PUBLIC LECTURE SERIES

Cassini's Grand Finale at Saturn

Featuring Guest Speaker:

Bonnie Meinke

1
00:00:04,430 --> 00:00:02,030
joy to be your host I am dr. Frank

2
00:00:07,789 --> 00:00:04,440
summers of the office of public outreach

3
00:00:10,250 --> 00:00:07,799
and we have an amazing audience here for

4
00:00:13,640 --> 00:00:10,260
you tonight Bonnie Saturn really sells

5
00:00:16,250 --> 00:00:13,650
okay so we have a packed house here

6
00:00:18,650 --> 00:00:16,260
tonight we may not have anymore we have

7
00:00:19,910 --> 00:00:18,660
a couple lithographs down here we

8
00:00:23,150 --> 00:00:19,920
started out giving out the monkey head

9
00:00:25,429 --> 00:00:23,160
nebula we sold out of the monkey head we

10
00:00:27,769 --> 00:00:25,439
had to go to the 30 Doradus which is

11
00:00:28,910 --> 00:00:27,779
also known as the tarantula nebula so if

12
00:00:30,950 --> 00:00:28,920
you didn't get monkeys you got

13
00:00:32,749 --> 00:00:30,960

tarantulas okay and if you're afraid of

14
00:00:35,360 --> 00:00:32,759
spiders well I'm sorry that's all we

15
00:00:38,900 --> 00:00:35,370
have left please come down and grab one

16
00:00:44,900 --> 00:00:38,910
if you didn't on the way in our talk do

17
00:00:50,479 --> 00:00:44,910
I even need to say tonight on our talk

18
00:00:53,150 --> 00:00:50,489
is Cassini's grand finale at saturn and

19
00:00:55,279 --> 00:00:53,160
we've been only waiting 19 years and 11

20
00:00:57,939 --> 00:00:55,289
months for this because that's what

21
00:01:00,500 --> 00:00:57,949
Cassini launched 19 years 11 months ago

22
00:01:03,560 --> 00:01:00,510
absolutely looking forward to it should

23
00:01:06,050 --> 00:01:03,570
it's a lot of fun upcoming next month

24
00:01:09,890 --> 00:01:06,060
Elizabeth Tasker from the Japan

25
00:01:12,730 --> 00:01:09,900
aerospace exploration agency she'll be

26
00:01:16,370 --> 00:01:12,740
coming in and talking about dangerous

27
00:01:19,730 --> 00:01:16,380
worlds yes exoplanets and such all right

28
00:01:24,200 --> 00:01:19,740
and you can see our familiar TBA coming

29
00:01:26,390 --> 00:01:24,210
in in December in January which means I

30
00:01:29,030 --> 00:01:26,400
was working on some stuff for the end of

31
00:01:31,749 --> 00:01:29,040
the fiscal year and didn't nag people to

32
00:01:33,859 --> 00:01:31,759
sign up for talks actually I have one

33
00:01:36,109 --> 00:01:33,869
scheduled for January but we may have to

34
00:01:41,300 --> 00:01:36,119
change that I don't know with the news

35
00:01:43,539 --> 00:01:41,310
so anyways okay so on some of the ninth

36
00:01:48,020 --> 00:01:43,549
great we can do it on the night okay

37
00:01:49,730 --> 00:01:48,030
okay ooh tag team on the 9th okay we

38
00:01:51,620 --> 00:01:49,740

have still have some there's a couple

39
00:01:52,760 --> 00:01:51,630
extra seats down here if the folks

40
00:01:55,249 --> 00:01:52,770
you're standing in the corner would like

41
00:01:56,959 --> 00:01:55,259
to if you have a seat next to you raise

42
00:01:58,850 --> 00:01:56,969
your hand so these guys can don't have

43
00:02:03,620 --> 00:01:58,860
to stand for the whole whole night okay

44
00:02:05,450 --> 00:02:03,630
all right let's see website if you go if

45
00:02:07,880 --> 00:02:05,460
you use your favorite search engine and

46
00:02:10,100 --> 00:02:07,890
look for Hubble public talks you'll find

47
00:02:12,920 --> 00:02:10,110
this page with the list of the upcoming

48
00:02:13,470 --> 00:02:12,930
lectures the links to watching it live

49
00:02:17,400 --> 00:02:13,480
on

50
00:02:19,350 --> 00:02:17,410
as well as in the archive and the boxes

51
00:02:22,020 --> 00:02:19,360
where you can subscribe or even

52
00:02:24,059 --> 00:02:22,030
unsubscribe to our mailing list and get

53
00:02:26,610 --> 00:02:24,069
the monthly reminders of the talks and

54
00:02:28,920 --> 00:02:26,620
actually also we send out the monthly

55
00:02:30,570 --> 00:02:28,930
listings of where is on the webcasts

56
00:02:33,030 --> 00:02:30,580
okay

57
00:02:34,860 --> 00:02:33,040
announcements sign up at the website or

58
00:02:36,570 --> 00:02:34,870
you just give me your email address and

59
00:02:39,509 --> 00:02:36,580
if you have comments or questions you

60
00:02:43,280 --> 00:02:39,519
can send them to public lecture at STScI

61
00:02:45,449 --> 00:02:43,290
dot edu if you would like social media

62
00:02:47,880 --> 00:02:45,459
we have Facebook Twitter YouTube

63
00:02:50,460 --> 00:02:47,890

Instagram and maybe a few more things

64
00:02:52,740 --> 00:02:50,470
that I'm not haven't listed here I

65
00:02:55,860 --> 00:02:52,750
myself I'm on Facebook Google+ and

66
00:02:57,449 --> 00:02:55,870
Twitter every now and then and have a

67
00:03:00,059 --> 00:02:57,459
blog on Hubbell site if you want to

68
00:03:02,039 --> 00:03:00,069
follow me the observatory

69
00:03:04,740 --> 00:03:02,049
yes the weather appears to be permitting

70
00:03:07,440 --> 00:03:04,750
tonight and ireenie sent me a text and

71
00:03:10,140 --> 00:03:07,450
said yes she will be doing it so we will

72
00:03:12,780 --> 00:03:10,150
be meeting at that door over there okay

73
00:03:15,059 --> 00:03:12,790
now unfortunately and it's really hard

74
00:03:19,259 --> 00:03:15,069
to tell an audience of this size she can

75
00:03:21,059 --> 00:03:19,269
only take 15 to 20 people over okay and

76
00:03:24,930 --> 00:03:21,069
I know there's like 200 of you here

77
00:03:26,970 --> 00:03:24,940
tonight so if you have been before

78
00:03:28,800 --> 00:03:26,980
please let somebody else who hasn't been

79
00:03:32,160 --> 00:03:28,810
and if you don't get to go tonight

80
00:03:33,900 --> 00:03:32,170
please come back and and you will be

81
00:03:37,920 --> 00:03:33,910
able to do it after another lecture or

82
00:03:40,470 --> 00:03:37,930
you can go to MD dot space grant o RG

83
00:03:43,590 --> 00:03:40,480
find this webpage and they have open

84
00:03:46,289 --> 00:03:43,600
houses most every Friday evening okay

85
00:03:49,050 --> 00:03:46,299
they update this web page at like 6:00

86
00:03:50,610 --> 00:03:49,060
p.m. or 5 or 6 p.m. on Friday to tell

87
00:03:52,949 --> 00:03:50,620
you whether or not it will be open and

88
00:03:54,750 --> 00:03:52,959

you will get a longer observing session

89
00:03:57,660 --> 00:03:54,760
at their open house then you will get

90
00:03:59,879 --> 00:03:57,670
after the lecture here okay and as we're

91
00:04:04,080 --> 00:03:59,889
going into fall we've just passed the

92
00:04:06,360 --> 00:04:04,090
equinox the nights get longer and so

93
00:04:10,559 --> 00:04:06,370
lots and lots of observing is possible

94
00:04:15,080 --> 00:04:10,569
okay all right and now my part news from

95
00:04:18,589 --> 00:04:15,090
the universe for October 2017

96
00:04:21,490 --> 00:04:18,599
unfortunately the top story tonight is

97
00:04:23,680 --> 00:04:21,500
JWST launch delay

98
00:04:30,130 --> 00:04:23,690
no no no you got to do that all together

99
00:04:32,770 --> 00:04:30,140
one two three thank you okay so this is

100
00:04:35,980 --> 00:04:32,780
the Jay this is a drawing of the James

101
00:04:39,880 --> 00:04:35,990
Webb Space Telescope it will be NASA's

102
00:04:42,760 --> 00:04:39,890
next great Observatory it is an infrared

103
00:04:46,600 --> 00:04:42,770
telescope with a six and a half meter

104
00:04:49,330 --> 00:04:46,610
mirror 18 segments it will be launched

105
00:04:52,060 --> 00:04:49,340
and go out a million miles from Earth so

106
00:04:53,290 --> 00:04:52,070
it is nice and cool and away from the

107
00:04:55,030 --> 00:04:53,300
influence of Earth

108
00:04:57,280 --> 00:04:55,040
it'll have these great Sun shields to

109
00:04:59,380 --> 00:04:57,290
also keep it cool it will do amazing

110
00:05:02,590 --> 00:04:59,390
things it will do things Hubble cannot

111
00:05:04,960 --> 00:05:02,600
do but it won't do them on the time

112
00:05:08,280 --> 00:05:04,970
scale we had hoped it would do them okay

113
00:05:12,460 --> 00:05:08,290

it was slated to launch in October 2018

114
00:05:15,040 --> 00:05:12,470
that is no longer the launch date NASA

115
00:05:17,140 --> 00:05:15,050
had a press release last week and I'm

116
00:05:18,520 --> 00:05:17,150
quoting from it it says is now is

117
00:05:22,300 --> 00:05:18,530
planning to launch between March and

118
00:05:24,760 --> 00:05:22,310
June of 2019 so it's about a six months

119
00:05:26,830 --> 00:05:24,770
slip in the schedule it is not

120
00:05:28,450 --> 00:05:26,840
indicative of hardware or technical

121
00:05:30,360 --> 00:05:28,460
performance concerns they want to make

122
00:05:32,860 --> 00:05:30,370
sure that look everything's going fine

123
00:05:35,020 --> 00:05:32,870
we just want to make sure it's perfect

124
00:05:38,260 --> 00:05:35,030
because unlike Hubble we can't go out

125
00:05:39,820 --> 00:05:38,270
and service this okay so integration of

126
00:05:42,370 --> 00:05:39,830
the various spacecraft elements is

127
00:05:44,230 --> 00:05:42,380
taking longer than expected all right

128
00:05:47,530 --> 00:05:44,240
and they want to make sure they do it

129
00:05:49,750 --> 00:05:47,540
right and one other thing in terms of

130
00:05:52,270 --> 00:05:49,760
the financials the existing program

131
00:05:54,490 --> 00:05:52,280
budget accommodates the change in launch

132
00:05:57,340 --> 00:05:54,500
date so you as taxpayers are not going

133
00:05:59,560 --> 00:05:57,350
to pay extra for this delay it's all

134
00:06:02,409 --> 00:05:59,570
within the program budget they build a

135
00:06:04,719 --> 00:06:02,419
lot of contingencies into these plans

136
00:06:07,320 --> 00:06:04,729
and unfortunately that we've had to add

137
00:06:10,480 --> 00:06:07,330
take take one of those contingencies so

138
00:06:13,630 --> 00:06:10,490

instead of October 2018 we're looking

139
00:06:15,610 --> 00:06:13,640
between March and June of 2019 it will

140
00:06:19,180 --> 00:06:15,620
be worth it though okay

141
00:06:25,360 --> 00:06:19,190
it really will all right our second

142
00:06:26,830 --> 00:06:25,370
story a tale of two comets yes I know I

143
00:06:29,469 --> 00:06:26,840
didn't quite come up with a real

144
00:06:31,420 --> 00:06:29,479
Dickensian story to go here but I just

145
00:06:33,670 --> 00:06:31,430
like the title alright so first of all

146
00:06:34,700 --> 00:06:33,680
what we're talking about here is the

147
00:06:37,490 --> 00:06:34,710
asteroid belt

148
00:06:40,100 --> 00:06:37,500
okay this is the orbit of Jupiter out

149
00:06:41,660 --> 00:06:40,110
here and in here we have in the center

150
00:06:44,300 --> 00:06:41,670
we have the orbits of Mercury Venus

151
00:06:46,280 --> 00:06:44,310
Earth and Mars in between where you see

152
00:06:49,730 --> 00:06:46,290
all these green things and the red

153
00:06:52,610 --> 00:06:49,740
things those are the main belt asteroids

154
00:06:57,080 --> 00:06:52,620
there are several hundred thousand of

155
00:07:00,470 --> 00:06:57,090
these asteroids however also in that

156
00:07:03,740 --> 00:07:00,480
area are a lot of comets a lot of short

157
00:07:09,160 --> 00:07:03,750
period comets and we're gonna talk about

158
00:07:13,400 --> 00:07:09,170
an object that is actually both here so

159
00:07:17,120 --> 00:07:13,410
in November 2006 they discovered an

160
00:07:18,530 --> 00:07:17,130
asteroid and they called it 2006 VW 139

161
00:07:20,540 --> 00:07:18,540
that's thus the standard nomenclature

162
00:07:22,970 --> 00:07:20,550
that we give to asteroids when we

163
00:07:26,480 --> 00:07:22,980

discover them and then they observed the

164
00:07:30,080 --> 00:07:26,490
same object in November 2011 and they

165
00:07:32,750 --> 00:07:30,090
found that it had a tail and tails

166
00:07:35,210 --> 00:07:32,760
indicate that it's a comet so they also

167
00:07:37,820 --> 00:07:35,220
gave it the designation of Comet two

168
00:07:40,940 --> 00:07:37,830
eight eight P alright so it had both

169
00:07:43,460 --> 00:07:40,950
asteroid designations and comet a comet

170
00:07:45,320 --> 00:07:43,470
designation well that's obviously an

171
00:07:47,600 --> 00:07:45,330
interesting object so what are you gonna

172
00:07:50,180 --> 00:07:47,610
do you're gonna take Hubble and you're

173
00:07:54,440 --> 00:07:50,190
gonna look at it and Hubble looked at it

174
00:07:59,360 --> 00:07:54,450
in August of 2016 and Hubble saw this

175
00:08:02,870 --> 00:07:59,370
ooh what do we see we see in the center

176
00:08:05,870 --> 00:08:02,880
not one but two bright spots in the

177
00:08:10,850 --> 00:08:05,880
center so as you can see I've updated it

178
00:08:12,350 --> 00:08:10,860
to be a binary asteroid 2006 WV 139 and

179
00:08:15,770 --> 00:08:12,360
I guess you could call it a double

180
00:08:18,500 --> 00:08:15,780
nucleus comet two eight eight P we have

181
00:08:20,540 --> 00:08:18,510
an object that appears to be two objects

182
00:08:23,900 --> 00:08:20,550
now in examining it and trying to

183
00:08:26,420 --> 00:08:23,910
understand it they estimate that it was

184
00:08:29,870 --> 00:08:26,430
a single object that broke apart about

185
00:08:33,140 --> 00:08:29,880
five thousand years ago and then the

186
00:08:35,330 --> 00:08:33,150
gases that are exposed caused jets and

187
00:08:39,410 --> 00:08:35,340
then the two pieces moved away from each

188
00:08:43,400 --> 00:08:39,420

other okay that also produced material

189
00:08:46,010 --> 00:08:43,410
that streams out as this tail so Hubble

190
00:08:47,000 --> 00:08:46,020
looked at it not just once but five

191
00:08:50,860 --> 00:08:47,010
times

192
00:08:54,790 --> 00:08:50,870
and we looked at in September first in

193
00:08:58,580 --> 00:08:54,800
September ninth in September 20th and

194
00:09:01,340 --> 00:08:58,590
September 29th and what do we see we see

195
00:09:04,640 --> 00:09:01,350
the tail wagging okay

196
00:09:07,220 --> 00:09:04,650
yes comets wag their tails right so here

197
00:09:09,620 --> 00:09:07,230
are those five images but you can see

198
00:09:12,920 --> 00:09:09,630
they only occur over this time scale of

199
00:09:15,260 --> 00:09:12,930
about a month now some of the change of

200
00:09:19,700 --> 00:09:15,270
the orientation of the tail is due to

201
00:09:22,040 --> 00:09:19,710
the geometry of Earth and and the comet

202
00:09:23,720 --> 00:09:22,050
or asteroid as it was but over the

203
00:09:27,590 --> 00:09:23,730
course of a month it wouldn't change

204
00:09:30,020 --> 00:09:27,600
that far so what they really think that

205
00:09:33,140 --> 00:09:30,030
it's also due to different types of

206
00:09:37,010 --> 00:09:33,150
particles being emitted the larger

207
00:09:38,990 --> 00:09:37,020
particles are here these are on order

208
00:09:41,390 --> 00:09:39,000
millimeter sized when I say large we're

209
00:09:43,970 --> 00:09:41,400
talking tiny tiny dust particles okay

210
00:09:45,770 --> 00:09:43,980
this is a dust tail a tiny tiny dust

211
00:09:48,230 --> 00:09:45,780
pyloric is about one millimeter those

212
00:09:51,080 --> 00:09:48,240
are large in astronomical terms here oh

213
00:09:53,030 --> 00:09:51,090

one millimeter in size are blowing off

214
00:09:57,160 --> 00:09:53,040
in this direction due to how they're

215
00:10:00,200 --> 00:09:57,170
being ejected but by this time the

216
00:10:03,200 --> 00:10:00,210
emission the dust was mostly very very

217
00:10:06,290 --> 00:10:03,210
small about 1/100 that size or 10

218
00:10:08,360 --> 00:10:06,300
microns and those 10 micron particles

219
00:10:10,850 --> 00:10:08,370
get actually pushed back by the

220
00:10:13,040 --> 00:10:10,860
radiation pressure of the Sun and so

221
00:10:15,530 --> 00:10:13,050
here is where the tail is actually

222
00:10:18,800 --> 00:10:15,540
pointing away from the Sun like a normal

223
00:10:20,990 --> 00:10:18,810
Comet dust tail does and here is it's

224
00:10:23,630 --> 00:10:21,000
not quite pointing away from the Sun due

225
00:10:26,660 --> 00:10:23,640
to the larger particles in it so we have

226
00:10:30,800 --> 00:10:26,670
a really cool object that's part

227
00:10:35,630 --> 00:10:30,810
asteroid part comet and it's able to wag

228
00:10:38,750 --> 00:10:35,640
its own tail kind of cool all right our

229
00:10:44,030 --> 00:10:38,760
final story for you is candles in the

230
00:10:47,180 --> 00:10:44,040
dark now candles is an acronym for a

231
00:10:49,910 --> 00:10:47,190
cosmic assembly deep extra galactic

232
00:10:53,780 --> 00:10:49,920
legacy survey blah blah blah what it

233
00:10:55,820 --> 00:10:53,790
really is is a huge project to study the

234
00:11:00,530 --> 00:10:55,830
development gap of galaxies over time

235
00:11:03,980 --> 00:11:00,540
they got more orbits on Hubble than any

236
00:11:05,950 --> 00:11:03,990
their project in history over 900 Hubble

237
00:11:08,780 --> 00:11:05,960
orbits and they looked at five different

238
00:11:11,270 --> 00:11:08,790

fields looking very deep into these

239
00:11:13,940 --> 00:11:11,280
fields alright and here's one of them

240
00:11:17,750 --> 00:11:13,950
it's called the ultra deep survey and

241
00:11:20,360 --> 00:11:17,760
this is filled with about twenty thirty

242
00:11:23,780 --> 00:11:20,370
thousand galaxies okay and these

243
00:11:27,320 --> 00:11:23,790
galaxies are spread out across across

244
00:11:30,770 --> 00:11:27,330
space but as we look out into space

245
00:11:32,360 --> 00:11:30,780
we're also looking back into time if you

246
00:11:35,090 --> 00:11:32,370
look a billion years out into space

247
00:11:38,570 --> 00:11:35,100
you're seeing that galaxy as it was a

248
00:11:40,250 --> 00:11:38,580
billion years ago if you go three

249
00:11:44,300 --> 00:11:40,260
billion years that's three billion years

250
00:11:47,030 --> 00:11:44,310
ago some of these galaxies are 10 11 12

251
00:11:50,000 --> 00:11:47,040
billion light years away so we're seeing

252
00:11:53,300 --> 00:11:50,010
them as they were 10 11 12 billion years

253
00:11:55,700 --> 00:11:53,310
ago by statistically looking at those

254
00:11:58,490 --> 00:11:55,710
galaxies at different distances we can

255
00:12:00,770 --> 00:11:58,500
assemble a view of galaxies as they were

256
00:12:04,640 --> 00:12:00,780
at different state ages of the universe

257
00:12:08,120 --> 00:12:04,650
which gives us a picture of how galaxies

258
00:12:09,890 --> 00:12:08,130
development so they gave us this data in

259
00:12:11,240 --> 00:12:09,900
the office of public outreach and we

260
00:12:13,820 --> 00:12:11,250
said well the first thing we want to do

261
00:12:16,460 --> 00:12:13,830
is we want to show people those galaxies

262
00:12:19,280 --> 00:12:16,470
at different distances so we created a

263
00:12:21,680 --> 00:12:19,290

visualization by cutting out into

264
00:12:23,180 --> 00:12:21,690
cutting out every one of those twenty

265
00:12:27,410 --> 00:12:23,190
six thousand three hundred and four

266
00:12:29,390 --> 00:12:27,420
galaxies in the catalog and then placing

267
00:12:32,360 --> 00:12:29,400
them into a computer model at their

268
00:12:34,040 --> 00:12:32,370
correct relative distances now we didn't

269
00:12:36,200 --> 00:12:34,050
put them at their absolute correct

270
00:12:37,970 --> 00:12:36,210
distances because then it would be so

271
00:12:40,160 --> 00:12:37,980
long that the fly-through would take

272
00:12:42,440 --> 00:12:40,170
probably two hours to do we want to do

273
00:12:45,770 --> 00:12:42,450
it in a minute or so so we compress them

274
00:12:50,660 --> 00:12:45,780
in the Z direction but we do have a

275
00:12:52,880 --> 00:12:50,670
relatively scientific the relative

276
00:12:55,520 --> 00:12:52,890
distances are all proper between the

277
00:12:58,580 --> 00:12:55,530
various galaxies okay can we take the

278
00:13:01,160 --> 00:12:58,590
lights down so people can see this cuz

279
00:13:05,300 --> 00:13:01,170
there's a lot of black here take the

280
00:13:08,780 --> 00:13:05,310
lights down there we go that look better

281
00:13:10,880 --> 00:13:08,790
to you guys okay and so here we have the

282
00:14:35,860 --> 00:13:10,890
the visualization of the candles

283
00:14:40,460 --> 00:14:38,120
so that was our experiential

284
00:14:42,410 --> 00:14:40,470
visualization for the candles

285
00:14:43,820 --> 00:14:42,420
alternative survey we also plan on doing

286
00:14:46,460 --> 00:14:43,830
some didactic ones where we'll have

287
00:14:47,870 --> 00:14:46,470
narration and point out some of the the

288
00:14:49,850 --> 00:14:47,880

really cool features of it are the

289
00:14:52,910 --> 00:14:49,860
scientific features of it do we have a

290
00:14:57,530 --> 00:14:52,920
question there you are travelling in a

291
00:14:58,460 --> 00:14:57,540
straight line there was some steering in

292
00:15:00,200 --> 00:14:58,470
a straight line

293
00:15:02,270 --> 00:15:00,210
I actually choreographed the camera to

294
00:15:04,340 --> 00:15:02,280
fly up near that one white galaxy then

295
00:15:06,620 --> 00:15:04,350
down through that cluster that swooped

296
00:15:08,270 --> 00:15:06,630
through to those three red galaxies so

297
00:15:09,890 --> 00:15:08,280
that you would said add something that's

298
00:15:13,930 --> 00:15:09,900
and I sort of thought of it as a

299
00:15:20,360 --> 00:15:16,970
you're traveling about 13 billion light

300
00:15:21,710 --> 00:15:20,370
years in a minute and 13 seconds so

301
00:15:31,010 --> 00:15:21,720
you're violating every known law of

302
00:15:33,380 --> 00:15:31,020
physics object that you saw there is a

303
00:15:35,930 --> 00:15:33,390
galaxy we cleaned out all the stars and

304
00:15:37,730 --> 00:15:35,940
all the other artifacts from it and we

305
00:15:39,590 --> 00:15:37,740
were left with twenty-six thousand three

306
00:15:41,450 --> 00:15:39,600
hundred four galaxies for which we had

307
00:15:44,270 --> 00:15:41,460
both an image and a measured or

308
00:15:52,610 --> 00:15:44,280
estimated redshift from the scientific

309
00:15:55,580 --> 00:15:52,620
team that's a great question so at the

310
00:15:57,680 --> 00:15:55,590
end there we went to black we got to the

311
00:15:59,690 --> 00:15:57,690
end of the data set we got to the

312
00:16:02,300 --> 00:15:59,700
greatest distance that Hubble can see

313
00:16:05,000 --> 00:16:02,310

because the galaxies further than that

314
00:16:13,049 --> 00:16:05,010
their light is redshifted into the

315
00:16:17,699 --> 00:16:14,969
okay one of the reasons we want the Jo

316
00:16:20,729 --> 00:16:17,709
is T is to look deeper into the universe

317
00:16:22,709 --> 00:16:20,739
because the light from those galaxies

318
00:16:23,999 --> 00:16:22,719
isn't the infrared and jaidev's t we'll

319
00:16:26,119 --> 00:16:24,009
be able to see the what's similar

320
00:16:29,669 --> 00:16:26,129
resolution to what Hubble has alright

321
00:16:32,369 --> 00:16:29,679
okay now let's go to our featured

322
00:16:36,329 --> 00:16:32,379
speaker tonight our speaker tonight is

323
00:16:39,299 --> 00:16:36,339
Bonnie bunkie she joined us about five

324
00:16:41,449 --> 00:16:39,309
years ago and she has been in the office

325
00:16:45,509 --> 00:16:41,459
of public outreach ever since that time

326
00:16:47,999 --> 00:16:45,519
but about a month ago she got a new

327
00:16:49,649 --> 00:16:48,009
position she in the office of public

328
00:16:51,959 --> 00:16:49,659
outreach she was one of the liaisons

329
00:16:53,819 --> 00:16:51,969
with the J diversity team she's now

330
00:16:57,209 --> 00:16:53,829
moved over to the Jade Ernestine Mission

331
00:16:59,639 --> 00:16:57,219
office team and is now a liaison oh so

332
00:17:02,849 --> 00:16:59,649
she just jumped over the fence and it's

333
00:17:05,489 --> 00:17:02,859
working with them she is an expert in

334
00:17:08,340 --> 00:17:05,499
SAP and on Saturday and she will here

335
00:17:11,999 --> 00:17:08,350
tonight having done her PhD at the

336
00:17:14,399 --> 00:17:12,009
University of Colorado yes and having

337
00:17:17,309 --> 00:17:14,409
worked at the fleet Reuben H fleet

338
00:17:19,470 --> 00:17:17,319

Science Center yes she didn't give me a

339
00:17:21,919 --> 00:17:19,480
biography she was late to come here so

340
00:17:29,310 --> 00:17:21,929
you have to do this remember

341
00:17:31,990 --> 00:17:29,320
she's overall a wonderful person ladies

342
00:17:40,720 --> 00:17:32,000
please welcome dr. Bonnie Mikey

343
00:17:44,870 --> 00:17:40,730
[Applause]

344
00:17:48,620 --> 00:17:44,880
hi everybody I am overwhelmed and a

345
00:17:51,800 --> 00:17:48,630
little intimidated by the audience no

346
00:17:55,840 --> 00:17:51,810
pressure and lots of familiar faces I'm

347
00:18:00,560 --> 00:17:55,850
very happy to see them I yes so Cassini

348
00:18:02,600 --> 00:18:00,570
sadly just ended how many people tuned

349
00:18:05,020 --> 00:18:02,610
in for some of the big events

350
00:18:08,630 --> 00:18:05,030
surrounding the grand finale

351
00:18:27,980 --> 00:18:08,640
alright lots of Saturn files out there I

352
00:18:30,140 --> 00:18:27,990
have no idea what's going on and yeah so

353
00:18:33,080 --> 00:18:30,150
like Frank said this this is a mission

354
00:18:37,340 --> 00:18:33,090
that launched almost 20 years ago it was

355
00:18:39,350 --> 00:18:37,350
October 15 1997 there are people in the

356
00:18:46,240 --> 00:18:39,360
audience that were even alive then I

357
00:18:50,390 --> 00:18:46,250
suspect there then it got to Saturn in

358
00:18:52,280 --> 00:18:50,400
2004 and I remember when that happened I

359
00:18:54,700 --> 00:18:52,290
was a fresh-faced grad student and I

360
00:18:57,230 --> 00:18:54,710
thought hey this is gonna be my mission

361
00:18:59,270 --> 00:18:57,240
and I kind of can't believe that it's

362
00:19:02,300 --> 00:18:59,280
already at its end thirteen years after

363
00:19:05,930 --> 00:19:02,310

that but one of the really amazing

364
00:19:08,030 --> 00:19:05,940
things about the Cassini mission is that

365
00:19:10,610 --> 00:19:08,040
it didn't just change our view of Saturn

366
00:19:15,890 --> 00:19:10,620
it changed our view of our solar system

367
00:19:19,130 --> 00:19:15,900
and of solar systems everywhere so I'm

368
00:19:20,990 --> 00:19:19,140
gonna walk you through the grand finale

369
00:19:25,520 --> 00:19:21,000
and the tour of everything Cassini

370
00:19:28,190 --> 00:19:25,530
learned as a way to bridge to the other

371
00:19:31,400 --> 00:19:28,200
types of planetary science that we now

372
00:19:35,060 --> 00:19:31,410
know about care about are dedicated to

373
00:19:36,830 --> 00:19:35,070
studying okay and I'm gonna cut to the

374
00:19:38,660 --> 00:19:36,840
chase I'm just gonna go ahead and lay it

375
00:19:42,530 --> 00:19:38,670
all on the table the biggest discoveries

376
00:19:43,760 --> 00:19:42,540
of the Cassini mission icy moons we knew

377
00:19:46,790 --> 00:19:43,770
about a whole bunch of them before we

378
00:19:49,690 --> 00:19:46,800
got there we discovered more and we

379
00:19:52,440 --> 00:19:49,700
discovered of the ones that we already

380
00:19:55,509 --> 00:19:52,450
new really amazing cool new things

381
00:19:57,250 --> 00:19:55,519
planetary rings of course we knew about

382
00:19:58,899 --> 00:19:57,260
Saturn's rings it's the ringed planet

383
00:20:01,600 --> 00:19:58,909
everybody knows about this

384
00:20:05,830 --> 00:20:01,610
Galileo studied it and thought it was

385
00:20:07,870 --> 00:20:05,840
amazing we've learned a whole lot of new

386
00:20:10,330 --> 00:20:07,880
stuff in the last 13 years about those

387
00:20:13,779 --> 00:20:10,340
planetary rings that we didn't know you

388
00:20:15,669 --> 00:20:13,789

know a decade ago and then finally to

389
00:20:17,169 --> 00:20:15,679
plant it itself I think that the Rings

390
00:20:19,240 --> 00:20:17,179
and the moons get so much attention that

391
00:20:22,060 --> 00:20:19,250
the actual planet itself gets ignored in

392
00:20:25,210 --> 00:20:22,070
some ways but it has all kinds of storms

393
00:20:29,789 --> 00:20:25,220
big hurricanes all kinds of wind

394
00:20:34,269 --> 00:20:29,799
patterns really some interesting things

395
00:20:37,080 --> 00:20:34,279
so those those are those from you know a

396
00:20:39,870 --> 00:20:37,090
geologist is excited about those a

397
00:20:42,519 --> 00:20:39,880
meteorologist is excited about those a

398
00:20:46,029 --> 00:20:42,529
dynamicists and orbit celestial

399
00:20:48,460 --> 00:20:46,039
mechanics enthusiast is excited about

400
00:20:49,570 --> 00:20:48,470
those and so we're I'm gonna say I'm

401
00:20:52,419 --> 00:20:49,580
gonna step you through these big

402
00:20:55,000 --> 00:20:52,429
discoveries because like I said they

403
00:20:59,769 --> 00:20:55,010
fundamentally changed our view of Saturn

404
00:21:02,409 --> 00:20:59,779
of our solar system and of other solar

405
00:21:08,889 --> 00:21:02,419
systems and I don't know why my slides

406
00:21:11,139 --> 00:21:08,899
keep jumping around so I'm gonna set the

407
00:21:14,409 --> 00:21:11,149
context a little bit for you guys

408
00:21:17,560 --> 00:21:14,419
show you the Saturn system so this of

409
00:21:20,560 --> 00:21:17,570
course is Saturn the big planet here

410
00:21:22,120 --> 00:21:20,570
these are the rings you have the the

411
00:21:27,090 --> 00:21:22,130
classical rings those are the things

412
00:21:30,879 --> 00:21:27,100
Galileo saw big icy bright pretty rings

413
00:21:33,519 --> 00:21:30,889

but those continue outwards as we skip

414
00:21:34,269 --> 00:21:33,529
through some of the moons and there's an

415
00:21:37,529 --> 00:21:34,279
arrow here

416
00:21:39,580 --> 00:21:37,539
lots and lots more moons out this way

417
00:21:42,759 --> 00:21:39,590
including the biggest moon of the Saturn

418
00:21:44,850 --> 00:21:42,769
system Titan how many Titan fans are out

419
00:21:50,070 --> 00:21:44,860
there

420
00:21:50,730 --> 00:21:50,080
Titan so I got to follow up with you

421
00:21:54,019 --> 00:21:50,740
guys tonight

422
00:21:56,639 --> 00:21:54,029
about about new ideas about Titan okay

423
00:22:00,960 --> 00:21:56,649
we have that big pretty planet it's

424
00:22:02,340 --> 00:22:00,970
mostly hydrogen helium similar to to

425
00:22:04,740 --> 00:22:02,350
Jupiter some more similar to Jupiter

426
00:22:06,840 --> 00:22:04,750
than it is to Uranus and Neptune but as

427
00:22:09,990 --> 00:22:06,850
I'll show Saturn tells us a lot about

428
00:22:12,060 --> 00:22:10,000
all of the giant planets like I said

429
00:22:14,039 --> 00:22:12,070
those broad dense readings and the big

430
00:22:17,490 --> 00:22:14,049
dusty rings and in between there's a

431
00:22:19,610 --> 00:22:17,500
bunch of gaps those gaps actually tell

432
00:22:22,320 --> 00:22:19,620
us a whole lot about other solar systems

433
00:22:25,200 --> 00:22:22,330
so I'll step you through that and

434
00:22:27,990 --> 00:22:25,210
finally all of these cool moons so many

435
00:22:30,899 --> 00:22:28,000
moons okay

436
00:22:33,450 --> 00:22:30,909
let's start out with basically the

437
00:22:35,370 --> 00:22:33,460
atmosphere the storms that happen the

438
00:22:36,710 --> 00:22:35,380

weather that happens on Saturn and what

439
00:22:41,159 --> 00:22:36,720
we've learned with the Cassini mission

440
00:22:43,409 --> 00:22:41,169
so it's changed our view of Saturn we

441
00:22:46,590 --> 00:22:43,419
got there and we knew the atmosphere was

442
00:22:49,830 --> 00:22:46,600
gonna be interesting but from distance

443
00:22:51,930 --> 00:22:49,840
it's not as dynamic looking as what

444
00:22:54,180 --> 00:22:51,940
jupiter has cooper has those big

445
00:22:57,299 --> 00:22:54,190
exciting bands it has the Great Red Spot

446
00:23:00,080 --> 00:22:57,309
this giant hurricane it's lasted for

447
00:23:02,279 --> 00:23:00,090
years and years and years for centuries

448
00:23:05,220 --> 00:23:02,289
we didn't think Saturn was gonna be that

449
00:23:07,320 --> 00:23:05,230
interesting we were wrong scientists

450
00:23:09,600 --> 00:23:07,330
love being wrong it's changed our view

451
00:23:11,220 --> 00:23:09,610
of our solar system because there's

452
00:23:13,350 --> 00:23:11,230
other giant planets as I mentioned

453
00:23:15,299 --> 00:23:13,360
there's Jupiter Saturn Uranus and

454
00:23:18,470 --> 00:23:15,309
Neptune in our in our solar system and

455
00:23:21,419 --> 00:23:18,480
those also have these really complex

456
00:23:23,789 --> 00:23:21,429
atmospheres that we can now tie what

457
00:23:25,379 --> 00:23:23,799
we've learned at Saturn too and finally

458
00:23:28,470 --> 00:23:25,389
it's changed our view of other solar

459
00:23:31,919 --> 00:23:28,480
systems so over the course of Saturn's

460
00:23:35,899 --> 00:23:31,929
are of Cassini's lifetime we have seen

461
00:23:38,460 --> 00:23:35,909
there's a lot of exoplanets out there

462
00:23:41,070 --> 00:23:38,470
you guys throw a little timeline later

463
00:23:43,830 --> 00:23:41,080

but when Cassini launched we only knew

464
00:23:46,680 --> 00:23:43,840
of five other exoplanets five planets

465
00:23:50,669 --> 00:23:46,690
around other stars other worlds beyond

466
00:23:55,139 --> 00:23:50,679
our solar system five one handful and

467
00:23:56,789 --> 00:23:55,149
now we know a thousands so learning

468
00:23:58,650 --> 00:23:56,799
about the types of planets we're seeing

469
00:24:01,040 --> 00:23:58,660
elsewhere is so important

470
00:24:04,620 --> 00:24:01,050
and Cassini helps us study that so let's

471
00:24:07,650 --> 00:24:04,630
dive into the atmosphere here and this

472
00:24:11,580 --> 00:24:07,660
is probably the most iconic of the

473
00:24:14,070 --> 00:24:11,590
Saturn as a planet images this is known

474
00:24:17,850 --> 00:24:14,080
as the hexagon and I'm not talking about

475
00:24:19,050 --> 00:24:17,860
France I'm talking about this amazing

476
00:24:23,460 --> 00:24:19,060
structure here if you notice it's

477
00:24:27,690 --> 00:24:23,470
six-sided one two three four five and

478
00:24:28,140 --> 00:24:27,700
six it's a ball it's in the this is the

479
00:24:29,910 --> 00:24:28,150
North Pole

480
00:24:34,140 --> 00:24:29,920
right here so this is looking straight

481
00:24:36,090 --> 00:24:34,150
down onto Saturn and you can see in this

482
00:24:39,570 --> 00:24:36,100
this this false-color or

483
00:24:40,890 --> 00:24:39,580
representational color image that

484
00:24:42,240 --> 00:24:40,900
there's a whole bunch of structure here

485
00:24:46,410 --> 00:24:42,250
in the atmosphere these are all

486
00:24:51,990 --> 00:24:46,420
different storms knots of different wind

487
00:24:56,160 --> 00:24:52,000
patterns and density clusters inside the

488
00:24:57,750 --> 00:24:56,170

atmosphere and you can think of that

489
00:24:59,730 --> 00:24:57,760
this looks strange we thought we had

490
00:25:03,180 --> 00:24:59,740
seen it with other means other

491
00:25:05,610 --> 00:25:03,190
observations both ground-based and and a

492
00:25:06,960 --> 00:25:05,620
Voyager flyby we thought we'd seen this

493
00:25:09,960 --> 00:25:06,970
hexagonal structure but we weren't

494
00:25:12,510 --> 00:25:09,970
really sure and it didn't quite click we

495
00:25:16,320 --> 00:25:12,520
weren't sure why this would exist and if

496
00:25:19,740 --> 00:25:16,330
it could exist for decades but now we

497
00:25:21,330 --> 00:25:19,750
know it's there we confirmed it and one

498
00:25:23,790 --> 00:25:21,340
of the cool things about the Cassini

499
00:25:25,800 --> 00:25:23,800
mission is it has several instruments

500
00:25:27,650 --> 00:25:25,810
and each one of those instruments looks

501
00:25:29,460 --> 00:25:27,660
at a different wavelength of light

502
00:25:33,200 --> 00:25:29,470
basically a different color of light

503
00:25:35,610 --> 00:25:33,210
some of which our eyes can't see and

504
00:25:38,550 --> 00:25:35,620
some of those colors help us look

505
00:25:42,480 --> 00:25:38,560
through things so this is this is

506
00:25:45,930 --> 00:25:42,490
actually an infrared image it looks down

507
00:25:49,950 --> 00:25:45,940
into the layers of Saturn's upper

508
00:25:54,660 --> 00:25:49,960
atmosphere and we can then see that the

509
00:26:01,620 --> 00:25:54,670
thing that makes this this hexagon this

510
00:26:05,250 --> 00:26:01,630
pattern of airflow is a jet stream

511
00:26:07,350 --> 00:26:05,260
there's a jet stream at a lower level of

512
00:26:10,340 --> 00:26:07,360
the atmosphere that is causing this

513
00:26:11,779 --> 00:26:10,350

pattern to be set up

514
00:26:14,390 --> 00:26:11,789
this is actually kind of like a standing

515
00:26:16,370 --> 00:26:14,400
wave if you've ever had a rope with a

516
00:26:18,110 --> 00:26:16,380
have another friend hold the other side

517
00:26:20,419 --> 00:26:18,120
of the rope like a jump rope or had it

518
00:26:22,490 --> 00:26:20,429
connected to a wall and eventually you

519
00:26:25,970 --> 00:26:22,500
can just get to go up and down up and

520
00:26:28,039 --> 00:26:25,980
down so instead of just doing this the

521
00:26:30,020 --> 00:26:28,049
Rope just goes up down up down up down

522
00:26:31,730 --> 00:26:30,030
that's a standing wave the pattern

523
00:26:32,510 --> 00:26:31,740
actually really doesn't change this is a

524
00:26:37,360 --> 00:26:32,520
standing wave

525
00:26:40,510 --> 00:26:37,370
except it's huge and it's six sided and

526
00:26:44,779 --> 00:26:40,520
it's really interesting and also

527
00:26:46,640 --> 00:26:44,789
coincidentally beautiful really cool so

528
00:26:48,320 --> 00:26:46,650
we learn lots of lots about what's going

529
00:26:51,190 --> 00:26:48,330
on with the interior structure of Saturn

530
00:26:55,850 --> 00:26:51,200
this way oh and if you look closely

531
00:26:58,419 --> 00:26:55,860
you'll see this hard right in the very

532
00:27:02,810 --> 00:26:58,429
center right at the North Pole this is

533
00:27:05,380 --> 00:27:02,820
what's been called the Rose because it

534
00:27:08,510 --> 00:27:05,390
was cleverly colored in red in this

535
00:27:10,970 --> 00:27:08,520
representation or color image and it

536
00:27:13,850 --> 00:27:10,980
does look like a beautiful rose this is

537
00:27:17,000 --> 00:27:13,860
a giant hurricane right at the North

538
00:27:20,350 --> 00:27:17,010

Pole and this has told us a lot about

539
00:27:23,000 --> 00:27:20,360
how giant planet atmospheres might work

540
00:27:24,560 --> 00:27:23,010
because we're not just again remember I

541
00:27:26,270 --> 00:27:24,570
said that different wavelengths of light

542
00:27:28,549 --> 00:27:26,280
could probe different levels of

543
00:27:31,549 --> 00:27:28,559
atmosphere that means we can see

544
00:27:34,789 --> 00:27:31,559
vertical structures being able to see

545
00:27:37,130 --> 00:27:34,799
how tall a storm is is really important

546
00:27:40,070 --> 00:27:37,140
to understanding how it forms how it

547
00:27:42,140 --> 00:27:40,080
works the dynamics of it um have you

548
00:27:43,970 --> 00:27:42,150
guys ever been out on a summer day and

549
00:27:47,080 --> 00:27:43,980
you see a thunderstorm forming in the

550
00:27:50,029 --> 00:27:47,090
distance and you see that the clouds

551
00:27:55,250 --> 00:27:50,039
billow up and it forms kind of an anvil

552
00:27:57,169 --> 00:27:55,260
shape you and then you say oh I better

553
00:27:58,940 --> 00:27:57,179
get inside or I better drive home from

554
00:28:00,830 --> 00:27:58,950
work right now because that's gonna be a

555
00:28:01,909 --> 00:28:00,840
huge thunderstorm and I know what's

556
00:28:03,730 --> 00:28:01,919
gonna rain and I know there's gonna be

557
00:28:05,899 --> 00:28:03,740
Sun during lightning I better get home

558
00:28:08,120 --> 00:28:05,909
that's the same kind of thing that we're

559
00:28:09,980 --> 00:28:08,130
learning about here those verticals that

560
00:28:15,799 --> 00:28:09,990
vertical structure is really important

561
00:28:18,289 --> 00:28:15,809
to informing us how this works another

562
00:28:22,880 --> 00:28:18,299
example of the amazing storms we've seen

563
00:28:24,000 --> 00:28:22,890

on Saturn is this guy right here - see

564
00:28:27,690 --> 00:28:24,010
it's starting to form over here this

565
00:28:30,570 --> 00:28:27,700
regular quiet Saturn nothing too

566
00:28:32,130 --> 00:28:30,580
exciting happening like I mentioned

567
00:28:35,580 --> 00:28:32,140
before you know no no huge bands

568
00:28:38,040 --> 00:28:35,590
typically an in regular visible light

569
00:28:40,650 --> 00:28:38,050
Saturn looks kind of yellow kind of

570
00:28:45,780 --> 00:28:40,660
orange nothing big and bold happening

571
00:28:49,500 --> 00:28:45,790
and then we see a storm form and slowly

572
00:28:52,220 --> 00:28:49,510
that storm creates awake as different

573
00:28:54,930 --> 00:28:52,230
layers of the atmosphere move around it

574
00:28:58,440 --> 00:28:54,940
and you can see this time series where

575
00:29:01,560 --> 00:28:58,450
then it keeps going along into a long

576
00:29:03,840 --> 00:29:01,570
band and it wraps itself all the way

577
00:29:09,540 --> 00:29:03,850
around Saturn and eventually you have a

578
00:29:11,070 --> 00:29:09,550
very interesting curly fringed band so

579
00:29:12,720 --> 00:29:11,080
that's telling us how we've learned a

580
00:29:16,920 --> 00:29:12,730
lot does this happened over the course

581
00:29:20,760 --> 00:29:16,930
of several months and this thing lasted

582
00:29:22,650 --> 00:29:20,770
a couple years I think and so through

583
00:29:27,990 --> 00:29:22,660
this we were able to really learn about

584
00:29:30,600 --> 00:29:28,000
how storms form how they persist what

585
00:29:31,620 --> 00:29:30,610
may be causing them to to die out and

586
00:29:33,270 --> 00:29:31,630
quiet down

587
00:29:34,890 --> 00:29:33,280
so this also tells us about stuff on our

588
00:29:37,250 --> 00:29:34,900

own planet right we know about

589
00:29:40,800 --> 00:29:37,260
hurricanes hurricanes exist on earth and

590
00:29:43,200 --> 00:29:40,810
when you're over the ocean especially

591
00:29:45,330 --> 00:29:43,210
when it's warm you have the the moisture

592
00:29:47,130 --> 00:29:45,340
you have the heat that hurricane can

593
00:29:49,710 --> 00:29:47,140
build up and build up and build up and

594
00:29:51,870 --> 00:29:49,720
get really strong but the second it hits

595
00:29:54,480 --> 00:29:51,880
land you lose the moisture and it may

596
00:29:56,820 --> 00:29:54,490
die out the second it hits goes too far

597
00:30:00,900 --> 00:29:56,830
north and it hits some cold water it may

598
00:30:04,200 --> 00:30:00,910
die out so what a storm that persist is

599
00:30:07,440 --> 00:30:04,210
telling us is what's going on underneath

600
00:30:10,380 --> 00:30:07,450
what is giving the storm its power what

601
00:30:12,630 --> 00:30:10,390
is driving that storm so learning about

602
00:30:15,660 --> 00:30:12,640
how these work on Saturn really tells us

603
00:30:20,610 --> 00:30:15,670
a lot about how these work elsewhere for

604
00:30:23,120 --> 00:30:20,620
example Jupiter so toward the end of the

605
00:30:27,660 --> 00:30:23,130
Cassini mission we have the fantastic

606
00:30:29,730 --> 00:30:27,670
sibling the sibling spacecraft that goes

607
00:30:34,440 --> 00:30:29,740
out to Jupiter called the Juno mission

608
00:30:36,549 --> 00:30:34,450
and Juno mission has Juno cam which is

609
00:30:38,830 --> 00:30:36,559
actually a public outreach in

610
00:30:40,450 --> 00:30:38,840
it was not intended for science but

611
00:30:41,919 --> 00:30:40,460
we're seeing some amazing images come

612
00:30:44,019 --> 00:30:41,929
back from it that we're doing some

613
00:30:46,899 --> 00:30:44,029

science with you can compare this sort

614
00:30:48,310 --> 00:30:46,909
of storm on Jupiter you can see some

615
00:30:50,110 --> 00:30:48,320
vertical structure there are some other

616
00:30:53,440 --> 00:30:50,120
interesting things to what we seen on

617
00:30:58,810 --> 00:30:53,450
Saturn or you can look at things like

618
00:31:01,210 --> 00:30:58,820
this this is Neptune every image I can

619
00:31:03,580 --> 00:31:01,220
see in the first like three pages of a

620
00:31:06,940 --> 00:31:03,590
Google search on Neptune images is this

621
00:31:09,669 --> 00:31:06,950
image or some version of it it has this

622
00:31:11,230 --> 00:31:09,679
big storm here and I know Frank's talked

623
00:31:12,430 --> 00:31:11,240
about this storm before I think Anna

624
00:31:14,470 --> 00:31:12,440
news from the universe or something

625
00:31:16,239 --> 00:31:14,480
before at a public lecture series that

626
00:31:19,210 --> 00:31:16,249
storm doesn't exist anymore

627
00:31:21,340 --> 00:31:19,220
it hasn't existed for years and we know

628
00:31:23,799 --> 00:31:21,350
this but this is such an interesting

629
00:31:26,109 --> 00:31:23,809
image that this is the Neptune image

630
00:31:28,419 --> 00:31:26,119
that everybody associates with it

631
00:31:32,799 --> 00:31:28,429
this storm probably only lasted a few

632
00:31:35,139 --> 00:31:32,809
years but Neptune is different then say

633
00:31:37,180 --> 00:31:35,149
Jupiter Neptune is farther out from the

634
00:31:39,899 --> 00:31:37,190
Sun so it's cooler it's made of

635
00:31:42,460 --> 00:31:39,909
different stuff like there's ammonia and

636
00:31:46,090 --> 00:31:42,470
some other like not it's not hydrogen

637
00:31:47,320 --> 00:31:46,100
helium like like Jupiter and Saturn lots

638
00:31:51,489 --> 00:31:47,330

of other things going on in the

639
00:31:53,320 --> 00:31:51,499
atmosphere so what we're learning is by

640
00:31:54,460 --> 00:31:53,330
looking at just the four examples in our

641
00:31:57,549 --> 00:31:54,470
solar system

642
00:32:01,029 --> 00:31:57,559
how much fears are different there's no

643
00:32:03,399 --> 00:32:01,039
cookie cutter formula for how these

644
00:32:05,919 --> 00:32:03,409
things work and now that we have

645
00:32:08,289 --> 00:32:05,929
thousands of candidates of exoplanets

646
00:32:10,899 --> 00:32:08,299
many of which are gas giants of some

647
00:32:13,029 --> 00:32:10,909
sort we can now start to put the pieces

648
00:32:17,590 --> 00:32:13,039
together and learn more about how these

649
00:32:22,539 --> 00:32:17,600
things work and not expect as scientists

650
00:32:25,509 --> 00:32:22,549
who model these things can't expect them

651
00:32:27,310 --> 00:32:25,519
all to work the same way especially when

652
00:32:29,440 --> 00:32:27,320
they're in different circumstances say

653
00:32:30,850 --> 00:32:29,450
you have a gas giant that's off that's a

654
00:32:33,639 --> 00:32:30,860
hot Jupiter who's here heard of a hot

655
00:32:36,220 --> 00:32:33,649
Jupiter that's something roughly Jupiter

656
00:32:40,590 --> 00:32:36,230
sized that's really close into the star

657
00:32:44,320 --> 00:32:40,600
closer than mercury is to our Sun so

658
00:32:45,609 --> 00:32:44,330
it's really hot right they're so hot in

659
00:32:47,919 --> 00:32:45,619
fact that you know the the atmosphere

660
00:32:49,320 --> 00:32:47,929
could bubble away could evaporate away

661
00:32:51,480 --> 00:32:49,330
from the heat of the Sun

662
00:32:52,770 --> 00:32:51,490
um it's so close that it's tidally

663
00:32:54,270 --> 00:32:52,780

locked that means there's one side

664
00:32:59,670 --> 00:32:54,280
that's always daytime one side that's

665
00:33:01,380 --> 00:32:59,680
always nighttime it could it could be

666
00:33:03,150 --> 00:33:01,390
really far far far far far far far away

667
00:33:06,900 --> 00:33:03,160
and be very very cold but still really

668
00:33:08,730 --> 00:33:06,910
big what happens there we we need to

669
00:33:10,890 --> 00:33:08,740
answer cities and so studying saying

670
00:33:12,690 --> 00:33:10,900
that what I call our backyard Laboratory

671
00:33:15,390 --> 00:33:12,700
versus that solar system is really

672
00:33:18,180 --> 00:33:15,400
important because now we have all these

673
00:33:19,950 --> 00:33:18,190
candidates we want to know what's going

674
00:33:21,450 --> 00:33:19,960
on with them we want to know how these

675
00:33:24,780 --> 00:33:21,460
work we also are finding out

676
00:33:26,520 --> 00:33:24,790
compositional information every day the

677
00:33:28,860 --> 00:33:26,530
Webb telescope is going to tell us what

678
00:33:31,770 --> 00:33:28,870
these atmospheres are made of and we

679
00:33:33,270 --> 00:33:31,780
need what we call ground truth the

680
00:33:36,750 --> 00:33:33,280
Cassini mission has given us some ground

681
00:33:39,720 --> 00:33:36,760
truth some some really concrete evidence

682
00:33:44,150 --> 00:33:39,730
nearby of something that we know of that

683
00:33:48,150 --> 00:33:44,160
we have observed for a long time and we

684
00:33:50,100 --> 00:33:48,160
we can compare to I turn them all use

685
00:33:53,220 --> 00:33:50,110
later and throughout this talk is

686
00:33:55,140 --> 00:33:53,230
comparative planetology so that's really

687
00:33:58,040 --> 00:33:55,150
important for what we're doing and what

688
00:34:00,450 --> 00:33:58,050

the Cassini mission has contributed okay

689
00:34:02,010 --> 00:34:00,460
Owen the planetary wings

690
00:34:03,540 --> 00:34:02,020
you saw that I talked a lot about

691
00:34:05,730 --> 00:34:03,550
atmospheres wait till you get me started

692
00:34:07,980 --> 00:34:05,740
on the planetary rings I love planetary

693
00:34:13,680 --> 00:34:07,990
rings that's my background I'm all about

694
00:34:14,970 --> 00:34:13,690
the Rings so for Saturn itself we

695
00:34:17,160 --> 00:34:14,980
weren't really sure about the Rings when

696
00:34:20,700 --> 00:34:17,170
we got there we've seen some cool stuff

697
00:34:23,520 --> 00:34:20,710
with Voyager we've seen some cool stuff

698
00:34:26,340 --> 00:34:23,530
from the ground but we weren't really

699
00:34:28,680 --> 00:34:26,350
sure what we've learned is the ring

700
00:34:31,860 --> 00:34:28,690
rings are ancient they've probably

701
00:34:34,260 --> 00:34:31,870
formed with Saturn they're massive

702
00:34:36,480 --> 00:34:34,270
they're probably you know a fractional

703
00:34:39,150 --> 00:34:36,490
size of a moon which is way bigger than

704
00:34:41,610 --> 00:34:39,160
we thought they were going to be they

705
00:34:44,670 --> 00:34:41,620
have all kinds of complex structures

706
00:34:48,720 --> 00:34:44,680
inside including small moons that we

707
00:34:51,170 --> 00:34:48,730
call moonlets they have the change on

708
00:34:53,760 --> 00:34:51,180
small timescales human timescales

709
00:34:57,330 --> 00:34:53,770
Cassini life time schedules which is

710
00:34:58,650 --> 00:34:57,340
unheard of for astronomical objects you

711
00:35:00,780 --> 00:34:58,660
know we're not dealing with millions and

712
00:35:03,030 --> 00:35:00,790
billions of years for a change we're

713
00:35:05,670 --> 00:35:03,040

talking about weeks

714
00:35:07,140 --> 00:35:05,680
months I once did a paper where I

715
00:35:13,410 --> 00:35:07,150
measured how things changed over the

716
00:35:15,420 --> 00:35:13,420
course of 28 days what you know you know

717
00:35:17,880 --> 00:35:15,430
the grass and my the the grass in my

718
00:35:21,200 --> 00:35:17,890
yard at home grows on the same time

719
00:35:23,640 --> 00:35:21,210
scales that some of these things happen

720
00:35:27,450 --> 00:35:23,650
thank goodness I don't have to mow the

721
00:35:31,260 --> 00:35:27,460
Rings okay it also changed our view of

722
00:35:34,380 --> 00:35:31,270
our solar system Ksenia our Saturn is

723
00:35:37,260 --> 00:35:34,390
not the only planet with rings Jupiter

724
00:35:40,320 --> 00:35:37,270
Uranus and Neptune also have rings

725
00:35:41,820 --> 00:35:40,330
they're different but now we know the

726
00:35:44,760 --> 00:35:41,830
ring systems are not necessarily

727
00:35:46,710 --> 00:35:44,770
temporary this makes sense because we

728
00:35:48,990 --> 00:35:46,720
see them around all four of the large

729
00:35:53,150 --> 00:35:49,000
planets in our solar system so it clicks

730
00:35:55,770 --> 00:35:53,160
and these rings are constantly evolving

731
00:35:57,960 --> 00:35:55,780
again helping us piece together the

732
00:35:59,280 --> 00:35:57,970
puzzles for these rings especially on

733
00:36:01,860 --> 00:35:59,290
Uranus and Neptune that we haven't

734
00:36:04,320 --> 00:36:01,870
gotten a really good look at we've only

735
00:36:06,990 --> 00:36:04,330
gotten some some Voyager data back from

736
00:36:09,360 --> 00:36:07,000
them so we really want to know more and

737
00:36:11,550 --> 00:36:09,370
finally told us about other solar

738
00:36:13,500 --> 00:36:11,560

systems so I'm not talking about the

739
00:36:15,900 --> 00:36:13,510
ring systems in other solar system I'm

740
00:36:18,840 --> 00:36:15,910
talking about the disks that surround

741
00:36:21,870 --> 00:36:18,850
those other Suns that planets are born

742
00:36:26,490 --> 00:36:21,880
from the rings are an excellent example

743
00:36:29,330 --> 00:36:26,500
of an Astrophysical disc and another

744
00:36:33,450 --> 00:36:29,340
example of an Astrophysical disc is a

745
00:36:37,290 --> 00:36:33,460
protoplanetary disc the the gas and dust

746
00:36:39,990 --> 00:36:37,300
and debris that forms new planets and by

747
00:36:42,780 --> 00:36:40,000
looking at Saturn and the Rings and how

748
00:36:48,030 --> 00:36:42,790
moons form in those rings we can learn

749
00:36:51,770 --> 00:36:48,040
about how complex worlds are built in

750
00:36:55,680 --> 00:36:51,780
the debris disks around new stars okay

751
00:36:59,940 --> 00:36:55,690
let's set the context again broad dense

752
00:37:02,820 --> 00:36:59,950
rings the classical rings ABC the gaps

753
00:37:05,430 --> 00:37:02,830
within those classical rings and then

754
00:37:07,750 --> 00:37:05,440
this huge dusty component which

755
00:37:14,050 --> 00:37:07,760
encompasses the E

756
00:37:16,240 --> 00:37:14,060
jee-in the Phoebe ring alright and what

757
00:37:19,390 --> 00:37:16,250
are Saturn's rings made of they are made

758
00:37:21,820 --> 00:37:19,400
of water ice so for those of you from

759
00:37:24,370 --> 00:37:21,830
Philadelphia I apologize it's not some

760
00:37:28,800 --> 00:37:24,380
delicious treat when I say water ice I'm

761
00:37:33,610 --> 00:37:28,810
talking about h2o so this is actual ice

762
00:37:36,550 --> 00:37:33,620
that is in all kinds of sizes so it's

763
00:37:39,430 --> 00:37:36,560

huge distribution from from dust sized

764
00:37:43,620 --> 00:37:39,440
grains of ice all the way up to things

765
00:37:46,470 --> 00:37:43,630
the size of cars and houses we have

766
00:37:49,090 --> 00:37:46,480
these things are constantly moving

767
00:37:50,800 --> 00:37:49,100
smashing into each other sticking and

768
00:37:53,080 --> 00:37:50,810
then those things are hitting each other

769
00:37:57,190 --> 00:37:53,090
and pulling each other apart this is a

770
00:37:59,320 --> 00:37:57,200
constant swirl of activity and what the

771
00:38:02,190 --> 00:37:59,330
Cassini mission has really shown us is

772
00:38:05,350 --> 00:38:02,200
how dynamic these rings are that this

773
00:38:09,720 --> 00:38:05,360
process of smashing and accretion and

774
00:38:12,640 --> 00:38:09,730
destruction is constantly happening

775
00:38:15,040 --> 00:38:12,650
okay so what we're really learning is

776
00:38:18,250 --> 00:38:15,050
that the Saturn system is not a ring

777
00:38:20,620 --> 00:38:18,260
system it is a ring moon system and

778
00:38:22,780 --> 00:38:20,630
these rings and moons are constantly

779
00:38:28,120 --> 00:38:22,790
doing a dance

780
00:38:29,860 --> 00:38:28,130
there are 62 named moons but I like to

781
00:38:32,320 --> 00:38:29,870
say that there are billions and billions

782
00:38:34,780 --> 00:38:32,330
of moons at Saturn because each one of

783
00:38:37,120 --> 00:38:34,790
those little particles in the Rings is a

784
00:38:40,060 --> 00:38:37,130
moon they're all orbiting Saturn

785
00:38:43,000 --> 00:38:40,070
together in this beautiful dance so

786
00:38:49,060 --> 00:38:43,010
let's zoom in into the outer be ring

787
00:38:51,690 --> 00:38:49,070
edge and we see vertical structure the

788
00:38:54,930 --> 00:38:51,700

Cassini mission was there for equinox

789
00:39:00,880 --> 00:38:54,940
equinoxes when the tilt of the Rings

790
00:39:03,130 --> 00:39:00,890
perfectly lines up with the the plane of

791
00:39:07,900 --> 00:39:03,140
our solar system so that the Sun is

792
00:39:10,390 --> 00:39:07,910
perfectly on edge and there's no so that

793
00:39:13,540 --> 00:39:10,400
means that it casts shadows anything

794
00:39:16,930 --> 00:39:13,550
sticking up from that flat plane of the

795
00:39:18,670 --> 00:39:16,940
Rings is going to cast a shadow this

796
00:39:22,200 --> 00:39:18,680
really helped us because we saw at the

797
00:39:26,040 --> 00:39:22,210
outer edge of the B ring we saw man

798
00:39:29,640 --> 00:39:26,050
these are all mountains and it's not an

799
00:39:32,330 --> 00:39:29,650
even distribution it's really really

800
00:39:35,070 --> 00:39:32,340
kind of a funky look in no symmetry

801
00:39:39,030 --> 00:39:35,080
these are I said these are mountains

802
00:39:41,370 --> 00:39:39,040
these are thousands of feet tall and we

803
00:39:44,940 --> 00:39:41,380
see those those those cool shadows

804
00:39:47,430 --> 00:39:44,950
coming out from them so we know what how

805
00:39:49,920 --> 00:39:47,440
tall they actually are so then it comes

806
00:39:52,830 --> 00:39:49,930
down to the dynamicists and we

807
00:39:55,560 --> 00:39:52,840
dynamicists looked at this and we've

808
00:39:56,970 --> 00:39:55,570
tracked out where other moons were we

809
00:40:01,590 --> 00:39:56,980
tried to figure out what was causing

810
00:40:04,800 --> 00:40:01,600
this and we said that's no moon well

811
00:40:08,010 --> 00:40:04,810
actually it is it's called - or Mimas

812
00:40:09,660 --> 00:40:08,020
people say it both ways and this is a

813
00:40:11,820 --> 00:40:09,670

moon that's just outside of the

814
00:40:16,230 --> 00:40:11,830
classical rings that's where its orbit

815
00:40:18,240 --> 00:40:16,240
is and it picks on the ring particles it

816
00:40:21,990 --> 00:40:18,250
tugs on them just a little bit with its

817
00:40:24,210 --> 00:40:22,000
gravity tug tug tug and just like you

818
00:40:25,620 --> 00:40:24,220
might have a tub of water and when you

819
00:40:28,830 --> 00:40:25,630
move it back and forth it actually

820
00:40:31,680 --> 00:40:28,840
sloshes so that stuff comes up the waves

821
00:40:34,170 --> 00:40:31,690
come up out of the tub that's what's

822
00:40:37,710 --> 00:40:34,180
happening here so we have vertical

823
00:40:41,070 --> 00:40:37,720
structure because of the sloshing that -

824
00:40:42,540 --> 00:40:41,080
causes so this causes vertical but if

825
00:40:44,130 --> 00:40:42,550
you were to look down on a vertical

826
00:40:46,380 --> 00:40:44,140
you'd really just see a density

827
00:40:50,070 --> 00:40:46,390
enhancement so you'd see a big clump of

828
00:40:52,080 --> 00:40:50,080
stuff it's very thick there and when we

829
00:40:53,880 --> 00:40:52,090
look at other solar systems other

830
00:40:57,510 --> 00:40:53,890
forming solar system we see a disc

831
00:40:59,700 --> 00:40:57,520
around a star so this is where that star

832
00:41:02,040 --> 00:40:59,710
would be this is the whole disc and you

833
00:41:05,880 --> 00:41:02,050
can see that's not a pretty uniform disc

834
00:41:09,390 --> 00:41:05,890
there are bright spots here kind of over

835
00:41:11,790 --> 00:41:09,400
here and empty spots up here that looks

836
00:41:14,040 --> 00:41:11,800
surprisingly like the kinds of weird

837
00:41:16,070 --> 00:41:14,050
structures we see at the B rings edge so

838
00:41:18,950 --> 00:41:16,080

a ring scientist sees that and says oh

839
00:41:23,790 --> 00:41:18,960
there's a planet there there's a planet

840
00:41:27,360 --> 00:41:23,800
so what we can learn from rings applies

841
00:41:30,690 --> 00:41:27,370
to protoplanetary discs - debris disks

842
00:41:33,240 --> 00:41:30,700
that sort of thing just for comparison

843
00:41:34,450 --> 00:41:33,250
this is this is really big this here

844
00:41:36,790 --> 00:41:34,460
would be

845
00:41:40,210 --> 00:41:36,800
Oh's orbit in our solar system so you

846
00:41:43,210 --> 00:41:40,220
can you can match how big this disk

847
00:41:44,950 --> 00:41:43,220
really is I mean the dynamicists can map

848
00:41:48,250 --> 00:41:44,960
that and figure out where to look for

849
00:41:50,410 --> 00:41:48,260
the planet in this system okay so let's

850
00:41:54,010 --> 00:41:50,420
go back to Saturn's rings for another

851
00:41:56,680 --> 00:41:54,020
example out to the Aerie the airing is

852
00:41:58,180 --> 00:41:56,690
where we see these gaps and we knew

853
00:41:59,920 --> 00:41:58,190
about this before Cassini we knew there

854
00:42:02,470 --> 00:41:59,930
were two gaps in the a ring

855
00:42:05,920 --> 00:42:02,480
there was the inky gap and the Keeler

856
00:42:08,260 --> 00:42:05,930
gap an inky gap was was big enough to

857
00:42:12,190 --> 00:42:08,270
really see pretty well the Keeler gap

858
00:42:16,390 --> 00:42:12,200
was very thin with the inky gap we saw a

859
00:42:19,480 --> 00:42:16,400
moon we call that pan and we saw it I

860
00:42:21,220 --> 00:42:19,490
mean we didn't know what Pam looked like

861
00:42:26,109 --> 00:42:21,230
till we got there but basically it's a

862
00:42:28,990 --> 00:42:26,119
sad twisted little potato you know maybe

863
00:42:33,130 --> 00:42:29,000

maybe the size of Manhattan Island

864
00:42:35,020 --> 00:42:33,140
something like that but we only saw the

865
00:42:35,470 --> 00:42:35,030
Keeler gap we didn't see anything inside

866
00:42:38,920 --> 00:42:35,480
of it

867
00:42:42,250 --> 00:42:38,930
so we thought well what else could

868
00:42:45,970 --> 00:42:42,260
cleared this whole gap there must be a

869
00:42:50,109 --> 00:42:45,980
moon there so Cassini looks for it and

870
00:42:52,960 --> 00:42:50,119
Cassini found it in this gap this Keeler

871
00:42:55,180 --> 00:42:52,970
gap that is only about 40 kilometers

872
00:42:58,810 --> 00:42:55,190
wide we were able to find it even

873
00:43:02,829 --> 00:42:58,820
smaller even sadder even more twisted

874
00:43:06,520 --> 00:43:02,839
and rotten potato and so we gave it the

875
00:43:08,740 --> 00:43:06,530
lovely name Daphna s-- and we learned

876
00:43:12,550 --> 00:43:08,750
something else because the Keeler gap is

877
00:43:15,520 --> 00:43:12,560
so small you can see Daphna spilling on

878
00:43:20,140 --> 00:43:15,530
the edges of it oh you could see it kind

879
00:43:21,609 --> 00:43:20,150
of here and this structure again it's

880
00:43:24,040 --> 00:43:21,619
the same kind of structure that happened

881
00:43:25,690 --> 00:43:24,050
in the outer B ring that vertical

882
00:43:27,940 --> 00:43:25,700
structure there's there's a wave or a

883
00:43:29,980 --> 00:43:27,950
wake kind of like if you think of a boat

884
00:43:32,470 --> 00:43:29,990
going through water or something very

885
00:43:35,140 --> 00:43:32,480
similar is happening there same kind of

886
00:43:38,620 --> 00:43:35,150
mechanics over in the width pan that it

887
00:43:41,470 --> 00:43:38,630
disturbs in the inky gap and so we know

888
00:43:43,690 --> 00:43:41,480

this is this kind of thing happens moons

889
00:43:46,510 --> 00:43:43,700
form within the Rings and they can clear

890
00:43:48,250 --> 00:43:46,520
large swaths of the Rings so again let's

891
00:43:49,750 --> 00:43:48,260
take that out to our gala

892
00:43:52,270 --> 00:43:49,760
see let's take that to other stars

893
00:43:54,790 --> 00:43:52,280
because we see debris disks everywhere

894
00:43:59,010 --> 00:43:54,800
and when we see a debris disc like we

895
00:44:03,690 --> 00:43:59,020
did here with Hubble we see a big gap

896
00:44:07,480 --> 00:44:03,700
around this particular star in its disk

897
00:44:09,070 --> 00:44:07,490
again a ring this person says oh there's

898
00:44:12,430 --> 00:44:09,080
a planet there there's a planet there I

899
00:44:13,840 --> 00:44:12,440
know it so you do something this is this

900
00:44:17,320 --> 00:44:13,850
an illustration of what could be

901
00:44:20,020 --> 00:44:17,330
happening here the same kind of ring

902
00:44:24,280 --> 00:44:20,030
exists so now we have we have a place to

903
00:44:26,850 --> 00:44:24,290
target our observations a mission like

904
00:44:29,740 --> 00:44:26,860
the like the James Webb Space Telescope

905
00:44:32,070 --> 00:44:29,750
will be able to do a good job of looking

906
00:44:36,220 --> 00:44:32,080
for a planet in there if it's big enough

907
00:44:39,610 --> 00:44:36,230
because the the dust and the gas and the

908
00:44:41,860 --> 00:44:39,620
debris disc will will the infrared light

909
00:44:45,400 --> 00:44:41,870
of the star may be able to pierce

910
00:44:47,470 --> 00:44:45,410
through it so at plus it has a

911
00:44:49,690 --> 00:44:47,480
coronagraph that'll block out the star

912
00:44:50,730 --> 00:44:49,700
so what we might be able to see it that

913
00:44:54,120 --> 00:44:50,740

way

914
00:45:02,560 --> 00:44:58,810
plus there's all kinds of other like I

915
00:45:03,160 --> 00:45:02,570
said before other systems in our solar

916
00:45:07,240 --> 00:45:03,170
system

917
00:45:11,110 --> 00:45:07,250
there's Uranus and Neptune here very

918
00:45:13,480 --> 00:45:11,120
thin very dark rings but they can teach

919
00:45:16,390 --> 00:45:13,490
us something as well and the lessons

920
00:45:19,000 --> 00:45:16,400
learned at Saturn with Cassini can be

921
00:45:21,550 --> 00:45:19,010
applied here to learn what's going on we

922
00:45:24,730 --> 00:45:21,560
think that there are moons being created

923
00:45:29,980 --> 00:45:24,740
in the ring system of Uranus we've seen

924
00:45:33,100 --> 00:45:29,990
rings change since Voyager in at Neptune

925
00:45:35,320 --> 00:45:33,110
so we know things are happening that

926
00:45:37,570 --> 00:45:35,330
these are dynamic rings as well so we're

927
00:45:39,550 --> 00:45:37,580
people who worked on the Cassini mission

928
00:45:42,150 --> 00:45:39,560
are now turning their attention to

929
00:45:45,340 --> 00:45:42,160
Uranus and Neptune especially using

930
00:45:47,080 --> 00:45:45,350
Hubble and putting in proposals for the

931
00:45:51,300 --> 00:45:47,090
James Webb Space Telescope to be able to

932
00:45:54,010 --> 00:45:51,310
study what's happening in those systems

933
00:45:58,000 --> 00:45:54,020
our solar system itself has two

934
00:46:00,490 --> 00:45:58,010
Astrophysical discs we have the asteroid

935
00:46:03,440 --> 00:46:00,500
belt which is here between Mars and

936
00:46:09,720 --> 00:46:06,090
when we have the Kuiper belt which is

937
00:46:12,960 --> 00:46:09,730
out beyond the orbit of Neptune kind of

938
00:46:16,410 --> 00:46:12,970

where Pluto sets and both of those are

939
00:46:18,840 --> 00:46:16,420
remnants of our solar system of the

940
00:46:21,420 --> 00:46:18,850
formation of our solar system and by

941
00:46:24,720 --> 00:46:21,430
looking at those by studying those we

942
00:46:28,110 --> 00:46:24,730
can tell what happened in the formation

943
00:46:30,300 --> 00:46:28,120
of our solar system and learning about

944
00:46:34,470 --> 00:46:30,310
the dynamics of health of the Saturn

945
00:46:37,500 --> 00:46:34,480
system applying that to the our solar

946
00:46:39,330 --> 00:46:37,510
system and what it looks like now we can

947
00:46:41,010 --> 00:46:39,340
start to put the piece the puzzle pieces

948
00:46:43,400 --> 00:46:41,020
together

949
00:46:45,450 --> 00:46:43,410
for example there's an interesting

950
00:46:48,180 --> 00:46:45,460
dynamical thing that probably happened

951
00:46:51,560 --> 00:46:48,190
in the asteroid belt a resonance that is

952
00:46:55,260 --> 00:46:51,570
evidence that the four giant planets

953
00:46:58,530 --> 00:46:55,270
used to be closer in together and that

954
00:47:00,180 --> 00:46:58,540
they jiggled out separated and while

955
00:47:04,020 --> 00:47:00,190
they were doing that Uranus and Neptune

956
00:47:05,340 --> 00:47:04,030
probably swapped spots so tracing out

957
00:47:07,800 --> 00:47:05,350
the dynamics of these kinds of

958
00:47:09,150 --> 00:47:07,810
Astrophysical discs is really important

959
00:47:12,720 --> 00:47:09,160
for us understanding our own solar

960
00:47:14,880 --> 00:47:12,730
system and as I mentioned before we know

961
00:47:17,760 --> 00:47:14,890
of all these debris disks plant

962
00:47:21,510 --> 00:47:17,770
protoplanetary discs across our galaxy

963
00:47:24,950 --> 00:47:21,520

that we can apply lessons learned to to

964
00:47:27,750 --> 00:47:24,960
be able to learn how planets are forming

965
00:47:30,030 --> 00:47:27,760
target where to find them in the disk

966
00:47:32,520 --> 00:47:30,040
and we have all these new telescopes

967
00:47:34,890 --> 00:47:32,530
coming up including the James Webb where

968
00:47:38,820 --> 00:47:34,900
we'll be able to look into these dusty

969
00:47:41,850 --> 00:47:38,830
discs using infrared all right so really

970
00:47:45,600 --> 00:47:41,860
this and this is my bike mantra Saturn's

971
00:47:47,370 --> 00:47:45,610
rings are a natural lab we must go back

972
00:47:49,830 --> 00:47:47,380
we've learned so much already and we can

973
00:47:54,930 --> 00:47:49,840
learn more okay

974
00:47:57,990 --> 00:47:54,940
and finally the Third Point icy moons of

975
00:48:02,760 --> 00:47:58,000
the big discoveries so big the icy moons

976
00:48:06,590 --> 00:48:02,770
we knew about but we didn't know until

977
00:48:09,450 --> 00:48:06,600
we got there that Enceladus has plumes

978
00:48:11,370 --> 00:48:09,460
meaning geysers something like Old

979
00:48:17,790 --> 00:48:11,380
Faithful which we like to call cold

980
00:48:22,680 --> 00:48:17,800
Faithful by the way Titan has lakes this

981
00:48:25,500 --> 00:48:22,690
big earth-like moon has lakes liquid

982
00:48:28,190 --> 00:48:25,510
lakes we didn't know that before we got

983
00:48:30,450 --> 00:48:28,200
to Saturday before Cassini got to Saturn

984
00:48:32,760 --> 00:48:30,460
so then we changed our view of our solar

985
00:48:35,310 --> 00:48:32,770
system because we learnt we realized icy

986
00:48:37,230 --> 00:48:35,320
moons can be geologically active we

987
00:48:40,700 --> 00:48:37,240
didn't think that was possible we

988
00:48:44,340 --> 00:48:40,710

thought icy moons were just hunks of ice

989
00:48:45,690 --> 00:48:44,350
leftover from maybe the formation of the

990
00:48:48,270 --> 00:48:45,700
planet itself or maybe they were

991
00:48:50,370 --> 00:48:48,280
captured from the Kuiper belt or you

992
00:48:53,610 --> 00:48:50,380
know some some kind of lone comment that

993
00:48:56,190 --> 00:48:53,620
got trapped but no this is really

994
00:48:57,830 --> 00:48:56,200
interesting and then when we applied to

995
00:49:03,150 --> 00:48:57,840
other solar systems we realized

996
00:49:05,070 --> 00:49:03,160
geologically active moons could Harbor

997
00:49:08,280 --> 00:49:05,080
life they could be warm enough that

998
00:49:10,350 --> 00:49:08,290
we're getting the right environmental

999
00:49:13,020 --> 00:49:10,360
conditions for life to exist on them and

1000
00:49:15,420 --> 00:49:13,030
this expands our whole view of what

1001
00:49:18,110 --> 00:49:15,430
habitability means of what a habitable

1002
00:49:21,570 --> 00:49:18,120
world is expanding those definitions is

1003
00:49:24,570 --> 00:49:21,580
huge because astrobiology is a

1004
00:49:26,070 --> 00:49:24,580
burgeoning field even today and we're

1005
00:49:28,620 --> 00:49:26,080
learning new things every day which

1006
00:49:31,860 --> 00:49:28,630
Cassini has really helped point to so

1007
00:49:35,400 --> 00:49:31,870
again setting the context all kinds of

1008
00:49:37,560 --> 00:49:35,410
moons going out from the Rings even more

1009
00:49:41,430 --> 00:49:37,570
farther out that we don't have room for

1010
00:49:44,540 --> 00:49:41,440
on this screen but let's start with

1011
00:49:49,830 --> 00:49:44,550
Titan so Titan is the biggest moon of

1012
00:49:52,530 --> 00:49:49,840
Saturn system Titan at first glance and

1013
00:49:55,140 --> 00:49:52,540

visible lights just looks fuzzy and

1014
00:50:00,090 --> 00:49:55,150
orange that's because it has this big

1015
00:50:02,940 --> 00:50:00,100
thick atmosphere really big and thick as

1016
00:50:06,300 --> 00:50:02,950
a matter of fact in in one of the the

1017
00:50:08,910 --> 00:50:06,310
more recent Star Trek movies the the

1018
00:50:11,640 --> 00:50:08,920
enterprise hid inside of those that hazy

1019
00:50:16,260 --> 00:50:11,650
atmosphere because it's so good at

1020
00:50:18,120 --> 00:50:16,270
hiding things in visible wavelengths but

1021
00:50:22,030 --> 00:50:18,130
once you get inside

1022
00:50:23,350 --> 00:50:22,040
and look at it underneath those layers

1023
00:50:26,530 --> 00:50:23,360
with the instruments that were on

1024
00:50:30,670 --> 00:50:26,540
Cassini and with the lander that went

1025
00:50:34,900 --> 00:50:30,680
down called the Huygens probe we could

1026
00:50:37,200 --> 00:50:34,910
see the actual surface of Titan and we

1027
00:50:41,350 --> 00:50:37,210
were able to make out methane lakes

1028
00:50:43,780 --> 00:50:41,360
these if you look carefully you study

1029
00:50:45,820 --> 00:50:43,790
other close-up photos you realize that

1030
00:50:49,080 --> 00:50:45,830
there are shorelines

1031
00:50:52,510 --> 00:50:49,090
you realize that this is actually liquid

1032
00:50:56,350 --> 00:50:52,520
standing liquid and you check out the

1033
00:51:00,430 --> 00:50:56,360
chemistry of the moon and you see that

1034
00:51:03,100 --> 00:51:00,440
it's methane so just like our earth has

1035
00:51:07,510 --> 00:51:03,110
a water cycle where we have water on the

1036
00:51:10,600 --> 00:51:07,520
ground he gets heated up becomes clouds

1037
00:51:12,850 --> 00:51:10,610
rains back down seeps into the ground

1038
00:51:16,660 --> 00:51:12,860

and two aquifers and then comes back up

1039
00:51:19,900 --> 00:51:16,670
into lakes that kind of cycle Titan has

1040
00:51:23,500 --> 00:51:19,910
something similar but for methane what a

1041
00:51:26,230 --> 00:51:23,510
bizarre and cool world and as a result

1042
00:51:29,500 --> 00:51:26,240
it makes it the most earth-like thing in

1043
00:51:36,430 --> 00:51:29,510
our solar system besides Earth this is

1044
00:51:39,430 --> 00:51:36,440
fantastic but it's also very cold so I

1045
00:51:41,020 --> 00:51:39,440
don't know that it's the best candidate

1046
00:51:44,670 --> 00:51:41,030
for habitability but it is stretching

1047
00:51:47,650 --> 00:51:44,680
our thinking on what habitability is

1048
00:51:50,200 --> 00:51:47,660
even if it's cold it does have this

1049
00:51:54,940 --> 00:51:50,210
liquid liquid on the surface it has

1050
00:51:57,820 --> 00:51:54,950
lakes it has it has dunes it has sand

1051
00:52:00,460 --> 00:51:57,830
dunes now some of its it's tiny pieces

1052
00:52:03,640 --> 00:52:00,470
of ice rather than rocky you type of

1053
00:52:06,670 --> 00:52:03,650
sand that we have on earth but how it

1054
00:52:11,350 --> 00:52:06,680
has winds it has weather it rains

1055
00:52:15,760 --> 00:52:11,360
liquid methane again but this is really

1056
00:52:20,110 --> 00:52:15,770
fascinating so we have a complex world

1057
00:52:22,990 --> 00:52:20,120
here that we're looking at then a little

1058
00:52:24,070 --> 00:52:23,000
bit later in the mission I actually got

1059
00:52:28,290 --> 00:52:24,080
to be part of this one so I'm really

1060
00:52:31,060 --> 00:52:28,300
excited about this story we were working

1061
00:52:33,850 --> 00:52:31,070
with a team the team that does the

1062
00:52:35,099 --> 00:52:33,860
imaging of course the imaging team Rives

1063
00:52:37,410 --> 00:52:35,109

all the benefits

1064
00:52:40,049 --> 00:52:37,420
on Cassini the beautiful images

1065
00:52:45,329 --> 00:52:40,059
everybody loves the imaging science

1066
00:52:47,549 --> 00:52:45,339
subsystem but they see something around

1067
00:52:48,269 --> 00:52:47,559
and celibacy and they think that can't

1068
00:52:49,949 --> 00:52:48,279
be right

1069
00:52:52,829 --> 00:52:49,959
there's got to be something wrong with

1070
00:52:55,079 --> 00:52:52,839
the detector we had some kind of anomaly

1071
00:52:58,259 --> 00:52:55,089
in the feed that came back to earth

1072
00:53:01,319 --> 00:52:58,269
we're not sure but I was lucky enough to

1073
00:53:04,680 --> 00:53:01,329
be on the the Uvas team the ultraviolet

1074
00:53:06,839 --> 00:53:04,690
imaging spectrograph team so we were

1075
00:53:08,910 --> 00:53:06,849
like okay well we took some moon just to

1076
00:53:12,509 --> 00:53:08,920
let they're not images but we took data

1077
00:53:14,130 --> 00:53:12,519
let us look at it let me see there's

1078
00:53:15,749 --> 00:53:14,140
evidence that there's something right

1079
00:53:17,459 --> 00:53:15,759
around here

1080
00:53:19,199 --> 00:53:17,469
the infrared instrument does the same

1081
00:53:20,999 --> 00:53:19,209
the radio science instrument does the

1082
00:53:23,969 --> 00:53:21,009
same and we all confirm that this

1083
00:53:26,279 --> 00:53:23,979
whatever it was right here is there I

1084
00:53:29,339 --> 00:53:26,289
wasn't just something weird that imaging

1085
00:53:33,930 --> 00:53:29,349
picked up so we go to work on it we

1086
00:53:36,779 --> 00:53:33,940
realized that it's a plume it's a series

1087
00:53:41,789 --> 00:53:36,789
of geysers that are erupting out of the

1088
00:53:45,839 --> 00:53:41,799

South Pole of Enceladus now Enceladus by

1089
00:53:48,089 --> 00:53:45,849
all accounts is yes it is the brightest

1090
00:53:54,390 --> 00:53:48,099
thing in our solar system because it's

1091
00:53:56,699 --> 00:53:54,400
covered in pure white ice but it's it's

1092
00:54:00,299 --> 00:53:56,709
small it's only like 250 kilometers

1093
00:54:04,049 --> 00:54:00,309
across that that ice looks to be really

1094
00:54:08,130 --> 00:54:04,059
really thick why would it have geologic

1095
00:54:10,079 --> 00:54:08,140
activity that would cause a geyser but

1096
00:54:12,599 --> 00:54:10,089
we've done studies we've we flown with

1097
00:54:17,069 --> 00:54:12,609
Cassini flew by and sell it as many many

1098
00:54:19,739 --> 00:54:17,079
many times and we mapped it out these

1099
00:54:21,509 --> 00:54:19,749
geysers were there these geysers changed

1100
00:54:25,229 --> 00:54:21,519
position over the course of the Cassini

1101
00:54:27,209 --> 00:54:25,239
mission they gave us evidence that

1102
00:54:31,079 --> 00:54:27,219
there's possibly liquid under the

1103
00:54:34,529 --> 00:54:31,089
surface and that these icy worlds that

1104
00:54:38,039 --> 00:54:34,539
seemed geologically dead are really

1105
00:54:40,229 --> 00:54:38,049
interesting and active we had hinted at

1106
00:54:42,289 --> 00:54:40,239
this before we weren't quite sure when

1107
00:54:47,999 --> 00:54:42,299
we got there we we saw and salad us

1108
00:54:48,470 --> 00:54:48,009
buried in the earring embedded in the

1109
00:54:50,150 --> 00:54:48,480
ear

1110
00:54:52,310 --> 00:54:50,160
and we thought well maybe that's why

1111
00:54:54,530 --> 00:54:52,320
it's so bright it's in a ring of ice and

1112
00:54:58,280 --> 00:54:54,540
it gets the ice dropped on it every day

1113
00:55:01,760 --> 00:54:58,290

and that's what happens but now we

1114
00:55:05,030 --> 00:55:01,770
realize that ring is there because the

1115
00:55:07,099 --> 00:55:05,040
plumes feed it it is created by

1116
00:55:09,620 --> 00:55:07,109
Enceladus itself and some of this is

1117
00:55:13,250 --> 00:55:09,630
spewing out all the contents of that

1118
00:55:17,349 --> 00:55:13,260
ring so that gives us a new a new

1119
00:55:20,180 --> 00:55:17,359
outlook on how rings are created okay I

1120
00:55:22,010 --> 00:55:20,190
mean like I said it's probably you know

1121
00:55:25,520 --> 00:55:22,020
we got some really close-up images after

1122
00:55:28,700 --> 00:55:25,530
that all these various geysers happening

1123
00:55:30,920 --> 00:55:28,710
all the time they you know I don't know

1124
00:55:34,609 --> 00:55:30,930
who's a who scene act actually seen Old

1125
00:55:36,880 --> 00:55:34,619
Faithful in in real life okay you know

1126
00:55:41,300 --> 00:55:36,890
it goes up maybe a couple hundred feet

1127
00:55:44,270 --> 00:55:41,310
at this highest point this however goes

1128
00:55:48,890 --> 00:55:44,280
up kilometres on you know it goes out

1129
00:55:51,339 --> 00:55:48,900
almost as tall as Enceladus is wide so

1130
00:55:55,730 --> 00:55:51,349
that's how it feeds the e-ring it's it's

1131
00:55:58,160 --> 00:55:55,740
phenomenal and we realize tracing back

1132
00:56:00,740 --> 00:55:58,170
the dynamics of how that must work that

1133
00:56:03,140 --> 00:56:00,750
there must be underneath this thick ice

1134
00:56:06,200 --> 00:56:03,150
shell of Enceladus some sort of

1135
00:56:11,569 --> 00:56:06,210
hemispheric sized lake of liquid water

1136
00:56:13,069 --> 00:56:11,579
that's feeding it and it stays warm so

1137
00:56:14,839 --> 00:56:13,079
then we start looking we think oh well

1138
00:56:18,140 --> 00:56:14,849

if that one's active let's look around

1139
00:56:20,870 --> 00:56:18,150
the solar system people of four years

1140
00:56:24,109 --> 00:56:20,880
loved Europa around Jupiter and we

1141
00:56:26,599 --> 00:56:24,119
thought oh you OPA could have subsurface

1142
00:56:29,089 --> 00:56:26,609
activity we think that there has a thin

1143
00:56:31,849 --> 00:56:29,099
ice shell based on on gravitational data

1144
00:56:33,760 --> 00:56:31,859
from the Galileo spacecraft we think

1145
00:56:36,079 --> 00:56:33,770
that it probably has a subsurface ocean

1146
00:56:38,990 --> 00:56:36,089
let's look at it see if it has any

1147
00:56:42,700 --> 00:56:39,000
geysers so Hubble looked at it and BAM

1148
00:56:45,109 --> 00:56:42,710
sure enough we see evidence for water in

1149
00:56:47,450 --> 00:56:45,119
certain areas at certain points at its

1150
00:56:49,790 --> 00:56:47,460
orbit which means it probably has some

1151
00:56:52,760 --> 00:56:49,800
kind of periodic geyser that's coming

1152
00:56:54,260 --> 00:56:52,770
out of again its South Pole now we're

1153
00:56:57,140 --> 00:56:54,270
not sure on the South Pole connection

1154
00:56:58,520 --> 00:56:57,150
but that's interesting and so you get

1155
00:57:01,140 --> 00:56:58,530
something that's kind of like this

1156
00:57:04,500 --> 00:57:01,150
artist's impression of what it might be

1157
00:57:07,289 --> 00:57:04,510
to stand on the surface of Europa a guys

1158
00:57:08,880 --> 00:57:07,299
are coming out of an ice field kind of

1159
00:57:15,269 --> 00:57:08,890
feels like you're in Iceland it's very

1160
00:57:18,029 --> 00:57:15,279
cool and you know the alternative is you

1161
00:57:21,240 --> 00:57:18,039
could trap a little little under under

1162
00:57:24,420 --> 00:57:21,250
crust lakes full of this stuff there's

1163
00:57:30,529 --> 00:57:24,430

the crux of it is there is heat below

1164
00:57:33,630 --> 00:57:30,539
the ice heat means energy liquid water

1165
00:57:36,539 --> 00:57:33,640
increases the potential for life to

1166
00:57:40,589 --> 00:57:36,549
exist so if there's energy and liquid

1167
00:57:42,569 --> 00:57:40,599
water perhaps there's life and as we're

1168
00:57:45,420 --> 00:57:42,579
thinking about our definition of what

1169
00:57:47,849 --> 00:57:45,430
earth 2.0 might look like what another

1170
00:57:50,160 --> 00:57:47,859
earth might look like perhaps we should

1171
00:57:53,700 --> 00:57:50,170
be expanding our definition maybe it

1172
00:57:54,630 --> 00:57:53,710
shouldn't just be a planet that is the

1173
00:57:57,390 --> 00:57:54,640
size of Earth

1174
00:57:59,549 --> 00:57:57,400
that's one AU from a Sun it's a g2 type

1175
00:58:03,720 --> 00:57:59,559
star maybe we should start thinking

1176
00:58:05,819 --> 00:58:03,730
about ice worlds and moons around giant

1177
00:58:07,650 --> 00:58:05,829
planets and those sorts of things so as

1178
00:58:10,440 --> 00:58:07,660
we look across our solar system and as

1179
00:58:12,960 --> 00:58:10,450
we look at other exoplanets we need to

1180
00:58:15,750 --> 00:58:12,970
have this in mind so we now Cassini has

1181
00:58:17,599 --> 00:58:15,760
given us this great gift of expanding

1182
00:58:21,839 --> 00:58:17,609
our vocabulary

1183
00:58:24,000 --> 00:58:21,849
- what habitable means so I promised you

1184
00:58:29,099 --> 00:58:24,010
a timeline just to put this all in

1185
00:58:31,470 --> 00:58:29,109
context again we had almost 20 years ago

1186
00:58:35,160 --> 00:58:31,480
to the day in two weeks it'll be 20

1187
00:58:37,440 --> 00:58:35,170
years ago the launch of the Cassini

1188
00:58:41,250 --> 00:58:37,450

mission Cassini and Huygens together and

1189
00:58:43,799 --> 00:58:41,260
there were five known exoplanets so

1190
00:58:47,789 --> 00:58:43,809
Cassini was truly just a Saturn mission

1191
00:58:54,480 --> 00:58:47,799
it was there to learn more about Saturn

1192
00:58:57,089 --> 00:58:54,490
as a planet then when in July 2004 when

1193
00:59:00,559 --> 00:58:57,099
Cassini got to Saturn and did its

1194
00:59:05,010 --> 00:59:00,569
orbital insertion there were 12

1195
00:59:07,620 --> 00:59:05,020
exoplanets 12 I remember that feeling of

1196
00:59:10,650 --> 00:59:07,630
oh this is about to happen this is so

1197
00:59:12,539 --> 00:59:10,660
exciting but Cassini's still just a

1198
00:59:13,819 --> 00:59:12,549
Saturn mission but it will be really

1199
00:59:17,959 --> 00:59:13,829
cool if we learn about why

1200
00:59:22,099 --> 00:59:17,969
fifteen or twenty exoplanets and then in

1201
00:59:24,709 --> 00:59:22,109
between 2004 and today we've had the

1202
00:59:26,509 --> 00:59:24,719
Kepler mission we've had Hubble looking

1203
00:59:28,849 --> 00:59:26,519
at stuff we've had lots of ground-based

1204
00:59:33,650 --> 00:59:28,859
campaigns looking for other worlds and

1205
00:59:37,130 --> 00:59:33,660
so today we know of over 3,600

1206
00:59:39,170 --> 00:59:37,140
exoplanets with so many more planned to

1207
00:59:41,900 --> 00:59:39,180
be observed those are on small patches

1208
00:59:43,999 --> 00:59:41,910
of the sky we know more exists when you

1209
00:59:46,759 --> 00:59:44,009
look up in the sky at night you know

1210
00:59:48,440 --> 00:59:46,769
that for every star you see out there on

1211
00:59:52,579 --> 00:59:48,450
average there's at least one planet

1212
00:59:54,499 --> 00:59:52,589
around that star and so now we can apply

1213
00:59:56,839 --> 00:59:54,509

these lessons we've learned over the

1214
01:00:00,890 --> 00:59:56,849
course of the Cassini mission to all of

1215
01:00:04,190 --> 01:00:00,900
those worlds especially since some of

1216
01:00:07,029 --> 01:00:04,200
those systems have more than one planet

1217
01:00:09,739 --> 01:00:07,039
so we're looking at at you know

1218
01:00:11,779 --> 01:00:09,749
ecosystems whole solar systems that are

1219
01:00:14,690 --> 01:00:11,789
forming in much the same way that

1220
01:00:17,690 --> 01:00:14,700
perhaps the Saturn system did and we can

1221
01:00:20,870 --> 01:00:17,700
apply those lessons to figure out how

1222
01:00:22,069 --> 01:00:20,880
how these worlds form and like I said

1223
01:00:24,349 --> 01:00:22,079
you know we know of even more

1224
01:00:29,269 --> 01:00:24,359
protoplanetary discs these discs where

1225
01:00:32,599 --> 01:00:29,279
planets form so getting back to that

1226
01:00:34,969 --> 01:00:32,609
first slide so these icy moons we've

1227
01:00:36,949 --> 01:00:34,979
learned are geologically active with the

1228
01:00:40,640 --> 01:00:36,959
Cassini mission and this has given us

1229
01:00:43,009 --> 01:00:40,650
the idea that they are bastions for life

1230
01:00:45,979 --> 01:00:43,019
we need to start looking there if we

1231
01:00:50,329 --> 01:00:45,989
want to find life beyond Earth we have

1232
01:00:52,009 --> 01:00:50,339
seen planetary rings that are ancient

1233
01:00:55,579 --> 01:00:52,019
they probably formed with the planet

1234
01:00:58,430 --> 01:00:55,589
they are active on short short

1235
01:01:03,439 --> 01:00:58,440
timescales and they are dynamic they're

1236
01:01:06,349 --> 01:01:03,449
constantly changing these are a model

1237
01:01:10,189 --> 01:01:06,359
for how worlds are both built and

1238
01:01:14,859 --> 01:01:10,199

destroyed in our system and beyond and

1239
01:01:19,279 --> 01:01:14,869
the weather the storms the incredible

1240
01:01:22,910 --> 01:01:19,289
complexity of Saturn's atmosphere has

1241
01:01:25,099 --> 01:01:22,920
helped us understand that the

1242
01:01:26,450 --> 01:01:25,109
atmospheres of other giant planets are

1243
01:01:30,559 --> 01:01:26,460
just as Kampai

1244
01:01:33,230 --> 01:01:30,569
dynamic and we can't have one computer

1245
01:01:35,540 --> 01:01:33,240
modeling code that we use as scientists

1246
01:01:40,609 --> 01:01:35,550
to model all of those worlds beyond our

1247
01:01:43,520 --> 01:01:40,619
own so really what it comes down to with

1248
01:01:47,569 --> 01:01:43,530
the Cassini mission is using our own

1249
01:01:49,819 --> 01:01:47,579
natural laboratory in our backyard for

1250
01:01:53,210 --> 01:01:49,829
answering questions that are fundamental

1251
01:01:55,720 --> 01:01:53,220
to us as human beings how did we get

1252
01:01:59,870 --> 01:01:55,730
here looking at the Rings

1253
01:02:03,260 --> 01:01:59,880
how does the universe work looking at

1254
01:02:06,890 --> 01:02:03,270
things like storms on Saturn and are we

1255
01:02:11,240 --> 01:02:06,900
alone looking at icy worlds beyond our

1256
01:02:14,089 --> 01:02:11,250
own so I think that the legacy of the

1257
01:02:15,859 --> 01:02:14,099
Cassini mission will be felt for years

1258
01:02:17,930 --> 01:02:15,869
and years

1259
01:02:19,700 --> 01:02:17,940
there are many research projects that

1260
01:02:23,470 --> 01:02:19,710
have yet to be done with the data

1261
01:02:26,930 --> 01:02:23,480
Cassini collected and many that have

1262
01:02:29,690 --> 01:02:26,940
results that have yet to be fully felt

1263
01:02:32,839 --> 01:02:29,700

and impacted in other branches of

1264
01:02:36,500 --> 01:02:32,849
astronomy so I think as we go forward

1265
01:02:42,140 --> 01:02:36,510
together as humans and as a scientific

1266
01:02:44,870 --> 01:02:42,150
community we can really come back to the

1267
01:02:45,559 --> 01:02:44,880
Cassini mission and thank it for

1268
01:02:48,790 --> 01:02:45,569
everything

1269
01:02:48,800 --> 01:03:22,840
[Applause]

1270
01:04:32,650 --> 01:03:33,590
[Music]

1271
01:04:49,570 --> 01:04:32,660
in some cases so there's a couple of

1272
01:04:49,580 --> 01:04:53,450
[Music]

1273
01:04:58,860 --> 01:04:56,790
so I'd be a little bit at history before

1274
01:05:02,400 --> 01:04:58,870
we got there with Cassini we thought

1275
01:05:09,480 --> 01:05:02,410
that the reasons were likely delivered

1276
01:05:12,240 --> 01:05:09,490
by comments comments we know they were

1277
01:05:15,150 --> 01:05:12,250
probably streaking by these out of the

1278
01:05:19,440 --> 01:05:15,160
system sound was big enough that they

1279
01:05:26,190 --> 01:05:19,450
got close enough rip it apart and voila

1280
01:05:28,320 --> 01:05:26,200
you've got a ring there were different

1281
01:05:30,330 --> 01:05:28,330
people debating how one thinks one so

1282
01:05:34,530 --> 01:05:30,340
comments must there have been to create

1283
01:05:36,750 --> 01:05:34,540
such vibrant rings and if the if this

1284
01:05:38,730 --> 01:05:36,760
gets true and these would still have

1285
01:05:41,340 --> 01:05:38,740
hadn't been pretty like rings less

1286
01:05:43,710 --> 01:05:41,350
massive then they would have over time

1287
01:05:47,610 --> 01:05:43,720
dating to those little ring part of the

1288
01:05:50,730 --> 01:05:47,620

spiral into Saturn until that tire read

1289
01:05:53,580 --> 01:05:50,740
was depleted in there wasn't a time

1290
01:05:57,000 --> 01:05:53,590
scale on that was something around 50 to

1291
01:06:02,520 --> 01:05:57,010
100 million years so roughly the age of

1292
01:06:05,460 --> 01:06:02,530
the dinosaurs well why then are we lucky

1293
01:06:07,350 --> 01:06:05,470
enough as human beings on a planet in

1294
01:06:09,300 --> 01:06:07,360
the Solar System is last billions of

1295
01:06:12,690 --> 01:06:09,310
years why are we lucky enough to be able

1296
01:06:15,180 --> 01:06:12,700
to see this now so that's when we are

1297
01:06:18,690 --> 01:06:15,190
against the being young but there's one

1298
01:06:21,510 --> 01:06:18,700
is for the ancients we got there and so

1299
01:06:22,140 --> 01:06:21,520
now we see that they are not quite

1300
01:06:25,890 --> 01:06:22,150
agents

1301
01:06:27,390 --> 01:06:25,900
ancient both spectroscopically and by

1302
01:06:31,170 --> 01:06:27,400
the dynamics we see we see them

1303
01:06:32,700 --> 01:06:31,180
effectively recycle so things booms

1304
01:06:36,210 --> 01:06:32,710
build-up and they break apart

1305
01:06:38,340 --> 01:06:36,220
so rather than all these vertical

1306
01:06:39,780 --> 01:06:38,350
spiraling inward because they're

1307
01:06:42,320 --> 01:06:39,790
possibly particles they come together

1308
01:06:46,830 --> 01:06:42,330
and there's kind of like a reservoir of

1309
01:07:00,059 --> 01:06:46,840
ice which then you smash back part of

1310
01:07:05,279 --> 01:07:02,999
well then our baby how still our Daniel

1311
01:07:07,529 --> 01:07:05,289
plantation where when you put that ice

1312
01:07:14,759 --> 01:07:07,539
and water initiative come from the

1313
01:07:20,309 --> 01:07:14,769

currents most likes idea is that the

1314
01:07:25,589 --> 01:07:20,319
initial system so something similar in

1315
01:07:28,589 --> 01:07:25,599
size Titan probably had half a dozen of

1316
01:07:33,319 --> 01:07:28,599
these and they so slowly moved in closer

1317
01:07:44,230 --> 01:07:33,329
to Saturn and we're over time by pies

1318
01:08:21,490 --> 01:07:44,240
and replanted so that makes sense to us

1319
01:08:21,500 --> 01:08:30,169
[Music]

1320
01:08:49,979 --> 01:08:47,339
so which is assault so so yeah lots of

1321
01:08:52,349 --> 01:08:49,989
lots of stuff in there I know some of

1322
01:08:53,700 --> 01:08:52,359
the stuff that most recently in the in

1323
01:08:57,329 --> 01:08:53,710
the plumes that they're they're finding

1324
01:09:03,660 --> 01:08:57,339
are in that plume besides water they're

1325
01:09:05,220 --> 01:09:03,670
finding exist in what what are under see

1326
01:09:07,890 --> 01:09:05,230
underwater events

1327
01:09:12,150 --> 01:09:07,900
on earth these deep ocean vents where we

1328
01:09:14,760 --> 01:09:12,160
see lots of life very small bacteria all

1329
01:09:19,079 --> 01:09:14,770
the way to like little blind crayfish

1330
01:09:22,620 --> 01:09:19,089
and that kind of thing so finding

1331
01:09:25,620 --> 01:09:22,630
evidence of those sorts of materials in

1332
01:09:28,079 --> 01:09:25,630
the plume lets us know where the plumes

1333
01:09:31,229 --> 01:09:28,089
may be coming from ultimately and that's

1334
01:09:33,210 --> 01:09:31,239
really exciting and and I think carbon

1335
01:09:35,360 --> 01:09:33,220
carbon is is one of those that would

1336
01:09:38,760 --> 01:09:35,370
give us evidence of them happening

1337
01:09:40,499 --> 01:09:38,770
farther down deep down and the kinds of

1338
01:09:54,590 --> 01:09:40,509

materials that are at those undersea

1339
01:10:05,729 --> 01:09:59,180
does it ever change not that we've seen

1340
01:10:11,490 --> 01:10:05,739
so far in all of our observations we

1341
01:10:16,830 --> 01:10:11,500
haven't seen we there was some evidence

1342
01:10:25,110 --> 01:10:16,840
of the hexagon I mean they're both

1343
01:10:27,840 --> 01:10:25,120
ground-based observations and Voyager so

1344
01:10:29,280 --> 01:10:27,850
we thought it was there which now builds

1345
01:10:32,250 --> 01:10:29,290
up evidence of you know something more

1346
01:10:39,600 --> 01:10:32,260
like 40 years of it being there and our

1347
01:11:00,290 --> 01:10:39,610
resolution wasn't good enough to know so

1348
01:11:00,300 --> 01:11:14,870
like the storms around

1349
01:11:19,919 --> 01:11:17,609
a question about the end of the Cassini

1350
01:11:21,359 --> 01:11:19,929
mission how deep did it get before it

1351
01:11:39,600 --> 01:11:21,369
burned up and did we get some useful

1352
01:11:43,649 --> 01:11:39,610
data but unfortunately because of how I

1353
01:11:48,479 --> 01:11:43,659
was going in we tried to position it so

1354
01:11:51,299 --> 01:11:48,489
that would send back data but there

1355
01:11:53,489 --> 01:11:51,309
wasn't much time for that the data that

1356
01:11:55,919 --> 01:11:53,499
comes back from my Cassini mission as a

1357
01:12:00,299 --> 01:11:55,929
men in deep space missions you were

1358
01:12:05,100 --> 01:12:00,309
called New Horizons was this way to very

1359
01:12:06,629 --> 01:12:05,110
very slow trickle of data so that's why

1360
01:12:09,359 --> 01:12:06,639
we first saw Cluedo with New Horizons

1361
01:12:10,560 --> 01:12:09,369
and still rainy and fuzzy and he had to

1362
01:12:12,689 --> 01:12:10,570
wait a couple of weeks

1363
01:12:15,739 --> 01:12:12,699

that wasn't just data processing that

1364
01:12:21,700 --> 01:12:15,749
was actually getting the data to earth

1365
01:12:21,710 --> 01:12:34,709
[Music]

1366
01:12:49,080 --> 01:12:38,550
the Hurricanes are short-lived is the

1367
01:12:50,959 --> 01:12:49,090
polar hurricane short-lived that was

1368
01:12:53,910 --> 01:12:50,969
that was there the northern latitudes

1369
01:13:12,120 --> 01:12:53,920
around who does that affect the hexagon

1370
01:13:13,590 --> 01:13:12,130
shape extra cold winter but I'm not that

1371
01:13:23,450 --> 01:13:13,600
I will say I don't understand sure

1372
01:13:29,450 --> 01:13:27,060
there's a theory that you robo's water

1373
01:13:32,040 --> 01:13:29,460
is liquid it's because of the

1374
01:13:34,590 --> 01:13:32,050
interaction between it and Jupiter the

1375
01:13:38,910 --> 01:13:34,600
gravitational pull of two places if that

1376
01:13:42,840 --> 01:13:38,920
is also true between Saturday until

1377
01:13:50,209 --> 01:13:42,850
Enceladus is it's water due to

1378
01:13:55,530 --> 01:13:52,770
the inner grab the gravitational

1379
01:13:59,250 --> 01:13:55,540
interaction kind of the title impression

1380
01:14:03,300 --> 01:13:59,260
that happens same way we have tides on

1381
01:14:07,860 --> 01:14:05,310
something similar happens with Jupiter

1382
01:14:10,590 --> 01:14:07,870
it's way better and its moons which are

1383
01:14:15,780 --> 01:14:10,600
a little bit smaller so effectively it

1384
01:14:20,990 --> 01:14:15,790
squeezes those moons and that squeezing

1385
01:14:48,520 --> 01:14:27,419
I do Kirby sense because these are very

1386
01:15:49,780 --> 01:14:50,760
[Music]

1387
01:15:56,950 --> 01:15:49,790
so are we really that fortunate and if

1388
01:15:58,690 --> 01:15:56,960

so you look at robot Wow to be living in

1389
01:16:01,330 --> 01:15:58,700
a time where both of those are active

1390
01:16:03,880 --> 01:16:01,340
and this or maybe the the actual

1391
01:16:06,190 --> 01:16:03,890
situation is that this activity is just

1392
01:16:09,100 --> 01:16:06,200
ongoing it always happens and we're not

1393
01:16:17,200 --> 01:16:09,110
special so sorry scientists tend to

1394
01:16:21,220 --> 01:16:17,210
think we're not special hexagons image

1395
01:16:23,920 --> 01:16:21,230
and about forefathers Oh with a fuzzy

1396
01:16:25,360 --> 01:16:23,930
white dot and about nine o'clock with a

1397
01:16:29,350 --> 01:16:25,370
funny little loop like a little

1398
01:16:38,000 --> 01:16:29,360
miniature spacecraft actually what

1399
01:16:43,560 --> 01:16:41,340
the hexagon image about four o'clock

1400
01:16:53,630 --> 01:16:43,570
there's there's some kind of let me just

1401
01:16:58,970 --> 01:16:56,910
there we go yeah okay

1402
01:17:06,870 --> 01:16:58,980
I four o'clock there's this thing I

1403
01:17:09,180 --> 01:17:06,880
don't know that's five o'clock there's

1404
01:17:12,710 --> 01:17:09,190
this kind of blobby thing and then over

1405
01:17:15,240 --> 01:17:12,720
here at nine o'clock there's this thing

1406
01:17:18,240 --> 01:17:15,250
what's going on

1407
01:17:20,880 --> 01:17:18,250
well this is this this is definitely

1408
01:17:23,330 --> 01:17:20,890
some sort of other storm and disturbance

1409
01:17:25,800 --> 01:17:23,340
that's happening within this structure

1410
01:17:28,680 --> 01:17:25,810
this isn't a you know this is a shape

1411
01:17:30,540 --> 01:17:28,690
but this isn't the shape here this

1412
01:17:33,840 --> 01:17:30,550
definition of the shape doesn't control

1413
01:17:37,140 --> 01:17:33,850

what's happening in here it sits like a

1414
01:17:39,030 --> 01:17:37,150
wall and it can find some of the things

1415
01:17:42,930 --> 01:17:39,040
inside of that wall but it doesn't have

1416
01:17:45,780 --> 01:17:42,940
necessarily make things happen in that

1417
01:17:47,760 --> 01:17:45,790
wall so so this this storm this is a

1418
01:17:52,530 --> 01:17:47,770
storm it may not be related to the

1419
01:17:54,810 --> 01:17:52,540
hexagonal and this I don't I don't know

1420
01:18:24,760 --> 01:17:54,820
that maybe that's I don't know maybe

1421
01:19:01,670 --> 01:18:50,940
[Music]

1422
01:19:10,260 --> 01:19:07,380
we clean clean by our standards from

1423
01:19:23,280 --> 01:19:10,270
when we don't want to accidentally

1424
01:19:35,040 --> 01:19:23,290
smacking into one of these moons and the

1425
01:20:05,450 --> 01:19:35,050
folks at Mars for similar reasons so

1426
01:20:05,460 --> 01:20:24,130
[Music]

1427
01:21:06,320 --> 01:21:03,290
we are yes you mentioned in your

1428
01:21:09,770 --> 01:21:06,330
presentation that hurricanes feed on

1429
01:21:11,930 --> 01:21:09,780
heat this is anymore

1430
01:21:12,560 --> 01:21:11,940
they sing hurricane what is the energy

1431
01:21:14,150 --> 01:21:12,570
source

1432
01:21:16,220 --> 01:21:14,160
okay so hurricanes if you don't heat

1433
01:21:21,860 --> 01:21:16,230
what's the energy source to power the

1434
01:21:23,740 --> 01:21:21,870
polar vortex here so just because it's

1435
01:21:25,980 --> 01:21:23,750
northern facing

1436
01:21:28,060 --> 01:21:25,990
it was facing away from the something

1437
01:21:30,700 --> 01:21:28,070
that's that's the first one

1438
01:21:33,220 --> 01:21:30,710

but Saturn itself has a lot of internal

1439
01:21:35,620 --> 01:21:33,230
heat that's all the giant planets had a

1440
01:21:37,360 --> 01:21:35,630
lot of internal there they're far away

1441
01:21:42,760 --> 01:21:37,370
from the Sun it really doesn't matter

1442
01:21:44,440 --> 01:21:42,770
how much they're warmed by the Sun but

1443
01:21:46,420 --> 01:21:44,450
for this particular thing it matters

1444
01:21:47,350 --> 01:21:46,430
more than that the internal tank is

1445
01:21:52,800 --> 01:21:47,360
there

1446
01:22:03,070 --> 01:21:57,510
it's very dense lots of gas layers and

1447
01:22:05,620 --> 01:22:03,080
AB something that big eventually kind of

1448
01:22:08,680 --> 01:22:05,630
settles out the different gas layers

1449
01:22:12,490 --> 01:22:08,690
settle out or over the lifetime of the

1450
01:22:14,790 --> 01:22:12,500
planet some of the the heavier elements

1451
01:22:18,070 --> 01:22:14,800
that are in the outer layers settle down

1452
01:22:22,620 --> 01:22:18,080
so basically what can happen at Saturn

1453
01:22:28,440 --> 01:22:22,630
as you could have liquid helium rain

1454
01:22:36,640 --> 01:22:28,450
into the inner layers of Saturn and that

1455
01:22:38,970 --> 01:22:36,650
energy those things falling when we look

1456
01:22:43,420 --> 01:22:38,980
at Jupiter for example another example

1457
01:22:46,660 --> 01:22:43,430
Jupiter's output of energy is greater

1458
01:22:49,840 --> 01:22:46,670
than its input the energy reserves from

1459
01:22:53,730 --> 01:22:49,850
the Sun is less than what we see

1460
01:22:56,260 --> 01:22:53,740
radiating back out for the same reason

1461
01:22:57,760 --> 01:22:56,270
okay we've got time for only one more

1462
01:23:05,370 --> 01:22:57,770
question do we have any kids in the

1463
01:23:09,620 --> 01:23:07,800

here's been waiting the whole time to

1464
01:23:12,060 --> 01:23:09,630
get the honor of the last question sorry

1465
01:23:14,820 --> 01:23:12,070
might apply the interest with extra

1466
01:23:17,340 --> 01:23:14,830
biology and I'm just wondering what are

1467
01:23:30,709 --> 01:23:17,350
the odds for life on the movies and and

1468
01:23:33,450 --> 01:23:32,939
specifically to look at those moons for

1469
01:23:36,629 --> 01:23:33,460
life

1470
01:23:39,689 --> 01:23:36,639
good question end with yeah I would rank

1471
01:23:42,750 --> 01:23:39,699
the moons of the solar system in terms

1472
01:23:46,860 --> 01:23:42,760
of probability of life as Europa and

1473
01:23:48,689 --> 01:23:46,870
sell it as tighten your rope up because

1474
01:23:54,360 --> 01:23:48,699
it probably has the most heat the

1475
01:23:57,330 --> 01:23:54,370
shallowest crust and the the largest

1476
01:24:00,720 --> 01:23:57,340
rocky core that could support some sort

1477
01:24:03,570 --> 01:24:00,730
of chemoautotrophs type organism at a

1478
01:24:06,000 --> 01:24:03,580
and a deep-sea event for example but I

1479
01:24:09,689 --> 01:24:06,010
can't put numbers on probability for

1480
01:24:12,930 --> 01:24:09,699
that the way to confirm this would be to

1481
01:24:15,689 --> 01:24:12,940
actually go there with a submarine

1482
01:24:18,240 --> 01:24:15,699
that's what I would like maybe something

1483
01:24:20,070 --> 01:24:18,250
that could land drill down but you know

1484
01:24:22,500 --> 01:24:20,080
even an orbiter or something would be

1485
01:24:25,200 --> 01:24:22,510
very cool the problem with that is the

1486
01:24:27,390 --> 01:24:25,210
Jupiter system full of radiation you

1487
01:24:31,200 --> 01:24:27,400
have to do with the Juno mission does

1488
01:24:32,729 --> 01:24:31,210

come in quickly and go way far out come

1489
01:24:34,800 --> 01:24:32,739
in quickly and go far out or else your

1490
01:24:37,129 --> 01:24:34,810
electronics are fried so this is one of

1491
01:24:39,390 --> 01:24:37,139
the tough things about a Europa mission

1492
01:24:40,800 --> 01:24:39,400
which makes which makes the Saturn

1493
01:24:44,189 --> 01:24:40,810
system a little more enticing less

1494
01:24:46,110 --> 01:24:44,199
radiation there but I think in the

1495
01:24:49,560 --> 01:24:46,120
community's opinion maybe less likely to

1496
01:24:52,080 --> 01:24:49,570
find life so what we can keep doing is

1497
01:24:55,220 --> 01:24:52,090
we can keep compiling evidence as

1498
01:24:58,439 --> 01:24:55,230
scientists we we want evidence and

1499
01:25:01,200 --> 01:24:58,449
there's never necessarily a smoking gun

1500
01:25:06,320 --> 01:25:01,210
unless we were to go there and pick up a

1501
01:25:13,379 --> 01:25:09,770
that was got one strong mission yeah

1502
01:25:15,090 --> 01:25:13,389
yeah but I would just echo I would echo

1503
01:25:17,280 --> 01:25:15,100
what she said is that you know when we

1504
01:25:19,500 --> 01:25:17,290
explored Mars we first sent an orbiter

1505
01:25:22,140 --> 01:25:19,510
alright and then we started to send to

1506
01:25:23,550 --> 01:25:22,150
send Landers and then Rovers etc it's

1507
01:25:24,660 --> 01:25:23,560
kind of if we're gonna explore any of

1508
01:25:26,790 --> 01:25:24,670
these moons it's got to be the same

1509
01:25:28,800 --> 01:25:26,800
thing we've got us in orbiters to map

1510
01:25:31,169 --> 01:25:28,810
all the places that we might want to

1511
01:25:33,270 --> 01:25:31,179
land and then Landers and then Rovers

1512
01:25:35,910 --> 01:25:33,280
and then diggers and submarines and such

1513
01:25:37,919 --> 01:25:35,920

so it's not gonna happen next year it's

1514
01:25:40,320 --> 01:25:37,929
not gonna happen this decade it's a long

1515
01:25:42,840 --> 01:25:40,330
term process all right so we have to

1516
01:25:46,830 --> 01:25:42,850
stop you there next month's talk will be

1517
01:25:49,260 --> 01:25:46,840
on dangerous worlds so we'll take this

1518
01:25:51,209 --> 01:25:49,270
even further lazy now let's give a real

1519
01:25:59,629 --> 01:25:51,219
big warm thank you for dr. Bonnie my

1520
01:26:05,149 --> 01:26:02,750
okay last thing ireenie

1521
01:26:09,169 --> 01:26:05,159
a rainy rate raised your hand Irene II

1522
01:26:11,479 --> 01:26:09,179
can take what 15 people okay I know

1523
01:26:14,570 --> 01:26:11,489
there's way too many than more than 15

1524
01:26:16,520 --> 01:26:14,580
but when you have enough just go do you

1525
01:26:18,770 --> 01:26:16,530
want to hang hang out by this store okay

1526
01:26:20,180 --> 01:26:18,780
Irene ease gonna hang by this store when

1527
01:26:21,950 --> 01:26:20,190
she has enough she'll take him across

1528
01:26:23,930 --> 01:26:21,960
the street for observing and if you

1529
01:26:25,970 --> 01:26:23,940
don't make it this month come back again

1530
01:26:27,680 --> 01:26:25,980
she'll do it every every month it says