309
00:11:20,630 --> 00:11:18,800
planet's equator

310
00:11:23,750 --> 00:11:20,640
and what you're going to soon see you're

311
00:11:26,470 --> 00:11:23,760
going to see where juno spacecraft

312
00:11:29,030 --> 00:11:26,480
is right here it's currently exploring

313
00:11:30,550 --> 00:11:29,040

the system of jupiter

314
00:11:33,350 --> 00:11:30,560
and then here

315
00:11:35,990 --> 00:11:33,360
far beyond orbit of callisto this is

316
00:11:38,150 --> 00:11:36,000
where party starts this is the realm of

317
00:11:41,750 --> 00:11:38,160
the outer moons of jupiter

318
00:11:44,150 --> 00:11:41,760
and there are 72 of them that we know of

319
00:11:45,750 --> 00:11:44,160
so the ones in yellow they are what we

320
00:11:47,910 --> 00:11:45,760
call the probate moons basically they're

321
00:11:49,910 --> 00:11:47,920
revolving around the planet in the same

322
00:11:52,150 --> 00:11:49,920
direction that planet is revolving

323
00:11:53,910 --> 00:11:52,160
around the sun and the red ones are

324
00:11:56,550 --> 00:11:53,920
revolving in the opposite direction so

325
00:11:59,190 --> 00:11:56,560
these are the retrograde moons and the

326
00:12:01,910 --> 00:11:59,200
largest representative of these

327
00:12:04,310 --> 00:12:01,920
moons in yellow it's called himalaya

328
00:12:05,590 --> 00:12:04,320
quite large it's about 140 kilometers in

329
00:12:06,550 --> 00:12:05,600
diameter

330
00:12:07,590 --> 00:12:06,560
and

331
00:12:10,069 --> 00:12:07,600
it's

332
00:12:12,550 --> 00:12:10,079
related to some other members of this

333
00:12:14,550 --> 00:12:12,560
group in yellow uh basically the idea is

334
00:12:15,590 --> 00:12:14,560
that once upon a time this was a larger

335
00:12:17,670 --> 00:12:15,600
object

336
00:12:19,750 --> 00:12:17,680
that collided with something and then

337
00:12:23,190 --> 00:12:19,760
we're looking at these shards that

338
00:12:25,269 --> 00:12:23,200

evolved into the or our own orbits

339
00:12:28,150 --> 00:12:25,279
and similar story you're looking at this

340
00:12:30,310 --> 00:12:28,160
yarn of red satellites

341
00:12:32,710 --> 00:12:30,320
so believe it or not they're like three

342
00:12:35,190 --> 00:12:32,720
relate there are three families there

343
00:12:36,710 --> 00:12:35,200
that also presumably once upon a time

344
00:12:38,790 --> 00:12:36,720
where much larger body that got

345
00:12:41,990 --> 00:12:38,800
collisionally disrupted

346
00:12:45,509 --> 00:12:42,000
and um you know we at

347
00:12:46,710 --> 00:12:45,519
ssd we um calculate the current orbits

348
00:12:48,389 --> 00:12:46,720
of these satellites but there are

349
00:12:50,790 --> 00:12:48,399
dynamicists out there

350
00:12:52,310 --> 00:12:50,800
that spin these orbits um

351
00:12:54,069 --> 00:12:52,320
backward and forwarding time for

352
00:12:56,629 --> 00:12:54,079
millions even billions of years because

353
00:12:59,910 --> 00:12:56,639
they they want to answer questions about

354
00:13:01,269 --> 00:12:59,920
their origin and their ultimate destiny

355
00:13:04,310 --> 00:13:01,279
and there are always some interesting

356
00:13:05,910 --> 00:13:04,320
stories to tell so um i really want to

357
00:13:08,790 --> 00:13:05,920
draw your attention to this moon in

358
00:13:10,629 --> 00:13:08,800
white it's called volitudo

359
00:13:11,910 --> 00:13:10,639
and that one is the outermost pro-grade

360
00:13:13,829 --> 00:13:11,920
moon

361
00:13:16,150 --> 00:13:13,839
basically it is orbiting in a region of

362
00:13:19,110 --> 00:13:16,160
space where everybody else is uh

363
00:13:21,030 --> 00:13:19,120

retrograde so so it is it is kind of

364
00:13:23,190 --> 00:13:21,040
driving against traffic

365
00:13:24,710 --> 00:13:23,200
um and what dynamical studies are

366
00:13:27,110 --> 00:13:24,720
showing is that sooner or later it's

367
00:13:28,790 --> 00:13:27,120
going to cross paths and have head-on

368
00:13:30,230 --> 00:13:28,800
collision

369
00:13:31,670 --> 00:13:30,240
and another thing we know about this

370
00:13:34,069 --> 00:13:31,680
moon it's very small it's about only

371
00:13:36,710 --> 00:13:34,079
maybe uh one kilometer in size perhaps

372
00:13:38,629 --> 00:13:36,720
smaller um and there is no

373
00:13:41,670 --> 00:13:38,639
it doesn't have any other

374
00:13:43,590 --> 00:13:41,680
piece that that is related to it so

375
00:13:45,430 --> 00:13:43,600
that kind of brings an interesting story

376
00:13:47,430 --> 00:13:45,440
and that is that it's perhaps the last

377
00:13:49,430 --> 00:13:47,440
surviving member

378
00:13:52,069 --> 00:13:49,440
that got ground down to this tiny little

379
00:13:54,150 --> 00:13:52,079
piece and that ended up uh creating

380
00:13:56,310 --> 00:13:54,160
perhaps some of these big retrograde

381
00:13:59,670 --> 00:13:56,320
families in a head-on past head-on

382
00:14:06,150 --> 00:14:02,790
i i love jupiter but personally i love

383
00:14:09,110 --> 00:14:06,160
looking at saturn and i know that saturn

384
00:14:11,189 --> 00:14:09,120
has more moons than jupiter

385
00:14:12,790 --> 00:14:11,199
first off am i right about that and how

386
00:14:15,750 --> 00:14:12,800
could how do the rings of saturn fit

387
00:14:17,750 --> 00:14:15,760
into this story about the satellites

388
00:14:20,629 --> 00:14:17,760

yeah okay well

389
00:14:22,389 --> 00:14:20,639
funny that i have an animation about um

390
00:14:25,350 --> 00:14:22,399
about saturn so so let's go to the next

391
00:14:27,269 --> 00:14:25,360
slide so you're correct saturn has 83

392
00:14:29,189 --> 00:14:27,279
moons uh natural satellites while

393
00:14:31,189 --> 00:14:29,199
jupiter has 80.

394
00:14:33,990 --> 00:14:31,199
the most obvious thing at saturn are

395
00:14:36,949 --> 00:14:34,000
this huge system that you know its rings

396
00:14:38,949 --> 00:14:36,959
uh we think they originate from a

397
00:14:40,550 --> 00:14:38,959
disruption of a small moon some hundred

398
00:14:42,710 --> 00:14:40,560
million years ago

399
00:14:44,629 --> 00:14:42,720
and even the current moons in the system

400
00:14:45,590 --> 00:14:44,639
they still play a role in the life of

401
00:14:47,430 --> 00:14:45,600
rings

402
00:14:50,790 --> 00:14:47,440
they're either

403
00:14:53,509 --> 00:14:50,800
responsible for these gaps in the rings

404
00:14:55,829 --> 00:14:53,519
or they're actually source of

405
00:14:59,430 --> 00:14:55,839
material themselves

406
00:15:02,389 --> 00:14:59,440
so let's take a tour here you are seeing

407
00:15:04,790 --> 00:15:02,399
there are 24 regular satellites of

408
00:15:06,550 --> 00:15:04,800
saturn so the blue colors are the large

409
00:15:08,629 --> 00:15:06,560
satellites so those would be like um

410
00:15:10,550 --> 00:15:08,639
rhea or titan

411
00:15:12,870 --> 00:15:10,560
and then in these light colors these are

412
00:15:15,670 --> 00:15:12,880
tiny little guys um so that would be

413
00:15:16,870 --> 00:15:15,680

like daphne or atlas

414
00:15:18,550 --> 00:15:16,880
and um

415
00:15:20,870 --> 00:15:18,560
moon that is actually really interesting

416
00:15:22,870 --> 00:15:20,880
here is uh enceladus you probably know

417
00:15:25,509 --> 00:15:22,880
about enceladus uh it's spewing these

418
00:15:27,829 --> 00:15:25,519
icy particles and it's a source of this

419
00:15:30,230 --> 00:15:27,839
very faint drink which is stretching

420
00:15:33,590 --> 00:15:30,240
from the orbit of mimas all the way to

421
00:15:34,790 --> 00:15:33,600
the orbit of titan so that is you know

422
00:15:36,949 --> 00:15:34,800
the moons are really kind of

423
00:15:39,110 --> 00:15:36,959
interconnected and interleaved with a

424
00:15:40,389 --> 00:15:39,120
system of rings

425
00:15:42,389 --> 00:15:40,399
and you are good to see yeah this is

426
00:15:45,749 --> 00:15:42,399
where cassini used to orbit the system

427
00:15:48,629 --> 00:15:45,759
toward the end of its mission

428
00:15:51,350 --> 00:15:48,639
and again we are entering the realm of

429
00:15:54,230 --> 00:15:51,360
the outer satellites uh

430
00:15:56,710 --> 00:15:54,240
the yellow ones those are the pro-grade

431
00:15:59,189 --> 00:15:56,720
satellites and this crowd of red ones

432
00:16:02,870 --> 00:15:59,199
are the retrogrades

433
00:16:05,030 --> 00:16:02,880
similar to jupiter we have several

434
00:16:08,629 --> 00:16:05,040
dynamical families so again presumably

435
00:16:11,509 --> 00:16:08,639
something much larger got collided and

436
00:16:12,790 --> 00:16:11,519
any the shards evolved into their own

437
00:16:16,069 --> 00:16:12,800
orbits

438
00:16:18,310 --> 00:16:16,079

and we have another traffic offender uh

439
00:16:20,470 --> 00:16:18,320
there is another little moon

440
00:16:23,990 --> 00:16:20,480
this time with a uh

441
00:16:26,230 --> 00:16:24,000
poetic name 2004 s24

442
00:16:29,030 --> 00:16:26,240
so this one is the outermost uh pro

443
00:16:30,550 --> 00:16:29,040
great moon uh it's again probably you

444
00:16:32,629 --> 00:16:30,560
know dynamically it could collide with

445
00:16:34,790 --> 00:16:32,639
some of the retrograde moons and

446
00:16:37,110 --> 00:16:34,800
and and perhaps you know it forms some

447
00:16:38,870 --> 00:16:37,120
of these retrograde families

448
00:16:41,350 --> 00:16:38,880
and in fact actually you know the the

449
00:16:43,509 --> 00:16:41,360
when you mentioned how kind of saturn

450
00:16:45,670 --> 00:16:43,519
overtook the number of satellites uh

451
00:16:48,870 --> 00:16:45,680
from jupiter that's that that occurred

452
00:16:52,790 --> 00:16:48,880
that happened in 2019 when there were 20

453
00:16:55,829 --> 00:16:52,800
new satellites of saturn announced

454
00:16:57,749 --> 00:16:55,839
and basically uh surveys are currently

455
00:17:00,470 --> 00:16:57,759
discovering a jupiter satellites that

456
00:17:03,350 --> 00:17:00,480
are say about 500 meters really small

457
00:17:05,510 --> 00:17:03,360
and on saturn um they are seeing things

458
00:17:07,189 --> 00:17:05,520
about few kilometers because saturn is

459
00:17:09,429 --> 00:17:07,199
you know farther away so it's more

460
00:17:11,510 --> 00:17:09,439
difficult to see small pieces

461
00:17:14,789 --> 00:17:11,520
uh but definitely we are missing a lot

462
00:17:17,429 --> 00:17:14,799
of these um so um we probably have still

463
00:17:19,669 --> 00:17:17,439

hundreds of objects to discover uh which

464
00:17:22,230 --> 00:17:19,679
is a very good news for me as an orbit

465
00:17:24,949 --> 00:17:22,240
fitter that is a job security

466
00:17:27,189 --> 00:17:24,959
so um i am not complaining for more

467
00:17:29,270 --> 00:17:27,199
moves

468
00:17:31,190 --> 00:17:29,280
for those those big old gas giants

469
00:17:33,350 --> 00:17:31,200
obviously they've got diverse ecosystems

470
00:17:34,710 --> 00:17:33,360
they've got moons they've got rings but

471
00:17:37,029 --> 00:17:34,720
if you go a little further out we've got

472
00:17:39,190 --> 00:17:37,039
our ice giants out there now you brought

473
00:17:41,830 --> 00:17:39,200
up the poetic name

474
00:17:43,270 --> 00:17:41,840
i am partial to uranus's moons with

475
00:17:46,150 --> 00:17:43,280
their named after the works of william

476
00:17:47,909 --> 00:17:46,160
shakespeare and william pope um i'm

477
00:17:49,990 --> 00:17:47,919
sorry alexander pope william william

478
00:17:52,310 --> 00:17:50,000
shakespeare alexander pope uh the inner

479
00:17:54,070 --> 00:17:52,320
moons that are close to this planet do

480
00:17:55,590 --> 00:17:54,080
they have the similar outline or their

481
00:17:58,230 --> 00:17:55,600
outer satellites and some in some

482
00:17:59,029 --> 00:17:58,240
strange orbits

483
00:18:01,830 --> 00:17:59,039
well

484
00:18:03,510 --> 00:18:01,840
yes and no um so you have the same kind

485
00:18:05,909 --> 00:18:03,520
of general outline you have the inner

486
00:18:08,390 --> 00:18:05,919
moons the the regular moons and you have

487
00:18:10,310 --> 00:18:08,400
the otter moons but both uranus and

488
00:18:12,150 --> 00:18:10,320

neptune are weird you know they're

489
00:18:15,669 --> 00:18:12,160
peculiar little systems

490
00:18:17,350 --> 00:18:15,679
um or big systems um so let's start

491
00:18:19,590 --> 00:18:17,360
let's start with uranus on the next side

492
00:18:21,669 --> 00:18:19,600
slide please and we'll be moving from

493
00:18:23,510 --> 00:18:21,679
outside inwards so you're seeing the

494
00:18:25,909 --> 00:18:23,520
realm of the outer satellites we know

495
00:18:28,870 --> 00:18:25,919
only uh nine of them at the moment

496
00:18:30,789 --> 00:18:28,880
margaret is the only pro-grade one these

497
00:18:32,070 --> 00:18:30,799
are orbiting at huge distances from the

498
00:18:34,470 --> 00:18:32,080
planets

499
00:18:36,789 --> 00:18:34,480
we are coming in these are five regular

500
00:18:38,870 --> 00:18:36,799
satellites of uranus

501
00:18:40,549 --> 00:18:38,880
but this story really gets interesting

502
00:18:42,390 --> 00:18:40,559
as when we start talking about these

503
00:18:45,270 --> 00:18:42,400
inner moons

504
00:18:48,630 --> 00:18:45,280
there are 13 of them they're small

505
00:18:51,990 --> 00:18:48,640
but extremely densely packed orbits so

506
00:18:54,470 --> 00:18:52,000
um imagine having 13 moons that would

507
00:18:56,230 --> 00:18:54,480
fit within one quarter of the earth moon

508
00:18:57,510 --> 00:18:56,240
distance

509
00:18:59,270 --> 00:18:57,520
and these moves are kind of you know

510
00:19:00,789 --> 00:18:59,280
they're small but they still have mass

511
00:19:03,270 --> 00:19:00,799
and they kind of keep bumping at each

512
00:19:06,230 --> 00:19:03,280
other and to make things worse

513
00:19:07,350 --> 00:19:06,240

they are in a um you know some of them

514
00:19:09,029 --> 00:19:07,360
have

515
00:19:10,710 --> 00:19:09,039
integer relationship between their

516
00:19:13,669 --> 00:19:10,720
orbital periods

517
00:19:16,470 --> 00:19:13,679
and these states are called resonances

518
00:19:19,590 --> 00:19:16,480
and uh so what that for example uh there

519
00:19:22,950 --> 00:19:19,600
are two moves um there is uh caressida

520
00:19:25,190 --> 00:19:22,960
and bianca they're in a 16 to 15 orbit

521
00:19:27,750 --> 00:19:25,200
orbit resonance what this means is that

522
00:19:30,150 --> 00:19:27,760
the inner moon keresida goes around 16

523
00:19:31,590 --> 00:19:30,160
times the other one bianca goes around

524
00:19:33,669 --> 00:19:31,600
15 times

525
00:19:36,070 --> 00:19:33,679
and they catch up

526
00:19:38,870 --> 00:19:36,080
and because you know this happens

527
00:19:40,870 --> 00:19:38,880
periodically and regularly so sooner or

528
00:19:42,870 --> 00:19:40,880
later the orbits start changing enough

529
00:19:44,549 --> 00:19:42,880
that um

530
00:19:46,870 --> 00:19:44,559
they start colliding these moons start

531
00:19:48,789 --> 00:19:46,880
colliding and and when dynamicists run

532
00:19:51,350 --> 00:19:48,799
studies and i told you they like to run

533
00:19:52,710 --> 00:19:51,360
these long studies for millions of years

534
00:19:54,390 --> 00:19:52,720
they see that this system is kind of

535
00:19:57,029 --> 00:19:54,400
recyclable

536
00:19:58,789 --> 00:19:57,039
uh it goes through periods of um you

537
00:20:00,630 --> 00:19:58,799
know the moons colliding you have a

538
00:20:02,070 --> 00:20:00,640

temporary system of rings

539
00:20:04,870 --> 00:20:02,080
and then they all

540
00:20:06,789 --> 00:20:04,880
coalesce again into moons so so we don't

541
00:20:09,190 --> 00:20:06,799
know how many times you know uranus went

542
00:20:11,750 --> 00:20:09,200
to this uh having system of rings having

543
00:20:15,029 --> 00:20:11,760
systema moons and back and forth and

544
00:20:17,270 --> 00:20:15,039
even today you have a very faint ring

545
00:20:19,270 --> 00:20:17,280
between the moons called porsche and

546
00:20:21,590 --> 00:20:19,280
rosalind so

547
00:20:23,909 --> 00:20:21,600
interesting kind of phoenix-like system

548
00:20:25,990 --> 00:20:23,919
that keeps you know going through these

549
00:20:27,270 --> 00:20:26,000
cycles

550
00:20:29,510 --> 00:20:27,280
well let's keep working our way out

551
00:20:32,789 --> 00:20:29,520
there let's get to neptune um voyager 2

552
00:20:35,350 --> 00:20:32,799
flew past in 1989. i kind of love this

553
00:20:37,190 --> 00:20:35,360
image of neptune's giant moon triton so

554
00:20:39,430 --> 00:20:37,200
if we bring up number 10 yeah there it

555
00:20:41,350 --> 00:20:39,440
is you can see evidence of nitrogen ice

556
00:20:42,789 --> 00:20:41,360
volcanoes on its surface so

557
00:20:44,549 --> 00:20:42,799
how unique

558
00:20:47,590 --> 00:20:44,559
is triton and are there other notable

559
00:20:49,909 --> 00:20:47,600
moons in the neptune system

560
00:20:52,149 --> 00:20:49,919
well you know uh triton as i said it's

561
00:20:56,230 --> 00:20:52,159
it's really neat i mean it's huge it's

562
00:20:59,510 --> 00:20:56,240
this is 27 2700 kilometers in diameter

563
00:21:00,710 --> 00:20:59,520

so um and giving how massive it is and

564
00:21:03,110 --> 00:21:00,720
everything you know this looks like a

565
00:21:05,750 --> 00:21:03,120
regular moon of neptune

566
00:21:08,310 --> 00:21:05,760
um kind of that formed with a planet

567
00:21:10,070 --> 00:21:08,320
itself but then you look at its orbit

568
00:21:12,390 --> 00:21:10,080
you know i always go back to the orbit

569
00:21:15,190 --> 00:21:12,400
and it tells us very different story

570
00:21:17,909 --> 00:21:15,200
so let's take a look at the orbit of

571
00:21:20,070 --> 00:21:17,919
triton on the next slide

572
00:21:21,830 --> 00:21:20,080
and so yeah this is what you see so you

573
00:21:23,830 --> 00:21:21,840
see the these little moons in yellow

574
00:21:26,149 --> 00:21:23,840
those are your well-behaved inner moons

575
00:21:28,149 --> 00:21:26,159
everybody's in circles and you know

576
00:21:30,070 --> 00:21:28,159
lined up with a planet equator and then

577
00:21:32,230 --> 00:21:30,080
you have triton and triton is obviously

578
00:21:33,590 --> 00:21:32,240
aligned and not only light it's going

579
00:21:35,270 --> 00:21:33,600
the other way

580
00:21:38,630 --> 00:21:35,280
so um

581
00:21:40,870 --> 00:21:38,640
the leading theory is that triton is

582
00:21:43,909 --> 00:21:40,880
actually captured object it's a captured

583
00:21:47,029 --> 00:21:43,919
kuiper belt object something similar to

584
00:21:49,430 --> 00:21:47,039
pluto and this capture happened early in

585
00:21:51,110 --> 00:21:49,440
the solar system history and as a result

586
00:21:55,350 --> 00:21:51,120
it completely destroyed the original

587
00:21:57,029 --> 00:21:55,360
population of the moons of neptune

588
00:21:59,350 --> 00:21:57,039

and let's take a look at the close-up on

589
00:22:01,110 --> 00:21:59,360
the next slide of the inner moons of

590
00:22:03,669 --> 00:22:01,120
neptune

591
00:22:06,470 --> 00:22:03,679
so next slide please yes so these are

592
00:22:08,470 --> 00:22:06,480
not original moons of of neptune this is

593
00:22:10,789 --> 00:22:08,480
these are again neptune probably ended

594
00:22:13,190 --> 00:22:10,799
up uh they the original population

595
00:22:15,350 --> 00:22:13,200
probably collided between themselves

596
00:22:17,110 --> 00:22:15,360
neptune had a system of rings

597
00:22:19,190 --> 00:22:17,120
and then this is what happened

598
00:22:21,510 --> 00:22:19,200
afterwards they coalesced from these

599
00:22:22,870 --> 00:22:21,520
rings into again clumps that we call

600
00:22:25,190 --> 00:22:22,880
moons

601
00:22:27,990 --> 00:22:25,200
there are seven of them again very

602
00:22:30,390 --> 00:22:28,000
tightly packed system um the entire

603
00:22:33,430 --> 00:22:30,400
system would fit within one third of the

604
00:22:35,909 --> 00:22:33,440
distance from earth to our moon

605
00:22:37,750 --> 00:22:35,919
the um they orbit really fast like

606
00:22:39,830 --> 00:22:37,760
proteus um

607
00:22:41,909 --> 00:22:39,840
the outermost moon it takes it's a

608
00:22:45,190 --> 00:22:41,919
little bit less a little bit more than

609
00:22:47,510 --> 00:22:45,200
one earth day uh to orbit orbit the

610
00:22:50,070 --> 00:22:47,520
planet but but you know weird

611
00:22:52,710 --> 00:22:50,080
weird little system but even bigger

612
00:22:56,549 --> 00:22:52,720
puzzle i'm going to show you on the next

613
00:23:00,070 --> 00:22:56,559

slide and let's see next slide yes this

614
00:23:02,070 --> 00:23:00,080
is moon call narrate and um if you

615
00:23:04,149 --> 00:23:02,080
remember in the beginning of your talk i

616
00:23:05,750 --> 00:23:04,159
was showing you my fit to orbit of

617
00:23:07,350 --> 00:23:05,760
narrate uh there are these those

618
00:23:09,669 --> 00:23:07,360
residuals

619
00:23:12,470 --> 00:23:09,679
and neri there is theory you know it has

620
00:23:14,630 --> 00:23:12,480
this very distant elongated orbit

621
00:23:16,789 --> 00:23:14,640
it's a pro-grade moon

622
00:23:20,310 --> 00:23:16,799
and uh the theory is that it could be

623
00:23:23,270 --> 00:23:20,320
the last original moon of neptune that

624
00:23:25,510 --> 00:23:23,280
neptune had before capture of triton and

625
00:23:26,710 --> 00:23:25,520
that it got scattered into this distant

626
00:23:28,230 --> 00:23:26,720
orbit

627
00:23:31,350 --> 00:23:28,240
after kind of

628
00:23:33,110 --> 00:23:31,360
triton barged into the system um narrate

629
00:23:35,510 --> 00:23:33,120
is fairly large it's about 360

630
00:23:36,630 --> 00:23:35,520
kilometers and it's orbiting around the

631
00:23:39,990 --> 00:23:36,640
planet

632
00:23:42,310 --> 00:23:40,000
just under one earth year about 360

633
00:23:45,029 --> 00:23:42,320
earth days

634
00:23:46,870 --> 00:23:45,039
um i don't want to forget about my outer

635
00:23:47,909 --> 00:23:46,880
satellites so let's go to the next slide

636
00:23:49,750 --> 00:23:47,919
because

637
00:23:52,549 --> 00:23:49,760
that kind of this is probably my you

638
00:23:54,710 --> 00:23:52,559

know the favorite system of the outers

639
00:23:57,029 --> 00:23:54,720
um i already mentioned you know so

640
00:23:59,110 --> 00:23:57,039
neptune has this the largest hill sphere

641
00:24:00,630 --> 00:23:59,120
where it can capture its satellites and

642
00:24:02,710 --> 00:24:00,640
this is what i mean large you see the

643
00:24:04,789 --> 00:24:02,720
scale here this is one astronomical unit

644
00:24:07,190 --> 00:24:04,799
so this would be between distance from

645
00:24:08,789 --> 00:24:07,200
the uh sun to the earth

646
00:24:10,630 --> 00:24:08,799
uh there are only five of them that we

647
00:24:13,269 --> 00:24:10,640
know of they're definitely more out

648
00:24:14,470 --> 00:24:13,279
there but they're very hard to find

649
00:24:16,310 --> 00:24:14,480
because they're very faint they're not

650
00:24:18,870 --> 00:24:16,320
that large and and surveys you know

651
00:24:21,110 --> 00:24:18,880
really have to dig deep to find them

652
00:24:23,350 --> 00:24:21,120
um the this one that you particularly

653
00:24:27,830 --> 00:24:23,360
see one this one called nesso nasa takes

654
00:24:29,909 --> 00:24:27,840
27 years to orbit around uh neptune

655
00:24:32,310 --> 00:24:29,919
and we actually have only data for like

656
00:24:35,669 --> 00:24:32,320
10 years so a lot more data to be

657
00:24:38,070 --> 00:24:35,679
collected here a lot more to learn

658
00:24:40,789 --> 00:24:38,080
um and and i'm saying this is you know

659
00:24:44,230 --> 00:24:40,799
the it's it's really a great story with

660
00:24:45,669 --> 00:24:44,240
these outer moons of of neptune

661
00:24:47,190 --> 00:24:45,679
a lot of great information tonight and a

662
00:24:49,110 --> 00:24:47,200
lot more information to come down the

663
00:24:51,510 --> 00:24:49,120

road as you as you keep studying and

664
00:24:53,909 --> 00:24:51,520
exploring these as we're getting closer

665
00:24:55,029 --> 00:24:53,919
to our audience questions um

666
00:24:58,470 --> 00:24:55,039
is there anything else you'd like to say

667
00:25:03,430 --> 00:25:00,549
well you know so far i was telling you

668
00:25:06,149 --> 00:25:03,440
why orbits are important in order to

669
00:25:08,310 --> 00:25:06,159
learn about um you know the science

670
00:25:10,390 --> 00:25:08,320
system science of the system about the

671
00:25:13,029 --> 00:25:10,400
origin of the moons and their dynamical

672
00:25:15,029 --> 00:25:13,039
evolution but um you know orbits are

673
00:25:17,029 --> 00:25:15,039
very practical things as well they're

674
00:25:19,029 --> 00:25:17,039
important for the missions

675
00:25:21,510 --> 00:25:19,039
uh because in order to fly a mission you

676
00:25:24,070 --> 00:25:21,520
need to know where your targets your

677
00:25:27,190 --> 00:25:24,080
destinations are

678
00:25:29,190 --> 00:25:27,200
so let's take a look at the next slide

679
00:25:31,510 --> 00:25:29,200
because i want to tell you about one of

680
00:25:32,789 --> 00:25:31,520
my favorite missions and that is new

681
00:25:34,950 --> 00:25:32,799
horizons

682
00:25:36,710 --> 00:25:34,960
that the spacecraft ended up flying

683
00:25:39,110 --> 00:25:36,720
through the system of pluto exactly

684
00:25:41,750 --> 00:25:39,120
through the bullseye of the system

685
00:25:44,630 --> 00:25:41,760
in 2015

686
00:25:47,990 --> 00:25:44,640
and spacecraft at that time was nine and

687
00:25:49,590 --> 00:25:48,000
a half years on the road so a long time

688
00:25:51,350 --> 00:25:49,600

and it was moving incredibly fast this

689
00:25:54,950 --> 00:25:51,360
was like you know bat from hell it was

690
00:25:56,870 --> 00:25:54,960
like 13.8 kilometers a second um and so

691
00:25:58,630 --> 00:25:56,880
you rush refresh to get to pluto and

692
00:26:00,789 --> 00:25:58,640
then all the data are collected within

693
00:26:02,870 --> 00:26:00,799
like several hours so those are the best

694
00:26:04,710 --> 00:26:02,880
data the highest resolution ones

695
00:26:06,549 --> 00:26:04,720
and you need to know where everybody is

696
00:26:08,070 --> 00:26:06,559
in order to correctly point your camera

697
00:26:09,269 --> 00:26:08,080
and you also you know you want to know

698
00:26:11,669 --> 00:26:09,279
that you're not going to collide with

699
00:26:12,470 --> 00:26:11,679
something as you're going through

700
00:26:14,390 --> 00:26:12,480
so

701
00:26:16,630 --> 00:26:14,400
every mission has a similar story like

702
00:26:19,350 --> 00:26:16,640
that it's it's you know incredible feat

703
00:26:22,149 --> 00:26:19,360
of engineering it takes hundreds of

704
00:26:23,350 --> 00:26:22,159
people and and many years and many years

705
00:26:26,070 --> 00:26:23,360
to complete

706
00:26:28,390 --> 00:26:26,080
but um ultimately they all start you

707
00:26:31,750 --> 00:26:28,400
know the same thing they they need to

708
00:26:34,630 --> 00:26:31,760
know where their destinations are

709
00:26:36,789 --> 00:26:34,640
and uh in a solar system dynamics group

710
00:26:39,830 --> 00:26:36,799
um you know this is we are we are the

711
00:26:41,830 --> 00:26:39,840
map makers um so we like to think that

712
00:26:43,750 --> 00:26:41,840
we are very important for the missions

713
00:26:46,470 --> 00:26:43,760

um and um

714
00:26:47,590 --> 00:26:46,480
you know i i always like kind of to say

715
00:26:49,990 --> 00:26:47,600
that

716
00:26:50,870 --> 00:26:50,000
the starting story

717
00:26:52,549 --> 00:26:50,880
of

718
00:26:55,029 --> 00:26:52,559
every mission

719
00:26:57,029 --> 00:26:55,039
becomes you know begins with a same

720
00:27:00,470 --> 00:26:57,039
sentence so kind of something like in

721
00:27:02,149 --> 00:27:00,480
the beginning there was a map

722
00:27:04,390 --> 00:27:02,159
so

723
00:27:05,669 --> 00:27:04,400
in the beginning there was a map

724
00:27:07,909 --> 00:27:05,679
i love that

725
00:27:09,510 --> 00:27:07,919
lindsay the chats have been busy

726
00:27:11,350 --> 00:27:09,520
what questions do they have about map

727
00:27:14,230 --> 00:27:11,360
making in these orbits out there what's

728
00:27:16,310 --> 00:27:14,240
what's going on with our audience

729
00:27:18,070 --> 00:27:16,320
absolutely marina i have to say i am not

730
00:27:20,950 --> 00:27:18,080
the only one who's been over the moon

731
00:27:23,269 --> 00:27:20,960
about your talk so shavash on linkedin

732
00:27:25,909 --> 00:27:23,279
asks is there a probability of earth

733
00:27:29,669 --> 00:27:25,919
catching a natural satellite and perhaps

734
00:27:30,950 --> 00:27:29,679
would it orbit in an irregular manner

735
00:27:33,510 --> 00:27:30,960
oh yes

736
00:27:36,149 --> 00:27:33,520
we have mini moons so earth has many

737
00:27:38,389 --> 00:27:36,159
moons and just recently one such object

738
00:27:40,710 --> 00:27:38,399

was captured so earth knows to capture

739
00:27:43,909 --> 00:27:40,720
these uh tiny little asteroids

740
00:27:45,830 --> 00:27:43,919
um and uh the last one and i don't

741
00:27:48,389 --> 00:27:45,840
remember exactly it was like

742
00:27:49,669 --> 00:27:48,399
it was very recent it was it was 2020

743
00:27:51,430 --> 00:27:49,679
something

744
00:27:54,470 --> 00:27:51,440
but you know these moves spend about

745
00:27:57,029 --> 00:27:54,480
several months to a year uh orbiting in

746
00:27:58,070 --> 00:27:57,039
a very very regular orbits and then they

747
00:28:01,350 --> 00:27:58,080
take off

748
00:28:04,070 --> 00:28:01,360
and um they start orbiting the sun again

749
00:28:05,029 --> 00:28:04,080
those could be great targets for space

750
00:28:07,350 --> 00:28:05,039
missions

751
00:28:08,870 --> 00:28:07,360
uh because it's um you know it's it's

752
00:28:11,510 --> 00:28:08,880
easy to get to them

753
00:28:13,430 --> 00:28:11,520
um and you know perhaps you could you

754
00:28:15,350 --> 00:28:13,440
know perhaps something like that we are

755
00:28:19,510 --> 00:28:15,360
going to see um you know sometimes in

756
00:28:24,630 --> 00:28:22,070
awesome marina paul on facebook is

757
00:28:26,870 --> 00:28:24,640
asking would it be reasonable to assume

758
00:28:31,669 --> 00:28:26,880
that some of the moons of jupiter are a

759
00:28:38,470 --> 00:28:36,310
yeah so the um so jupiter has a ring

760
00:28:40,630 --> 00:28:38,480
um it has um

761
00:28:42,149 --> 00:28:40,640
you know there is a io spewing whole

762
00:28:45,590 --> 00:28:42,159
bunch of particles

763
00:28:47,430 --> 00:28:45,600

uh and also the inner moons um that i

764
00:28:49,590 --> 00:28:47,440
that i mentioned that are orbiting

765
00:28:51,750 --> 00:28:49,600
closer to the planets than io they're

766
00:28:53,190 --> 00:28:51,760
also sources of a material they're

767
00:28:56,470 --> 00:28:53,200
thought to be sources of material that

768
00:29:02,630 --> 00:28:56,480
are creating this this very faint rings

769
00:29:08,870 --> 00:29:06,230
great uh fidello on youtube asked if you

770
00:29:11,590 --> 00:29:08,880
marina could pick any target for a probe

771
00:29:12,549 --> 00:29:11,600
mission what would it be

772
00:29:15,190 --> 00:29:12,559
oh

773
00:29:19,110 --> 00:29:15,200
so many targets so many targets

774
00:29:21,750 --> 00:29:19,120
well um triton would be a natural choice

775
00:29:22,870 --> 00:29:21,760
um that is a weird moon as i said you

776
00:29:27,669 --> 00:29:22,880
kind of have

777
00:29:29,350 --> 00:29:27,679
a kuiper belt object um caught around

778
00:29:31,269 --> 00:29:29,360
neptune

779
00:29:33,350 --> 00:29:31,279
and i would also you know narrate always

780
00:29:35,510 --> 00:29:33,360
kind of picks my interest because

781
00:29:38,870 --> 00:29:35,520
um it could be an original satellite of

782
00:29:40,470 --> 00:29:38,880
map too so so so i it's it's it's

783
00:29:43,269 --> 00:29:40,480
perhaps a very

784
00:29:45,430 --> 00:29:43,279
you know different object um so it would

785
00:29:47,590 --> 00:29:45,440
be interesting to to to triton i think i

786
00:29:49,350 --> 00:29:47,600
think triton would be would be something

787
00:29:52,950 --> 00:29:49,360
that i would like but there are many

788
00:29:57,830 --> 00:29:55,430

thank you uh dean on facebook would like

789
00:30:01,750 --> 00:29:57,840
to know how large are the objects that

790
00:30:07,269 --> 00:30:05,190
so i'm not sure objects um so i don't

791
00:30:09,269 --> 00:30:07,279
know so i can tell you if he's asking

792
00:30:11,830 --> 00:30:09,279
about current surveys

793
00:30:13,669 --> 00:30:11,840
uh around jupiter i mentioned that the

794
00:30:15,269 --> 00:30:13,679
outer moons of jupiter that are

795
00:30:17,750 --> 00:30:15,279
currently being found

796
00:30:21,110 --> 00:30:17,760
they're about 500 meters in size so

797
00:30:23,750 --> 00:30:21,120
quite small and saturn um outer moons of

798
00:30:25,350 --> 00:30:23,760
saturn they are um slightly larger

799
00:30:27,909 --> 00:30:25,360
because they said you can't go as deep

800
00:30:30,549 --> 00:30:27,919
saturn is for the way so surveys have

801
00:30:32,630 --> 00:30:30,559
been finding um objects that are about

802
00:30:34,070 --> 00:30:32,640
um you know a few kilometers in size and

803
00:30:35,990 --> 00:30:34,080
and we are estimating there should be

804
00:30:40,630 --> 00:30:36,000
you know probably hundreds of such

805
00:30:44,630 --> 00:30:41,669
thank you

806
00:30:46,789 --> 00:30:44,640
zap fan on youtube asks are any captured

807
00:30:49,830 --> 00:30:46,799
interstellar objects among these

808
00:30:51,350 --> 00:30:49,840
retrograde moons

809
00:30:52,149 --> 00:30:51,360
that's a that's a that's a that's a good

810
00:30:55,190 --> 00:30:52,159
one

811
00:31:01,909 --> 00:30:58,149
i am not i think there could be some

812
00:31:05,269 --> 00:31:01,919
studies um out there that are wondering

813
00:31:08,149 --> 00:31:05,279

about that question i think that i even

814
00:31:11,029 --> 00:31:08,159
i think there was this a moon of jupiter

815
00:31:13,190 --> 00:31:11,039
that they were maybe speculating but but

816
00:31:15,909 --> 00:31:13,200
i'm not i'm not going to i'm not going

817
00:31:18,149 --> 00:31:15,919
to guess because i said it's it's it's

818
00:31:19,750 --> 00:31:18,159
it's in the literature people are very

819
00:31:21,350 --> 00:31:19,760
interested you know so far we had two

820
00:31:22,710 --> 00:31:21,360
interstellar objects visiting their

821
00:31:24,549 --> 00:31:22,720
solar system

822
00:31:26,389 --> 00:31:24,559
um they come in

823
00:31:27,990 --> 00:31:26,399
they can you know they move at such

824
00:31:30,710 --> 00:31:28,000
incredible speed and they come in and

825
00:31:32,470 --> 00:31:30,720
out so fast it would be really not easy

826
00:31:34,870 --> 00:31:32,480
to capture such thing even in

827
00:31:38,149 --> 00:31:34,880
heliocentric orbit let alone um it would

828
00:31:40,789 --> 00:31:38,159
have to be perfect storm that a a

829
00:31:43,590 --> 00:31:40,799
you know a planet ends up catching it

830
00:31:45,110 --> 00:31:43,600
uh but uh you know i think i think you

831
00:31:47,269 --> 00:31:45,120
know it's it's i'm going to check out

832
00:31:48,710 --> 00:31:47,279
after this talk um basically if there

833
00:31:50,149 --> 00:31:48,720
are some papers out there i think that

834
00:31:52,710 --> 00:31:50,159
somebody was already looking into that

835
00:31:56,230 --> 00:31:52,720
but i i'll double my head i i can't i

836
00:32:00,789 --> 00:31:58,789
thanks marina and jimmy on facebook ask

837
00:32:03,669 --> 00:32:00,799
is there a minimum size requirement to

838
00:32:06,230 --> 00:32:03,679

be considered a moon

839
00:32:09,110 --> 00:32:06,240
is there a minimum size well i think

840
00:32:11,350 --> 00:32:09,120
that as long as you're a small object

841
00:32:13,269 --> 00:32:11,360
orbiting a larger object you're

842
00:32:16,789 --> 00:32:13,279
considered the moon i can tell you that

843
00:32:20,389 --> 00:32:16,799
i work with um i work on asteroids

844
00:32:23,509 --> 00:32:20,399
and uh we have some very tiny binary

845
00:32:25,269 --> 00:32:23,519
near-earth asteroids so you know i i

846
00:32:29,830 --> 00:32:25,279
think that the smallest moon that we

847
00:32:32,870 --> 00:32:29,840
observed with radar um is is only maybe

848
00:32:34,789 --> 00:32:32,880
10 20 meters so you know it's it's it

849
00:32:36,630 --> 00:32:34,799
can be really tiny so so you have

850
00:32:38,470 --> 00:32:36,640
presumably you know you know nearest

851
00:32:39,509 --> 00:32:38,480
asteroids you know they they come in all

852
00:32:41,990 --> 00:32:39,519
sizes

853
00:32:44,470 --> 00:32:42,000
um and the smallest binary yeah perhaps

854
00:32:47,509 --> 00:32:44,480
the the the primary is maybe a few tens

855
00:32:49,190 --> 00:32:47,519
of meters and then you have a satellite

856
00:32:51,830 --> 00:32:49,200
as maybe 10 meters

857
00:32:57,029 --> 00:32:51,840
so you know it's it's just a kind of uh

858
00:33:02,870 --> 00:32:59,590
jonathan on linkedin asks what kind of

859
00:33:05,750 --> 00:33:02,880
mapping software do you use

860
00:33:08,789 --> 00:33:05,760
yeah this is uh this is custom in-house

861
00:33:11,590 --> 00:33:08,799
software um that that we built

862
00:33:13,750 --> 00:33:11,600
so so this is um this is kind of you

863
00:33:17,029 --> 00:33:13,760

know jpl software that's been developed

864
00:33:19,350 --> 00:33:17,039
for for many decades and and tested on

865
00:33:22,149 --> 00:33:19,360
on you know many moons and and many

866
00:33:25,750 --> 00:33:23,590
all right lindsay i think we've got time

867
00:33:26,789 --> 00:33:25,760
for one last question oh yeah one last

868
00:33:28,870 --> 00:33:26,799
question

869
00:33:31,909 --> 00:33:28,880
okay sounds good thank you brian and

870
00:33:34,789 --> 00:33:31,919
cliff on facebook ask does our moon have

871
00:33:40,310 --> 00:33:34,799
any mini moons

872
00:33:42,149 --> 00:33:40,320
uh not that i know of

873
00:33:44,470 --> 00:33:42,159
uh that's a good one because it's kind

874
00:33:46,710 --> 00:33:44,480
of one of these kind of neat question

875
00:33:49,830 --> 00:33:46,720
can a moon have a moon

876
00:33:52,549 --> 00:33:49,840
and dynamically it can the answer is yes

877
00:33:54,549 --> 00:33:52,559
but um it is it is probably not

878
00:33:56,789 --> 00:33:54,559
long-lived because kind of everybody's

879
00:33:58,630 --> 00:33:56,799
tugging on it you know you have a planet

880
00:34:00,950 --> 00:33:58,640
that's tugging on it and

881
00:34:02,870 --> 00:34:00,960
and so so it's it's dynamically it's

882
00:34:05,269 --> 00:34:02,880
it's possible but not not for a very

883
00:34:07,029 --> 00:34:05,279
long time

884
00:34:09,030 --> 00:34:07,039
good one good one

885
00:34:11,109 --> 00:34:09,040
that was a great one to end on i'm happy

886
00:34:12,629 --> 00:34:11,119
we got to so many questions tonight that

887
00:34:14,550 --> 00:34:12,639
was wonderful but that is all the time

888
00:34:16,550 --> 00:34:14,560

that we have for tonight uh go ahead and

889
00:34:18,869 --> 00:34:16,560
join us next month for our special earth

890
00:34:21,109 --> 00:34:18,879
day talk i'd like to thank our speaker

891
00:34:23,030 --> 00:34:21,119
dr marina brozovich for taking the time

892
00:34:24,790 --> 00:34:23,040
to share her expertise with us this

893
00:34:26,950 --> 00:34:24,800
evening it was wonderful talk and such

894
00:34:28,629 --> 00:34:26,960
great animations i just loved all of it

895
00:34:30,629 --> 00:34:28,639
thank you to lindsay and everyone behind

896
00:34:32,869 --> 00:34:30,639
the scenes who make these talks possible

897
00:34:35,270 --> 00:34:32,879
and finally a big thank you to all of

898
00:34:38,550 --> 00:34:35,280
you who join us each and every month

899
00:34:42,740 --> 00:34:38,560
stay safe stay kind stay curious and