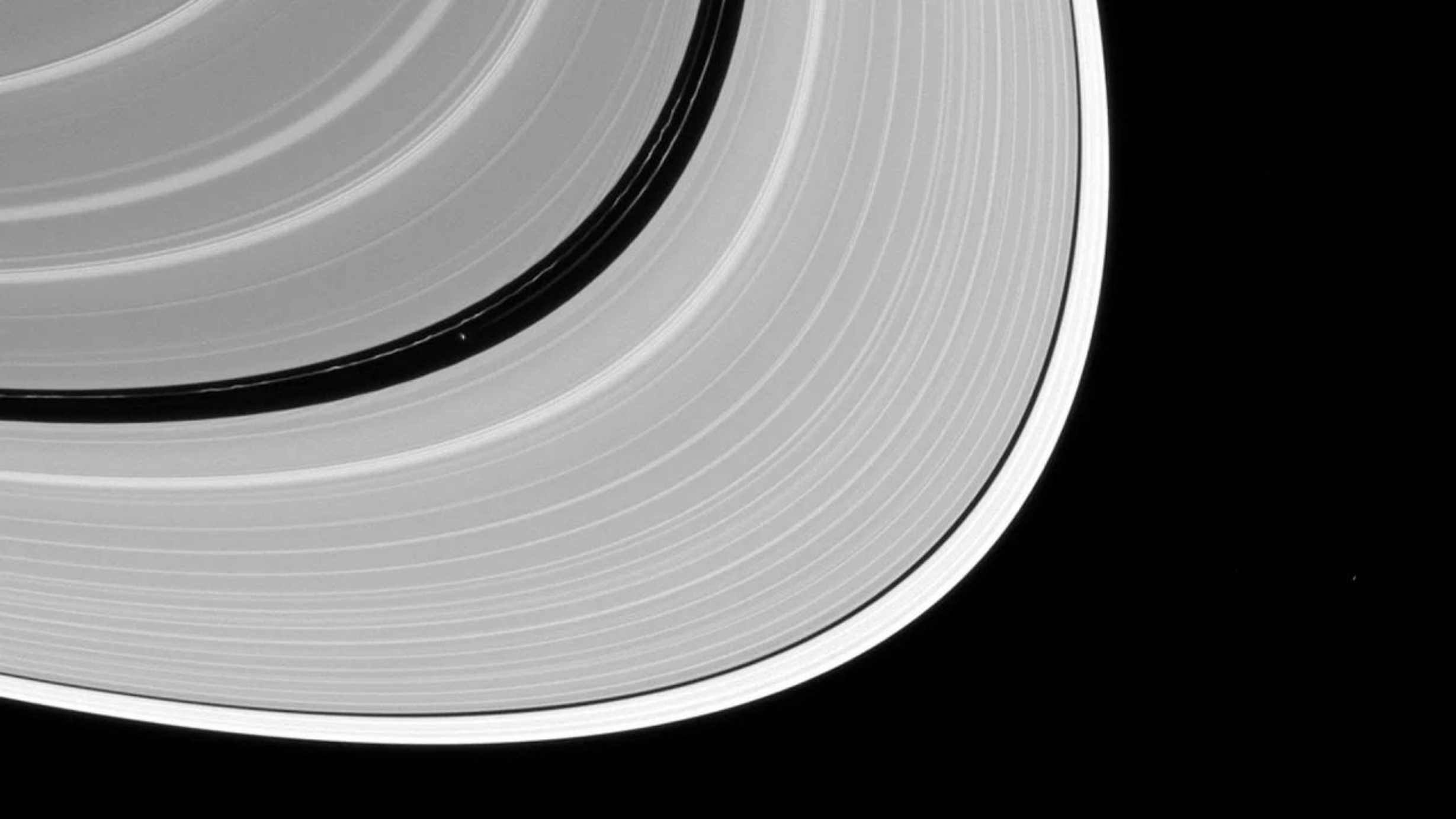

1
00:00:00,400 --> 00:00:01,567
(upbeat music)

2
00:00:01,600 --> 00:00:05,038
- [Narrator] NASA's Jet
Propulsion Laboratory presents

3
00:00:05,071 --> 00:00:08,408
The Von Karman Lecture, a
series of talks by scientists

4
00:00:08,441 --> 00:00:11,344
and engineers who are
exploring our planet,

5
00:00:11,377 --> 00:00:14,981
our solar system, and
all that lies beyond.

6
00:00:31,097 --> 00:00:34,167
- Wow, we packed
the house tonight.

7
00:00:34,200 --> 00:00:36,002
How's everybody doing?

8
00:00:36,035 --> 00:00:38,337
Excellent, well thank you
all very much for, again,

9
00:00:38,370 --> 00:00:40,339
coming to attend these
wonderful lectures.

10
00:00:40,372 --> 00:00:42,442
We very much appreciate them.

11
00:00:42,475 --> 00:00:45,378
The Cassini Mission, a

cooperative undertaking by NASA

12
00:00:45,411 --> 00:00:48,381
and the European and
Italian Space Agencies has

13
00:00:48,414 --> 00:00:50,550
revolutionized our
understanding of Saturn,

14
00:00:50,583 --> 00:00:53,086
it's rings, and amazing
assortment of moons and the

15
00:00:53,119 --> 00:00:55,388
planets dynamic, dynamic?

16
00:00:55,421 --> 00:00:57,223
Magnetic environment.

17
00:00:57,256 --> 00:00:59,459
The astonishing discoveries
continue to this day

18
00:00:59,492 --> 00:01:01,227
and we can't wait to see
what happens when Cassini

19
00:01:01,260 --> 00:01:03,896
repeatedly dives between
the inner-most ring

20
00:01:03,929 --> 00:01:06,799
and the top of Saturn's
atmosphere during it's final

21
00:01:06,832 --> 00:01:09,902
six months, starting
in April 2017,

22
00:01:09,935 --> 00:01:12,839
before finally plunging
into Saturn's atmosphere in

23
00:01:12,872 --> 00:01:14,407
September.

24
00:01:14,440 --> 00:01:17,510
Tonight we have two guests
who will present highlights,

25
00:01:17,543 --> 00:01:20,012
expectations, challenges,
and the promise of Cassini's

26
00:01:20,045 --> 00:01:20,947
final year.

27
00:01:22,348 --> 00:01:24,550
Dr. Earl Maze is the manager
of the Cassini program.

28
00:01:24,583 --> 00:01:27,487
A veteran of 32 years at JPL,
he began his career working

29
00:01:27,520 --> 00:01:30,289
on the navigation
and engineering
teams for the Galileo

30
00:01:30,322 --> 00:01:31,757
mission to Jupiter.

31
00:01:31,790 --> 00:01:34,527
After Galileo's final earth
flyby, he transferred to

32
00:01:34,560 --> 00:01:37,864

Cassini as the spacecraft
operations manager and then

33
00:01:37,897 --> 00:01:39,866
deputy project manager.

34
00:01:39,899 --> 00:01:42,101
He left the project for eight
years to hold management

35
00:01:42,134 --> 00:01:44,604
positions in guidance,
navigation, and control in

36
00:01:44,637 --> 00:01:47,673
avionics, then return to
Cassini as the program manager

37
00:01:47,706 --> 00:01:49,042
in January 2013.

38
00:01:50,509 --> 00:01:53,379
Dr. Linda Spilker is the
Cassini project scientist

39
00:01:53,412 --> 00:01:55,781
and the co-investigator
on the Cassini composite

40
00:01:55,814 --> 00:01:58,618
infrared spectrometer team
and has worked on Cassini

41
00:01:58,651 --> 00:01:59,552
since 1988.

42
00:02:01,053 --> 00:02:04,690
Since joining JPL almost 40
years ago, her first and only

43
00:02:04,723 --> 00:02:09,028
out of college job, by the
way, she has worked on the

44
00:02:09,061 --> 00:02:11,631
Voyager project, the Cassini
project, and conducted

45
00:02:11,664 --> 00:02:14,634
independent research on
the origin and evolution of

46
00:02:14,667 --> 00:02:16,536
planetary ring systems.

47
00:02:16,569 --> 00:02:19,872
She also supports proposals
and concept studies for new

48
00:02:19,905 --> 00:02:21,874
missions to the outer planets.

49
00:02:21,907 --> 00:02:24,177
She enjoys yoga and hiking,
especially through her

50
00:02:24,210 --> 00:02:26,445
favorite park, Yosemite,
and is married with three

51
00:02:26,478 --> 00:02:28,581
daughters and five
grandchildren.

52
00:02:28,614 --> 00:02:30,683
So, up first tonight,
perhaps one of the coolest

53
00:02:30,716 --> 00:02:33,586

grandmothers ever,
Dr. Linda Spilker.

54
00:02:33,619 --> 00:02:35,889
(applause)

55
00:02:43,529 --> 00:02:45,531
- Thanks Marc, that was
a great introduction.

56
00:02:45,564 --> 00:02:49,268
And, as Marc indicated,
Cassini has truly re-written

57
00:02:49,301 --> 00:02:52,939
whole textbooks on
the Saturn system.

58
00:02:52,972 --> 00:02:56,676
From the planet itself, to
the complex ring system,

59
00:02:56,709 --> 00:02:59,445
to these just amazing and
astonishing moons that come in

60
00:02:59,478 --> 00:03:02,915
all shapes and sizes, and
then the great magnetic field

61
00:03:02,948 --> 00:03:05,017
that surrounds
the planet itself.

62
00:03:05,050 --> 00:03:07,653
Now I'm going to cover some
of the highlights of Cassini's

63
00:03:07,686 --> 00:03:12,525
journey in the Saturn system,

her 12 year voyage around

64
00:03:12,558 --> 00:03:14,026
Saturn.

65
00:03:14,059 --> 00:03:16,495
And Earl is going to talk
about the grand finale.

66
00:03:16,528 --> 00:03:20,866
Those last precious orbits
of Cassini with truly unique

67
00:03:20,899 --> 00:03:22,134
science.

68
00:03:22,167 --> 00:03:24,403
Essentially like a
brand new mission.

69
00:03:24,436 --> 00:03:28,541
And then those final
moments with Cassini.

70
00:03:28,574 --> 00:03:30,710
Now, if you look at
the picture behind me,

71
00:03:30,743 --> 00:03:34,780
this is one of my very
favorite montages from Cassini.

72
00:03:34,813 --> 00:03:37,683
And as a ring scientist,
you can probably guess why.

73
00:03:37,716 --> 00:03:40,620
In this you can see all
of the major rings of the

74
00:03:40,653 --> 00:03:42,321
Saturn system.

75
00:03:42,354 --> 00:03:44,624
And it's a unique geometry.

76
00:03:44,657 --> 00:03:47,460
The planet itself is
covering up the sun,

77
00:03:47,493 --> 00:03:50,696
allowing Cassini's sensitive
cameras and detectors

78
00:03:50,729 --> 00:03:53,366
to mosaic this back-lit view.

79
00:03:53,399 --> 00:03:55,534
It's kind of like looking
through, you know,

80
00:03:55,567 --> 00:03:57,837
a dusty windshield or
something and these particles

81
00:03:57,870 --> 00:04:00,606
brighten up and
you can see them.

82
00:04:00,639 --> 00:04:02,375
So what you see is the
planet itself then the main

83
00:04:02,408 --> 00:04:03,776
ring system.

84
00:04:03,809 --> 00:04:06,445
That faint ring just
outside the main ring system

85
00:04:06,478 --> 00:04:09,849
is the G ring, and that
beautiful blue ring is

86
00:04:09,882 --> 00:04:11,317
Saturn's E ring.

87
00:04:11,350 --> 00:04:15,087
And it's created by tiny
icy particles that come from

88
00:04:15,120 --> 00:04:18,491
the south pole of Enceladus
that go on to form a ring

89
00:04:18,524 --> 00:04:20,493
that fills Enceladus' orbit.

90
00:04:20,526 --> 00:04:23,629
These particles even go all
the way out to the orbit

91
00:04:23,662 --> 00:04:26,999
of Titan, one of the
distant moons at Saturn.

92
00:04:27,032 --> 00:04:29,635
Now, if you look closely at
Saturn, you'll notice that

93
00:04:29,668 --> 00:04:32,838
there's a white ring
around the planet.

94
00:04:32,871 --> 00:04:36,742
And this is where the sunlight
is refracted through the

95

00:04:36,775 --> 00:04:38,844
top of the atmosphere
into your eyes.

96
00:04:38,877 --> 00:04:41,681
And it's so beautiful because
when you look at this ring

97
00:04:41,714 --> 00:04:45,618
around Saturn, you're seeing
every sunrise and sunset

98
00:04:45,651 --> 00:04:49,021
on the planet at
the very same time.

99
00:04:49,054 --> 00:04:52,558
And you're looking at
the dark side of Saturn,

100
00:04:52,591 --> 00:04:55,628
and yet, something is
lighting up the night side.

101
00:04:55,661 --> 00:04:58,964
And what's lighting up
the night side is actually

102
00:04:58,997 --> 00:05:00,666
light coming from
Saturn's rings.

103
00:05:00,699 --> 00:05:02,968
So the sunlight hits the
rings on one side and it

104
00:05:03,001 --> 00:05:06,439
then reflects onto the
night side of Saturn.

105

00:05:06,472 --> 00:05:09,275
So, just one of the
many incredible images

106
00:05:09,308 --> 00:05:13,079
that have come back from
the Cassini mission.

107
00:05:14,480 --> 00:05:17,783
Now, I'm often asked,
"Why do we explore space?

108
00:05:17,816 --> 00:05:21,520
"Why do we send robotic
emissaries out like Cassini?

109
00:05:21,553 --> 00:05:24,457
"What are some of the grand
questions we hope to answer?"

110
00:05:24,490 --> 00:05:26,559
And Cassini addresses
two of those.

111
00:05:26,592 --> 00:05:29,161
These are something that were
in a survey for planetary

112
00:05:29,194 --> 00:05:31,731
science, we do these
once ever 10 years.

113
00:05:31,764 --> 00:05:33,833
So the first grand question is,

114
00:05:33,866 --> 00:05:36,836
are we alone in the universe?

115
00:05:36,869 --> 00:05:40,106
Has life originated

somewhere other than Earth?

116
00:05:40,139 --> 00:05:42,808
Perhaps in our own solar system?

117
00:05:42,841 --> 00:05:46,179
And how did life
originate on the earth?

118
00:05:47,679 --> 00:05:50,383
Another grand question is
how did the solar system

119
00:05:50,416 --> 00:05:53,486
and the earth within
it come to be?

120
00:05:53,519 --> 00:05:56,455
How is it evolving and
where is it headed?

121
00:05:56,488 --> 00:05:58,858
By studying the planets in
our solar system we can learn

122
00:05:58,891 --> 00:06:02,061
about how our solar system
formed, how the planets may

123
00:06:02,094 --> 00:06:05,331
have migrated as the system
evolved and where we might

124
00:06:05,364 --> 00:06:06,832
be headed.

125
00:06:06,865 --> 00:06:09,168
And it's a good analogy
for other systems around

126
00:06:09,201 --> 00:06:10,203
other stars.

127
00:06:12,704 --> 00:06:15,241
Now, here's the, I just
want to go back briefly here

128
00:06:15,274 --> 00:06:16,976
and show you these are
the eight planets in our

129
00:06:17,009 --> 00:06:18,577
solar system.

130
00:06:18,610 --> 00:06:21,113
Saturn is the sixth
planet out from the sun,

131
00:06:21,146 --> 00:06:24,483
it's the second largest
planet and it takes 30 years

132
00:06:24,516 --> 00:06:27,820
to circle the sun a single time.

133
00:06:27,853 --> 00:06:29,388
Now, Saturn is indeed huge.

134
00:06:29,421 --> 00:06:30,890
It's the second largest planet.

135
00:06:30,923 --> 00:06:34,960
This shows the earth and the
moon to scale and the distance

136
00:06:34,993 --> 00:06:36,495
in between them.

137

00:06:36,528 --> 00:06:40,132
So you can see that Saturn
would just fit in between

138
00:06:40,165 --> 00:06:41,700
the earth and the moon.

139
00:06:41,733 --> 00:06:45,304
And if the earth were a tiny
marble it would take 764

140
00:06:45,337 --> 00:06:49,175
earths to fill up
the volume of Saturn.

141
00:06:49,208 --> 00:06:51,777
So truly a giant planet.

142
00:06:51,810 --> 00:06:53,679
And what you're seeing
are just cloud tops.

143
00:06:53,712 --> 00:06:55,948
Saturn doesn't have a solid
surface like the earth.

144
00:06:55,981 --> 00:06:58,684
It's all clouds, mostly
hydrogen and helium,

145
00:06:58,717 --> 00:07:02,121
and maybe a tiny rocky core
about the size of the earth

146
00:07:02,154 --> 00:07:03,889
in the center.

147
00:07:03,922 --> 00:07:06,325
Here's an overview of
the Cassini mission.

148
00:07:06,358 --> 00:07:09,462
Cassini was launched
from the earth in 1997.

149
00:07:09,495 --> 00:07:12,965
We used gravity
assists, two of Venus,

150
00:07:12,998 --> 00:07:15,000
one flyby of the
Earth, one of Jupiter,

151
00:07:15,033 --> 00:07:19,004
and arriving at Saturn
in July of 2004.

152
00:07:19,037 --> 00:07:21,740
Now, originally Cassini
was funded for a four year

153
00:07:21,773 --> 00:07:23,275
prime mission.

154
00:07:23,308 --> 00:07:25,511
And by the end of the prime
mission we found we had

155
00:07:25,544 --> 00:07:27,880
enough fuel and a healthy
spacecraft that we actually

156
00:07:27,913 --> 00:07:30,249
had two extended mission.

157
00:07:30,282 --> 00:07:32,885
The Equinox Mission where
the sun was shining right on

158

00:07:32,918 --> 00:07:35,754
Saturn's equator
edge onto the rings,

159
00:07:35,787 --> 00:07:38,858
and then a seven year
Solstice mission.

160
00:07:38,891 --> 00:07:41,494
And norther summer Solstice
at Saturn will be in May

161
00:07:41,527 --> 00:07:45,097
of 2017 and the mission
will last just past that,

162
00:07:45,130 --> 00:07:47,933
ending in September of 2017.

163
00:07:47,966 --> 00:07:49,768
And you can see there at
the end in the green box

164
00:07:49,801 --> 00:07:53,205
what we call the proximal,
so grand finale orbits,

165
00:07:53,238 --> 00:07:55,808
and they're shown above
highlighted in this box.

166
00:07:55,841 --> 00:07:59,211
And this whole mission is
shown against the 30 year

167
00:07:59,244 --> 00:08:01,313
orbital period for Saturn.

168
00:08:01,346 --> 00:08:05,017
So by the end of the Cassini

mission, at the end of 13 years

169
00:08:05,050 --> 00:08:07,253
we'll have been in orbit
in the Saturn system for

170
00:08:07,286 --> 00:08:09,455
almost two seasons.

171
00:08:09,488 --> 00:08:12,725
They change very very
slowly at Saturn.

172
00:08:14,159 --> 00:08:17,329
And right now Cassini is
almost to that green box.

173
00:08:17,362 --> 00:08:20,132
We're going up in inclination
and we're getting ready

174
00:08:20,165 --> 00:08:22,502
for out final set of orbits.

175
00:08:23,902 --> 00:08:27,106
This is another view of the
Cassini mission by year.

176
00:08:27,139 --> 00:08:30,009
You can look across the top
bar, shows the number of orbits

177
00:08:30,042 --> 00:08:32,278
and the shapes of those orbits.

178
00:08:32,311 --> 00:08:34,246
Then you can see that by the
end of the mission we'll have

179

00:08:34,279 --> 00:08:37,216
127 flybys of the
giant moon Titan.

180
00:08:38,917 --> 00:08:42,087
And Titan is like a
giant rocket engine.

181
00:08:42,120 --> 00:08:45,357
Every time we flyby Titan,
it's like expending almost

182
00:08:45,390 --> 00:08:49,094
as much fuel as we spent
to go into orbit for Saturn

183
00:08:49,127 --> 00:08:50,596
orbit insertion.

184
00:08:50,629 --> 00:08:52,998
And we get great views of
this very interesting body,

185
00:08:53,031 --> 00:08:54,667
as well.

186
00:08:54,700 --> 00:08:57,603
We've had 23 flybys
of Enceladus, and
the prime mission,

187
00:08:57,636 --> 00:08:59,672
the first four
years we had three.

188
00:08:59,705 --> 00:09:03,509
We discovered Enceladus
was so interesting that it

189
00:09:03,542 --> 00:09:06,946

reshaped our thinking for
the extended mission and we

190
00:09:06,979 --> 00:09:09,982
added 20 more
flybys of Enceladus.

191
00:09:10,015 --> 00:09:13,352
We have 15 flybys of
the other IC satellites,

192
00:09:13,385 --> 00:09:16,155
and then you can see the
seasons changing from northern

193
00:09:16,188 --> 00:09:18,791
winter to northern summer
over the course of the

194
00:09:18,824 --> 00:09:20,159
Cassini mission.

195
00:09:21,593 --> 00:09:23,128
And then, of course, those
proximal or grand final

196
00:09:23,161 --> 00:09:25,798
orbits at the end, and Earl
will be talking about those

197
00:09:25,831 --> 00:09:27,099
in more detail.

198
00:09:30,035 --> 00:09:33,672
This is a Cassini Orbiter
and the Hoygens Probe.

199
00:09:33,705 --> 00:09:35,975
You can see a great model,
a quarter scale model over

200
00:09:36,008 --> 00:09:38,544
in the corner of the
Cassini spacecraft.

201
00:09:38,577 --> 00:09:41,313
Cassini, she's
about 22 feet tall.

202
00:09:41,346 --> 00:09:44,483
That antenna at the top is
about 13 feet in diameter,

203
00:09:44,516 --> 00:09:46,685
it's comparable to
the voyager antenna.

204
00:09:46,718 --> 00:09:49,188
You can see over in this
other spacecraft here.

205
00:09:49,221 --> 00:09:51,390
You can see people
for reference.

206
00:09:51,423 --> 00:09:55,361
And, fully fueled,
Cassini weighed six tons.

207
00:09:55,394 --> 00:09:59,031
And about half of that was
fuel that we spent about

208
00:09:59,064 --> 00:10:03,002
a third of that just to go
into orbit around Saturn.

209
00:10:03,035 --> 00:10:05,437
The Hoygens probe was
provided by the European Space

210
00:10:05,470 --> 00:10:09,475
Agency and it was specifically
designed with the goal of

211
00:10:09,508 --> 00:10:12,711
being thrust into Saturn
and Titan's atmosphere,

212
00:10:12,744 --> 00:10:16,916
parachuting down, and landing
on the surface of Titan.

213
00:10:18,684 --> 00:10:21,420
Now, Cassini isn't just a
spacecraft that's made up of

214
00:10:21,453 --> 00:10:24,556
metal and bolts and bits and
pieces, but this is kind of

215
00:10:24,589 --> 00:10:26,291
my view of Cassini.

216
00:10:26,324 --> 00:10:29,161
I see Cassini as made up
of all the people that are

217
00:10:29,194 --> 00:10:30,529
on her team.

218
00:10:30,562 --> 00:10:33,966
The scientists, the
engineers, the support staff,

219
00:10:33,999 --> 00:10:36,935
and in a way, Cassini
represents all of their hopes

220

00:10:36,968 --> 00:10:41,707
and dreams, all of the things
that we want to accomplish.

221
00:10:41,740 --> 00:10:44,009
There are times when I
almost picture myself there

222
00:10:44,042 --> 00:10:47,112
with Cassini in the Saturn
system as we get back some

223
00:10:47,145 --> 00:10:50,649
of these wonderful images
or spectra or data of these

224
00:10:50,682 --> 00:10:52,418
incredible places.

225
00:10:52,451 --> 00:10:54,553
I almost feel like I'm
right there looking through

226
00:10:54,586 --> 00:10:58,824
Cassini's eyes and watching
as she collects her data.

227
00:10:58,857 --> 00:11:01,660
And I feel very proud to be
a part of this incredible

228
00:11:01,693 --> 00:11:02,528
mission.

229
00:11:03,428 --> 00:11:05,330
Now, onto some of the science.

230
00:11:05,363 --> 00:11:07,266
This is the tiny
moon, Enceladus.

231
00:11:07,299 --> 00:11:10,102
Enceladus is only
300 miles across.

232
00:11:10,135 --> 00:11:13,372
Enceladus would fit between
Los Angeles and San Francisco

233
00:11:13,405 --> 00:11:15,274
so it's a very tiny moon.

234
00:11:15,307 --> 00:11:17,342
And yet a very interesting one.

235
00:11:17,375 --> 00:11:20,245
When we saw it with Voyager
we saw a very bright

236
00:11:20,278 --> 00:11:21,647
icy surface.

237
00:11:21,680 --> 00:11:24,083
Generally in the solar
system something bright means

238
00:11:24,116 --> 00:11:25,584
that it's young.

239
00:11:25,617 --> 00:11:27,553
You haven't had a chance
to build up the pollution

240
00:11:27,586 --> 00:11:29,688
from the micro-meteorite
bombardment.

241
00:11:29,721 --> 00:11:32,925
Also you'll notice as you

go south, there are very few

242
00:11:32,958 --> 00:11:36,528
craters, in fact there are
no craters at the south pole

243
00:11:36,561 --> 00:11:37,730
of Enceladus.

244
00:11:37,763 --> 00:11:40,332
And you can see four
tiger stripe fractures,

245
00:11:40,365 --> 00:11:43,235
that's our nickname for
those bluish features there.

246
00:11:43,268 --> 00:11:46,672
Alexandria, Baghdad,
Cairo, and Damascus.

247
00:11:48,106 --> 00:11:51,110
Very interesting names and
those fractures were something

248
00:11:51,143 --> 00:11:53,378
that were in darkness when
the voyager spacecraft flew

249
00:11:53,411 --> 00:11:54,847
through the Saturn system.

250
00:11:54,880 --> 00:11:57,149
So we didn't know they
were there until we had the

251
00:11:57,182 --> 00:11:58,484
Cassini spacecraft.

252

00:11:58,517 --> 00:12:01,653
Now, our first flyby
in July of 2005,

253
00:12:01,686 --> 00:12:04,523
our magnetometer team said
there's something interesting

254
00:12:04,556 --> 00:12:06,358
going on with Enceladus.

255
00:12:06,391 --> 00:12:09,061
The magnetic field lines from
Saturn don't go down to the

256
00:12:09,094 --> 00:12:11,363
icy surface like they
normally would for a body

257
00:12:11,396 --> 00:12:13,098
frozen solid.

258
00:12:13,131 --> 00:12:15,734
Instead it kind of
reminds us of a comet.

259
00:12:15,767 --> 00:12:18,036
Those field lines are standing
off, there's something

260
00:12:18,069 --> 00:12:20,639
going on in the
southern hemisphere.

261
00:12:20,672 --> 00:12:23,375
And so they encouraged us,
we had 1,000 kilometer flyby

262
00:12:23,408 --> 00:12:24,877
the first time.

263
00:12:24,910 --> 00:12:26,512
They said, "Go closer, we
can really get a lot better

264
00:12:26,545 --> 00:12:27,980
"data."

265
00:12:28,013 --> 00:12:29,815
So we went closer and also
trained our other instruments

266
00:12:29,848 --> 00:12:32,351
on Enceladus and we
found, here this is with a

267
00:12:32,384 --> 00:12:35,888
composite infrared spectrometer,
the team that I work with,

268
00:12:35,921 --> 00:12:39,224
they found that the
Enceladus south pole was hot.

269
00:12:39,257 --> 00:12:42,861
It was about 100 degrees hotter
than the rest of Enceladus.

270
00:12:42,894 --> 00:12:44,997
And if Enceladus were frozen
solid it was much hotter

271
00:12:45,030 --> 00:12:46,498
than it should be.

272
00:12:46,531 --> 00:12:49,168
And in looking more closely,
that heat lined up with

273

00:12:49,201 --> 00:12:51,804
those tiger stripe
like fractures.

274
00:12:51,837 --> 00:12:53,405
So this excess
heat was a puzzle.

275
00:12:53,438 --> 00:12:57,042
We had an auscultation of a
star going behind this region,

276
00:12:57,075 --> 00:13:00,312
we looked at these tiger
stripes in more detail on the

277
00:13:00,345 --> 00:13:01,880
various flybys.

278
00:13:01,913 --> 00:13:04,950
Here's a tiger stripe, it's
about a mile or so across.

279
00:13:04,983 --> 00:13:07,820
Typically about 100 miles
wide, and it's just this

280
00:13:07,853 --> 00:13:09,354
large gash.

281
00:13:09,387 --> 00:13:11,356
Four of them in the south pole.

282
00:13:11,389 --> 00:13:13,892
You can almost see what
looks like a frosted side

283
00:13:13,925 --> 00:13:16,028
on the left hand side there.

284
00:13:16,061 --> 00:13:19,031
We wondered what could be going
on with these tiger stripes.

285
00:13:19,064 --> 00:13:22,835
We also had images and the
answer, it was very clear.

286
00:13:22,868 --> 00:13:27,072
There are jets of material,
water vapor, water ice particles

287
00:13:27,105 --> 00:13:30,475
shooting out of these tiger
stripe like fractures.

288
00:13:30,508 --> 00:13:33,779
Here's another view of
those jets coming out,

289
00:13:33,812 --> 00:13:37,816
just going all
different directions,
continuously going off

290
00:13:37,849 --> 00:13:40,252
ever since Cassini arrived
at Saturn and we've been

291
00:13:40,285 --> 00:13:42,154
watching Enceladus.

292
00:13:42,187 --> 00:13:45,123
So not only do you get
water vapor and water ice

293
00:13:45,156 --> 00:13:48,060
coming out, you have things
like ammonia, methane,

294
00:13:48,093 --> 00:13:49,595
carbon dioxide.

295
00:13:49,628 --> 00:13:52,297
You have many of the key
ingredients that you might

296
00:13:52,330 --> 00:13:56,502
need to find life, coming out
of these jets on Enceladus.

297
00:13:57,969 --> 00:14:00,706
And part of the goal of
our flybys is actually to

298
00:14:00,739 --> 00:14:02,975
fly through this material.

299
00:14:04,142 --> 00:14:06,812
And in October we came
within 50 kilometers of

300
00:14:06,845 --> 00:14:09,982
Enceladus' surface, right
under the south pole.

301
00:14:10,015 --> 00:14:12,951
And it gave us a chance to,
essentially, taste and smell

302
00:14:12,984 --> 00:14:15,787
those particles, figure
out what they were made of,

303
00:14:15,820 --> 00:14:20,325
and try and figure out the
activity inside of Enceladus.

304
00:14:20,358 --> 00:14:22,327

Here's another view
of those icy jets.

305
00:14:22,360 --> 00:14:25,230
This is a back-lit view,
similar to what you saw earlier

306
00:14:25,263 --> 00:14:26,698
in the Saturn image.

307
00:14:26,731 --> 00:14:29,668
You can see the sunlight shining
through each of these jets.

308
00:14:29,701 --> 00:14:33,538
And we found in the particles
that some of those were salty.

309
00:14:33,571 --> 00:14:36,675
It says that there's a global
ocean underneath Enceladus'

310
00:14:36,708 --> 00:14:40,178
icy crust and it's as though
they were frozen sea spray

311
00:14:40,211 --> 00:14:42,948
and they contained sodium
and potassium salts.

312
00:14:42,981 --> 00:14:46,151
And we know the PH of the
ocean, very similar to the

313
00:14:46,184 --> 00:14:48,320
oceans here on the earth.

314
00:14:48,353 --> 00:14:51,356
So very interesting finding
in the particle data.

315
00:14:51,389 --> 00:14:54,893
This is an interesting view,
this is another Enceladus.

316
00:14:54,926 --> 00:14:58,463
This is a fountain at Versailles
in their gardens there

317
00:14:58,496 --> 00:15:01,600
and this particular Enceladus
is a Greek giant and

318
00:15:01,633 --> 00:15:04,603
he had a run-in with
his grand niece, Athena,

319
00:15:04,636 --> 00:15:06,038
and he lost.

320
00:15:06,071 --> 00:15:09,875
And so his fate was to be
forever buried under Mount Etna.

321
00:15:09,908 --> 00:15:12,911
So I think here he's protesting
a bit with this giant

322
00:15:12,944 --> 00:15:15,514
82 foot high geyser of water.

323
00:15:15,547 --> 00:15:17,983
Who knew in the 1670s that
Enceladus would actually

324
00:15:18,016 --> 00:15:21,120
kind of be doing
something like this?

325

00:15:22,921 --> 00:15:25,424
Now here's an artists concept
of what might be going on.

326
00:15:25,457 --> 00:15:28,694
You have the liquid water
ocean underneath the icy crust

327
00:15:28,727 --> 00:15:31,229
and that carbon dioxide
might be sort of like shaking

328
00:15:31,262 --> 00:15:32,965
up a champagne bottle.

329
00:15:32,998 --> 00:15:36,535
You pop the cork and perhaps
that's the energy that's

330
00:15:36,568 --> 00:15:39,438
there to raise that water
vapor and icy particles

331
00:15:39,471 --> 00:15:43,375
to send them
continuously into space.

332
00:15:43,408 --> 00:15:46,078
Now, most of the material
falls back onto the surface

333
00:15:46,111 --> 00:15:47,312
of Enceladus.

334
00:15:47,345 --> 00:15:49,081
The particles are too
large and they just,

335
00:15:49,114 --> 00:15:51,283
they fall back, and

it's like it's snowing.

336
00:15:51,316 --> 00:15:53,919
If you could stand near a
tiger stripe underneath it

337
00:15:53,952 --> 00:15:55,954
you could put out your
hands and it would be like

338
00:15:55,987 --> 00:15:57,723
it would be snowing
on Enceladus.

339
00:15:57,756 --> 00:16:01,727
Maybe a future vacation
destination, who knows?

340
00:16:01,760 --> 00:16:05,831
But some of the tiniest
grains escape into space.

341
00:16:07,265 --> 00:16:09,334
And they're what go on to
form that very beautiful

342
00:16:09,367 --> 00:16:12,738
blue E ring that you
saw in the first image.

343
00:16:12,771 --> 00:16:14,606
If you look carefully in
this image you can see

344
00:16:14,639 --> 00:16:17,709
this tiny black dot,
that's Enceladus.

345
00:16:17,742 --> 00:16:21,346
Underneath it is the bright

plume of material coming out.

346
00:16:21,379 --> 00:16:25,250
And you can see wisps and
tendrils of those icy particles

347
00:16:25,283 --> 00:16:27,419
going out to form the E ring.

348
00:16:27,452 --> 00:16:29,788
Now, the E ring particles
are so tiny that they spread

349
00:16:29,821 --> 00:16:32,324
throughout the system and
if you turned off Enceladus'

350
00:16:32,357 --> 00:16:36,328
jets it might only take
100 or 200 years until the

351
00:16:36,361 --> 00:16:38,330
E ring is gone completely.

352
00:16:38,363 --> 00:16:41,066
So that's sort of a clue,
we see the E ring we know

353
00:16:41,099 --> 00:16:44,103
the jets are going
off at Enceladus.

354
00:16:45,503 --> 00:16:48,340
This is just an artists concept
of the inside of Enceladus.

355
00:16:48,373 --> 00:16:50,375
We know it's differentiated,
that just means it's

356
00:16:50,408 --> 00:16:54,312
separated into a rocky
core, a global ocean,

357
00:16:54,345 --> 00:16:56,181
and an icy crust.

358
00:16:56,214 --> 00:16:58,784
We've also found that in
looking at some of our particle

359
00:16:58,817 --> 00:17:01,420
data there are tiny
grains of silica.

360
00:17:01,453 --> 00:17:03,488
We call these
nano-silica grains.

361
00:17:03,521 --> 00:17:06,425
What's unique about them
is these nano-silica grains

362
00:17:06,458 --> 00:17:10,195
can only form in water
that's near boiling.

363
00:17:10,228 --> 00:17:12,631
So what we think happens
is that the water goes into

364
00:17:12,664 --> 00:17:16,334
the rocky core of Enceladus,
it's heated up there,

365
00:17:16,367 --> 00:17:19,104
Enceladus is kept warm by a
resonance with another moon,

366

00:17:19,137 --> 00:17:23,075
Dione, that's essentially just
pumping heat energy into it.

367
00:17:23,108 --> 00:17:25,877
And once that water is
heated up it absorbs these

368
00:17:25,910 --> 00:17:28,080
minerals, in particular silica.

369
00:17:28,113 --> 00:17:31,083
When the silica comes back
out through these hydrothermal

370
00:17:31,116 --> 00:17:34,786
vents, hits the cold water,
those minerals condense into

371
00:17:34,819 --> 00:17:36,354
tiny particles.

372
00:17:36,387 --> 00:17:39,091
Then those particles are
frozen into the particles that

373
00:17:39,124 --> 00:17:41,993
go out into space that
Cassini can measure.

374
00:17:42,026 --> 00:17:45,097
So this is an indication
that there's a possibility

375
00:17:45,130 --> 00:17:49,000
of hydro-thermal vents on
the sea floor of Enceladus.

376
00:17:49,033 --> 00:17:51,503
Now, if we look at our own

planet, we have the same kind

377
00:17:51,536 --> 00:17:55,006
of hydro-thermal vents on
the sea floor of the earth.

378
00:17:55,039 --> 00:17:58,710
This is along the mid-oceanic
ridge in the Atlantic Ocean,

379
00:17:58,743 --> 00:18:00,378
it's very very deep.

380
00:18:00,411 --> 00:18:03,448
No sunlight penetrates
to that depth.

381
00:18:03,481 --> 00:18:05,750
This is illuminated from
basically the headlight of

382
00:18:05,783 --> 00:18:09,321
the submarine that's looking
at this particular event.

383
00:18:09,354 --> 00:18:12,023
And here you have silica and
potassium and other minerals

384
00:18:12,056 --> 00:18:15,861
that condense in the cold
water on the earth's sea floor,

385
00:18:15,894 --> 00:18:17,696
forming what looks like smoke.

386
00:18:17,729 --> 00:18:21,166
And these are what is known
as white smokers on the earth.

387
00:18:21,199 --> 00:18:22,834
There's also something
along the sea,

388
00:18:22,867 --> 00:18:24,903
depending on the composition,
there are black smokers

389
00:18:24,936 --> 00:18:26,404
as well.

390
00:18:26,437 --> 00:18:28,607
They're more iron rich, so
a different composition.

391
00:18:28,640 --> 00:18:31,910
What's interesting is here
in the deep cold ocean

392
00:18:31,943 --> 00:18:35,814
where you have no sunlight,
the only heat energy and

393
00:18:35,847 --> 00:18:38,583
nutrients are what's
coming out of these vents,

394
00:18:38,616 --> 00:18:41,920
you find an amazing
array of life.

395
00:18:41,953 --> 00:18:44,723
You find tiny crabs,
you find tube worms,

396
00:18:44,756 --> 00:18:48,693
you find little tiny animals,
all sorts of life in an

397

00:18:48,726 --> 00:18:52,164
island around these
hydro-thermal vents.

398
00:18:52,197 --> 00:18:56,301
So we wonder if we can
find life in our own ocean,

399
00:18:56,334 --> 00:19:00,772
perhaps might there be life
in the ocean of Enceladus?

400
00:19:00,805 --> 00:19:03,275
So some of the factors
that life might exist there

401
00:19:03,308 --> 00:19:07,812
include a global salty ocean
PH very similar to our own.

402
00:19:07,845 --> 00:19:10,649
We know it's long-lived, a
global ocean probably formed

403
00:19:10,682 --> 00:19:13,351
at the same time as Enceladus.

404
00:19:13,384 --> 00:19:15,587
There's organics coming
from the ocean to the limits

405
00:19:15,620 --> 00:19:18,089
of the instruments we
have to detect them.

406
00:19:18,122 --> 00:19:21,927
Carbon chains up to C6,
C7, they're probably even

407
00:19:21,960 --> 00:19:24,596

longer but that's the
cutoff of the instruments,

408
00:19:24,629 --> 00:19:26,097
what we can measure.

409
00:19:26,130 --> 00:19:28,466
Heat energy coming from
the hydro-thermal vents on

410
00:19:28,499 --> 00:19:32,370
the sea floor, and best
of all for Enceladus,

411
00:19:32,403 --> 00:19:34,439
it's giving us free samples.

412
00:19:34,472 --> 00:19:37,943
And it turns out when we
launched Cassini we had no idea

413
00:19:37,976 --> 00:19:39,644
that there'd be
these jets, or vents,

414
00:19:39,677 --> 00:19:42,414
coming out of Enceladus so we
didn't carry the instruments

415
00:19:42,447 --> 00:19:46,084
that we would've needed to
look for amino acids and

416
00:19:46,117 --> 00:19:49,721
fatty acids and long chain
molecules that could tell us

417
00:19:49,754 --> 00:19:51,323
that life is there.

418
00:19:51,356 --> 00:19:54,259
So this just means that this
is a wonderful destination,

419
00:19:54,292 --> 00:19:57,329
this ocean world, to go
back to Enceladus and to

420
00:19:57,362 --> 00:19:59,864
keep exploring and
answer the question,

421
00:19:59,897 --> 00:20:02,601
are we alone in the universe
or perhaps might there

422
00:20:02,634 --> 00:20:04,970
be life in Enceladus' ocean?

423
00:20:07,605 --> 00:20:10,141
Now, another very interesting
moon is Saturn's moon,

424
00:20:10,174 --> 00:20:11,643
Titan.

425
00:20:11,676 --> 00:20:13,945
Titan is about 10 times
bigger than Enceladus and,

426
00:20:13,978 --> 00:20:17,549
in fact, Titan is about the
size of the planet Mercury.

427
00:20:17,582 --> 00:20:20,085
If Titan had formed anywhere
else in the solar system,

428
00:20:20,118 --> 00:20:23,121

Titan would be a planet
instead of a moon.

429
00:20:23,154 --> 00:20:26,057
Now, this was a
Voyager view of Titan.

430
00:20:26,090 --> 00:20:29,261
And we just saw this hazy
world and we couldn't see

431
00:20:29,294 --> 00:20:31,096
through to the surface.

432
00:20:31,129 --> 00:20:33,865
So after the Voyager
flybys in the 1980s,

433
00:20:33,898 --> 00:20:36,001
a group of scientists
got together and said,

434
00:20:36,034 --> 00:20:38,370
"You know, we really need
to start thinking about

435
00:20:38,403 --> 00:20:39,804
"going back."

436
00:20:39,837 --> 00:20:42,674
And it was both US and European
scientists and that was

437
00:20:42,707 --> 00:20:45,510
basically the birth of
the idea for what became

438
00:20:45,543 --> 00:20:47,445
the Cassini mission.

439
00:20:47,478 --> 00:20:49,648
Now, Titan has a very
dense atmosphere,

440
00:20:49,681 --> 00:20:51,983
it's made mostly of Nitrogen,
very similar to the Earth's

441
00:20:56,454 --> 00:20:53,451
atmosphere.

442
00:20:56,487 --> 00:20:59,257
And methane is really
the key at Titan.

443
00:20:59,290 --> 00:21:02,294
Because, you see, methane
plays the role at Titan

444
00:21:02,327 --> 00:21:04,663
that water plays
here on the earth.

445
00:21:04,696 --> 00:21:08,033
The methane can be a
gas, it can be a liquid,

446
00:21:08,066 --> 00:21:12,437
it can form clouds, it can
rain onto the surface of Titan.

447
00:21:12,470 --> 00:21:15,240
That the temperature of
Titan's surface is just right

448
00:21:15,273 --> 00:21:18,143
to be at the triple point
where you could have a liquid,

449

00:21:18,176 --> 00:21:20,845
a solid, or a gas for methane.

450
00:21:20,878 --> 00:21:22,914
Now, the methane is also
part of the problem with the

451
00:21:22,947 --> 00:21:24,449
smog on Titan.

452
00:21:24,482 --> 00:21:26,518
Because you see some of the
methane goes high up in the

453
00:21:26,551 --> 00:21:29,788
atmosphere, the solar photons,
the UV breaks the methane

454
00:21:29,821 --> 00:21:32,791
apart, they grow into
larger and larger chains of

455
00:21:32,824 --> 00:21:36,294
molecules, and that forms
haze very similar to the smog

456
00:21:36,327 --> 00:21:38,763
that we have here on the earth.

457
00:21:38,796 --> 00:21:40,832
When the particles grow
large enough they actually

458
00:21:40,865 --> 00:21:43,869
fall down onto the
surface of Titan.

459
00:21:46,838 --> 00:21:50,308
Now, the Hoygens probe was
built specifically to go through

460
00:21:50,341 --> 00:21:52,977
the atmosphere, land on
the surface, and reveal the

461
00:21:53,010 --> 00:21:54,879
surface for the first time.

462
00:21:54,912 --> 00:21:57,582
So this is an artists
concept of the Hoygens probe.

463
00:21:57,615 --> 00:21:59,317
You can see it coming in.

464
00:21:59,350 --> 00:22:03,154
It was released from
Cassini on December 25, 2004

465
00:22:03,187 --> 00:22:05,590
and entered into the
atmosphere and landed on Titan

466
00:22:05,623 --> 00:22:07,459
on January 15 of 2005.

467
00:22:09,060 --> 00:22:11,329
So the heat shield
basically ablated away,

468
00:22:11,362 --> 00:22:13,198
carrying away the heat energy.

469
00:22:13,231 --> 00:22:15,467
And once the probe had
slowed down enough,

470
00:22:15,500 --> 00:22:18,536
then the parachute could

come out and for the next

471
00:22:18,569 --> 00:22:22,340
two and a half hours the Hoygens
probe floated gently down

472
00:22:22,373 --> 00:22:26,978
to the surface of Titan,
softly landed on the surface,

473
00:22:27,011 --> 00:22:29,047
and returned data for
another half hour.

474
00:22:29,080 --> 00:22:31,916
Cassini was the relay so as
the Hoygens probe was floating

475
00:22:31,949 --> 00:22:35,453
down Cassini was flying
overhead collecting the data

476
00:22:35,486 --> 00:22:38,923
then to send back to the
earth for the Hoygens probe.

477
00:22:38,956 --> 00:22:40,725
So really an amazing mission.

478
00:22:40,758 --> 00:22:42,560
With Hoygens we didn't
know what we'd find.

479
00:22:42,593 --> 00:22:44,295
Would we land in an ocean?

480
00:22:44,328 --> 00:22:46,231
Global ocean of methane?

481

00:22:46,264 --> 00:22:49,234
That was a possibility so
we built the Hoygens probe

482
00:22:49,267 --> 00:22:51,436
to float, at least
for a few minutes.

483
00:22:51,469 --> 00:22:53,605
But it turns that we didn't
have to worry about landing

484
00:22:53,638 --> 00:22:55,073
in an ocean.

485
00:22:55,106 --> 00:22:57,275
Instead, here's the view
that we had with the cameras.

486
00:22:57,308 --> 00:22:59,611
We measured not only the
pressure, temperature,

487
00:22:59,644 --> 00:23:02,280
and composition of Titan's
atmosphere on the way down,

488
00:23:02,313 --> 00:23:04,482
but the cameras
took these pictures.

489
00:23:04,515 --> 00:23:08,019
At about 60 kilometers
above the surface the haze

490
00:23:08,052 --> 00:23:11,423
finally started to clear and
we got a view of the surface.

491
00:23:11,456 --> 00:23:14,125

And we started to see
what looked like mountains

492
00:23:14,158 --> 00:23:16,027
as we went on our way down.

493
00:23:16,060 --> 00:23:19,330
And, in fact, the Hoygens probe
became the very first object

494
00:23:19,363 --> 00:23:22,634
to land in the outer solar
system, land on a body the

495
00:23:22,667 --> 00:23:26,304
furthest away from anything
we've had previously.

496
00:23:26,337 --> 00:23:28,306
Here's a view of the surface.

497
00:23:28,339 --> 00:23:30,809
You can see on the leftmost
panel these are rounded

498
00:23:30,842 --> 00:23:32,310
icy pebbles.

499
00:23:32,343 --> 00:23:34,813
That tells us that fluid
has flowed in this region.

500
00:23:34,846 --> 00:23:36,581
Probably we landed in what
was the equivalent of a

501
00:23:36,614 --> 00:23:38,116
dry lake bed.

502

00:23:38,149 --> 00:23:41,352
We had a lamp, you can see
the spot for the lamp here

503
00:23:41,385 --> 00:23:43,822
to give us an idea of
what the color might be

504
00:23:43,855 --> 00:23:46,458
of the surface, and you can
see the icy pebbles here.

505
00:23:46,491 --> 00:23:48,560
And here's a really
neat comparison.

506
00:23:48,593 --> 00:23:51,229
This is from our own moon,
here's a footprint of

507
00:23:51,262 --> 00:23:53,164
one of the Apollo astronauts.

508
00:23:53,197 --> 00:23:55,767
You can see the astronaut
and the little flag up here

509
00:23:55,800 --> 00:23:58,570
so this is sort of the same
perspective view that we

510
00:23:58,603 --> 00:24:00,305
had on Titan.

511
00:24:00,338 --> 00:24:02,474
And we also could see
all of these channels,

512
00:24:02,507 --> 00:24:05,677
indicating that, indeed,

methane was flowing.

513
00:24:05,710 --> 00:24:08,646
We found a world that was
remarkably like the earth

514
00:24:08,679 --> 00:24:10,015
in so many ways.

515
00:24:11,415 --> 00:24:14,319
In fact, there were lakes and
seas at Titans north pole.

516
00:24:14,352 --> 00:24:16,087
Lakes of methane.

517
00:24:16,120 --> 00:24:19,624
In fact, this lake by
Geomare is about 50% larger

518
00:24:19,657 --> 00:24:21,526
than Lake Superior.

519
00:24:21,559 --> 00:24:24,596
It's about 500 feet deep,
which is about the depth

520
00:24:24,629 --> 00:24:26,264
of the great lakes, as well.

521
00:24:26,297 --> 00:24:29,901
So there's a tremendous
volume of methane

522
00:24:29,934 --> 00:24:31,603
on the surface of Titan.

523
00:24:31,636 --> 00:24:33,905
And, in fact, if you could

gather up all of that

524
00:24:33,938 --> 00:24:37,008
methane knowing the depth of
this sea is a typical depth,

525
00:24:37,041 --> 00:24:40,945
you'd have 10 times more
hydracarbons than all of the

526
00:24:40,978 --> 00:24:43,781
reservoirs we have
here on the earth.

527
00:24:43,814 --> 00:24:47,151
So if only we could build
a pipeline big enough

528
00:24:47,184 --> 00:24:49,587
to go from Titan all the
way back to the earth,

529
00:24:49,620 --> 00:24:51,589
our problems would be solved.

530
00:24:51,622 --> 00:24:53,358
But there's just a tremendous
amount of hydracarbons

531
00:24:53,391 --> 00:24:54,792
on the surface.

532
00:24:54,825 --> 00:24:57,128
And you can see the
channels flowing into that

533
00:24:57,161 --> 00:24:58,396
particular sea.

534

00:24:59,864 --> 00:25:01,833
Dunes, those particles that
form high in the atmosphere

535
00:25:01,866 --> 00:25:04,836
fall down, form these long
dark linear dunes that

536
00:25:04,869 --> 00:25:07,171
wrap around the
equator of Titan.

537
00:25:07,204 --> 00:25:09,908
So those long dark
linear features.

538
00:25:09,941 --> 00:25:11,075
There's also mountains.

539
00:25:11,108 --> 00:25:13,978
This is a mountain
color-coded with height.

540
00:25:14,011 --> 00:25:17,649
Mountains can be as high as
a kilometer or so on titan

541
00:25:17,682 --> 00:25:20,585
and we think, perhaps in
this case, you look at it

542
00:25:20,618 --> 00:25:23,121
it might've even been
an ancient cryovolcano.

543
00:25:23,154 --> 00:25:25,657
Perhaps water mixed with
ammonia flowed out on the

544
00:25:25,690 --> 00:25:27,525

surface of Titan.

545
00:25:27,558 --> 00:25:30,428
And perhaps with that water
perhaps came the methane.

546
00:25:30,461 --> 00:25:33,264
There's not enough methane
in Titan's atmosphere to have

547
00:25:33,297 --> 00:25:35,800
lasted from the
time Titan formed.

548
00:25:35,833 --> 00:25:39,704
So there needs to be some
internal source periodically

549
00:25:39,737 --> 00:25:41,239
releasing methane.

550
00:25:41,272 --> 00:25:43,975
Otherwise, once the methane
gets divided up in the

551
00:25:44,008 --> 00:25:46,878
upper atmosphere, the
atmosphere would collapse.

552
00:25:46,911 --> 00:25:49,847
So there's some source
of that methane.

553
00:25:49,880 --> 00:25:51,616
Clouds, we've seen
lots of clouds.

554
00:25:51,649 --> 00:25:53,084
This is a colorized cloud.

555
00:25:53,117 --> 00:25:55,920
We've seen lots of clouds
and weather on Titan.

556
00:25:55,953 --> 00:25:59,223
We even saw a rainstorm, a
methane rainstorm on Titan

557
00:25:59,256 --> 00:26:01,993
that darkened the surface
and then we watched with time

558
00:26:02,026 --> 00:26:04,562
as the surface slowly dried up.

559
00:26:04,595 --> 00:26:08,399
Then here's a view of
the dry river beds.

560
00:26:08,432 --> 00:26:10,868
Now, in looking at these
images, what you see here,

561
00:26:10,901 --> 00:26:14,872
the lakes and the dunes are
taken at radar wavelengths.

562
00:26:14,905 --> 00:26:17,375
Radar wavelengths are very
good at penetrating through

563
00:26:17,408 --> 00:26:20,678
the haze and so we really
have gotten tremendous views

564
00:26:20,711 --> 00:26:23,314
of a large portion
of Titan's surface.

565

00:26:23,347 --> 00:26:25,483
This view is what you
would see with the cameras.

566
00:26:25,516 --> 00:26:27,385
You can see hints of the lakes.

567
00:26:27,418 --> 00:26:29,754
In the north polar region
what we did is we carried

568
00:26:29,787 --> 00:26:33,324
near infrared filters
specifically designed
to go through

569
00:26:33,357 --> 00:26:36,294
and penetrate the haze
and look at those.

570
00:26:36,327 --> 00:26:38,963
One of the things
in the beginning we
didn't know for sure

571
00:26:38,996 --> 00:26:43,067
is in those lakes was that
truly a liquid or some kind of

572
00:26:43,100 --> 00:26:44,402
a goo or something?

573
00:26:44,435 --> 00:26:45,903
What really was it?

574
00:26:45,936 --> 00:26:47,739
And we were trying to figure
out, how do we find out if

575
00:26:47,772 --> 00:26:50,942

it's a liquid without going
there, landing in the lake,

576
00:26:50,975 --> 00:26:52,443
and finding out?

577
00:26:52,476 --> 00:26:54,212
And it turns out we
have another instrument,

578
00:26:54,245 --> 00:26:56,614
the visual and infrared
mapping spectrometer.

579
00:26:56,647 --> 00:26:58,916
Looking at near
infrared wavelengths.

580
00:26:58,949 --> 00:27:01,119
And at five microns it
found a bright spot called

581
00:27:01,152 --> 00:27:02,920
a specular reflection.

582
00:27:02,953 --> 00:27:05,490
If you have sunlight coming
at an angle reflecting off

583
00:27:05,523 --> 00:27:08,593
a liquid surface, it comes
out at the same angle,

584
00:27:08,626 --> 00:27:11,496
and if Cassini is looking at
that angle you'll see a bright

585
00:27:11,529 --> 00:27:13,131
spot over the lake.

586
00:27:14,532 --> 00:27:15,967
If you've ever been on an
airplane, sometimes if you're

587
00:27:16,000 --> 00:27:18,436
looking out the afternoon
window as you go across a lake

588
00:27:18,469 --> 00:27:21,539
or a river you might notice
there's this bright spot

589
00:27:21,572 --> 00:27:23,408
that pops up when
you go over a liquid.

590
00:27:23,441 --> 00:27:26,411
And that's a
specular reflection.

591
00:27:26,444 --> 00:27:29,080
I just wanted to say a
little bit about the rings.

592
00:27:29,113 --> 00:27:32,050
The rings have very
simple names, A through G.

593
00:27:32,083 --> 00:27:34,585
We keep naming them with
other letters as more of the

594
00:27:34,618 --> 00:27:36,287
rings are discovered.

595
00:27:36,320 --> 00:27:39,057
The main rings of Saturn,
Saturn is off to your left,

596

00:27:39,090 --> 00:27:42,093
the main rings that you
would see through a telescope

597
00:27:42,126 --> 00:27:43,795
are the A ring, the
Cassini division,

598
00:27:43,828 --> 00:27:46,764
which is astronomer that
discovered the Cassini division

599
00:27:46,797 --> 00:27:48,866
and for which our
mission is named.

600
00:27:48,899 --> 00:27:51,736
The B ring, which is the
most optically thick ring,

601
00:27:51,769 --> 00:27:53,171
and then the C ring.

602
00:27:53,204 --> 00:27:54,706
And there are also additional
rings just shown in the

603
00:27:54,739 --> 00:27:56,207
bottom panel.

604
00:27:56,240 --> 00:27:59,077
Here's the inner-most D
ring, it's very very faint.

605
00:27:59,110 --> 00:28:03,014
You've got the tenuous very
narrow F ring just outside.

606
00:28:03,047 --> 00:28:05,349
Then here you have the

E ring going all the way

607
00:28:05,382 --> 00:28:06,818
out to Titan.

608
00:28:06,851 --> 00:28:09,887
And it turns out there's
one more ring in the Saturn

609
00:28:09,920 --> 00:28:11,089
system.

610
00:28:11,122 --> 00:28:12,323
And this ring wasn't
discovered by Cassini,

611
00:28:12,356 --> 00:28:13,725
but it was discovered by
ground-based observers

612
00:28:13,758 --> 00:28:15,793
and it has created by Phoebe.

613
00:28:15,826 --> 00:28:19,297
So there's the Phoebe ring
that actually comes in to the

614
00:28:19,330 --> 00:28:21,266
Saturn system, as well.

615
00:28:22,433 --> 00:28:25,303
Here's a Cassini view
of the rings of Saturn.

616
00:28:25,336 --> 00:28:27,438
They're made mostly of water
ice and on average they're

617
00:28:27,471 --> 00:28:29,474

only 30 feet thick.

618
00:28:29,507 --> 00:28:32,243
So incredibly narrow for
the hundreds of thousands

619
00:28:32,276 --> 00:28:36,047
of kilometers that they
span from end to end.

620
00:28:36,080 --> 00:28:38,983
There's tremendous amount
of detailed structure there.

621
00:28:39,016 --> 00:28:41,018
Some of it we understand is
the interactions with the

622
00:28:41,051 --> 00:28:42,854
tiny moons just outside.

623
00:28:42,887 --> 00:28:46,624
But so much of that structure
we still have no idea

624
00:28:46,657 --> 00:28:50,495
what's causing that
incredible structure.

625
00:28:50,528 --> 00:28:52,730
We do know that there are
two moons that actually orbit

626
00:28:52,763 --> 00:28:54,198
in the rings.

627
00:28:54,231 --> 00:28:56,334
There's one that orbits in
the Yankee gap named Daphnis,

628
00:28:56,367 --> 00:28:57,735
another one named Pan.

629
00:28:57,768 --> 00:29:00,104
These two moons keep
their gaps open.

630
00:29:00,137 --> 00:29:03,040
So we know that information
about the rings.

631
00:29:03,073 --> 00:29:05,076
And here's a nice
view of the very dark,

632
00:29:05,109 --> 00:29:07,178
very very tenuous D ring.

633
00:29:08,345 --> 00:29:09,981
Now this is the lit
side of the rings,

634
00:29:10,014 --> 00:29:11,649
what you would see
through a telescope.

635
00:29:11,682 --> 00:29:13,951
But there's also another side
to the rings and this movie

636
00:29:13,984 --> 00:29:16,053
was taken by Cassini.

637
00:29:16,086 --> 00:29:19,490
Basically you're riding along
as Cassini is plunging down

638
00:29:19,523 --> 00:29:21,225
through the ring plane.

639
00:29:21,258 --> 00:29:24,729
You can see the A ring
Cassini division and B ring.

640
00:29:24,762 --> 00:29:27,698
Every once in a while you'll
see a tiny moon go by.

641
00:29:27,731 --> 00:29:31,202
There's Titan, you can
see it's much larger.

642
00:29:31,235 --> 00:29:33,337
Now you get to see
the other side,

643
00:29:33,370 --> 00:29:35,439
the dark side of the rings.

644
00:29:35,472 --> 00:29:37,675
The side where the
sun isn't shining.

645
00:29:37,708 --> 00:29:40,411
In this case, the B ring
blocks out all the sunlight.

646
00:29:40,444 --> 00:29:42,547
The Cassini division is very
bright, the A ring is bright,

647
00:29:42,580 --> 00:29:46,217
and you can just see a
hint of the bright C ring.

648
00:29:46,250 --> 00:29:48,352
So the rings look
very different.

649
00:29:48,385 --> 00:29:49,854
And that's the advantage.

650
00:29:49,887 --> 00:29:51,589
If you go to a place like
Saturn you can see the rings

651
00:29:51,622 --> 00:29:54,826
on both their lit and
their unlit sides.

652
00:29:54,859 --> 00:29:58,029
Now, Cassini also had a
rare opportunity at Equinox.

653
00:29:58,062 --> 00:30:01,732
In fact, we just had our
autumn Equinox and just,

654
00:30:01,765 --> 00:30:03,534
I think, very
early this morning.

655
00:30:03,567 --> 00:30:06,771
And that's when the sun shines
directly on the equator.

656
00:30:06,804 --> 00:30:10,107
And in this case it shines
on the rings edge on.

657
00:30:10,140 --> 00:30:12,643
And that's important
because with the sun edge on

658
00:30:12,676 --> 00:30:15,179
to the rings, essentially,
you've turned the sunlight off

659

00:30:15,212 --> 00:30:16,681
for the rings.

660
00:30:16,714 --> 00:30:19,283
And in this mosaic taken
by Cassini what we've had

661
00:30:19,316 --> 00:30:21,452
to do here is increase the
brightness of the rings

662
00:30:21,485 --> 00:30:24,355
by about a factor of 20 so you
could even see them because

663
00:30:24,388 --> 00:30:27,225
they're only now
illuminated by Saturn shine.

664
00:30:27,258 --> 00:30:30,328
And around on the dark side
of the rings where it's

665
00:30:30,361 --> 00:30:32,864
dark before Saturn's shadow,
you had to increase the

666
00:30:32,897 --> 00:30:35,566
contrast by about
a factor of 60.

667
00:30:35,599 --> 00:30:38,970
Here you can see the narrow F
ring, but it's slightly tilted

668
00:30:39,003 --> 00:30:43,341
so it can still catch the
sunlight, even around Equinox.

669
00:30:43,374 --> 00:30:46,177

Now, with 30 foot thick rings
what's unique is you can

670
00:30:46,210 --> 00:30:49,480
look for anything that sticks
up above or below the rings.

671
00:30:49,513 --> 00:30:51,782
So if you're bigger
than 30 feet in size,

672
00:30:51,815 --> 00:30:54,986
there's a chance you'll cast
a shadow and we can see you.

673
00:30:55,019 --> 00:30:57,521
So we're looking for objects
with Cassini that would be

674
00:30:57,554 --> 00:31:00,024
larger and would cast shadows.

675
00:31:00,057 --> 00:31:01,626
And so I'm just going to
show you an image now.

676
00:31:01,659 --> 00:31:04,729
This is the outer edge
of this ring, the B ring.

677
00:31:04,762 --> 00:31:06,631
And it's stretched out.

678
00:31:06,664 --> 00:31:10,301
And low and behold we found
shadows, lots of them.

679
00:31:10,334 --> 00:31:12,069
Turns out that the outer
edge of the B ring is held

680
00:31:12,102 --> 00:31:14,972
in place by a resonance
with one of Saturn's moon.

681
00:31:15,005 --> 00:31:17,208
And it looks like some
of the largest particles,

682
00:31:17,241 --> 00:31:19,944
or maybe they form and grow
right there at the edge

683
00:31:19,977 --> 00:31:21,412
of the B ring.

684
00:31:21,445 --> 00:31:24,248
Now some of these are probably
a kilometer or two in size

685
00:31:24,281 --> 00:31:26,017
casting very long shadows.

686
00:31:26,050 --> 00:31:28,586
But they're hundreds of
them across the B ring.

687
00:31:28,619 --> 00:31:32,189
Almost looking like little
mountains along the B ring.

688
00:31:32,222 --> 00:31:35,159
And a good analogy is
if you wanted to, say,

689
00:31:35,192 --> 00:31:36,761
find the pyramids if
you're looking out from a

690

00:31:36,794 --> 00:31:40,164
space station, if you looked
around noon they'd be hard

691
00:31:40,197 --> 00:31:42,733
to see against their
sandy background.

692
00:31:42,766 --> 00:31:45,569
But if you looked
near dawn or dusk,

693
00:31:45,602 --> 00:31:49,006
the equivalent of Equinox,
they would cast long shadows,

694
00:31:49,039 --> 00:31:52,376
making them much easier
to pick out against the

695
00:31:52,409 --> 00:31:53,878
sandy background.

696
00:31:53,911 --> 00:31:56,347
So in the same way, Cassini
used this to look for

697
00:31:56,380 --> 00:31:58,549
structures and we found a
number of different structures

698
00:31:58,582 --> 00:32:01,319
like this that would
cast shadows in the ring.

699
00:32:01,352 --> 00:32:03,888
So, as a ring scientist,
a very exciting time

700
00:32:03,921 --> 00:32:06,591

to be looking at Saturn's rings.

701
00:32:07,958 --> 00:32:10,261
And, finally, here's a
very interesting discovery

702
00:32:10,294 --> 00:32:11,762
for the rings.

703
00:32:11,795 --> 00:32:14,498
It turns out that there is a
feature, this feature is about

704
00:32:14,531 --> 00:32:18,869
1,200 kilometers long,
10 kilometers or so wide,

705
00:32:18,902 --> 00:32:21,305
indicating that there's a
tiny object two or three

706
00:32:21,338 --> 00:32:24,241
kilometers in size
creating this feature.

707
00:32:24,274 --> 00:32:27,645
This feature is right at
the edge of the A ring.

708
00:32:27,678 --> 00:32:31,782
So it was discovered in 2013,
it's discoverer Carl Murray

709
00:32:31,815 --> 00:32:34,352
discovered it on his
mother-in-law's birthday

710
00:32:34,385 --> 00:32:37,188
so he nicknamed it
Peggy after her.

711
00:32:37,221 --> 00:32:40,324
So this tiny object that's
here creating this feature,

712
00:32:40,357 --> 00:32:43,828
Peggy, we've been watching
for her ever since.

713
00:32:43,861 --> 00:32:46,664
She comes and goes, we're
wondering will she break free

714
00:32:46,697 --> 00:32:49,166
of the rings and become
a moon in her own right?

715
00:32:49,199 --> 00:32:51,736
Or will she be torn apart
and jostled by the other

716
00:32:51,769 --> 00:32:54,071
particles in the
rings and disappear?

717
00:32:54,104 --> 00:32:56,507
So, so far she's still there
and we're going to keep

718
00:32:56,540 --> 00:32:59,110
watching for her through the
end of the Cassini mission.

719
00:32:59,143 --> 00:33:01,212
We're kind of rooting for
her by now 'cause she's been

720
00:33:01,245 --> 00:33:03,247
around for a few years.

721
00:33:06,216 --> 00:33:08,652
Moving on to Saturn, one
very interesting event

722
00:33:08,685 --> 00:33:09,920
happened at Saturn.

723
00:33:09,953 --> 00:33:13,758
A giant storm developed
toward the end of 2010.

724
00:33:15,159 --> 00:33:17,795
This storm grew so huge it
was a giant vortex and that

725
00:33:17,828 --> 00:33:20,531
vortex swirled off
this huge tail.

726
00:33:20,564 --> 00:33:23,834
The tail of the storm wrapped
itself around the planet.

727
00:33:23,867 --> 00:33:26,103
There was another
vortex on the other end,

728
00:33:26,136 --> 00:33:27,571
kind of like a hurricane.

729
00:33:27,604 --> 00:33:30,307
When these two vortices
merged, that marked the end

730
00:33:30,340 --> 00:33:31,809
of the storm.

731
00:33:31,842 --> 00:33:34,845
A tremendous amount of energy

was released in this storm

732
00:33:34,878 --> 00:33:36,347
at Saturn.

733
00:33:36,380 --> 00:33:38,049
And typically these storms
happen about once every

734
00:33:38,082 --> 00:33:39,550
30 years.

735
00:33:39,583 --> 00:33:42,119
So this was the fifth time
we've seen a giant storm

736
00:33:42,152 --> 00:33:43,687
like this at Saturn.

737
00:33:43,720 --> 00:33:45,890
But what was unique is
this storm was early.

738
00:33:45,923 --> 00:33:49,093
It had only been 20 years
since the last storm

739
00:33:49,126 --> 00:33:51,962
and so it came early so
Cassini could get a good view

740
00:33:51,995 --> 00:33:53,464
of it and watch it.

741
00:33:53,497 --> 00:33:55,699
And so we watched it, as
did ground-based observers.

742
00:33:55,732 --> 00:33:58,536

It lasted about nine
months and started to fade.

743
00:33:58,569 --> 00:34:00,905
This in the visible, if you
look toward the near infrared

744
00:34:00,938 --> 00:34:03,407
you see deeper into
the atmosphere.

745
00:34:03,440 --> 00:34:07,111
The colors in this view, if
it's white or yellow that's

746
00:34:07,144 --> 00:34:10,881
high up in the atmosphere,
green is also high up,

747
00:34:10,914 --> 00:34:12,983
that's the center of the storm.

748
00:34:13,016 --> 00:34:16,420
Then the oranges and the
reds are looking deeper.

749
00:34:16,453 --> 00:34:19,256
So we're basically getting
a profile of what that

750
00:34:19,289 --> 00:34:22,226
storm looked like and
how those clouds behaved.

751
00:34:22,259 --> 00:34:26,197
And we can model that and
perhaps use it as an analogy

752
00:34:26,230 --> 00:34:28,532
to storms in the

earths atmosphere.

753
00:34:28,565 --> 00:34:30,935
Looking at some of the
longest infrared wavelengths,

754
00:34:30,968 --> 00:34:33,571
the thermal infrared, turns
out that the storm was in

755
00:34:33,604 --> 00:34:36,407
the lower atmosphere of
Saturn, the troposphere.

756
00:34:36,440 --> 00:34:39,443
But when those two spots
merged it released a tremendous

757
00:34:39,476 --> 00:34:42,313
amount of energy, kind
of like a giant burp.

758
00:34:42,346 --> 00:34:45,616
And here up in the
stratosphere there is a large,

759
00:34:45,649 --> 00:34:47,084
very hot, feature.

760
00:34:47,117 --> 00:34:49,453
And this feature persisted
for a couple of years

761
00:34:49,486 --> 00:34:50,888
and has slowly cooled.

762
00:34:50,921 --> 00:34:53,724
So a very dynamic
and active Saturn,

763
00:34:53,757 --> 00:34:56,060
at least in that time period.

764
00:34:56,093 --> 00:34:58,395
Now, Saturn has a very
interesting feature at it's

765
00:34:58,428 --> 00:34:59,897
north pole.

766
00:34:59,930 --> 00:35:02,366
Here's that feature, you're
looking right down at the

767
00:35:02,399 --> 00:35:04,235
north pole of Saturn.

768
00:35:04,268 --> 00:35:06,670
That feature is a
six sided jet stream,

769
00:35:06,703 --> 00:35:08,139
called the hexagon.

770
00:35:08,172 --> 00:35:11,008
The Voyager spacecraft first
saw this feature in the

771
00:35:11,041 --> 00:35:15,246
1980s and it was still
here when Cassini arrived.

772
00:35:15,279 --> 00:35:17,414
You can see the pinkish
clouds, this is a false color

773
00:35:17,447 --> 00:35:19,116
view, rotating around.

774
00:35:19,149 --> 00:35:22,486
And they go faster the closer
you get directly to the

775
00:35:22,519 --> 00:35:24,021
north pole.

776
00:35:24,054 --> 00:35:27,491
And at the north pole
there's a giant hurricane.

777
00:35:27,524 --> 00:35:30,327
And this hurricane is about
50 times larger than a

778
00:35:30,360 --> 00:35:34,532
typical earth hurricane, blowing
about 340 miles and hour.

779
00:35:37,000 --> 00:35:39,537
And, finally, before I
pass it over to Earl,

780
00:35:39,570 --> 00:35:41,672
this is a view of
the changing seasons.

781
00:35:41,705 --> 00:35:44,608
In fact, Saturn's shadow
on the rings you can think

782
00:35:44,641 --> 00:35:46,577
of as a giant sun dial.

783
00:35:46,610 --> 00:35:49,947
And this picture taken back
in April of 2016 you can

784
00:35:49,980 --> 00:35:53,717

see that the shadow of
Saturn goes out just past

785
00:35:53,750 --> 00:35:55,252
the Cassini division.

786
00:35:55,285 --> 00:35:59,156
At Solstice, that shadow
will pull in until it's about

787
00:35:59,189 --> 00:36:00,891
in the middle of the B ring.

788
00:36:00,924 --> 00:36:04,261
And so as that shadow
pulls in, so will Cassini's

789
00:36:04,294 --> 00:36:06,864
time shorter at Saturn.

790
00:36:06,897 --> 00:36:08,832
With that, I'd like to
turn it over to Earl

791
00:36:08,865 --> 00:36:11,635
to talk about the grand finale.

792
00:36:11,668 --> 00:36:13,905
(applause)

793
00:36:22,879 --> 00:36:25,249
- So how does
Cassini follow that?

794
00:36:25,282 --> 00:36:26,183
How do I follow that?

795
00:36:26,216 --> 00:36:28,786
I want to go first next time.

796
00:36:28,819 --> 00:36:30,821
You know, one of the things
about Cassini is it always

797
00:36:30,854 --> 00:36:32,323
trumps itself.

798
00:36:32,356 --> 00:36:34,858
As we keep finding, one year
we announce a sub-surface

799
00:36:34,891 --> 00:36:38,329
ocean the next we
announce a global ocean.

800
00:36:38,362 --> 00:36:40,364
So it keeps building and
building and building

801
00:36:40,397 --> 00:36:42,766
and you look at the last
12 years and how do we

802
00:36:42,799 --> 00:36:46,670
do something even more
spectacular in our final year?

803
00:36:46,703 --> 00:36:50,174
Well I'm going to tell you at
least the potential for that.

804
00:36:50,207 --> 00:36:54,378
Before we do that I want just
a little bit of a backup here.

805
00:36:55,779 --> 00:36:57,581
I'm going to go to the end.

806

00:36:57,614 --> 00:37:01,719
This is September 14, 2017,
it's about two o'clock

807
00:37:03,153 --> 00:37:06,624
in the afternoon here in
Pasadena and Cassini has just

808
00:37:06,657 --> 00:37:10,894
wrapped up a 30 hour or
so observing session.

809
00:37:10,927 --> 00:37:15,266
The recorders are packed
full of images and fuels

810
00:37:15,299 --> 00:37:18,002
and particles data and so
now it's time for Cassini

811
00:37:18,035 --> 00:37:21,438
to turn back to Earth and
begin to play those back.

812
00:37:21,471 --> 00:37:24,875
So this is a high speed
slow speed version of the

813
00:37:24,908 --> 00:37:26,744
last of these periods.

814
00:37:28,145 --> 00:37:29,847
So Cassini's going to be
working with this for about

815
00:37:29,880 --> 00:37:31,015
10 hours.

816
00:37:31,048 --> 00:37:32,516
DSN's going to be

receiving all this data,

817
00:37:32,549 --> 00:37:34,385
we're going to be streaming
these back and as soon as

818
00:37:34,418 --> 00:37:36,253
we see them, you'll see them.

819
00:37:36,286 --> 00:37:39,223
Some spectacular images of
the poles and of the rings

820
00:37:39,256 --> 00:37:40,658
as we come in.

821
00:37:40,691 --> 00:37:43,260
And then when the SSR's,
the solid state records are

822
00:37:43,293 --> 00:37:47,398
empty, be about 10 hours,
Cassini's going to reconfigure

823
00:37:47,431 --> 00:37:50,100
for the periapsis
here at Saturn.

824
00:37:50,133 --> 00:37:54,305
So we've done that 292 times
over the last seven years.

825
00:37:55,706 --> 00:37:59,043
Periapsis at Saturn is pretty
routine, but not this one.

826
00:37:59,076 --> 00:38:01,478
This one is absolutely unique.

827

00:38:01,511 --> 00:38:03,614
Because it's Cassini's last.

828
00:38:03,647 --> 00:38:07,818
Three days before this event
Cassini had a close encounter

829
00:38:09,386 --> 00:38:11,021
with Titan.

830
00:38:11,054 --> 00:38:13,390
Titan gave it a
little gravitational
nudge and that nudge

831
00:38:13,423 --> 00:38:15,759
has pretty much
sealed Cassini's fate.

832
00:38:15,792 --> 00:38:19,063
As a matter of fact, it's not
coming out of this periapsis.

833
00:38:19,096 --> 00:38:21,665
It's moved the periapsis the
closest approach distance

834
00:38:21,698 --> 00:38:25,736
inside the capture radius
of the Saturn's atmosphere.

835
00:38:25,769 --> 00:38:30,074
And so, Cassini, this one is
going to reconfigure itself

836
00:38:30,107 --> 00:38:31,875
so that it doesn't put
the data on the recorder,

837
00:38:31,908 --> 00:38:33,744

it's going to put everything
out on the pipe as quick

838
00:38:33,777 --> 00:38:35,179
as it can.

839
00:38:35,212 --> 00:38:37,981
So the minute you see,
it's going to start to turn

840
00:38:38,014 --> 00:38:39,917
colors here as
Cassini reconfigures.

841
00:38:39,950 --> 00:38:42,119
Cassini's going to go into
the atmosphere and every

842
00:38:42,152 --> 00:38:45,389
second of this data is going
to be coming back to the earth.

843
00:38:45,422 --> 00:38:50,094
And, unfortunately, Cassini
is going to be going 77,000

844
00:38:50,127 --> 00:38:51,395
miles per hour.

845
00:38:53,063 --> 00:38:55,165
You can get around the
earth in about 20 minutes

846
00:38:55,198 --> 00:38:56,700
at that speed.

847
00:38:56,733 --> 00:38:59,169
So what's going to happen,
it's going to happen very,

848
00:38:59,202 --> 00:39:00,671
very fast.

849
00:39:00,704 --> 00:39:02,506
We are going to have every
piece of data streaming

850
00:39:02,539 --> 00:39:04,041
back down.

851
00:39:04,074 --> 00:39:05,476
We're going to be sampling
the atmosphere and trying

852
00:39:05,509 --> 00:39:07,044
to answer some of the
fundamental questions about

853
00:39:07,077 --> 00:39:08,746
Saturn's atmosphere.

854
00:39:10,714 --> 00:39:13,650
But it's not going
to be very long.

855
00:39:13,683 --> 00:39:17,154
At 77,000 miles per hour,
Cassini is going to be going in

856
00:39:17,187 --> 00:39:19,456
with it's antenna
pointing to the earth,

857
00:39:19,489 --> 00:39:22,192
but the atmosphere is going
to quickly overpower it's

858
00:39:22,225 --> 00:39:23,560
ability to point.

859
00:39:23,593 --> 00:39:25,429
It just doesn't have
that kind of control.

860
00:39:25,462 --> 00:39:29,933
It's going to push it off
and then we'll lose com.

861
00:39:29,966 --> 00:39:32,736
It essentially will disappear
from our monitors and about

862
00:39:32,769 --> 00:39:36,073
three or four minutes later
that speed and the density of

863
00:39:36,106 --> 00:39:39,843
Saturn's atmosphere will
vaporize Cassini and it is over.

864
00:39:39,876 --> 00:39:43,781
One of the most spectacular
missions ever to leave earth.

865
00:39:43,814 --> 00:39:46,116
A discovery machine
like you will never see

866
00:39:46,149 --> 00:39:48,752
and it's going to be done.

867
00:39:48,785 --> 00:39:51,255
So why are you doing that?

868
00:39:51,288 --> 00:39:52,756
First thing.

869
00:39:52,789 --> 00:39:55,759

Did you guys ask anybody's
permission to take something

870
00:39:55,792 --> 00:39:59,163
that has rewritten science
programs, redirected NASA

871
00:39:59,196 --> 00:40:02,433
programs and re-contoured
missions, you're just going to

872
00:40:02,466 --> 00:40:03,367
destroy it?

873
00:40:04,768 --> 00:40:07,070
Let me give you, try to
explain why we think that's

874
00:40:07,103 --> 00:40:08,572
a good idea.

875
00:40:08,605 --> 00:40:12,142
In order to do that I've got
to go back a little ways.

876
00:40:12,175 --> 00:40:16,814
So back to 2009, Linda told
you about the prime mission

877
00:40:16,847 --> 00:40:18,315
and the extended missions.

878
00:40:18,348 --> 00:40:21,919
We got to Saturn in 2004, right,
we had a four year mission,

879
00:40:21,952 --> 00:40:23,554
but we didn't have any end.

880

00:40:23,587 --> 00:40:25,222
There was no end-game planned.

881
00:40:25,255 --> 00:40:27,558
But we got to the
end of that mission,

882
00:40:27,591 --> 00:40:29,927
realized we had an
incredibly good spacecraft,

883
00:40:29,960 --> 00:40:32,429
lots of propellant, so we
went for another two years.

884
00:40:32,462 --> 00:40:35,899
About midway through that
second mission, 2009,

885
00:40:35,932 --> 00:40:39,837
geeze, all sub-systems are
great, this system is wonderful,

886
00:40:39,870 --> 00:40:41,672
we've got a lot of
gas in the tank,

887
00:40:41,705 --> 00:40:43,207
let's do something else.

888
00:40:43,240 --> 00:40:44,074
So what?

889
00:40:46,376 --> 00:40:48,111
What's next?

890
00:40:48,144 --> 00:40:50,414
And we actually got a
lot of studies done.

891
00:40:50,447 --> 00:40:54,084
There's a lot of opportunities
at this point with all

892
00:40:54,117 --> 00:40:55,519
the sub-systems going.

893
00:40:55,552 --> 00:40:57,321
We could've left Saturn.

894
00:40:57,354 --> 00:41:00,557
We could've gone off the
Centaur Asteroids and turn

895
00:41:00,590 --> 00:41:04,127
ourselves into, re-configured,
re-purposed Cassini as

896
00:41:04,160 --> 00:41:05,662
an asteroid mission.

897
00:41:05,695 --> 00:41:08,532
We could've, believe it or
not, left Saturn and gone

898
00:41:08,565 --> 00:41:12,636
to Jupiter, or gone out to
Uranus, or gone out to Neptune.

899
00:41:12,669 --> 00:41:16,240
Now, I gotta say this
was a 40 year cruise.

900
00:41:17,340 --> 00:41:19,943
So it would've
been a long cruise,

901
00:41:19,976 --> 00:41:22,079
but look where Voyager is.

902
00:41:22,112 --> 00:41:23,447
It was possible.

903
00:41:25,248 --> 00:41:27,217
We could've gone
back to Jupiter.

904
00:41:27,250 --> 00:41:29,620
That actually is an image
we took on our way out

905
00:41:29,653 --> 00:41:31,989
and we could've gone back
and spent the same set of

906
00:41:32,022 --> 00:41:34,691
resources on Jupiter
as we did on Saturn.

907
00:41:34,724 --> 00:41:36,593
Uranus is also a possibility.

908
00:41:36,626 --> 00:41:37,895
Or more Saturn.

909
00:41:40,263 --> 00:41:42,399
Well, this is kind
of a no-brainer.

910
00:41:42,432 --> 00:41:45,269
I mean, we had barely
scratched the surface.

911
00:41:45,302 --> 00:41:47,704
Saturn is just incredible.

912
00:41:47,737 --> 00:41:50,807
You couldn't have asked for

a more dynamic environment.

913
00:41:50,840 --> 00:41:52,309
You've got the rings,
you've got the planet,

914
00:41:52,342 --> 00:41:54,711
you've got the icy satellites,
you've got Titan and

915
00:41:54,744 --> 00:41:59,182
Enceladus little pre-biotic
worlds on their own

916
00:41:59,215 --> 00:42:01,318
and Cassini's still
unwrapping this.

917
00:42:01,351 --> 00:42:03,854
So it's really not hard to
figure, "Okay, we gotta stay."

918
00:42:03,887 --> 00:42:06,356
So I'll jump to the
chase real quick.

919
00:42:06,389 --> 00:42:07,791
Nah, we're not going there.

920
00:42:07,824 --> 00:42:10,294
Nah, we're not going
there, we're going to stay.

921
00:42:10,327 --> 00:42:11,996
But there's a catch.

922
00:42:13,363 --> 00:42:16,567
If you want to stay at
Saturn, there's some rules.

923
00:42:16,600 --> 00:42:20,337
And they are, we call
it planetary protection,

924
00:42:20,370 --> 00:42:23,640
but the real essence of this
is you've got to protect

925
00:42:23,673 --> 00:42:25,075
Saturn's ocean worlds.

926
00:42:25,108 --> 00:42:29,746
Cassini is essentially a
victim of her own discoveries.

927
00:42:29,779 --> 00:42:33,050
My apologies to the Oakridge
boys, but you can visit,

928
00:42:33,083 --> 00:42:35,385
but you can't stay.

929
00:42:35,418 --> 00:42:38,589
So you've got to make sure
that if you stay in the

930
00:42:38,622 --> 00:42:41,959
Saturn system, there is
no possibility of a crash

931
00:42:41,992 --> 00:42:44,495
landing on Enceladus or Titan.

932
00:42:45,795 --> 00:42:49,132
Cassini is room
temperature inside.

933
00:42:49,165 --> 00:42:50,901
If there are little microbes

in there that don't mind

934
00:42:50,934 --> 00:42:53,870
a vacuum, they
could last forever.

935
00:42:53,903 --> 00:42:56,974
We are running essentially
at about 72 degrees inside

936
00:42:57,007 --> 00:42:58,508
this spacecraft.

937
00:42:58,541 --> 00:43:01,878
So going and taking some of
our earth microbes or spores

938
00:43:01,911 --> 00:43:05,749
onto Enceladus in particular
where we know there's water,

939
00:43:05,782 --> 00:43:09,086
warm water, would just be
absolutely unacceptable.

940
00:43:09,119 --> 00:43:12,222
So you guys can stay, but
you've got to be careful

941
00:43:12,255 --> 00:43:16,360
about what you do about
Titan and Enceladus.

942
00:43:16,393 --> 00:43:17,995
So, with that in
mind you'll say,

943
00:43:18,028 --> 00:43:19,696
"How are we going to do that?"

944
00:43:19,729 --> 00:43:22,399
We could stay and
go big long orbits,

945
00:43:22,432 --> 00:43:24,601
stay way outside the
orbits of Enceladus,

946
00:43:24,634 --> 00:43:27,838
way outside orbits of Titan,
but guess where all the

947
00:43:27,871 --> 00:43:29,306
science is?

948
00:43:29,339 --> 00:43:31,475
It's down there with
Titan an Enceladus.

949
00:43:31,508 --> 00:43:33,777
So, we want to explore
these guys but we want,

950
00:43:33,810 --> 00:43:35,512
at the same time,
to remain safe.

951
00:43:35,545 --> 00:43:38,248
So we go to the trajectory
designers, got fair bit of

952
00:43:38,281 --> 00:43:41,051
propellant, got good
subsystems, what can you guys do

953
00:43:41,084 --> 00:43:42,552
for us?

954
00:43:42,585 --> 00:43:45,155

We want to be able to stay
inside Saturn's system,

955
00:43:45,188 --> 00:43:47,224
we want to explore all
the icy satellites,

956
00:43:47,257 --> 00:43:48,825
we want to explore
the rings of Saturn,

957
00:43:48,858 --> 00:43:53,030
but we want to still remain
safe for these two incredible

958
00:43:54,130 --> 00:43:55,632
worlds.

959
00:43:55,665 --> 00:43:59,169
So what these guys gave us
was the Solstice mission

960
00:43:59,202 --> 00:44:00,637
trajectory.

961
00:44:00,670 --> 00:44:05,308
This started in 2010 and this
is a trajectory designer's

962
00:44:05,341 --> 00:44:06,343
masterpiece.

963
00:44:08,378 --> 00:44:11,748
A lot of squiggly lines, but
each of those is an orbit

964
00:44:11,781 --> 00:44:13,684
and every time that
orbit changes shape,

965
00:44:13,717 --> 00:44:16,420
it's because Titan moved us.

966
00:44:16,453 --> 00:44:19,089
As Linda said, we
get essentially a
Saturn orbit insertion

967
00:44:19,122 --> 00:44:21,992
velocity change every
time flyby Titan.

968
00:44:22,025 --> 00:44:24,561
So we want to go up, you
fly under Titan and it

969
00:44:24,594 --> 00:44:25,796
pulls you up.

970
00:44:25,829 --> 00:44:26,930
You want to go in,
you go to the right,

971
00:44:26,963 --> 00:44:28,165
go to the left.

972
00:44:28,198 --> 00:44:30,367
And it can take you
all over this system.

973
00:44:30,400 --> 00:44:31,968
So what we did, what the
trajectory designers did,

974
00:44:32,001 --> 00:44:34,805
they took these orbits
that stayed very flat in

975
00:44:34,838 --> 00:44:36,239

Saturn's plane.

976
00:44:36,272 --> 00:44:37,741
By the way, that's Saturn
there in the middle.

977
00:44:37,774 --> 00:44:40,243
Very flat and then you
could stay and do all the

978
00:44:40,276 --> 00:44:42,279
satellite
interrogation you want.

979
00:44:42,312 --> 00:44:45,115
You could go very inclined,
very looping orbits and do

980
00:44:45,148 --> 00:44:49,019
magnetic fields and to do
the poles and the rings,

981
00:44:49,052 --> 00:44:53,156
and as a bonus to all of
that, this is the first six

982
00:44:53,189 --> 00:44:57,361
years of this mission,
the mission that
Linda just reported,

983
00:44:58,862 --> 00:45:00,630
you also get this.

984
00:45:00,663 --> 00:45:03,366
This is the last
year of the mission.

985
00:45:03,399 --> 00:45:05,969
And this is,

unfortunately, at the end,

986
00:45:06,002 --> 00:45:09,172
the demise of Cassini
as I described just
a few moments ago.

987
00:45:09,205 --> 00:45:14,044
But on the way in, we have
an entirely new mission,

988
00:45:14,077 --> 00:45:16,113
something we have
never done before.

989
00:45:16,146 --> 00:45:18,081
We're going to flirt with
the outside of the rings

990
00:45:18,114 --> 00:45:20,717
and then we're going to
go diving deep in between

991
00:45:20,750 --> 00:45:22,152
Saturn and the rings.

992
00:45:22,185 --> 00:45:23,787
And I'll show you a
little bit more about that

993
00:45:23,820 --> 00:45:26,189
just to show off some here.

994
00:45:26,222 --> 00:45:28,158
These things are
just phenomenal.

995
00:45:28,191 --> 00:45:30,727
The key orbital characteristics
of this final set of

996
00:45:30,760 --> 00:45:33,263
orbits, which we call
the F ring approximals,

997
00:45:33,296 --> 00:45:36,666
you'll hear some of the
flight team call them FERPPO,

998
00:45:36,699 --> 00:45:40,604
which sounds more like a dog
food than a real acronym.

999
00:45:40,637 --> 00:45:43,473
But really the F ring orbits
and what we're now calling

1000
00:45:43,506 --> 00:45:45,041
the grand finale.

1001
00:45:45,074 --> 00:45:46,710
42 short period orbits.

1002
00:45:46,743 --> 00:45:48,411
Each of these orbits
lasts about a week.

1003
00:45:48,444 --> 00:45:49,913
The flight team is going
to be running around like

1004
00:45:49,946 --> 00:45:52,048
you've never seen.

1005
00:45:52,081 --> 00:45:56,386
20 of them are going to
be, oops I've hit the wrong

1006
00:45:56,419 --> 00:45:57,588

button, sorry.

1007
00:45:58,421 --> 00:45:59,623
I hit it again.

1008
00:46:00,557 --> 00:46:02,025
There we go.

1009
00:46:02,058 --> 00:46:04,895
20 of them are going to be
just outside the F ring.

1010
00:46:04,928 --> 00:46:06,797
This is the
outer-most ring here.

1011
00:46:06,830 --> 00:46:09,833
Titan is going to be, both
of these essentially run

1012
00:46:09,866 --> 00:46:12,302
into Titan right out here.

1013
00:46:12,335 --> 00:46:15,472
20 of these outside with
great coverage of the poles

1014
00:46:15,505 --> 00:46:17,774
and the rings, and then
another Titan flyby

1015
00:46:17,807 --> 00:46:22,112
is going to move us in to the
gap between the inner most

1016
00:46:22,145 --> 00:46:26,116
D ring and the outer most
edges of Saturn's atmosphere.

1017

00:46:26,149 --> 00:46:27,151
22 of those.

1018
00:46:28,618 --> 00:46:31,855
The periapsis is going to
be what we call the 2,400

1019
00:46:31,888 --> 00:46:35,425
kilometer clear zone between
the, essentially (mumbling).

1020
00:46:35,458 --> 00:46:38,829
We've got their dust on
the left and we've got the

1021
00:46:38,862 --> 00:46:39,963
Saturn on the right.

1022
00:46:39,996 --> 00:46:42,533
We've got to
navigate in between.

1023
00:46:43,967 --> 00:46:47,504
Next slide is, I think, a
look at the view from Earth.

1024
00:46:47,537 --> 00:46:50,173
Not only are these things
phenomenal from their

1025
00:46:50,206 --> 00:46:53,610
proximity to the system, the
geometry is also phenomenal

1026
00:46:53,643 --> 00:46:56,646
because, if you look
at what happens here,

1027
00:46:56,679 --> 00:47:00,083
these orbits go behind the

rings and behind Saturn,

1028
00:47:00,116 --> 00:47:02,385
almost every one of them
from a view from earth,

1029
00:47:02,418 --> 00:47:05,188
provides what we call (mumbles).

1030
00:47:05,221 --> 00:47:07,958
Not only do we have
instruments that can photograph

1031
00:47:07,991 --> 00:47:10,694
and sample, we also have
instruments that can send

1032
00:47:10,727 --> 00:47:14,998
a very very precisely tuned
radio signal to earth.

1033
00:47:15,031 --> 00:47:19,502
And passing that signal
through the rings and the

1034
00:47:19,535 --> 00:47:21,771
atmosphere can tell us a
tremendous amount about

1035
00:47:21,804 --> 00:47:23,240
their internal structure.

1036
00:47:23,273 --> 00:47:25,508
The opportunities here
are absolutely phenomenal

1037
00:47:25,541 --> 00:47:29,012
and we, by the way Saturn
has obliged by never,

1038
00:47:29,045 --> 00:47:31,214
if you recall back
to Linda's picture,

1039
00:47:31,247 --> 00:47:35,018
never opening up the rings
more than they are right now.

1040
00:47:35,051 --> 00:47:37,020
So essentially be passing
these waves right through.

1041
00:47:37,053 --> 00:47:41,225
It's an absolutely unique
and spectacular opportunity.

1042
00:47:43,626 --> 00:47:47,230
This, again, is just to
show a little bit of what

1043
00:47:47,263 --> 00:47:48,665
happens at the periapses.

1044
00:47:48,698 --> 00:47:49,833
You can see, you don't
quite see the F ring on this

1045
00:47:49,866 --> 00:47:52,903
illustration, but it is right--

1046
00:47:52,936 --> 00:47:54,771
Oops, I done it again.

1047
00:47:59,742 --> 00:48:00,743
There we go.

1048
00:48:02,145 --> 00:48:04,281
We have these rings here,
the F ring is actually

1049
00:48:04,314 --> 00:48:06,049
coming out right here.

1050
00:48:06,082 --> 00:48:08,952
We have about an 8,000
kilometer gap there,

1051
00:48:08,985 --> 00:48:10,720
but there's extended dust.

1052
00:48:10,753 --> 00:48:12,422
And if you look at the F
ring, I'm actually more

1053
00:48:12,455 --> 00:48:15,025
terrified about that than
I am about the gap because

1054
00:48:15,058 --> 00:48:17,527
of these tendrils that keep
coming off of the F ring.

1055
00:48:17,560 --> 00:48:19,529
But nevertheless, that's
where we're going.

1056
00:48:19,562 --> 00:48:23,667
And then again you see the
proximity of these periapses

1057
00:48:23,700 --> 00:48:27,371
here inside the, what
we call the proximals,

1058
00:48:28,237 --> 00:48:29,539
the grand finale.

1059
00:48:29,572 --> 00:48:31,775

This is, again, just
kind of showing off,

1060
00:48:31,808 --> 00:48:34,811
but here is a
flattened out version.

1061
00:48:36,212 --> 00:48:39,015
These are the rings of Saturn,
here's the F ring up here,

1062
00:48:39,048 --> 00:48:41,084
and here is Saturn's
atmosphere down here.

1063
00:48:41,117 --> 00:48:42,919
Saturn atmosphere.

1064
00:48:42,952 --> 00:48:45,588
Saturn doesn't have a surface,
or if it does it's way

1065
00:48:45,621 --> 00:48:47,090
down in there.

1066
00:48:47,123 --> 00:48:50,260
So what we call the surface
is essentially one bar level.

1067
00:48:50,293 --> 00:48:52,495
Essentially the
pressure at sea level.

1068
00:48:52,528 --> 00:48:55,298
So that's what we're calling
the surface of Saturn.

1069
00:48:55,331 --> 00:48:59,269
So here are, graphically,
each of our periapses.

1070
00:48:59,302 --> 00:49:02,706
So we're flirting around in
this safe little gap between

1071
00:49:02,739 --> 00:49:04,274
the F ring dust--

1072
00:49:04,307 --> 00:49:05,876
I've done it again.

1073
00:49:06,943 --> 00:49:08,011
We'll get to that.

1074
00:49:08,044 --> 00:49:09,879
(laughs)

1075
00:49:09,912 --> 00:49:12,149
Between the the rings here.

1076
00:49:13,716 --> 00:49:16,353
Incredibly precise navigation
to stay between the dust

1077
00:49:16,386 --> 00:49:20,490
hazards between the F ring
and the (mumbles) rings here.

1078
00:49:20,523 --> 00:49:24,094
Then the Titan flyby that
brings us down in here.

1079
00:49:24,127 --> 00:49:27,297
And then we stay very
carefully and very precisely

1080
00:49:27,330 --> 00:49:29,833
within the gap between
Saturn's atmosphere

1081
00:49:29,866 --> 00:49:33,536
and the dust until
our final flyby here.

1082
00:49:33,569 --> 00:49:36,239
I should point out there are
a couple that are actually

1083
00:49:36,272 --> 00:49:37,707
flirting with this and we're
going to do some things

1084
00:49:37,740 --> 00:49:39,142
here to keep ourselves safe
because they're a little

1085
00:49:39,175 --> 00:49:42,145
bit more dicey than the others.

1086
00:49:42,178 --> 00:49:44,381
Okay, so what's it like to
be on Cassini when we're

1087
00:49:44,414 --> 00:49:46,049
doing this?

1088
00:49:46,082 --> 00:49:48,585
I've already stolen my
thunder on this slide a couple

1089
00:49:48,618 --> 00:49:49,853
of times.

1090
00:49:49,886 --> 00:49:53,523
Imagine you're sitting
on the prow of Cassini

1091
00:49:53,556 --> 00:49:54,858

going through.

1092
00:49:54,891 --> 00:49:58,661
This is seven seconds of
terror every seven days

1093
00:49:58,694 --> 00:50:01,064
for seven, plus two months.

1094
00:50:01,097 --> 00:50:03,666
(chuckles)

1095
00:50:03,699 --> 00:50:05,001
So, Mars has got
their seven minutes,

1096
00:50:05,034 --> 00:50:06,970
we've got seven seconds
every seven weeks.

1097
00:50:07,003 --> 00:50:09,906
And this is exactly, this
is the white knuckle time

1098
00:50:09,939 --> 00:50:11,408
for us.

1099
00:50:11,441 --> 00:50:12,876
Now, we won't know, because
most of the time going through

1100
00:50:12,909 --> 00:50:16,312
here we don't want to have
the spacecraft talking to us,

1101
00:50:16,345 --> 00:50:18,848
we want it to be doing science.

1102
00:50:18,881 --> 00:50:20,884

So we'll find out if we've
survived these ring plane

1103
00:50:20,917 --> 00:50:23,420
crossings much
later in the game.

1104
00:50:23,453 --> 00:50:25,155
But that's the way it goes.

1105
00:50:25,188 --> 00:50:26,956
You want to get the science,
you don't want to find out

1106
00:50:26,989 --> 00:50:28,458
if you're going to make it.

1107
00:50:28,491 --> 00:50:32,862
So this is going to happen
22 times, every Tuesday,

1108
00:50:32,895 --> 00:50:33,930
I believe.

1109
00:50:33,963 --> 00:50:36,433
But I could be wrong about that.

1110
00:50:36,466 --> 00:50:39,769
So the flight team, there
are many of them here,

1111
00:50:39,802 --> 00:50:42,205
we are going to be very busy.

1112
00:50:44,907 --> 00:50:46,243
So, the science.

1113
00:50:47,443 --> 00:50:50,313
I love the engineering

of all this, but really,

1114
00:50:50,346 --> 00:50:52,782
the engineering is all
because of the science.

1115
00:50:52,815 --> 00:50:55,318
And this is, this is just
some of the unique things.

1116
00:50:55,351 --> 00:50:58,555
You've seen what Linda
showed already and it is

1117
00:50:58,588 --> 00:51:01,124
phenomenal and we're going
to continue to do some more

1118
00:51:01,157 --> 00:51:02,659
of that even while we're here.

1119
00:51:02,692 --> 00:51:04,761
But these are opportunities
that we will never ever get

1120
00:51:04,794 --> 00:51:06,696
any other time.

1121
00:51:06,729 --> 00:51:09,799
Saturn internal structure,
magnetic fields, and gravity.

1122
00:51:09,832 --> 00:51:11,968
We'll actually be able to
determine for the first time

1123
00:51:12,001 --> 00:51:14,737
the mass of the rings by
flying in between the rings

1124
00:51:14,770 --> 00:51:17,841
and Saturn we can get a
sense of which one's which.

1125
00:51:17,874 --> 00:51:19,742
And that tells us
something very fundamental.

1126
00:51:19,775 --> 00:51:22,078
Believe it or not, we don't
know how old the rings are.

1127
00:51:22,111 --> 00:51:23,813
They could be a couple
hundred million years,

1128
00:51:23,846 --> 00:51:25,482
they could be a billion years.

1129
00:51:25,515 --> 00:51:27,484
There's a big argument
about that and very,

1130
00:51:27,517 --> 00:51:30,453
very intelligent people
on both sides of the case.

1131
00:51:30,486 --> 00:51:35,058
We think we can help with
some of these measurements.

1132
00:51:35,091 --> 00:51:38,161
Saturn's atmosphere and the
inner-most ring particles

1133
00:51:38,194 --> 00:51:41,464
and the highest resolution
ever ring observations

1134

00:51:41,497 --> 00:51:42,999
themselves.

1135
00:51:43,032 --> 00:51:44,934
We went into orbit in 2004
we went over the rings,

1136
00:51:44,967 --> 00:51:47,770
but they were not lit,
we got the dark side.

1137
00:51:47,803 --> 00:51:51,574
So now we can finally see
these rings fully illuminated

1138
00:51:51,607 --> 00:51:52,809
by the sun.

1139
00:51:52,842 --> 00:51:54,310
And as I showed in
that picture earlier,

1140
00:51:54,343 --> 00:51:56,880
Saturn's cooperating by
providing an incredibly good

1141
00:51:56,913 --> 00:51:58,381
phase angle at the sun.

1142
00:51:58,414 --> 00:52:00,884
Also, we're going
to radar the rings.

1143
00:52:00,917 --> 00:52:02,919
You saw the radar
images of Titan,

1144
00:52:02,952 --> 00:52:05,955
we're going to try to do the
same thing with the rings.

1145
00:52:05,988 --> 00:52:08,791
Pole observations
and aurora of Saturn.

1146
00:52:08,824 --> 00:52:12,162
And then, finally, as I
mentioned in my first slide,

1147
00:52:12,195 --> 00:52:15,598
we are actually going to
sample Saturn's atmosphere.

1148
00:52:15,631 --> 00:52:19,869
Every ounce of Cassini's
last effort will be made in

1149
00:52:19,902 --> 00:52:23,206
sampling the atmosphere and
trying to understand and

1150
00:52:23,239 --> 00:52:25,141
answer some of the
fundamental issues about the

1151
00:52:25,174 --> 00:52:27,810
constituents of the hydrogen
helium ratios and things

1152
00:52:27,843 --> 00:52:28,978
like that.

1153
00:52:29,011 --> 00:52:30,080
So we'll see.

1154
00:52:32,415 --> 00:52:33,883
Let me just quickly
run through this.

1155

00:52:33,916 --> 00:52:36,419
November 30, right
after Thanksgiving,

1156
00:52:36,452 --> 00:52:38,188
this whole thing starts.

1157
00:52:38,221 --> 00:52:41,624
And this is just to
show you that not only,

1158
00:52:41,657 --> 00:52:44,427
sometimes you get your good
and sometimes you're lucky.

1159
00:52:44,460 --> 00:52:46,796
The longitudinal
coverage of the F rings

1160
00:52:46,829 --> 00:52:48,598
is absolutely phenomenal,
we're going to get the whole

1161
00:52:48,631 --> 00:52:52,802
planet covered with the F
ring timeline, 20 orbits.

1162
00:52:54,237 --> 00:52:57,440
April 22 is our
first targeted flyby,

1163
00:52:57,473 --> 00:52:59,008
last targeted flyby.

1164
00:52:59,041 --> 00:53:01,544
And this is the one from
Titan's going to push us in.

1165
00:53:01,577 --> 00:53:04,914
So I'm going to try to not hit

the go button and show you.

1166
00:53:04,947 --> 00:53:07,984
Titan's going to come in from
over here, here's the F ring,

1167
00:53:08,017 --> 00:53:10,253
final F ring orbit.

1168
00:53:10,286 --> 00:53:12,188
We're going to come out back
around and then here comes

1169
00:53:12,221 --> 00:53:15,825
Titan and watch what
happens to this orbit.

1170
00:53:16,726 --> 00:53:17,560
Boom.

1171
00:53:18,728 --> 00:53:21,764
It's about a couple
thousand kilometers,

1172
00:53:21,797 --> 00:53:22,966
so it's pretty close.

1173
00:53:22,999 --> 00:53:26,503
But now, rather than
going outside, in we go.

1174
00:53:28,271 --> 00:53:31,307
And that's going to
happen for 22 times.

1175
00:53:31,340 --> 00:53:35,445
And so there's that and
I won't show you 22 more.

1176

00:53:36,879 --> 00:53:40,617
April 23 the grand finale
begins and we have a lot of

1177
00:53:40,650 --> 00:53:43,386
Titan flybys pushing us around.

1178
00:53:43,419 --> 00:53:46,122
I won't show you a
whole lot of those.

1179
00:53:46,155 --> 00:53:48,024
But the first dive
through the gap,

1180
00:53:48,057 --> 00:53:51,127
and here's our longitudinal
coverage with the proximals.

1181
00:53:51,160 --> 00:53:53,963
Again, it's almost a perfect
grid all the way around

1182
00:53:53,996 --> 00:53:54,864
the planet.

1183
00:53:54,897 --> 00:53:56,399
Absolutely phenomenal.

1184
00:53:56,432 --> 00:53:59,068
First dive through the gap
is on April 26 and then

1185
00:53:59,101 --> 00:54:02,205
September 11 out
last flyby of Titan.

1186
00:54:03,839 --> 00:54:04,974
And I mentioned that before.

1187
00:54:05,007 --> 00:54:06,843
We call it T292.

1188
00:54:06,876 --> 00:54:09,679
It's a distance flyby,
about 100,000 kilometers,

1189
00:54:09,712 --> 00:54:12,915
but it doesn't take much to
push us in to an impacting

1190
00:54:12,948 --> 00:54:14,150
trajectory.

1191
00:54:14,183 --> 00:54:16,653
And September 15,
boom, we're in.

1192
00:54:18,120 --> 00:54:21,891
The end of mission and the
end of a very spectacular

1193
00:54:22,892 --> 00:54:25,762
set of investigations, etc.

1194
00:54:25,795 --> 00:54:28,998
So, I want to share a cartoon
with you that we at the

1195
00:54:29,031 --> 00:54:31,701
flight team like to pass around.

1196
00:54:33,436 --> 00:54:35,471
"Hey Cassini, I hear
you're retiring.

1197
00:54:35,504 --> 00:54:38,174
"How about that, congrats.
Do you want to celebrate?

1198
00:54:38,207 --> 00:54:40,977
"Maybe lunch with
me and my moons."

1199
00:54:41,010 --> 00:54:42,745
How about that?

1200
00:54:42,778 --> 00:54:45,148
"Nah, I'm just going to
go barreling straight into

1201
00:54:45,181 --> 00:54:47,650
"your atmosphere, learning
as much as I can before

1202
00:54:47,683 --> 00:54:51,154
"I'm crushed to death and
vaporized to spectacular

1203
00:54:51,187 --> 00:54:55,858
"whirling inferno beneath your
mysterious stormy clouds."

1204
00:54:55,891 --> 00:54:59,295
So you can imagine
Saturn's reaction to that.

1205
00:54:59,328 --> 00:55:00,697
It's the same.

1206
00:55:00,730 --> 00:55:02,432
(laughter)

1207
00:55:02,465 --> 00:55:03,966
It's the same one
that we all have,

1208
00:55:03,999 --> 00:55:05,435

maybe you all have when
you see that we're going to

1209
00:55:05,468 --> 00:55:07,303
burn this thing up.

1210
00:55:07,336 --> 00:55:09,605
You think about that for
a little bit and hopefully

1211
00:55:09,638 --> 00:55:13,242
what I just told you might
come to agree with all of us

1212
00:55:13,275 --> 00:55:16,579
that it's too bad, it's
a wonderful machine,

1213
00:55:16,612 --> 00:55:20,049
it's been an incredible
discovery machine,

1214
00:55:20,082 --> 00:55:21,518
but it's awesome.

1215
00:55:23,953 --> 00:55:26,189
(applause)

1216
00:55:36,799 --> 00:55:38,835
Okay, I think we're--

1217
00:55:38,868 --> 00:55:43,606
We'd be happy to entertain
any questions you might have.

1218
00:55:43,639 --> 00:55:45,908
And if you do have a question,
we appreciate you going up

1219

00:55:45,941 --> 00:55:47,444
to the microphone.

1220
00:55:50,613 --> 00:55:53,750
- Thank you for a really
awesome presentation.

1221
00:55:53,783 --> 00:55:57,954
So, I believe that the Juno
mission is using highly

1222
00:55:59,655 --> 00:56:02,291
elliptical orbits to explore
the internal structure

1223
00:56:02,324 --> 00:56:05,728
of Jupiter, and I assume,
you mentioned that you're

1224
00:56:05,761 --> 00:56:07,730
going to be probing the
magnetic and gravitational

1225
00:56:07,763 --> 00:56:09,732
fields of Saturn.

1226
00:56:09,765 --> 00:56:13,937
So my question is, at Jupiter
they expect to confirm

1227
00:56:16,138 --> 00:56:20,076
the existence of metallic
hydrogen inside of Jupiter.

1228
00:56:20,109 --> 00:56:24,280
Is Saturn having enough
gravitational pressure to form

1229
00:56:25,981 --> 00:56:28,518
metallic hydrogen,

do you believe?

1230
00:56:28,551 --> 00:56:31,220
- Yes, Saturn certainly
has enough pressure inside

1231
00:56:31,253 --> 00:56:32,989
to form metallic hydrogen.

1232
00:56:33,022 --> 00:56:36,058
We're wondering if we can
maybe also detect that boundary

1233
00:56:36,091 --> 00:56:37,660
inside of Saturn.

1234
00:56:37,693 --> 00:56:39,162
I just want to point out
one difference between Juno

1235
00:56:39,195 --> 00:56:41,764
and Cassini, Juno
is in a polar orbit,

1236
00:56:41,797 --> 00:56:44,467
basically going over the poles,
Cassini we're only tipped

1237
00:56:44,500 --> 00:56:46,302
at 63 degrees.

1238
00:56:46,335 --> 00:56:48,171
And that's basically our
optimum orbit to keep the

1239
00:56:48,204 --> 00:56:51,474
periapses from precessing
and putting us prematurely

1240

00:56:51,507 --> 00:56:53,009
into the rings.

1241
00:56:53,042 --> 00:56:56,179
So very similar complementary
science for the two missions,

1242
00:56:56,212 --> 00:56:59,115
probing the interiors of
two gas giants and then

1243
00:56:59,148 --> 00:57:01,050
comparing the results.

1244
00:57:01,083 --> 00:57:02,085
- Thank you.

1245
00:57:04,487 --> 00:57:06,055
- Thank you for the
great presentation,

1246
00:57:06,088 --> 00:57:10,159
I wanted to ask about
contingencies during
this final year.

1247
00:57:10,192 --> 00:57:14,364
You're on a risky pathway and
if something were to happen

1248
00:57:15,731 --> 00:57:17,233
to the spacecraft on one
of these passes through the

1249
00:57:17,266 --> 00:57:22,171
rings, what do you expect
to become of the rest of the

1250
00:57:22,204 --> 00:57:23,706
mission?

1251
00:57:23,739 --> 00:57:26,108
Is there a chance that it
can still have it's crash

1252
00:57:26,141 --> 00:57:27,043
into Saturn?

1253
00:57:27,076 --> 00:57:27,911
- Yeah.

1254
00:57:30,746 --> 00:57:33,483
One of the things that's
pretty amazing about this

1255
00:57:33,516 --> 00:57:37,687
trajectory, once we've flown
by the final Titan flyby,

1256
00:57:39,054 --> 00:57:41,724
if we lose the spacecraft,
it's still going in.

1257
00:57:41,757 --> 00:57:46,128
And as a matter of fact
after T125 we require,

1258
00:57:46,161 --> 00:57:48,431
which is the
penultimate Titan flyby,

1259
00:57:48,464 --> 00:57:51,701
very minimal
trajectory maintenance.

1260
00:57:51,734 --> 00:57:55,204
We're essentially on a ballistic
trajectory to our entry.

1261

00:57:55,237 --> 00:57:58,174
Now, that being said, we're
still going to try to get,

1262
00:57:58,207 --> 00:58:01,711
we've worked contingencies
in case we find the dust

1263
00:58:01,744 --> 00:58:04,747
is higher than we want, we
can hide behind the high

1264
00:58:04,780 --> 00:58:06,148
gain antenna.

1265
00:58:06,181 --> 00:58:08,651
If the atmosphere is
thicker than we would like,

1266
00:58:08,684 --> 00:58:11,420
although some of the scientists
think that's just great,

1267
00:58:11,453 --> 00:58:13,089
we can move ourselves
out a little bit.

1268
00:58:13,122 --> 00:58:15,191
So we have worked all the
contingency plans to make sure

1269
00:58:15,224 --> 00:58:17,693
the mission is as
successful as possible,

1270
00:58:17,726 --> 00:58:20,897
but if we are damaged, we
still will be able to keep our

1271
00:58:20,930 --> 00:58:23,500

promise to Enceladus and Titan.

1272
00:58:24,667 --> 00:58:26,135
- In fact, if the
atmosphere shrinks,

1273
00:58:26,168 --> 00:58:28,504
and that's a possibility,
we also have a plan we could

1274
00:58:28,537 --> 00:58:31,674
go a little bit lower because
we want to dip our toe,

1275
00:58:31,707 --> 00:58:34,978
for sure, in that
atmosphere of Saturn.

1276
00:58:36,378 --> 00:58:40,783
- Hi, this is more of a
question about the capability

1277
00:58:40,816 --> 00:58:43,085
of the spacecraft.

1278
00:58:43,118 --> 00:58:45,655
So I understand that the
decision to de-orbit it is

1279
00:58:45,688 --> 00:58:50,560
quite final, but it would
it ever have been possible

1280
00:58:50,593 --> 00:58:54,430
to attempt, is there
sufficient delta V in the tanks

1281
00:58:54,463 --> 00:58:57,633
to attempt a rocky or icy
moon, smaller moon landing

1282
00:58:57,666 --> 00:59:01,671
like a janky near style
landing, use the low gain

1283
00:59:03,005 --> 00:59:05,508
antenna, send another spacecraft
later and have a passive

1284
00:59:05,541 --> 00:59:07,777
station sitting in
orbit around Saturn.

1285
00:59:07,810 --> 00:59:10,980
- I'm afraid, well
that could've been,

1286
00:59:12,615 --> 00:59:14,850
in that set of scenarios
there may have been a landing

1287
00:59:14,883 --> 00:59:18,554
scenario that we didn't work,
but now there absolutely

1288
00:59:18,587 --> 00:59:19,989
is not.

1289
00:59:20,022 --> 00:59:22,925
When we designed the solstice
mission we designed it,

1290
00:59:22,958 --> 00:59:26,329
you don't want to end a
mission with a full tank.

1291
00:59:26,362 --> 00:59:28,264
In fact, you want to end the
mission with a completely

1292
00:59:28,297 --> 00:59:32,468
empty tank and right now we
are almost completely empty.

1293
00:59:32,501 --> 00:59:37,073
So the possibility of a
controlled landing on anything

1294
00:59:37,106 --> 00:59:39,609
would be absolutely
out of the question.

1295
00:59:39,642 --> 00:59:42,845
Again, those sort of things,
most of the controlled

1296
00:59:42,878 --> 00:59:45,381
landings that we see are
really more like controlled

1297
00:59:45,414 --> 00:59:46,882
crashes.

1298
00:59:46,915 --> 00:59:49,385
They're low speed crashes
and so really the realistic

1299
00:59:49,418 --> 00:59:52,622
opportunity to create a
beacon, I think you want to

1300
00:59:52,655 --> 00:59:56,359
design something like Hoygens
that actually was built

1301
00:59:56,392 --> 00:59:57,727
to broadcast up.

1302
00:59:59,194 --> 01:00:01,430

But unfortunately it was on
batteries and that was that.

1303
01:00:01,463 --> 01:00:04,333
But now it's, like you
said, the decision is made

1304
01:00:04,366 --> 01:00:07,269
and we have spent all our
propellant doing what we've

1305
01:00:07,302 --> 01:00:08,838
been doing.

1306
01:00:08,871 --> 01:00:10,873
Thanks for the question.

1307
01:00:12,574 --> 01:00:15,344
- Thank you both for that
presentation, it was excellent.

1308
01:00:15,377 --> 01:00:18,514
You noted earlier your
concern over contaminating

1309
01:00:18,547 --> 01:00:21,651
the environments of
Enceladus and Titan.

1310
01:00:21,684 --> 01:00:23,486
How were you able to
prevent that when you landed

1311
01:00:23,519 --> 01:00:26,188
Hoygens probe on the
surface of Titan?

1312
01:00:26,221 --> 01:00:28,290
- Ah, good question.

1313
01:00:28,323 --> 01:00:31,027
I think the key difference
between those is that Cassini

1314
01:00:31,060 --> 01:00:33,596
is powered by these radio
isotope thermo-electric

1315
01:00:33,629 --> 01:00:36,098
generators with
plutonium on board.

1316
01:00:36,131 --> 01:00:39,435
And to access the ocean on
Enceladus you'd probably have

1317
01:00:39,468 --> 01:00:41,437
to melt through some ice.

1318
01:00:41,470 --> 01:00:43,439
And with the heat
from that plutonium,

1319
01:00:43,472 --> 01:00:45,207
that might be a possibility.

1320
01:00:45,240 --> 01:00:48,744
Hoygens probe had batteries
and it has some small

1321
01:00:48,777 --> 01:00:49,779
RHU heaters.

1322
01:00:51,280 --> 01:00:53,883
And also, when we landed on
Titan, we didn't know about

1323
01:00:53,916 --> 01:00:57,186
the methane lakes, we didn't

know that Titan also had

1324
01:00:57,219 --> 01:01:00,523
a global ocean, we didn't
know about Enceladus.

1325
01:01:00,556 --> 01:01:03,759
So a lot of things, as Earl
said, Cassini is kind of

1326
01:01:03,792 --> 01:01:06,462
a victim of her own discoveries.

1327
01:01:07,596 --> 01:01:09,198
- I see, thank you.

1328
01:01:10,632 --> 01:01:14,003
- Absolutely superb
presentations, of course.

1329
01:01:14,036 --> 01:01:16,605
Quick questions, what's
the cause of the highlights

1330
01:01:16,638 --> 01:01:18,908
that we see here at 12
o'clock and six o'clock

1331
01:01:18,941 --> 01:01:21,444
on the outer most rings?

1332
01:01:21,477 --> 01:01:23,212
- Excellent question,
what is the cause of those

1333
01:01:23,245 --> 01:01:24,347
bright spots?

1334
01:01:25,481 --> 01:01:27,450

It turns out that those
spots are actually,

1335
01:01:27,483 --> 01:01:29,919
you can think of somewhat
pulled in closer to the sun

1336
01:01:29,952 --> 01:01:32,288
and so it's sort of
a phase angle effect.

1337
01:01:32,321 --> 01:01:35,057
If you can think of it that
way, the ansa are further away

1338
01:01:35,090 --> 01:01:39,528
from the sun than the points
at the north and the south.

1339
01:01:39,561 --> 01:01:42,198
And so they are brighter, as
many things brighten as you

1340
01:01:42,231 --> 01:01:44,166
get toward that very
low phase angle,

1341
01:01:44,199 --> 01:01:47,436
or that distance between the
sun and your target is small.

1342
01:01:47,469 --> 01:01:50,306
Good question,
though, good catch.

1343
01:01:53,375 --> 01:01:55,411
- To start, thank you for
a wonderful presentation,

1344
01:01:55,444 --> 01:01:57,880

I really enjoyed it.

1345
01:01:57,913 --> 01:02:02,017
Knowing what we know now
about Saturn, what's next?

1346
01:02:02,050 --> 01:02:04,220
And when do we get to go?

1347
01:02:07,623 --> 01:02:09,225
- That's yours.

1348
01:02:09,258 --> 01:02:12,328
- Well there's a proposal
cycle underway now within

1349
01:02:12,361 --> 01:02:14,130
NASA called New Frontiers.

1350
01:02:14,163 --> 01:02:17,066
And there's a fixed list of
missions for New Frontiers,

1351
01:02:17,099 --> 01:02:19,535
one of those is a Saturn probe.

1352
01:02:19,568 --> 01:02:21,537
Much as we had a probe in
the Galileo's atmosphere,

1353
01:02:21,570 --> 01:02:23,672
we'd like to send a probe
into Saturn's atmosphere,

1354
01:02:23,705 --> 01:02:26,842
in particular to measure the
nobel gases that you can't

1355
01:02:26,875 --> 01:02:28,577

really measure any other way.

1356
01:02:28,610 --> 01:02:30,012
And there are a host of
other things you could do

1357
01:02:30,045 --> 01:02:31,447
with a probe.

1358
01:02:31,480 --> 01:02:33,149
There are also now, two
targets that were added to the

1359
01:02:33,182 --> 01:02:36,552
list for New Frontiers,
those targets are Enceladus

1360
01:02:36,585 --> 01:02:38,053
and Titan.

1361
01:02:38,086 --> 01:02:41,290
Basically, these new ocean
worlds unveiled by Cassini.

1362
01:02:41,323 --> 01:02:44,560
And so there are missions to
go to fly through the plumes

1363
01:02:44,593 --> 01:02:47,630
of Enceladus with more capable
instruments to, perhaps,

1364
01:02:47,663 --> 01:02:50,499
look for those amino
and fatty acids.

1365
01:02:50,532 --> 01:02:53,135
Missions to maybe land
something in one of those seas

1366
01:02:53,168 --> 01:02:55,638
on Titan and make
measurements there.

1367
01:02:55,671 --> 01:02:58,007
So there's a whole host of
proposals, there's probably

1368
01:02:58,040 --> 01:03:00,910
30 or 40 or who knows how
many NASA will get sometime

1369
01:03:00,943 --> 01:03:03,546
next spring and then they'll
get to pick one of those

1370
01:03:03,579 --> 01:03:05,114
missions.

1371
01:03:05,147 --> 01:03:08,150
So we might go back as early,
but it still is a long trip.

1372
01:03:08,183 --> 01:03:11,787
You're talking about maybe
a launch in the mid-2020s,

1373
01:03:11,820 --> 01:03:16,192
'25, '26 and then maybe a
decade or so to get back

1374
01:03:16,225 --> 01:03:17,426
to Saturn.

1375
01:03:17,459 --> 01:03:19,962
It's not a quick
trip to get there.

1376
01:03:21,296 --> 01:03:22,998

- I can't wait.

1377
01:03:23,031 --> 01:03:24,433
Thank you.

1378
01:03:24,466 --> 01:03:25,968
- And don't forget Uranus
and Neptune, I mean,

1379
01:03:26,001 --> 01:03:28,103
they're out there too and
it would be great to send

1380
01:03:28,136 --> 01:03:30,739
a flagship mission like
Cassini on out to one of the

1381
01:03:30,772 --> 01:03:32,842
ice giants, Uranus or Neptune.

1382
01:03:32,875 --> 01:03:35,678
We've just had tantalizing
glimpses with Voyager and

1383
01:03:35,711 --> 01:03:39,048
to go back to one of those
places for a future flagship,

1384
01:03:39,081 --> 01:03:40,282
maybe after Europa.

1385
01:03:40,315 --> 01:03:42,918
Maybe a flagship to
Uranus or Neptune.

1386
01:03:42,951 --> 01:03:44,620
- Thank you so much.

1387
01:03:48,290 --> 01:03:51,126

- I'll jump in for
one more question.

1388
01:03:51,159 --> 01:03:55,331
How long does it take for
an image to get from Cassini

1389
01:03:57,099 --> 01:03:58,000
to earth?

1390
01:03:58,033 --> 01:03:59,468
Like, to get the data here?

1391
01:03:59,501 --> 01:04:03,406
My iPhone I think has eight
megapixels, what's Cassini have?

1392
01:04:05,073 --> 01:04:08,177
- One megapixel, and
it's black and white.

1393
01:04:08,210 --> 01:04:10,346
(laughs)

1394
01:04:10,379 --> 01:04:14,516
We colorize our images with
filters and it takes anywhere

1395
01:04:14,549 --> 01:04:18,654
from an hour to 90 minutes
for the image to get from

1396
01:04:18,687 --> 01:04:21,257
Cassini here to the earth.

1397
01:04:21,290 --> 01:04:23,259
- Whole megapixel image.

1398
01:04:23,292 --> 01:04:27,463

- The megapixel, let's see,
we do 140 kilobits per second.

1399
01:04:29,598 --> 01:04:32,568
So it'd take 10
seconds or so, roughly,

1400
01:04:32,601 --> 01:04:35,771
let's say 20 counting overhead
to get an image down here

1401
01:04:35,804 --> 01:04:37,273
once it starts.

1402
01:04:37,306 --> 01:04:41,010
But Saturn is an hour and
a half light time away.

1403
01:04:41,043 --> 01:04:43,746
So when we start, when Cassini
starts to send a signal,

1404
01:04:43,779 --> 01:04:48,484
her bits don't get to the
ground for an hour and a half.

1405
01:04:48,517 --> 01:04:51,387
So when we want to send
something to Cassini and have

1406
01:04:51,420 --> 01:04:56,191
it answer, we have
to wait anywhere from
two to three hours.

1407
01:04:56,224 --> 01:04:59,495
- Wow, that was really
great, thank you.

1408
01:05:00,829 --> 01:05:03,265

- It just means Cassini
has to be very smart.

1409
01:05:03,298 --> 01:05:05,634
She has to basically have
commands on board to keep

1410
01:05:05,667 --> 01:05:08,570
her going typically
for 10 weeks at a time.

1411
01:05:08,603 --> 01:05:11,640
Where to point, where to
look, when to send data back,

1412
01:05:11,673 --> 01:05:14,110
and so very smart spacecraft.

1413
01:05:15,544 --> 01:05:18,514
- Actually, speaking of
photos, I was wondering what's

1414
01:05:18,547 --> 01:05:21,650
the plan for the grand
finale photo wise?

1415
01:05:21,683 --> 01:05:23,819
Like, what are you
expecting to see?

1416
01:05:23,852 --> 01:05:25,587
If you're expecting to take
photos or expecting to see

1417
01:05:25,620 --> 01:05:29,158
maybe some resolving some
individual clumps of ice

1418
01:05:29,191 --> 01:05:31,560
in the rings since

you're going so close,

1419
01:05:31,593 --> 01:05:34,463
or looking at clouds of
Saturn 'cause the periapses

1420
01:05:34,496 --> 01:05:35,831
are going to be so close?

1421
01:05:35,864 --> 01:05:37,666
Are you guys expecting
to take a lot of photos

1422
01:05:37,699 --> 01:05:39,735
from this mission?

1423
01:05:39,768 --> 01:05:41,704
- We'll be taking a lot of
photos of both the rings

1424
01:05:41,737 --> 01:05:43,205
and the planet.

1425
01:05:43,238 --> 01:05:45,174
Ring particles, on average,
are millimeters to centimeters

1426
01:05:45,207 --> 01:05:48,110
in size, even if they
were 10s of meters,

1427
01:05:48,143 --> 01:05:50,779
we still couldn't resolve
an individual ring particle.

1428
01:05:50,812 --> 01:05:53,615
But we certainly could
resolve the structure that we

1429

01:05:53,648 --> 01:05:56,018
see in the rings at
much higher resolution.

1430
01:05:56,051 --> 01:05:58,620
SOIs are also just on the
dark side of the rings,

1431
01:05:58,653 --> 01:06:01,056
this is a chance to
look at that resolution,

1432
01:06:01,089 --> 01:06:02,925
but on the lighted
side of the rings.

1433
01:06:02,958 --> 01:06:04,693
Radar of the rings, as well.

1434
01:06:04,726 --> 01:06:07,129
Also we'll get close
up views of the planet,

1435
01:06:07,162 --> 01:06:08,998
of the poles of the
atmosphere itself.

1436
01:06:09,031 --> 01:06:11,533
I think that the surprises
might be the questions

1437
01:06:11,566 --> 01:06:13,235
that we don't yet know to ask.

1438
01:06:13,268 --> 01:06:15,137
When we look at those pictures,
whether it's the rings

1439
01:06:15,170 --> 01:06:17,039
or the planet,

what might we see?

1440
01:06:17,072 --> 01:06:19,375
Also we have a detector
that some of those tiny ring

1441
01:06:19,408 --> 01:06:21,477
particles from the
main rings charge up

1442
01:06:21,510 --> 01:06:24,747
and the fill bines then will
go into one of our sensors,

1443
01:06:24,780 --> 01:06:27,983
the cosmic dust analyzer and
we'll get, for the first time,

1444
01:06:28,016 --> 01:06:30,452
the direct composition
of the rings.

1445
01:06:30,485 --> 01:06:32,588
We know they're water ice,
but we don't know if the

1446
01:06:32,621 --> 01:06:36,992
non-icy component is
silicates, iron, tholens,

1447
01:06:37,025 --> 01:06:38,494
we don't know what it is.

1448
01:06:38,527 --> 01:06:40,129
So we'll get the answer
for that for sure for the

1449
01:06:40,162 --> 01:06:41,563
first time.

1450
01:06:41,596 --> 01:06:44,733
- I might also add that,
as we enter the atmosphere,

1451
01:06:44,766 --> 01:06:48,237
everything is going to
be focused on atmospheric

1452
01:06:48,270 --> 01:06:51,306
construction and constituents.

1453
01:06:51,339 --> 01:06:53,809
The spectrometers, the
fields and particles,

1454
01:06:53,842 --> 01:06:55,544
they're going to be
pointing at the atmosphere,

1455
01:06:55,577 --> 01:06:57,312
unfortunately that means
the camera is going to be

1456
01:06:57,345 --> 01:06:59,014
pointing someplace else.

1457
01:06:59,047 --> 01:07:02,017
And furthermore, in order
to play all that data back

1458
01:07:02,050 --> 01:07:05,254
as fast as we can, we have
to narrow down the bandwidth

1459
01:07:05,287 --> 01:07:07,523
and a megapixel is a megapixel.

1460
01:07:07,556 --> 01:07:11,627
We could get 10 or 20 mass

spectrometer packets down

1461
01:07:11,660 --> 01:07:13,128
for one image.

1462
01:07:13,161 --> 01:07:15,397
So the camera is not
even going to be recorded

1463
01:07:15,430 --> 01:07:18,434
and sent down during
those final seconds.

1464
01:07:18,467 --> 01:07:19,468
- Thank you.

1465
01:07:22,170 --> 01:07:25,107
- You said in response to
an earlier question that

1466
01:07:25,140 --> 01:07:27,576
you're getting pictures in
black and white and then

1467
01:07:27,609 --> 01:07:29,578
you're coloring
them with filters.

1468
01:07:29,611 --> 01:07:31,080
How does that work?

1469
01:07:31,113 --> 01:07:33,048
Are you choosing or do you
know what colors to use?

1470
01:07:33,081 --> 01:07:35,584
- Our cameras have
two filter wheels.

1471

01:07:35,617 --> 01:07:37,786
You know, essentially you
can take a green, blue,

1472
01:07:37,819 --> 01:07:42,191
and magenta, blue, green,
and whatever three colors

1473
01:07:42,224 --> 01:07:45,060
you pick and
colorize them, right?

1474
01:07:45,093 --> 01:07:48,630
It has infrared filters
that penetrate the haze.

1475
01:07:48,663 --> 01:07:52,067
And so each of these filter
wheels, you actually rotate

1476
01:07:52,100 --> 01:07:55,938
that filter into the image
path and take an image,

1477
01:07:55,971 --> 01:07:58,073
then rotate another
filter, take another image,

1478
01:07:58,106 --> 01:08:01,210
and they're combined and
colorized on the ground.

1479
01:08:01,243 --> 01:08:03,479
- So the colors you end up
with represent what you're

1480
01:08:03,512 --> 01:08:05,147
actually looking at or is it?

1481
01:08:05,180 --> 01:08:07,082

- They can, or they can
represent some of the false

1482
01:08:07,115 --> 01:08:09,251
colors that you've seen
like the red hurricanes

1483
01:08:09,284 --> 01:08:12,087
and things like that
that accentuate levels of

1484
01:08:12,120 --> 01:08:14,990
elevation or of
chemical constituents.

1485
01:08:15,023 --> 01:08:17,993
A lot of the pictures
you've seen were natural,

1486
01:08:18,026 --> 01:08:21,230
but some of the others were
false colored to highlight

1487
01:08:21,263 --> 01:08:25,234
whatever (mumbles) or
chemical item you're trying

1488
01:08:25,267 --> 01:08:26,202
to look at.

1489
01:08:27,102 --> 01:08:28,537
- But you can get true color.

1490
01:08:28,570 --> 01:08:30,405
You take those filters and
add them together in different

1491
01:08:30,438 --> 01:08:32,841
ways and you get the true
color that you would see

1492
01:08:32,874 --> 01:08:35,777
with your eyes in
those pictures.

1493
01:08:35,810 --> 01:08:36,812
- Thank you.

1494
01:08:41,416 --> 01:08:42,584
- Hi.

1495
01:08:42,617 --> 01:08:44,319
Thank you for your
presentations.

1496
01:08:44,352 --> 01:08:46,288
I have two questions
here I want to ask.

1497
01:08:46,321 --> 01:08:50,159
First is you guys said
that Cassini satellite,

1498
01:08:51,626 --> 01:08:55,631
I mean the Cassini drone,
whatever, is the farthest

1499
01:08:57,532 --> 01:09:01,070
in the solar system
that we have ever gone.

1500
01:09:02,771 --> 01:09:03,606
- Oh no.

1501
01:09:05,106 --> 01:09:07,743
- No, what I said was that
Hoygens probe landing on the

1502
01:09:07,776 --> 01:09:10,812

surface on Titan is the
furthest we've landed a probe

1503
01:09:10,845 --> 01:09:12,247
on the surface.

1504
01:09:12,280 --> 01:09:14,683
But the furthest spacecraft,
now, away from the sun

1505
01:09:14,716 --> 01:09:16,518
would be the Voyager spacecraft.

1506
01:09:16,551 --> 01:09:20,255
They're well past the
orbits of Neptune, Pluto,

1507
01:09:20,288 --> 01:09:22,958
they're on out, even one of
them into the interstellar

1508
01:09:22,991 --> 01:09:23,826
winds.

1509
01:09:25,193 --> 01:09:27,529
- Even at light time,
they're a day and a half for

1510
01:09:27,562 --> 01:09:30,132
a signal to get from
the probe to Earth.

1511
01:09:30,165 --> 01:09:32,467
So they're way out there.

1512
01:09:32,500 --> 01:09:35,537
- I see and the other
question I have is that,

1513

01:09:35,570 --> 01:09:39,742
I remember correctly, Saturn
has five big moons, correct?

1514
01:09:43,345 --> 01:09:47,349
And so why do you only
land on two of those moons?

1515
01:09:47,382 --> 01:09:50,185
- Titan is the very biggest
moon and it's the only

1516
01:09:50,218 --> 01:09:53,488
moon in our solar system
with a thick atmosphere.

1517
01:09:53,521 --> 01:09:56,258
And it was the one that
had the most questions and

1518
01:09:56,291 --> 01:09:57,726
puzzles about it.

1519
01:09:57,759 --> 01:10:00,629
So we really had the weight
on Cassini to carry just

1520
01:10:00,662 --> 01:10:04,199
a single probe and so it was
easiest to land on Titan.

1521
01:10:04,232 --> 01:10:06,268
You could land with a parachute,
you didn't need rockets

1522
01:10:06,301 --> 01:10:07,803
or anything fancy.

1523
01:10:07,836 --> 01:10:10,339
And we wanted to see what

that surface looked like.

1524
01:10:10,372 --> 01:10:12,808
So if we go back we could
carry probes that could land

1525
01:10:12,841 --> 01:10:16,411
on multiple moons and
look at those, as well.

1526
01:10:16,444 --> 01:10:17,879
- Okay.

1527
01:10:17,912 --> 01:10:20,616
So you mean that you choose
the moons you will land

1528
01:10:20,649 --> 01:10:21,550
before--

1529
01:10:21,583 --> 01:10:23,318
- Right, we chose Titan.

1530
01:10:23,351 --> 01:10:26,455
Before Cassini even launched
we had chosen Titan.

1531
01:10:26,488 --> 01:10:28,557
- Okay, I see, thank you.

1532
01:10:31,426 --> 01:10:33,295
- Thank you for the
very amazing talk.

1533
01:10:33,328 --> 01:10:37,499
I had a question on
a radio (mumbles).

1534
01:10:38,833 --> 01:10:40,535

For the three different
frequency centers that you have

1535
01:10:40,568 --> 01:10:43,372
available on the spacecraft,
can you characterize

1536
01:10:43,405 --> 01:10:47,576
a little bit on ring particles
that are smaller than

1537
01:10:49,044 --> 01:10:51,580
the shortest wavelength
and larger than the longer

1538
01:10:51,613 --> 01:10:54,916
wavelengths and the defraction
patterns and how we would

1539
01:10:54,949 --> 01:10:58,687
be able to ascertain
the particle population.

1540
01:10:58,720 --> 01:11:01,290
- The three wavelengths of
the radio science are very

1541
01:11:01,323 --> 01:11:04,526
diagnostic in helping us
understand the particle size

1542
01:11:04,559 --> 01:11:07,429
distribution of
the ring particles.

1543
01:11:07,462 --> 01:11:09,965
And what we've found in
looking at those is they're

1544
01:11:09,998 --> 01:11:13,902

pretty much seeing all
of the particles in that

1545
01:11:13,935 --> 01:11:16,305
particular size range for that.

1546
01:11:16,338 --> 01:11:21,276
So they do a good job, the
KA, X band, and S band,

1547
01:11:21,309 --> 01:11:22,744
in looking through the rings.

1548
01:11:22,777 --> 01:11:25,747
And sometimes the S band
signal is blocked out first

1549
01:11:25,780 --> 01:11:28,250
because the rings are
so optically thick.

1550
01:11:28,283 --> 01:11:32,587
- And how does the defraction
or dispersion occur

1551
01:11:32,620 --> 01:11:35,791
on particles that are
outside those wavelength

1552
01:11:35,824 --> 01:11:36,825
correlation?

1553
01:11:38,293 --> 01:11:40,195
- The radio science actually
there's a fairly large

1554
01:11:40,228 --> 01:11:42,931
field of view so it's
integrated particles all the way

1555
01:11:42,964 --> 01:11:44,499
across that field of view.

1556
01:11:44,532 --> 01:11:47,035
And sometimes we see defraction
patterns that tell us

1557
01:11:47,068 --> 01:11:50,105
that the ring particles are
lining up and are structured

1558
01:11:50,138 --> 01:11:52,107
in a certain way forming
these things we call

1559
01:11:52,140 --> 01:11:53,608
self-gravity wakes.

1560
01:11:53,641 --> 01:11:56,345
We can actually do some work
to detect those in radio

1561
01:11:56,378 --> 01:11:57,879
science, as well.

1562
01:11:57,912 --> 01:11:59,348
If you want more detailed
answer I can give those

1563
01:11:59,381 --> 01:12:01,149
if you want to
come up afterwards.

1564
01:12:01,182 --> 01:12:02,184
- Thank you.

1565
01:12:04,986 --> 01:12:06,788
- So this is more of an
engineering than a science

1566
01:12:06,821 --> 01:12:09,958
question, but for all these
precise orbital maneuvers,

1567
01:12:09,991 --> 01:12:11,827
how do you know you're
positioned accurately enough

1568
01:12:11,860 --> 01:12:14,096
to perform these maneuvers?

1569
01:12:15,397 --> 01:12:17,432
'Cause you can't exactly
open Google Maps and get

1570
01:12:17,465 --> 01:12:18,867
your GPS, right?

1571
01:12:18,900 --> 01:12:20,836
- I've got to brag a little
bit because JPL is an

1572
01:12:20,869 --> 01:12:24,172
absolute center of
excellence for navigation.

1573
01:12:24,205 --> 01:12:26,975
What we do a couple
of different things.

1574
01:12:27,008 --> 01:12:30,212
First of all, we track the
spacecraft very carefully,

1575
01:12:30,245 --> 01:12:34,416
we use doppler and ranging
to measure it's velocity

1576

01:12:35,283 --> 01:12:37,786
and distance very precisely.

1577
01:12:37,819 --> 01:12:40,756
We fit that to an orbit
and at the same time we're

1578
01:12:40,789 --> 01:12:43,492
solving for all
the ephemeralities.

1579
01:12:43,525 --> 01:12:47,829
Essentially the positional
points of all the satellites

1580
01:12:47,862 --> 01:12:49,064
and Saturn.

1581
01:12:49,097 --> 01:12:50,565
And that's a daily process.

1582
01:12:50,598 --> 01:12:52,934
As a matter of fact, we're
going to do a very tiny OTM

1583
01:12:52,967 --> 01:12:56,171
tonight, over trim
maneuver tonight based on

1584
01:12:56,204 --> 01:12:57,706
latest observations.

1585
01:12:57,739 --> 01:13:00,442
Because we move, you know,
we're moving a kilometer

1586
01:13:00,475 --> 01:13:02,911
or maybe a few hundred
meters just being pushed

1587
01:13:02,944 --> 01:13:07,883
around by our own shennanigans
as well as smaller forces.

1588
01:13:07,916 --> 01:13:10,419
So we're constantly
tracking the spacecraft.

1589
01:13:10,452 --> 01:13:13,622
And over the decades
we've hit comets,

1590
01:13:15,056 --> 01:13:19,795
I gotta say the navigation
at Saturn is one of the

1591
01:13:19,828 --> 01:13:22,831
triumphs of modern
interplanetary
navigation because

1592
01:13:22,864 --> 01:13:25,834
of the precision that
we're able to do this.

1593
01:13:25,867 --> 01:13:29,738
You could do the same thing
with much coarser measurements,

1594
01:13:29,771 --> 01:13:31,606
but you'd have to be carrying
tremendous amounts of

1595
01:13:31,639 --> 01:13:33,074
propellant.

1596
01:13:33,107 --> 01:13:35,110
Because every time you miss
you've got to fix it to

1597
01:13:35,143 --> 01:13:36,678
get back on track.

1598
01:13:36,711 --> 01:13:39,147
So I'd be happy to share
a paper with you, or two,

1599
01:13:39,180 --> 01:13:41,183
we've got a lot of
papers about this.

1600
01:13:41,216 --> 01:13:42,717
(chuckles)

1601
01:13:42,750 --> 01:13:45,253
- And one of the comments,
the navigation is so good

1602
01:13:45,286 --> 01:13:47,522
it's allowed us to go
closer and closer and closer

1603
01:13:47,555 --> 01:13:50,592
to these targets until we
came within just 50 kilometers

1604
01:13:50,625 --> 01:13:52,527
of the south pole of Enceladus.

1605
01:13:52,560 --> 01:13:56,131
In fact, our closest
flyby was 25 kilometers,

1606
01:13:56,164 --> 01:13:57,599
but it just wasn't
under the pole.

1607
01:13:57,632 --> 01:14:00,202
So we have just gotten

so good we can go close,

1608
01:14:00,235 --> 01:14:03,839
know where we're going to
hit, and we don't miss.

1609
01:14:03,872 --> 01:14:04,773
- Thanks.

1610
01:14:09,043 --> 01:14:10,979
- I have some online
questions here.

1611
01:14:11,012 --> 01:14:14,683
Just want to go through
a couple of those.

1612
01:14:14,716 --> 01:14:18,553
A question from Titan82
wants to know what is the

1613
01:14:18,586 --> 01:14:21,623
temperature of the surface,
sub-surface ocean of

1614
01:14:21,656 --> 01:14:23,158
Enceladus?

1615
01:14:23,191 --> 01:14:26,127
Well if it's true that we
have hydro-thermal vents,

1616
01:14:26,160 --> 01:14:28,730
it might be as high as
close to boiling point

1617
01:14:28,763 --> 01:14:30,532
around those sub-surface vents.

1618

01:14:30,565 --> 01:14:34,135
But clearly if the water is
a liquid, even though it's

1619
01:14:34,168 --> 01:14:35,704
under a little bit of
pressure and perhaps with some

1620
01:14:35,737 --> 01:14:39,774
ammonia, it must be very
close, it must be above the

1621
01:14:39,807 --> 01:14:41,776
freezing point of water.

1622
01:14:41,809 --> 01:14:45,180
So we know that, otherwise the
ocean wouldn't be a liquid.

1623
01:14:45,213 --> 01:14:47,716
The next question is will
Cassini be able to photograph

1624
01:14:47,749 --> 01:14:51,186
the vertical ring structures
as it passes through

1625
01:14:51,219 --> 01:14:52,587
the ring plane.

1626
01:14:52,620 --> 01:14:55,724
That's a great question,
unfortunately the answer is no.

1627
01:14:55,757 --> 01:14:58,793
We can't photograph these
vertical structures very well

1628
01:14:58,826 --> 01:15:00,962
because they aren't very big.

1629
01:15:00,995 --> 01:15:03,231
We don't think we'll have
the resolution to resolve

1630
01:15:03,264 --> 01:15:06,301
something that's a
kilometer or less.

1631
01:15:06,334 --> 01:15:08,436
And we don't think there's
vertical structure in the

1632
01:15:08,469 --> 01:15:10,672
C ring and D ring where
we'll get the very closest to

1633
01:15:10,705 --> 01:15:12,173
the rings.

1634
01:15:12,206 --> 01:15:14,075
So I'm sure we'll be looking
and in fact we have looked

1635
01:15:14,108 --> 01:15:16,678
as we've gone through
the ring plane crossings,

1636
01:15:16,711 --> 01:15:19,147
I don't think we'll have
the resolution to be able

1637
01:15:19,180 --> 01:15:20,082
to do that.

1638
01:15:21,449 --> 01:15:23,051
And then if we really
wanted to look for shadows,

1639

01:15:23,084 --> 01:15:25,787
which is a really great
way to look for structure,

1640
01:15:25,820 --> 01:15:27,389
during this point in the
mission there'll be no

1641
01:15:27,422 --> 01:15:30,959
shadows cast by
the ring particles.

1642
01:15:30,992 --> 01:15:32,995
We're not in equinox so.

1643
01:15:34,195 --> 01:15:36,665
Okay, are there any
other questions?

1644
01:15:36,698 --> 01:15:38,333
Okay, if not, thank
you very much.

1645
01:15:38,366 --> 01:15:40,602
(applause)