



1  
00:00:01,701 --> 00:00:04,971  
- [Narrator] NASA's Jet  
Propulsion Laboratory presents

2  
00:00:04,971 --> 00:00:07,740  
the Von Karman Lecture,  
a series of talks

3  
00:00:07,740 --> 00:00:11,678  
by scientists and engineers  
who are exploring our planet,

4  
00:00:11,678 --> 00:00:15,048  
our solar system, and  
all that lies beyond.

5  
00:00:15,048 --> 00:00:17,550  
(light music)

6  
00:00:27,627 --> 00:00:29,796  
- Good evening, everybody.

7  
00:00:30,796 --> 00:00:32,565  
May the fourth be with you.

8  
00:00:32,565 --> 00:00:34,601  
(audience laughing)

9  
00:00:34,601 --> 00:00:38,004  
(applauding and whistling)

10  
00:00:38,004 --> 00:00:38,838  
Wow.

11  
00:00:40,406 --> 00:00:42,909  
I got a live long and prosper  
sign right there in the back.

12

00:00:42,909 --> 00:00:44,744

Thank you for joining  
us here at JPL,

13

00:00:44,744 --> 00:00:46,546

and thank you for  
joining us at home,

14

00:00:46,546 --> 00:00:49,515

for the Von Karman lecture  
series, now let's get to it.

15

00:00:49,515 --> 00:00:51,484

The Cassini mission  
has revolutionized

16

00:00:51,484 --> 00:00:53,920

our understanding of Saturn,  
from its complex rings

17

00:00:53,920 --> 00:00:57,823

or magnetic environment  
to its menagerie of moons.

18

00:00:57,823 --> 00:01:00,593

Icy jets shoot from the  
tiny moon Enceladus,

19

00:01:00,593 --> 00:01:02,661

liquid ethane and  
methane dominate

20

00:01:02,661 --> 00:01:05,364

Titan's hydrocarbon  
lakes and seas,

21

00:01:05,364 --> 00:01:08,034

and Hyperion has  
a static charge.

22

00:01:08,034 --> 00:01:09,902

We look forward to the  
puzzles Cassini will solve

23

00:01:09,902 --> 00:01:13,105

as it goes out in  
a blaze of glory.

24

00:01:13,105 --> 00:01:14,340

Tonight our guests will reveal

25

00:01:14,340 --> 00:01:15,741

some of the recent  
science discoveries

26

00:01:15,741 --> 00:01:18,344

and share the excitement  
and challenges

27

00:01:18,344 --> 00:01:20,646

expected during  
Cassini's final orbits.

28

00:01:20,646 --> 00:01:23,449

Now Dr. Earl Maize is the  
Cassini program manager,

29

00:01:23,449 --> 00:01:26,585

a veteran of 32 years at JPL.

30

00:01:26,585 --> 00:01:28,387

He began his career  
working on the navigation

31

00:01:28,387 --> 00:01:31,524

and engineering teams of the  
Galileo mission to Jupiter.

32

00:01:31,524 --> 00:01:35,194

After Galileo's final Earth

flyby, he transferred to Cassini

33

00:01:35,194 --> 00:01:36,962  
as a spacecraft  
operations manager

34

00:01:36,962 --> 00:01:39,298  
and then deputy program manager.

35

00:01:39,298 --> 00:01:40,866  
He left the project  
for eight years

36

00:01:40,866 --> 00:01:44,537  
to hold management positions  
in guidance, navigation,

37

00:01:44,537 --> 00:01:47,307  
and control in avionics,  
then returned to Cassini

38

00:01:47,307 --> 00:01:50,877  
as program manager  
in January of 2013.

39

00:01:50,877 --> 00:01:54,480  
Dr. Linda Spilker is the  
Cassini project scientist,

40

00:01:54,480 --> 00:01:56,382  
and co-investigator  
on the Cassini

41

00:01:56,382 --> 00:01:59,118  
composite infrared  
spectrometer team,

42

00:01:59,118 --> 00:02:02,555  
and has worked on  
Cassini since 1988.

43

00:02:02,555 --> 00:02:06,359

Since joining JPL  
almost 40 years ago,

44

00:02:06,359 --> 00:02:09,929

her first and only job  
out of college by the way,

45

00:02:09,929 --> 00:02:11,431

she has worked on  
the Voyager project,

46

00:02:11,431 --> 00:02:14,033

the Cassini project, and  
conducted independent research

47

00:02:14,033 --> 00:02:16,702

on the origin and evolution  
of planetary ring systems

48

00:02:16,702 --> 00:02:19,038

while also supporting  
proposals and concept studies

49

00:02:19,038 --> 00:02:22,007

for new missions to  
the outer planets.

50

00:02:22,007 --> 00:02:24,176

She enjoys yoga and hiking,

51

00:02:24,176 --> 00:02:25,944

especially through her  
favorite park, Yosemite,

52

00:02:25,944 --> 00:02:28,514

and is married with  
three daughters and  
five grandchildren.

53

00:02:28,514 --> 00:02:29,582  
(murmuring)

54

00:02:29,582 --> 00:02:30,416  
Right?

55

00:02:30,416 --> 00:02:31,884  
(audience laughing)

56

00:02:31,884 --> 00:02:35,120  
Ladies and gentlemen, Going  
Out in a Blaze of Glory.

57

00:02:35,120 --> 00:02:37,557  
(applauding)

58

00:02:53,539 --> 00:02:56,809  
(slow, dramatic music)

59

00:02:59,244 --> 00:03:01,614  
- [Narrator] A lone explorer,

60

00:03:02,781 --> 00:03:05,585  
on a mission to reveal  
the grandeur of Saturn,

61

00:03:05,585 --> 00:03:07,253  
its rings and moons.

62

00:03:12,758 --> 00:03:16,896  
After 20 years in space,  
NASA's Cassini spacecraft

63

00:03:16,896 --> 00:03:18,831  
is running out of fuel.

64

00:03:20,433 --> 00:03:23,469

And so, to protect  
moons of Saturn

65

00:03:23,469 --> 00:03:27,073

that could have conditions  
suitable for life,

66

00:03:27,073 --> 00:03:29,008

a spectacular end  
has been planned

67

00:03:29,008 --> 00:03:32,345

for this long-lived  
traveler from Earth.

68

00:03:35,047 --> 00:03:38,551

- [Announcer] Five,  
four, three, two, one.

69

00:03:40,619 --> 00:03:43,222

And liftoff of the  
Cassini spacecraft

70

00:03:43,222 --> 00:03:45,892

on its million mile  
trek to Saturn.

71

00:03:45,892 --> 00:03:47,760

We have cleared the tower.

72

00:03:47,760 --> 00:03:49,596

Pitch program is in...

73

00:03:51,397 --> 00:03:55,134

- [Narrator] In 2004,  
following a seven year journey

74

00:03:55,134 --> 00:03:59,305

through the solar system,  
Cassini arrived at Saturn.

75

00:04:00,706 --> 00:04:03,876

- [Man] Light up the rockets.

76

00:04:03,876 --> 00:04:06,345

- [Narrator] The spacecraft  
carried a passenger,

77

00:04:06,345 --> 00:04:10,817

the European Huygens probe,  
the first human made object

78

00:04:10,817 --> 00:04:14,988

to land on a world in the  
distant outer solar system.

79

00:04:17,923 --> 00:04:22,161

For over a decade, Cassini has  
shared the wonders of Saturn

80

00:04:22,161 --> 00:04:26,332

and its family of icy moons,  
taking us to astounding worlds

81

00:04:27,499 --> 00:04:31,270

where methane rivers  
run to a methane sea,

82

00:04:31,270 --> 00:04:35,641

where jets of ice and gas are  
blasting material into space

83

00:04:35,641 --> 00:04:37,944

from a liquid water ocean

84

00:04:37,944 --> 00:04:41,547

that might harbor the  
ingredients for life.

85

00:04:43,249 --> 00:04:47,753

And Saturn, a giant world  
rule by raging storms

86

00:04:47,753 --> 00:04:50,590

and delicate  
harmonies of gravity.

87

00:04:53,425 --> 00:04:57,163

Now, Cassini has one  
last, daring assignment.

88

00:05:06,205 --> 00:05:10,209

Cassini's grand finale  
is a brand new adventure.

89

00:05:12,478 --> 00:05:16,649

22 dives through the space  
between Saturn and its rings.

90

00:05:20,886 --> 00:05:24,657

As it repeatedly braves  
this unexplored region,

91

00:05:24,657 --> 00:05:28,594

Cassini seeks new insights  
about the origins of the rings

92

00:05:28,594 --> 00:05:31,464

and the nature of the  
planet's interior,

93

00:05:31,464 --> 00:05:34,300

closer to Saturn  
than ever before.

94

00:05:40,939 --> 00:05:45,111

On the final orbit, Cassini  
will plunge into Saturn,

95

00:05:46,345 --> 00:05:49,915  
fighting to keep its  
antenna pointed at Earth

96  
00:05:49,915 --> 00:05:52,352  
as it transmits its farewell.

97  
00:05:54,487 --> 00:05:57,890  
In the skies of Saturn,  
the journey ends.

98  
00:06:01,560 --> 00:06:05,331  
As Cassini becomes part  
of the planet itself.

99  
00:06:28,921 --> 00:06:31,324  
(applauding)

100  
00:06:48,975 --> 00:06:52,879  
- Cassini is on a collision  
course with Saturn.

101  
00:06:54,513 --> 00:06:58,517  
In the next four months,  
every week we'll be coming

102  
00:06:58,517 --> 00:07:01,186  
a little bit closer, and  
a little further away,

103  
00:07:01,186 --> 00:07:03,823  
until finally on September 15th,

104  
00:07:03,823 --> 00:07:06,958  
very early in the morning  
here, about three AM,

105  
00:07:06,958 --> 00:07:08,628  
it will enter the atmosphere,

106

00:07:08,628 --> 00:07:11,697

going at about 75,000  
miles per hour.

107

00:07:13,032 --> 00:07:16,068

At that speed, that  
spacecraft won't last long.

108

00:07:16,068 --> 00:07:19,872

It will quickly lose  
control, begin to melt,

109

00:07:19,872 --> 00:07:22,575

and eventually vaporize  
into the very planet

110

00:07:22,575 --> 00:07:26,579

that it went to explore  
some 20 years ago today,

111

00:07:27,880 --> 00:07:28,981

20 years ago.

112

00:07:30,416 --> 00:07:35,220

So, you might wonder, you  
know, that such a hot idea?

113

00:07:35,220 --> 00:07:37,023

You've got a perfect spacecraft,

114

00:07:37,023 --> 00:07:39,992

you've been rewriting history  
books and science texts

115

00:07:39,992 --> 00:07:42,795

ever since you got there,  
and in fact even beforehand.

116

00:07:42,795 --> 00:07:46,765

Well, for the next  
maybe 45 minutes or so,

117

00:07:46,765 --> 00:07:50,035

Linda and I are going to  
try to at least explain why

118

00:07:50,035 --> 00:07:54,207

we not only think this is a  
good idea, but a great idea.

119

00:07:58,010 --> 00:08:01,480

So quickly to the pad and  
beyond, as the movie showed you,

120

00:08:01,480 --> 00:08:04,517

we launched in 1997,  
absolutely flawless,

121

00:08:04,517 --> 00:08:08,020

a beautiful launch from  
the cape on a Titan 4B,

122

00:08:08,020 --> 00:08:11,657

and six and a half years later,  
after a very circuitous tour

123

00:08:11,657 --> 00:08:16,094

of the, well, middle  
and outer solar system,

124

00:08:16,094 --> 00:08:19,431

we finally arrived at  
Saturn on July 30th,

125

00:08:19,431 --> 00:08:21,901

June 30th, sorry, 2004,

126

00:08:21,901 --> 00:08:26,005

and had an absolutely

flawless orbit insertion.

127

00:08:26,005 --> 00:08:30,409

For the next 13 years, we  
were doing pretty much this.

128

00:08:30,409 --> 00:08:31,878

(audience laughing)

129

00:08:31,878 --> 00:08:34,447

Now don't be alarmed,  
this is something we call

130

00:08:34,447 --> 00:08:38,184

the ball of yarn, this  
is the entire mission,

131

00:08:38,184 --> 00:08:42,788

all 293 orbits, some of which  
we haven't finished yet,

132

00:08:42,788 --> 00:08:45,925

beginning with SOI  
and continuing on.

133

00:08:45,925 --> 00:08:50,129

What happens here is that  
for the last 12 years,

134

00:08:50,129 --> 00:08:53,299

we've been using  
Cassini's rocket fuel

135

00:08:54,800 --> 00:08:58,471

and Saturn's largest  
satellite, moon, Titan,

136

00:08:59,671 --> 00:09:02,040

which is a mission  
designer's dream,

137

00:09:02,040 --> 00:09:05,110  
to move us all through  
this Saturn system.

138

00:09:05,110 --> 00:09:06,878  
So we've been able to...

139

00:09:06,878 --> 00:09:08,614  
Probably can't see it in here,

140

00:09:08,614 --> 00:09:11,017  
but right in the middle of  
all this there is Saturn.

141

00:09:11,017 --> 00:09:12,751  
So we've been able  
to actually go

142

00:09:12,751 --> 00:09:14,686  
to these very highly  
inclined orbits,

143

00:09:14,686 --> 00:09:16,088  
so we come down over the tops

144

00:09:16,088 --> 00:09:17,923  
and look at the rings  
and look at the poles

145

00:09:17,923 --> 00:09:20,492  
at these very long,  
looping orbits

146

00:09:20,492 --> 00:09:22,494  
out to examine the magnetosphere

147

00:09:22,494 --> 00:09:25,898  
way outside of the

influence of Saturn itself,

148

00:09:25,898 --> 00:09:28,501  
and then of course  
these in tight orbits

149

00:09:28,501 --> 00:09:31,870  
to investigate Enceladus  
and the icy moons.

150

00:09:31,870 --> 00:09:35,974  
So for the last 12 years,  
up until last November,

151

00:09:35,974 --> 00:09:37,910  
this is pretty much  
what we've been up to.

152

00:09:37,910 --> 00:09:42,414  
A fascinating tour, and an  
amazing set of discoveries.

153

00:09:42,414 --> 00:09:45,150  
We'll get to a little  
bit of those later,

154

00:09:45,150 --> 00:09:48,287  
and I think Linda will show  
you even more as we move on.

155

00:09:48,287 --> 00:09:49,121  
But,

156

00:09:50,556 --> 00:09:53,326  
I want to jump  
back to the reason

157

00:09:54,526 --> 00:09:56,328  
that I started with  
this whole premise,

158

00:09:56,328 --> 00:09:58,196  
and why are you doing this?

159

00:09:58,196 --> 00:10:01,767  
Well, Saturn's got  
some ocean worlds.

160

00:10:01,767 --> 00:10:05,537  
These are pictures, essentially  
Voyager class pictures

161

00:10:05,537 --> 00:10:08,207  
of the moon Enceladus and Titan,

162

00:10:09,375 --> 00:10:11,243  
both mysterious  
in their own ways,

163

00:10:11,243 --> 00:10:15,147  
Titan enshrouded by  
this veil of orange haze

164

00:10:15,147 --> 00:10:16,748  
that we couldn't penetrate,

165

00:10:16,748 --> 00:10:19,118  
and Enceladus  
exceptionally bright,

166

00:10:19,118 --> 00:10:21,587  
but quite small,  
300 miles across,

167

00:10:21,587 --> 00:10:23,688  
so essentially a  
bright snowball.

168

00:10:23,688 --> 00:10:25,391

Well, by the time we were done,

169

00:10:25,391 --> 00:10:27,526

or Cassini was  
done, I should say,

170

00:10:27,526 --> 00:10:30,729

I'll take some credit, but  
not all of it by any stretch.

171

00:10:30,729 --> 00:10:32,464

(audience laughing)

172

00:10:32,464 --> 00:10:35,668

Enceladus had turned out to  
not only be differentiated,

173

00:10:35,668 --> 00:10:39,839

but to have plumes, a warm  
global saltwater ocean,

174

00:10:42,007 --> 00:10:43,776

and hydrothermal activity.

175

00:10:43,776 --> 00:10:45,644

And if you notice that we  
just had a press release

176

00:10:45,644 --> 00:10:48,180

not too long ago that  
there is atomic hydrogen

177

00:10:48,180 --> 00:10:49,681

out in these plumes.

178

00:10:49,681 --> 00:10:53,752

All the ingredients for life,  
on this little tiny moon.

179

00:10:53,752 --> 00:10:57,055

Absolutely  
Earth-shaking discovery.

180

00:10:57,055 --> 00:10:58,624

Sorry, that's a bad pun.

181

00:10:58,624 --> 00:10:59,959

(audience laughing)

182

00:10:59,959 --> 00:11:02,161

But really, just  
everybody was floored.

183

00:11:02,161 --> 00:11:04,730

We had no idea this  
was gonna happen.

184

00:11:04,730 --> 00:11:06,665

And then on top of that,

185

00:11:06,665 --> 00:11:10,836

Titan was revealed to have  
lakes, a hydrologic cycle,

186

00:11:12,271 --> 00:11:14,172

of course it's not water,  
it's methane and ethane,

187

00:11:14,172 --> 00:11:16,408

rain, clouds, rivers, estuaries,

188

00:11:16,408 --> 00:11:19,245

and it too has a  
subsurface ocean.

189

00:11:20,645 --> 00:11:24,015

So we've got two places  
that really just need to be

190  
00:11:24,015 --> 00:11:27,152  
kept as pristine  
as we possibly can.

191  
00:11:27,152 --> 00:11:30,589  
And I gotta say that there's  
something about Cassini

192  
00:11:30,589 --> 00:11:32,758  
that you know, while it  
was a perfect spacecraft,

193  
00:11:32,758 --> 00:11:35,394  
it's not all that perfect.

194  
00:11:35,394 --> 00:11:37,462  
We're outta gas.

195  
00:11:37,462 --> 00:11:39,198  
There's very little fuel left.

196  
00:11:39,198 --> 00:11:41,967  
And what happens, even though  
we were able to use Titan,

197  
00:11:41,967 --> 00:11:44,903  
as I showed in the other  
slide, quite effectively

198  
00:11:44,903 --> 00:11:46,838  
to move around in  
the Saturn system,

199  
00:11:46,838 --> 00:11:49,541  
we still need the propellant  
to keep the spacecraft,

200  
00:11:49,541 --> 00:11:52,144  
you know, oriented and on track.

201

00:11:52,144 --> 00:11:53,979

So without propellant,  
eventually it would be

202

00:11:53,979 --> 00:11:55,480

running out of control,

203

00:11:55,480 --> 00:11:58,884

and as we've come to discover  
with Titan and Enceladus,

204

00:11:58,884 --> 00:12:03,555

an uncontrolled spacecraft  
encountering these moons

205

00:12:03,555 --> 00:12:06,725

could eventually result  
in an inadvertent impact,

206

00:12:06,725 --> 00:12:09,661

which would cause us all  
sorts of embarrassment

207

00:12:09,661 --> 00:12:13,232

and some concern for  
future exploration.

208

00:12:13,232 --> 00:12:14,066

So.

209

00:12:15,500 --> 00:12:19,037

We had to do something about  
it, and what we decided to do

210

00:12:19,037 --> 00:12:20,972

was what we've called  
the grand finale.

211

00:12:20,972 --> 00:12:24,309

So let me back up a  
little bit and talk about,

212

00:12:24,309 --> 00:12:26,845

these are the final six  
years of the mission,

213

00:12:26,845 --> 00:12:29,548

without the F-ring orbits.

214

00:12:29,548 --> 00:12:33,719

When we were discussing  
various options for the...

215

00:12:36,088 --> 00:12:37,756

The eventual...

216

00:12:37,756 --> 00:12:40,326

There's no euphemistic  
way to put this.

217

00:12:40,326 --> 00:12:42,528

The eventual  
disposal of Cassini,

218

00:12:42,528 --> 00:12:44,930

a lot of different  
options became available.

219

00:12:44,930 --> 00:12:47,966

But the one that just  
absolutely was most compelling

220

00:12:47,966 --> 00:12:51,302

was to actually stay  
inside the Saturn system,

221

00:12:51,302 --> 00:12:52,971

investigate as much as we can,

222

00:12:52,971 --> 00:12:54,740

use all of the gas  
we possibly could,

223

00:12:54,740 --> 00:12:56,241

and then put it into Saturn.

224

00:12:56,241 --> 00:12:58,744

So this is what  
we've settled on,

225

00:12:58,744 --> 00:13:01,046

and I think I'm gonna try  
to continue to lead you

226

00:13:01,046 --> 00:13:03,882

towards the fact that this is  
an absolutely phenomenal end

227

00:13:03,882 --> 00:13:05,351

to a great mission.

228

00:13:05,351 --> 00:13:08,520

So this again is the ball  
of yarn, if you will,

229

00:13:08,520 --> 00:13:09,688

for the last six years.

230

00:13:09,688 --> 00:13:11,557

This began back in 2010.

231

00:13:11,557 --> 00:13:12,857

And what we've been doing,

232

00:13:12,857 --> 00:13:14,626

as you can see it  
even better here,

233

00:13:14,626 --> 00:13:17,029

every one of these little  
nodes, these little knots,

234

00:13:17,029 --> 00:13:18,730

is a crossing of titan,

235

00:13:18,730 --> 00:13:21,000

and Titan has been moving  
us all through the system

236

00:13:21,000 --> 00:13:22,968

as it did for the  
previous six years,

237

00:13:22,968 --> 00:13:26,539

and what happens next  
though is really fun.

238

00:13:27,506 --> 00:13:29,674

We find a Titan orbit,

239

00:13:29,674 --> 00:13:31,176

and the mission  
designers have just been

240

00:13:31,176 --> 00:13:32,978

absolutely brilliant with this,

241

00:13:32,978 --> 00:13:35,013

found a Titan that took  
us into what we call

242

00:13:35,013 --> 00:13:36,615

the ring grazing orbits.

243

00:13:36,615 --> 00:13:39,184

These orbits

actually are in tight

244

00:13:39,184 --> 00:13:42,121  
and are grazing  
tantalizingly close

245

00:13:42,121 --> 00:13:44,289  
to the F ring right here.

246

00:13:44,289 --> 00:13:47,159  
20 of these, and we  
just finished them up

247

00:13:47,159 --> 00:13:48,293  
a little while ago.

248

00:13:48,293 --> 00:13:50,796  
Absolutely phenomenal  
set of orbits

249

00:13:50,796 --> 00:13:55,333  
that have provided entirely  
new insights into the rings,

250

00:13:55,333 --> 00:13:57,603  
and some of the ring moons.

251

00:13:58,804 --> 00:14:01,240  
Better than we've  
ever been since SOI.

252

00:14:01,240 --> 00:14:04,242  
Closer we've ever been  
since the orbit insertion.

253

00:14:04,242 --> 00:14:06,612  
We've never been in this  
close again, before.

254

00:14:06,612 --> 00:14:07,446  
So.

255  
00:14:08,547 --> 00:14:11,116  
Well, what do we do next?

256  
00:14:11,116 --> 00:14:14,119  
There's one more  
Titan flyby coming.

257  
00:14:16,321 --> 00:14:18,189  
This is the final of  
the F ring orbits.

258  
00:14:18,189 --> 00:14:20,192  
Now what I want you to look for

259  
00:14:20,192 --> 00:14:22,728  
is the Titan flyby that's  
gonna come sneaking around here

260  
00:14:22,728 --> 00:14:24,563  
and give us one  
last little push.

261  
00:14:24,563 --> 00:14:27,999  
This is the last orbit,  
boom, around the F rings,

262  
00:14:27,999 --> 00:14:29,801  
now watch it, here it comes.

263  
00:14:29,801 --> 00:14:31,670  
Here comes Titan.

264  
00:14:31,670 --> 00:14:34,606  
Watch what's gonna  
happen to our orbit.

265

00:14:34,606 --> 00:14:36,775

It's gonna such just  
a little tiny bit

266

00:14:36,775 --> 00:14:38,777

of energy from Cassini.

267

00:14:38,777 --> 00:14:42,281

Just enough, just  
enough to put it between

268

00:14:44,550 --> 00:14:47,352

the rings and the planet.

269

00:14:47,352 --> 00:14:50,422

The first of our ring  
plane orbits she goes.

270

00:14:50,422 --> 00:14:52,491

And that's number one,

271

00:14:52,491 --> 00:14:55,694

we just did number two  
yesterday, actually Tuesday,

272

00:14:55,694 --> 00:14:58,130

and we've got 20 more to go.

273

00:14:58,130 --> 00:15:01,399

Those are the grand  
finale orbits.

274

00:15:01,399 --> 00:15:04,703

It's an absolute  
pinnacle of astrodynamics

275

00:15:04,703 --> 00:15:08,540

and science achievement,  
so very exciting.

276

00:15:08,540 --> 00:15:12,711

Let me just give you another  
quick glimpse of these.

277

00:15:14,112 --> 00:15:16,281

This is gonna be all 22 of  
them, so hang on for a while.

278

00:15:16,281 --> 00:15:17,816

(audience laughing)

279

00:15:17,816 --> 00:15:20,886

But what I wanted  
to show you is that

280

00:15:22,321 --> 00:15:25,457

Titan has been our friend  
and moving us all around

281

00:15:25,457 --> 00:15:29,094

for the last 13 years,  
and we're calling

282

00:15:29,094 --> 00:15:33,232

this final Titan flyby  
the goodbye kiss.

283

00:15:33,232 --> 00:15:35,634

It is coming in right now,

284

00:15:35,634 --> 00:15:38,403

and it's going to slow  
down just a little bit

285

00:15:38,403 --> 00:15:40,138

after 22 of these,

286

00:15:40,138 --> 00:15:42,574

Titan's gonna come

swirling in from the side,

287

00:15:42,574 --> 00:15:44,576

there it goes right there,

288

00:15:44,576 --> 00:15:47,045

and what that's gonna

do is it's gonna steal

289

00:15:47,045 --> 00:15:48,980

just a little bit more energy.

290

00:15:48,980 --> 00:15:52,484

Just enough so that

Cassini is gonna go

291

00:15:52,484 --> 00:15:54,553

into the planet itself.

292

00:15:54,553 --> 00:15:59,158

That's the 75,000 mile

per hour hit a brick wall

293

00:15:59,158 --> 00:16:03,695

kind of encounter that the

spacecraft will not survive.

294

00:16:03,695 --> 00:16:07,566

And again, the point is

that we absolutely must

295

00:16:07,566 --> 00:16:09,701

put the spacecraft

into a position

296

00:16:09,701 --> 00:16:12,004

where it can't

inadvertently contact either

297

00:16:12,004 --> 00:16:16,441  
Enceladus or Titan, or actually  
any of the icy satellites

298  
00:16:16,441 --> 00:16:21,179  
which we believe are  
also potential for  
further exploration.

299  
00:16:21,179 --> 00:16:23,248  
So let's just see  
how we do here.

300  
00:16:23,248 --> 00:16:25,784  
All right, so we've  
got the orbits, right?

301  
00:16:25,784 --> 00:16:27,486  
We've got a challenging  
new set of orbits,

302  
00:16:27,486 --> 00:16:29,020  
a whole new regime,

303  
00:16:29,020 --> 00:16:31,856  
but we've got an old spacecraft.

304  
00:16:31,856 --> 00:16:33,992  
So the first question  
we've got to ask is

305  
00:16:33,992 --> 00:16:36,628  
can we teach the  
spacecraft new tricks?

306  
00:16:36,628 --> 00:16:37,895  
It's gonna go into a new region,

307  
00:16:37,895 --> 00:16:39,364  
it's gonna do different things,

308

00:16:39,364 --> 00:16:41,933

and of course with any kind  
of learning experience,

309

00:16:41,933 --> 00:16:43,435

there are constraints.

310

00:16:43,435 --> 00:16:46,705

We've got folks on the  
science side who say,

311

00:16:46,705 --> 00:16:47,873

"look over here!

312

00:16:47,873 --> 00:16:48,974

"Look over here!

313

00:16:48,974 --> 00:16:51,110

"Saturn's really cool!"

314

00:16:51,110 --> 00:16:55,380

On the other side, they're  
looking at the rings.

315

00:16:55,380 --> 00:16:57,049

"No, look over here."

316

00:16:57,049 --> 00:17:00,251

And then you've got  
the engineers, I  
consider myself one,

317

00:17:00,251 --> 00:17:02,153

that are saying  
"you gotta be bold,

318

00:17:02,153 --> 00:17:05,056

"you gotta do, you know,

dare mighty things."

319

00:17:05,056 --> 00:17:07,926

Well wait a minute,  
we gotta be careful.

320

00:17:07,926 --> 00:17:09,394

(laughs)

321

00:17:09,394 --> 00:17:12,030

It's dangerous over there,  
and it's dangerous over there.

322

00:17:12,030 --> 00:17:13,866

So what's gonna happen?

323

00:17:13,866 --> 00:17:15,867

The spacecraft of  
course is you know,

324

00:17:15,867 --> 00:17:17,336

"I'll do what you tell me.

325

00:17:17,336 --> 00:17:18,803

"Just gotta tell me, give  
me the right orders."

326

00:17:18,803 --> 00:17:20,372

So it's a bit of confusion.

327

00:17:20,372 --> 00:17:22,674

Let me just try to  
answer the question

328

00:17:22,674 --> 00:17:25,376

that we've tried to deal  
with between the bold,

329

00:17:25,376 --> 00:17:28,947

the mighty things, and be  
careful not to do anything

330

00:17:28,947 --> 00:17:29,782  
too crazy.

331

00:17:31,617 --> 00:17:33,285  
And that is the gap.

332

00:17:34,753 --> 00:17:35,820  
(audience laughing)

333

00:17:35,820 --> 00:17:37,956  
There is a very narrow gap.

334

00:17:37,956 --> 00:17:40,391  
It's a billion miles  
away, so 1200 kilometer,

335

00:17:40,391 --> 00:17:43,128  
1200 mile gap is kinda narrow,

336

00:17:43,128 --> 00:17:47,065  
and it's been a big deal  
for us to worry about this.

337

00:17:47,065 --> 00:17:48,834  
So let me just give you  
a couple of animations

338

00:17:48,834 --> 00:17:50,868  
that one of our mission  
design engineers put together,

339

00:17:50,868 --> 00:17:52,503  
which really I think give you

340

00:17:52,503 --> 00:17:54,039  
an idea of what's going on here.

341

00:17:54,039 --> 00:17:56,809

This, or these  
are the 22 orbits,

342

00:17:58,343 --> 00:18:00,345

and this is the final orbit,

343

00:18:00,345 --> 00:18:04,216

and here is actually pretty  
nice and pretty accurate

344

00:18:04,216 --> 00:18:06,918

rendition of Saturn  
and its rings,

345

00:18:06,918 --> 00:18:09,021

an artistic representation.

346

00:18:09,021 --> 00:18:13,524

Here is what it looks like  
with a high contrast photo.

347

00:18:13,524 --> 00:18:16,895

So you can see, we are  
flirting very close,

348

00:18:16,895 --> 00:18:20,199

the atmosphere on one side  
and the dust on the other.

349

00:18:20,199 --> 00:18:24,236

So it's not quite as easy  
a shot as it first appears.

350

00:18:24,236 --> 00:18:27,272

Now take a look at this  
a little bit closer up,

351

00:18:27,272 --> 00:18:31,343

get a bit better view of  
our ring plane crossings

352

00:18:32,577 --> 00:18:35,514

and our periapsis,  
or minimum altitudes,

353

00:18:35,514 --> 00:18:38,650

which are all in the souther  
hemisphere of Saturn.

354

00:18:38,650 --> 00:18:41,819

One last look, and you can  
kinda look down the orbital path

355

00:18:41,819 --> 00:18:45,090

and you can just get a  
sense of just how close

356

00:18:45,090 --> 00:18:46,992

these are to Saturn itself,

357

00:18:46,992 --> 00:18:50,162

and how much Titan, who's still  
out there pushing us around,

358

00:18:50,162 --> 00:18:52,730

is moving these  
various orbits around,

359

00:18:52,730 --> 00:18:55,133

and finally you see our  
final orbit over on the end,

360

00:18:55,133 --> 00:18:57,835

it doesn't show up well  
here, but it's there.

361

00:18:57,835 --> 00:18:59,471

So, what do you do with that?

362

00:18:59,471 --> 00:19:00,739

Well, first thing  
we engineers do

363

00:19:00,739 --> 00:19:02,874

is we put that into  
a XY chart, right?

364

00:19:02,874 --> 00:19:04,142

(audience laughing)

365

00:19:04,142 --> 00:19:05,277

What else would you do?

366

00:19:05,277 --> 00:19:06,645

It's data.

367

00:19:06,645 --> 00:19:08,913

And so here are our  
minimum altitudes,

368

00:19:08,913 --> 00:19:11,583

and here are our  
XY plane crossings,

369

00:19:11,583 --> 00:19:13,218

but then of course  
what you want to do

370

00:19:13,218 --> 00:19:14,953

is put your boundaries on.

371

00:19:14,953 --> 00:19:17,489

And what we've done is  
we've more or less decided

372

00:19:17,489 --> 00:19:20,025

that the extensible  
edge of the D-ring

373

00:19:20,025 --> 00:19:23,661

is about 6400 kilometers  
from the center of Saturn.

374

00:19:23,661 --> 00:19:27,032

And we picked some orbits that  
we thought were pretty cool.

375

00:19:27,032 --> 00:19:29,301

They've got a lot of, you  
know, moving around in here,

376

00:19:29,301 --> 00:19:30,769

they go down into  
the atmosphere,

377

00:19:30,769 --> 00:19:32,937

and then finally down here  
you'll notice our final orbit.

378

00:19:32,937 --> 00:19:34,839

But they do some things up here

379

00:19:34,839 --> 00:19:36,174

that are a little bit alarming.

380

00:19:36,174 --> 00:19:39,344

They take us up into the dust.

381

00:19:39,344 --> 00:19:43,048

So we had to figure out what  
we're gonna do about that

382

00:19:43,048 --> 00:19:45,717

There's a high contrast  
photo again of the dust,

383

00:19:45,717 --> 00:19:47,919

and there's that boundary,

384

00:19:47,919 --> 00:19:50,154

and there's the

range that we're in.

385

00:19:50,154 --> 00:19:52,156

So, we had to come up

with some sort of scheme

386

00:19:52,156 --> 00:19:53,658

as to how to deal with the dust.

387

00:19:53,658 --> 00:19:56,895

We modeled it completely,

we feel like it's safe,

388

00:19:56,895 --> 00:20:00,498

in all the models that

the ring scientists have,

389

00:20:00,498 --> 00:20:02,434

and we've got the best ring

scientists in the world,

390

00:20:02,434 --> 00:20:04,035

as you could imagine,

on the project,

391

00:20:04,035 --> 00:20:07,172

so we really didn't

have a lot of worry,

392

00:20:07,172 --> 00:20:09,007

but you never know, we've

never been there before,

393

00:20:09,007 --> 00:20:10,508

so we had to see  
what was going on.

394  
00:20:10,508 --> 00:20:12,543  
And so there's the region  
we were trying to avoid,

395  
00:20:12,543 --> 00:20:16,148  
and what we decided to  
do for these up here

396  
00:20:17,416 --> 00:20:18,616  
was shield them.

397  
00:20:18,616 --> 00:20:20,619  
Now if you notice the  
images of Cassini,

398  
00:20:20,619 --> 00:20:23,088  
it's got a large, well  
it's right over there.

399  
00:20:23,088 --> 00:20:26,991  
There's a very large, saucer  
shaped antenna on the front.

400  
00:20:26,991 --> 00:20:28,994  
Pretty solid piece of material,

401  
00:20:28,994 --> 00:20:31,830  
and almost all the  
instruments are behind it.

402  
00:20:31,830 --> 00:20:33,331  
So if we go into the dust

403  
00:20:33,331 --> 00:20:35,733  
with that antenna  
pointing into the dust,

404  
00:20:35,733 --> 00:20:38,236  
everybody's pretty  
fine except of course

405  
00:20:38,236 --> 00:20:41,439  
for that long magnetometer  
boom, which is exposed,

406  
00:20:41,439 --> 00:20:43,641  
but there's not a thing  
we can do about that.

407  
00:20:43,641 --> 00:20:45,610  
So for these  
crossings, we decided

408  
00:20:45,610 --> 00:20:48,579  
that we would protect  
the spacecraft

409  
00:20:48,579 --> 00:20:50,815  
by hiding it in the shielding.

410  
00:20:50,815 --> 00:20:53,185  
Furthermore, since  
we really didn't know

411  
00:20:56,021 --> 00:20:54,485  
where we were going,

412  
00:20:56,021 --> 00:20:57,556  
we just didn't know  
what was in there,

413  
00:20:57,556 --> 00:21:01,560  
we decided to put a shield  
on our first flyby as well.

414  
00:21:01,560 --> 00:21:03,862

We've now completed that  
flyby, and completed...

415  
00:21:03,862 --> 00:21:05,796  
Oh they're not  
calling them flybys,

416  
00:21:05,796 --> 00:21:06,964  
they're ring plane crossings.

417  
00:21:06,964 --> 00:21:08,666  
Completed that one and that one,

418  
00:21:08,666 --> 00:21:10,936  
and I gotta happy to  
say the spacecraft's

419  
00:21:10,936 --> 00:21:12,203  
come out just fine.

420  
00:21:12,203 --> 00:21:14,072  
So let me show you  
just a little bit

421  
00:21:14,072 --> 00:21:15,106  
of what that looked like.

422  
00:21:15,106 --> 00:21:17,609  
This was our first crossing.

423  
00:21:17,609 --> 00:21:19,143  
Right?

424  
00:21:19,143 --> 00:21:20,945  
And you're gonna watch the  
spacecraft reorient itself

425  
00:21:20,945 --> 00:21:23,381  
as it goes through the dust

426

00:21:23,381 --> 00:21:25,483  
and point the antenna right into

427

00:21:25,483 --> 00:21:27,218  
what we call the ram direction.

428

00:21:27,218 --> 00:21:28,987  
That is the direction  
of oncoming dust.

429

00:21:28,987 --> 00:21:31,389  
And of course, being as  
opportunistic as we can,

430

00:21:31,389 --> 00:21:32,490  
the minute we're  
through the dust,

431

00:21:32,490 --> 00:21:33,758  
we turn the  
spacecraft back around

432

00:21:33,758 --> 00:21:35,327  
and start imaging  
the planet again.

433

00:21:35,327 --> 00:21:36,961  
So just for a few minutes

434

00:21:36,961 --> 00:21:38,796  
on either side of the  
ring plane crossing,

435

00:21:38,796 --> 00:21:41,632  
we used the spacecraft  
antenna as a shield

436

00:21:41,632 --> 00:21:43,969

for the rest of the instruments.

437

00:21:43,969 --> 00:21:45,303

That went perfectly fine.

438

00:21:45,303 --> 00:21:47,973

Now, you want to see some drama,

439

00:21:49,173 --> 00:21:51,409

it's not this, it's me

trying to make it work.

440

00:21:51,409 --> 00:21:54,412

(audience laughing)

441

00:21:54,412 --> 00:21:56,781

I'm gonna see if we can do this.

442

00:21:56,781 --> 00:21:57,616

This is...

443

00:21:59,084 --> 00:22:00,518

Let me explain a

little bit first,

444

00:22:00,518 --> 00:22:02,888

because I'm gonna, yeah,

I'm gonna mess it up.

445

00:22:02,888 --> 00:22:04,056

This is the...

446

00:22:06,524 --> 00:22:10,595

What we call the radio

plasma wave spectral analysis

447

00:22:10,595 --> 00:22:12,997

of the ring plane crossing,

448

00:22:12,997 --> 00:22:16,234

and what happens is as dust  
strikes the spacecraft,

449

00:22:16,234 --> 00:22:19,637

it creates a plasma,  
it's an ionized gas,

450

00:22:19,637 --> 00:22:21,239

and our antenna  
can pick them up,

451

00:22:21,239 --> 00:22:23,274

and so the more  
dust you run into,

452

00:22:23,274 --> 00:22:25,610

the more energetic,  
more plasma you get,

453

00:22:25,610 --> 00:22:27,512

and you get exactly  
what you think you see.

454

00:22:27,512 --> 00:22:29,113

This is time,

455

00:22:29,113 --> 00:22:31,349

and this is in a certain sense

456

00:22:31,349 --> 00:22:33,585

a measure of the  
plasma or energy.

457

00:22:33,585 --> 00:22:35,654

And so you see a very peak

458

00:22:35,654 --> 00:22:37,322

right here at the

ring plane crossing.

459

00:22:37,322 --> 00:22:40,658

This happened during one of  
our F ring grazing orbits,

460

00:22:40,658 --> 00:22:44,830

and it was just classic, you  
know, ring grazing material.

461

00:22:46,498 --> 00:22:49,067

So what I want to do  
if I can get this,

462

00:22:49,067 --> 00:22:53,104

if I can find my mouse  
here, oh, there it is.

463

00:22:53,104 --> 00:22:56,140

So this is the sound  
file of what we consider

464

00:22:56,140 --> 00:22:58,476

a normal dust crossing.

465

00:22:58,476 --> 00:23:01,046

And you can see the  
little line going through.

466

00:23:01,046 --> 00:23:03,715

(static sounds)

467

00:23:41,152 --> 00:23:42,353

So you can so both,

468

00:23:42,353 --> 00:23:45,823

hear both of the  
low level particles,

469

00:23:45,823 --> 00:23:47,592  
kind of the smaller particles,

470  
00:23:47,592 --> 00:23:50,594  
every now and then you hear a  
larger bip of a more energetic

471  
00:23:50,594 --> 00:23:54,566  
or a larger particle  
striking the antenna.

472  
00:23:54,566 --> 00:23:57,402  
That was with the high  
gain antenna shielding us.

473  
00:23:57,402 --> 00:23:59,137  
So here's what we saw

474  
00:24:00,571 --> 00:24:02,974  
during our first  
proximal orbit passage.

475  
00:24:02,974 --> 00:24:07,312  
After all these dire  
concerns about the dust,

476  
00:24:07,312 --> 00:24:09,914  
I'm not gonna spend  
a whole lot of time

477  
00:24:09,914 --> 00:24:12,184  
trying to find this audio file

478  
00:24:12,184 --> 00:24:13,918  
that doesn't sound  
like anything,

479  
00:24:13,918 --> 00:24:16,521  
because this was  
absolutely silent.

480

00:24:16,521 --> 00:24:19,224

We had the noise turned up  
so we could find something,

481

00:24:19,224 --> 00:24:22,694

turns out that all of this  
drama about the D ring

482

00:24:22,694 --> 00:24:25,830

and all that dust in between  
that gap was actually

483

00:24:25,830 --> 00:24:27,798

just a big empty.

484

00:24:27,798 --> 00:24:30,335

We don't quite understand it.

485

00:24:30,335 --> 00:24:31,936

Well, I should say  
the ring scientists

486

00:24:31,936 --> 00:24:33,271

are still befuddled by it.

487

00:24:33,271 --> 00:24:34,905

There shouldn't be  
that little dust there,

488

00:24:34,905 --> 00:24:36,474

but something's  
cleaned it all out.

489

00:24:36,474 --> 00:24:39,643

So I think as one of our  
mission design folks quipped,

490

00:24:39,643 --> 00:24:42,614

Saturn has swept the  
doorstep free for us.

491

00:24:42,614 --> 00:24:43,781  
(audience laughing)

492

00:24:43,781 --> 00:24:45,282  
Like a good host.

493

00:24:45,282 --> 00:24:48,687  
So indeed, so far, we've had  
perfect ring plane crossings,

494

00:24:48,687 --> 00:24:51,489  
and the drama about any dust  
issues or things like that

495

00:24:51,489 --> 00:24:53,492  
seemed to be for naught.

496

00:24:54,859 --> 00:24:57,428  
Okay, so we've just  
talked a little bit about

497

00:24:57,428 --> 00:24:59,764  
how to avoid the dangers  
using the high gain antenna

498

00:24:59,764 --> 00:25:00,998  
and things like that.

499

00:25:00,998 --> 00:25:04,068  
Now what about look over  
here, look over there?

500

00:25:04,068 --> 00:25:07,272  
We've had 22 orbits, sounds  
like a lot, but the instruments,

501

00:25:07,272 --> 00:25:08,807  
we've got 11  
functioning instruments

502  
00:25:08,807 --> 00:25:11,475  
and five other investigations  
that try to share instruments,

503  
00:25:11,475 --> 00:25:13,945  
and there's a huge amount  
of conflict between this.

504  
00:25:13,945 --> 00:25:16,414  
And so it was very hard  
when we started working on

505  
00:25:16,414 --> 00:25:19,484  
this years ago, that the  
instruments figured out new ways

506  
00:25:19,484 --> 00:25:23,088  
to use an cooperate  
on these 22 orbits.

507  
00:25:23,088 --> 00:25:25,823  
For example, we have  
the gravity folks

508  
00:25:25,823 --> 00:25:27,325  
that are doing gravity science,

509  
00:25:27,325 --> 00:25:29,593  
they want to have the antenna  
pointing to the Earth,

510  
00:25:29,593 --> 00:25:31,562  
they want to have it rock solid

511  
00:25:31,562 --> 00:25:32,764  
because they're

trying to measure

512

00:25:32,764 --> 00:25:35,533

incredibly subtle  
variations in the signal

513

00:25:35,533 --> 00:25:37,768

as it passes between  
the rings and Saturn.

514

00:25:37,768 --> 00:25:40,004

The magnetometer  
folks want to roll,

515

00:25:40,004 --> 00:25:42,072

because they want to  
spin that big boom

516

00:25:42,072 --> 00:25:44,409

through as much space  
as they possibly can

517

00:25:44,409 --> 00:25:47,078

in order to get the best  
magnetic field data.

518

00:25:47,078 --> 00:25:50,515

Well they found a way  
to spin on an axis

519

00:25:50,515 --> 00:25:53,918

that keeps the radio bore sight  
directly pointed at Earth,

520

00:25:53,918 --> 00:25:57,488

and so they get to spin  
and gravity science gets

521

00:25:57,488 --> 00:25:58,690

the benefit of their...

522

00:25:58,690 --> 00:26:00,291

Again, a beautiful  
collaboration.

523

00:26:00,291 --> 00:26:02,560

We figured out a way  
to repurpose the INMS

524

00:26:02,560 --> 00:26:04,428

to become an atmospheric probe.

525

00:26:04,428 --> 00:26:07,399

The spacecraft can now use  
the data that's on board,

526

00:26:07,399 --> 00:26:09,367

normally stored on board and  
shoot it down immediately,

527

00:26:09,367 --> 00:26:11,402

so as we're burrowing  
in the atmosphere,

528

00:26:11,402 --> 00:26:13,271

we're sampling data to  
the very last instant.

529

00:26:13,271 --> 00:26:15,206

There are bunches  
of examples of that.

530

00:26:15,206 --> 00:26:18,276

So let me just go  
to this last slide.

531

00:26:19,744 --> 00:26:22,947

This again is all of  
the periapsis passages,  
all along here.

532

00:26:22,947 --> 00:26:26,050

As you can see, they  
are spread around,

533

00:26:26,050 --> 00:26:28,052

but we really had a tremendous  
amount of contention

534

00:26:28,052 --> 00:26:32,957

and what happened is that  
almost all of them shared.

535

00:26:32,957 --> 00:26:36,294

Instruments are collaborating  
on all those circled orbits,

536

00:26:36,294 --> 00:26:38,930

there's a collaboration  
between the radio science

537

00:26:38,930 --> 00:26:41,432

and magnetometer, between  
dust and mass spectrometers,

538

00:26:41,432 --> 00:26:42,266

between...

539

00:26:42,266 --> 00:26:43,468

It goes on and on.

540

00:26:43,468 --> 00:26:45,803

So we've maximized  
every piece of science

541

00:26:45,803 --> 00:26:47,872

that we can get out  
of these orbits.

542

00:26:47,872 --> 00:26:48,973

And with that...

543

00:26:48,973 --> 00:26:49,907

(laughs)

544

00:26:49,907 --> 00:26:51,609

The amount of time I've wasted.

545

00:26:51,609 --> 00:26:55,713

Here is the Cassini poised  
for its first flyby,

546

00:26:55,713 --> 00:26:58,583

and I'm gonna segue into  
the grand finale objectives,

547

00:26:58,583 --> 00:27:02,386

some of the unique  
science, and Linda Spilker.

548

00:27:02,386 --> 00:27:04,722

Thank you for your patience.

549

00:27:04,722 --> 00:27:07,158

(applauding)

550

00:27:12,796 --> 00:27:14,666

Okay, well I'm Linda Spilker,

551

00:27:14,666 --> 00:27:16,767

and I'm the Cassini  
Project Scientist,

552

00:27:16,767 --> 00:27:18,168

and I have a really cool job.

553

00:27:18,168 --> 00:27:20,571

I get to coordinate

amongst 300 scientists

554

00:27:20,571 --> 00:27:22,506

spread around the world

555

00:27:22,506 --> 00:27:26,577

to get the best science possible  
for the Cassini mission.

556

00:27:26,577 --> 00:27:28,780

And I've been lucky enough  
to be with this mission

557

00:27:28,780 --> 00:27:30,281

for a long time.

558

00:27:30,281 --> 00:27:33,984

It's been almost 30 years  
that I've worked on Cassini.

559

00:27:33,984 --> 00:27:36,454

In fact, my oldest  
daughter Jennifer

560

00:27:36,454 --> 00:27:40,525

just started kindergarten when  
I started working on Cassini,

561

00:27:40,525 --> 00:27:44,395

and now she's married and she  
has a daughter of her own.

562

00:27:44,395 --> 00:27:47,665

And what's so amazing  
is how quickly

563

00:27:47,665 --> 00:27:50,467

those 30 years have flown by.

564

00:27:50,467 --> 00:27:52,770

And in fact, here's sort of...

565

00:27:52,770 --> 00:27:55,006

Basically I've been  
on the Cassini mission

566

00:27:55,006 --> 00:27:56,808

for one Saturn orbit.

567

00:27:56,808 --> 00:27:59,277

It takes Saturn about 30  
years to go around the sun

568

00:27:59,277 --> 00:28:00,511

a single time.

569

00:28:00,511 --> 00:28:03,013

And so what's show here  
are the mission phases

570

00:28:03,013 --> 00:28:05,149

as a function of Saturn orbit.

571

00:28:05,149 --> 00:28:08,552

So you can see, as Earl  
said, we arrived in 2004,

572

00:28:08,552 --> 00:28:10,855

had a four year prime mission,

573

00:28:10,855 --> 00:28:12,457

two year equinox mission,

574

00:28:12,457 --> 00:28:14,992

we're now in our seven  
year solstice mission,

575

00:28:14,992 --> 00:28:18,396

and we're at the very tail  
end, as Earl showed you.

576

00:28:18,396 --> 00:28:20,831

We had just finished  
our ring grazing orbits,

577

00:28:20,831 --> 00:28:24,669

and we're now two dives  
into the grand finale.

578

00:28:26,137 --> 00:28:27,771

So what I'm gonna do is I'm  
gonna step back and show you

579

00:28:27,771 --> 00:28:30,874

some amazing pictures  
and science results

580

00:28:30,874 --> 00:28:33,544

from those ring grazing orbits.

581

00:28:33,544 --> 00:28:36,780

We basically pulled  
Cassini's orbit in very close

582

00:28:36,780 --> 00:28:38,882

to Saturn's F ring,  
which is nestled

583

00:28:38,882 --> 00:28:40,484

right against the main rings,

584

00:28:40,484 --> 00:28:43,087

giving us a chance to  
get incredible pictures.

585

00:28:43,087 --> 00:28:44,722

In fact, if you look  
in the blue region,

586

00:28:44,722 --> 00:28:47,325

we can get incredible  
pictures of tiny little moons

587

00:28:47,325 --> 00:28:50,828

that orbit in the gaps in  
the rings, next to the rings,

588

00:28:50,828 --> 00:28:54,999

and the best pictures ever  
of the rings themselves.

589

00:28:56,167 --> 00:28:58,035

So here you can see  
a couple of gaps,

590

00:28:58,035 --> 00:29:00,038

the wider gap over on the left,

591

00:29:00,038 --> 00:29:02,674

that's the Encke gap and  
inside of the Encke gap

592

00:29:02,674 --> 00:29:04,709

is the moon Pan.

593

00:29:04,709 --> 00:29:06,777

Now Pan was actually  
discovered in the Voyager data

594

00:29:06,777 --> 00:29:09,547

but not until 10 years  
after the Voyager flyby

595

00:29:09,547 --> 00:29:12,950

where Mark Showalter  
put together the images

596

00:29:12,950 --> 00:29:15,419  
and figured out there was a  
moon and where to look for it.

597

00:29:15,419 --> 00:29:18,789  
The next gap out includes a  
little tiny moon named Daphnis.

598

00:29:18,789 --> 00:29:22,293  
Cassini discovered  
Daphnis in 2005.

599

00:29:22,293 --> 00:29:26,831  
And finally out hugging the  
edge of the A ring is Atlas,

600

00:29:26,831 --> 00:29:29,233  
and Atlas was discovered in  
the Voyager data as well,

601

00:29:29,233 --> 00:29:31,469  
so to really see these  
little tiny moons

602

00:29:31,469 --> 00:29:33,470  
it takes a spacecraft.

603

00:29:33,470 --> 00:29:34,572  
So let's take a look at those.

604

00:29:34,572 --> 00:29:36,574  
First let's look at Pan.

605

00:29:38,042 --> 00:29:39,744  
Here's a movie that we took  
with the Cassini spacecraft,

606

00:29:39,744 --> 00:29:42,980  
these are raw images, you can  
see cosmic ray hits and so on.

607

00:29:42,980 --> 00:29:45,550

But here, I'll back it  
up and show it again,

608

00:29:45,550 --> 00:29:48,386

we went zooming  
by this tiny moon.

609

00:29:49,587 --> 00:29:50,855

And you can see,  
it looks unusual.

610

00:29:50,855 --> 00:29:52,924

It's not, doesn't  
look like a potato,

611

00:29:52,924 --> 00:29:54,726

it doesn't look  
like a round moon,

612

00:29:54,726 --> 00:29:57,194

in fact, here's a  
couple views of Pan,

613

00:29:57,194 --> 00:30:01,065

Pan's about 20 miles  
across at its equator,

614

00:30:01,065 --> 00:30:04,569

it's nestled in a 200  
mile wide Encke gap,

615

00:30:06,003 --> 00:30:07,471

and you can see it also  
has this very interesting

616

00:30:07,471 --> 00:30:11,042

equatorial ridge or  
skirt of particles.

617

00:30:11,042 --> 00:30:13,143

And what it does is in  
accumulating particles

618

00:30:13,143 --> 00:30:15,045

from the edges of the Encke gap,

619

00:30:15,045 --> 00:30:17,415

and they go around the  
equator of the moon,

620

00:30:17,415 --> 00:30:19,817

and sometimes those particles  
actually slide down.

621

00:30:19,817 --> 00:30:21,819

It's hard to see here,  
but there's actually,

622

00:30:21,819 --> 00:30:25,056

you can see a landslide of  
particles in a couple of places

623

00:30:25,056 --> 00:30:27,759

where they slide down  
onto the main central

624

00:30:27,759 --> 00:30:29,159

frozen moon itself.

625

00:30:29,159 --> 00:30:33,331

You can see tiny little  
craters, some ridges inside of,

626

00:30:33,331 --> 00:30:36,234

along this ridge here, so  
very interesting and unique.

627

00:30:36,234 --> 00:30:38,436

In fact, one of the Cassini  
scientists said, "hmm,

628

00:30:38,436 --> 00:30:41,772

"that reminds me of  
cheese dumplings."

629

00:30:41,772 --> 00:30:44,107

So you can see the edges  
on these cheese dumplings,

630

00:30:44,107 --> 00:30:46,511

so a very very unusual shape.

631

00:30:48,145 --> 00:30:50,281

Well it's moving on to Daphnis,

632

00:30:50,281 --> 00:30:51,682

Daphnis is much smaller.

633

00:30:51,682 --> 00:30:54,017

Daphnis is only  
six miles across.

634

00:30:54,017 --> 00:30:57,822

And it's holding open  
a 25 mile wide gap.

635

00:30:57,822 --> 00:30:59,457

Turns out that these  
moons are big enough

636

00:30:59,457 --> 00:31:01,825

they literally shove  
aside the ring particles

637

00:31:01,825 --> 00:31:04,996

and create a gap that  
goes all the way around

638

00:31:04,996 --> 00:31:07,031

Saturn's rings, so  
if you're a big guy,

639

00:31:07,031 --> 00:31:08,933

you get in the rings and  
you say "move out of my way"

640

00:31:08,933 --> 00:31:10,735

and you can create a gap.

641

00:31:10,735 --> 00:31:13,604

Daphnis also as well  
as Pan creates waves

642

00:31:13,604 --> 00:31:15,372

along the edge of the gap.

643

00:31:15,372 --> 00:31:17,275

Here's another view of  
those waves you can see

644

00:31:17,275 --> 00:31:19,543

actually a tiny tendril  
of ring particles

645

00:31:19,543 --> 00:31:21,512

that Daphnis has pulled out,

646

00:31:21,512 --> 00:31:23,113

and just like the  
waves in an ocean

647

00:31:23,113 --> 00:31:26,384

you can see this wave going  
along and slowly damping out,

648

00:31:26,384 --> 00:31:28,919

and the particles  
actually sheering apart.

649  
00:31:28,919 --> 00:31:31,522  
So just very beautiful,  
very close up views,

650  
00:31:31,522 --> 00:31:35,693  
incredible detail in the  
rings themselves as well.

651  
00:31:37,962 --> 00:31:40,163  
Let me go in the  
right direction.

652  
00:31:40,163 --> 00:31:42,200  
And this is a movie of Atlas.

653  
00:31:42,200 --> 00:31:46,370  
Now Atlas is the moon, it is  
about 26 kilometers across

654  
00:31:46,370 --> 00:31:49,073  
and only 11 miles  
north to south.

655  
00:31:49,073 --> 00:31:52,109  
And so you can see here's  
a close up view of Atlas,

656  
00:31:52,109 --> 00:31:54,679  
it's not washed out  
like this on my screen

657  
00:31:54,679 --> 00:31:57,181  
but it's much smoother,  
very few craters,

658  
00:31:57,181 --> 00:32:00,184  
there's a big icy

particle in the center.

659

00:32:00,184 --> 00:32:02,086

It turns out these  
moons can't accumulate

660

00:32:02,086 --> 00:32:03,721

ring particles forever.

661

00:32:03,721 --> 00:32:06,390

They get out to a certain  
size and then their gravity

662

00:32:06,390 --> 00:32:08,592

gets balanced by  
Saturn's gravity.

663

00:32:08,592 --> 00:32:10,527

So any ring particles  
that try and stick

664

00:32:10,527 --> 00:32:12,596

get pulled away by  
Saturn's gravity.

665

00:32:12,596 --> 00:32:16,801

So Atlas has grown pretty much  
to the biggest size it can

666

00:32:16,801 --> 00:32:18,870

around its equator.

667

00:32:18,870 --> 00:32:21,806

And here are the three  
moons shown to scale.

668

00:32:21,806 --> 00:32:23,707

There's a scale  
bar of six miles,

669

00:32:23,707 --> 00:32:25,877

so you can see

Daphnis truly is tiny,

670

00:32:25,877 --> 00:32:29,880

and it really took Cassini's

very stable, good cameras

671

00:32:29,880 --> 00:32:32,550

to be able to find tiny Daphnis.

672

00:32:33,718 --> 00:32:35,119

Now here's one of my

favorite pictures,

673

00:32:35,119 --> 00:32:37,421

this is going all

the way back to 2009,

674

00:32:37,421 --> 00:32:39,924

the sun was edge

on to the rings,

675

00:32:39,924 --> 00:32:42,059

and at that point in time,

676

00:32:42,059 --> 00:32:43,961

basically the sun's edge on,

677

00:32:43,961 --> 00:32:45,496

at that point in time,

anything that sticks

678

00:32:45,496 --> 00:32:48,299

above or below the rings

will cast a shadow.

679

00:32:48,299 --> 00:32:50,968

And that's called equinox,

and so you can see shadows,

680

00:32:50,968 --> 00:32:53,504

many many shadows,  
cast by objects

681

00:32:53,504 --> 00:32:56,273

probably a third to  
half a mile in size,

682

00:32:56,273 --> 00:32:58,542

probably accumulations  
of particles,

683

00:32:58,542 --> 00:33:00,945

maybe bigger particles as well.

684

00:33:00,945 --> 00:33:03,681

But we've never been able  
to really resolve or see

685

00:33:03,681 --> 00:33:07,117

one of those particles,  
up until very recently.

686

00:33:07,117 --> 00:33:09,119

This is the same view  
now turned sideways,

687

00:33:09,119 --> 00:33:10,621

here's the edge of the B ring,

688

00:33:10,621 --> 00:33:12,422

you see all of this speckling,

689

00:33:12,422 --> 00:33:14,658

and those are  
individual clumps now

690

00:33:14,658 --> 00:33:18,462

that we can resolve at  
the edge of the B ring.

691

00:33:18,462 --> 00:33:20,697

Incredibly detailed structure.

692

00:33:20,697 --> 00:33:22,967

We were thinking as we  
got to higher resolution

693

00:33:22,967 --> 00:33:24,902

the ringlets would just  
appear to get wider

694

00:33:24,902 --> 00:33:27,404

and we'd see more  
structure, but instead,

695

00:33:27,404 --> 00:33:29,073

we see more and more ringlets.

696

00:33:29,073 --> 00:33:31,575

Every time we get closer,  
the ringlet that's there

697

00:33:31,575 --> 00:33:33,411

divides into more and into more

698

00:33:33,411 --> 00:33:36,214

and it's just an incredible  
detailed structure.

699

00:33:36,214 --> 00:33:38,048

I got this picture  
from Matt Tiscarino,

700

00:33:38,048 --> 00:33:40,051

and he tried  
something very clever.

701

00:33:40,051 --> 00:33:43,420

He realized if you could fold  
the picture over essentially,

702

00:33:43,420 --> 00:33:46,523

along a line that's  
perpendicular to the rings

703

00:33:46,523 --> 00:33:48,326

and subtract the two halves,

704

00:33:48,326 --> 00:33:51,328

anything that's different  
as you go along the azimuth

705

00:33:51,328 --> 00:33:53,598

in this direction  
along the rings

706

00:33:53,598 --> 00:33:56,333

would show up as  
additional speckling.

707

00:33:56,333 --> 00:33:58,068

So he did just that, and  
you can see of course

708

00:33:58,068 --> 00:34:00,871

the edge of the B ring has  
lots of these little speckles,

709

00:34:00,871 --> 00:34:03,841

it's very different as you  
go from one place to another,

710

00:34:03,841 --> 00:34:06,510

slowly dies away, but then  
there's a couple of other places

711  
00:34:06,510 --> 00:34:09,413  
that have a lot of  
speckles in them too,

712  
00:34:09,413 --> 00:34:11,448  
and very sort of hidden  
away in that other image,

713  
00:34:11,448 --> 00:34:14,151  
but you can see them now,  
and so now we have to explain

714  
00:34:14,151 --> 00:34:16,787  
why can you get  
clumping so far away

715  
00:34:16,787 --> 00:34:18,322  
from the edge of the B ring?

716  
00:34:18,322 --> 00:34:21,391  
So lots of new science in  
just a handful of pictures

717  
00:34:21,391 --> 00:34:24,795  
that have come back in  
the ring grazing orbits.

718  
00:34:24,795 --> 00:34:26,663  
And then of course these  
very interesting objects

719  
00:34:26,663 --> 00:34:28,266  
called propellers.

720  
00:34:28,266 --> 00:34:31,101  
If you're a tiny moon, you're  
not big enough to make a gap,

721  
00:34:31,101 --> 00:34:33,303

what these propeller  
objects are trying to do,

722

00:34:33,303 --> 00:34:35,139

there's an object  
in the middle here

723

00:34:35,139 --> 00:34:37,107

trying to open up a gap.

724

00:34:37,107 --> 00:34:39,009

It gets a partial gap,

725

00:34:39,009 --> 00:34:41,312

those are the two arms  
of the propellers,

726

00:34:41,312 --> 00:34:42,446

and we had a lot of fun,

727

00:34:42,446 --> 00:34:44,682

we named the propellers  
after aviators.

728

00:34:44,682 --> 00:34:48,819

So you'll find an Earhart, in  
this case it's Santos Dumont.

729

00:34:48,819 --> 00:34:51,188

And you're seeing a view  
on the lit and unlit side.

730

00:34:51,188 --> 00:34:54,057

This is about a mile  
across in width here,

731

00:34:54,057 --> 00:34:57,261

the object is probably a  
quarter mile or so in size,

732

00:34:57,261 --> 00:35:00,431

and so these objects are like  
the seeds that you would have

733

00:35:00,431 --> 00:35:03,600

in a disc from which  
the solar system formed.

734

00:35:03,600 --> 00:35:06,870

So Saturn's rings are  
really a laboratory

735

00:35:06,870 --> 00:35:09,106

where we can watch  
dust interacting,

736

00:35:09,106 --> 00:35:11,775

how you could grow larger  
objects, planetesimals,

737

00:35:11,775 --> 00:35:14,244

that could go on to  
form a solar system.

738

00:35:14,244 --> 00:35:16,413

So studying the rings  
gives us ideas about

739

00:35:16,413 --> 00:35:18,249

how our solar system formed

740

00:35:18,249 --> 00:35:22,119

and how you could get solar  
systems around other stars.

741

00:35:22,119 --> 00:35:25,423

So very exciting  
to look at as well.

742

00:35:25,423 --> 00:35:26,958

And this is a very  
interesting picture.

743

00:35:26,958 --> 00:35:31,628

This dot here, it isn't a star,  
it's not a cosmic ray hit,

744

00:35:31,628 --> 00:35:33,164

that's the Earth.

745

00:35:33,164 --> 00:35:36,467

That we turned the Cassini  
cameras on April 12th

746

00:35:36,467 --> 00:35:38,803

to take our last  
picture of Earth

747

00:35:38,803 --> 00:35:43,040

in between the edge of the  
A ring and Saturn's F ring.

748

00:35:43,040 --> 00:35:45,042

And if you look very  
carefully and blow it up,

749

00:35:45,042 --> 00:35:46,744

there's the moon.

750

00:35:46,744 --> 00:35:48,678

So you're actually seeing  
the Earth and the moon,

751

00:35:48,678 --> 00:35:50,580

and what if you're on the Earth,

752

00:35:50,580 --> 00:35:53,383

this was over the middle  
of the Atlantic Ocean

753

00:35:53,383 --> 00:35:55,018  
when we snapped this picture.

754

00:35:55,018 --> 00:35:57,287  
So it's a very special time,

755

00:35:57,287 --> 00:35:59,223  
we have to use Saturn  
to cover up the sun

756

00:35:59,223 --> 00:36:02,326  
so we can turn our delicate  
cameras close enough to the sun,

757

00:36:02,326 --> 00:36:05,729  
but the sun's covered to  
take this very unique image.

758

00:36:05,729 --> 00:36:08,098  
So this is our farewell picture,

759

00:36:08,098 --> 00:36:10,601  
our last picture of the Earth.

760

00:36:15,806 --> 00:36:18,876  
Now Earl showed this, this is  
the historic first passage,

761

00:36:18,876 --> 00:36:21,578  
this is the start  
now, the grand finale,

762

00:36:21,578 --> 00:36:23,580  
going in between the  
rings and the planet,

763

00:36:23,580 --> 00:36:28,585  
flying in a place

that no spacecraft  
has ever flown before,

764

00:36:28,585 --> 00:36:29,719  
and that's very exciting because

765

00:36:29,719 --> 00:36:32,289  
every time you go someplace new,

766

00:36:32,289 --> 00:36:34,391  
you're going to make  
new discoveries,

767

00:36:34,391 --> 00:36:36,327  
and that's exactly  
what Cassini did.

768

00:36:36,327 --> 00:36:38,495  
You're riding along with  
the Cassini spacecraft,

769

00:36:38,495 --> 00:36:40,063  
here's what it might feel like

770

00:36:40,063 --> 00:36:41,899  
as you're peering over  
the edge of the antenna

771

00:36:41,899 --> 00:36:45,236  
to dive in between the  
rings and the planet.

772

00:36:45,236 --> 00:36:48,306  
You're going at  
76,000 miles an hour,

773

00:36:49,440 --> 00:36:52,576  
and it only takes you  
an hour to go from

774

00:36:52,576 --> 00:36:55,912  
over one pole of  
Saturn to over another,

775

00:36:55,912 --> 00:36:57,681  
and then you come back  
out the other side,

776

00:36:57,681 --> 00:37:00,284  
and you do this every  
six and a half days.

777

00:37:00,284 --> 00:37:02,186  
So you're coming  
in very quickly,

778

00:37:02,186 --> 00:37:03,954  
you can see the background  
of the Milky Way,

779

00:37:03,954 --> 00:37:06,089  
you come out the other side,

780

00:37:06,089 --> 00:37:09,560  
you can see the sun  
here as you go on out,

781

00:37:09,560 --> 00:37:12,863  
so just a very exciting  
time in the mission.

782

00:37:12,863 --> 00:37:16,199  
So, what did we see  
on that first dive?

783

00:37:16,199 --> 00:37:17,868  
We actually on this first dive,

784

00:37:17,868 --> 00:37:20,437

we used the high gain antenna  
to protect the spacecraft,

785

00:37:20,437 --> 00:37:23,941

but we rotated to point  
the cameras at Saturn.

786

00:37:23,941 --> 00:37:26,010

We started at  
Saturn's north pole

787

00:37:26,010 --> 00:37:29,847

and we just kept taking  
pictures every 17 seconds

788

00:37:29,847 --> 00:37:33,150

from the north pole  
down toward the equator.

789

00:37:33,150 --> 00:37:35,085

And here you can see  
views of some of those.

790

00:37:35,085 --> 00:37:37,688

Here's the giant  
vortex, hurricane-like,

791

00:37:37,688 --> 00:37:39,857

right at the north pole.

792

00:37:39,857 --> 00:37:42,459

Some of these clouds  
that are better resolved

793

00:37:42,459 --> 00:37:43,960

than we've seen before,

794

00:37:43,960 --> 00:37:46,196

here's the edge of  
the giant hexagon,

795

00:37:46,196 --> 00:37:49,733

a six-sided jet stream that's  
two Earth diameters across

796

00:37:49,733 --> 00:37:51,635

centered on the north pole,

797

00:37:51,635 --> 00:37:53,671

then down to some  
of the other images.

798

00:37:53,671 --> 00:37:56,073

So I'm gonna show you some  
of the other additional ways

799

00:37:56,073 --> 00:37:57,574

to look at this data.

800

00:37:57,574 --> 00:38:00,510

One is here, here is what  
the spacecraft was doing

801

00:38:00,510 --> 00:38:03,781

as we were taking those  
pictures and looking at Saturn.

802

00:38:03,781 --> 00:38:05,248

So you can see that  
we're going down,

803

00:38:05,248 --> 00:38:07,451

you can watch those  
little picture frames

804

00:38:07,451 --> 00:38:09,520

getting smaller and  
smaller and smaller,

805

00:38:09,520 --> 00:38:12,489  
as we go down it, you'll  
see shortly a turn

806  
00:38:12,489 --> 00:38:14,224  
as we point the  
high gain antenna

807  
00:38:14,224 --> 00:38:16,559  
down into the  
direction of particles,

808  
00:38:16,559 --> 00:38:18,062  
but we're still taking pictures,

809  
00:38:18,062 --> 00:38:21,532  
we're still taking science  
data all of the way through.

810  
00:38:21,532 --> 00:38:23,200  
Here's another view,

811  
00:38:23,200 --> 00:38:25,169  
I like this view  
because the red dot

812  
00:38:25,169 --> 00:38:26,804  
is showing you where  
you are on Saturn,

813  
00:38:26,804 --> 00:38:29,206  
and here's those pictures  
as if you're gazing out

814  
00:38:29,206 --> 00:38:33,376  
of a tiny window looking  
down on the planet.

815  
00:38:33,376 --> 00:38:35,178  
So you can see all of

the detailed structure.

816

00:38:35,178 --> 00:38:37,147

These are all up on our web page

817

00:38:37,147 --> 00:38:40,717

if you want to go and  
take a look at those.

818

00:38:40,717 --> 00:38:43,020

There's the turn for  
the high gain antenna.

819

00:38:43,020 --> 00:38:46,089

And it'll stop here  
shortly and then just to,

820

00:38:46,089 --> 00:38:48,358

you know, this is just  
really an up close view

821

00:38:48,358 --> 00:38:51,128

of those first pictures  
that game back.

822

00:38:51,128 --> 00:38:53,597

And we were gathered  
on Wednesday night,

823

00:38:53,597 --> 00:38:56,133

it was just, you know,  
a little over a week ago

824

00:38:56,133 --> 00:38:59,169

we were gathered to  
wait for the first,

825

00:38:59,169 --> 00:39:01,505

you know, dive to come through,

826

00:39:01,505 --> 00:39:03,340

it was actually on April  
26th, which was my birthday,

827

00:39:03,340 --> 00:39:05,075

and what a great  
birthday present

828

00:39:05,075 --> 00:39:08,211

to make it through successfully  
through the rings, so.

829

00:39:08,211 --> 00:39:09,146

(applauding)

830

00:39:09,146 --> 00:39:11,147

That was really a good day.

831

00:39:11,147 --> 00:39:13,384

And as we watch these  
pictures come back,

832

00:39:13,384 --> 00:39:16,353

lots of us were here until  
about two in the morning or so,

833

00:39:16,353 --> 00:39:18,722

one of the leading  
Saturn scientists

834

00:39:18,722 --> 00:39:22,092

said "I've never seen  
anything like it in my life.

835

00:39:22,092 --> 00:39:23,661

"I don't know what it is."

836

00:39:23,661 --> 00:39:25,629

And that's half the

fun, you go there,

837

00:39:25,629 --> 00:39:28,298

you're not sure what  
you're gonna find.

838

00:39:28,298 --> 00:39:29,900

Now this is the second dive,

839

00:39:29,900 --> 00:39:31,602

what you're seeing  
here is a movie,

840

00:39:31,602 --> 00:39:33,603

it's showing the  
Cassini spacecraft

841

00:39:33,603 --> 00:39:36,474

along this orbital  
cycle a few times.

842

00:39:36,474 --> 00:39:38,609

Well here, let me back  
it up, it'll cycle again.

843

00:39:38,609 --> 00:39:39,910

Here's Cassini.

844

00:39:39,910 --> 00:39:41,478

This is the magnetic  
field lines,

845

00:39:41,478 --> 00:39:43,180

the strength is color coded,

846

00:39:43,180 --> 00:39:45,048

and we're turning  
the spacecraft.

847

00:39:45,048 --> 00:39:46,783

This is showing you an hour,

848

00:39:46,783 --> 00:39:50,954

and we're turning Cassini the whole way through that time.

849

00:39:50,954 --> 00:39:54,291

And that's to calibrate the magnetometer and get that data,

850

00:39:54,291 --> 00:39:57,027

and we were clever enough to add just the right instep

851

00:39:57,027 --> 00:39:59,563

in that turn to have the cosmic dust analyzer

852

00:39:59,563 --> 00:40:01,665

looking in the direction of the ring plane.

853

00:40:01,665 --> 00:40:03,600

Our hope was it would sample the ring particles

854

00:40:03,600 --> 00:40:04,968

and give us composition,

855

00:40:04,968 --> 00:40:07,438

but as Earl said, it's pretty empty,

856

00:40:07,438 --> 00:40:11,008

and so there wasn't a lot to see for that time.

857

00:40:11,008 --> 00:40:12,709

Here are some pictures

that came back,

858

00:40:12,709 --> 00:40:15,111

I just went to the web and  
pulled off a few of them.

859

00:40:15,111 --> 00:40:17,681

This is a star, and this  
is what happens when a star

860

00:40:17,681 --> 00:40:21,151

gets overexposed and the  
camera is extra bright.

861

00:40:21,151 --> 00:40:25,456

Here's the F ring, and then  
here's part of Saturn's A ring.

862

00:40:25,456 --> 00:40:28,958

Another one of the F ring,  
it's very kinky and clumpy,

863

00:40:28,958 --> 00:40:30,794

very unusual, and we  
took a very long movie

864

00:40:30,794 --> 00:40:33,530

as we flew through on  
this particular pass

865

00:40:33,530 --> 00:40:35,032

of Saturn's F ring.

866

00:40:35,032 --> 00:40:37,468

Let me give you some of the  
highlights of the science

867

00:40:37,468 --> 00:40:40,670

that we're going to be doing  
in the remaining 20 dives

868

00:40:40,670 --> 00:40:42,672  
between Saturn and the rings.

869

00:40:42,672 --> 00:40:45,709  
Well of course it involves the  
planet itself and the rings.

870

00:40:45,709 --> 00:40:47,044  
If we start with the rings,

871

00:40:47,044 --> 00:40:48,745  
one of the things  
that Cassini can do

872

00:40:48,745 --> 00:40:52,516  
is for the very first time  
measure the mass of the rings.

873

00:40:52,516 --> 00:40:55,953  
Right now that mass is  
uncertain to 100 percent,

874

00:40:55,953 --> 00:40:57,220  
we don't know what it is.

875

00:40:57,220 --> 00:40:58,955  
But by diving in between  
Saturn and the rings,

876

00:40:58,955 --> 00:41:01,624  
we get just the mass  
of Saturn by itself.

877

00:41:01,624 --> 00:41:03,493  
Earlier in the mission, we have

878

00:41:03,493 --> 00:41:05,496  
the mass of Saturn

plus the rings,

879

00:41:05,496 --> 00:41:07,698

subtract the two, you get  
the mass of the rings.

880

00:41:07,698 --> 00:41:10,367

Now if the rings are more  
massive than we expect,

881

00:41:10,367 --> 00:41:12,102

then they could've  
perhaps formed

882

00:41:12,102 --> 00:41:14,071

at the same time as Saturn.

883

00:41:14,071 --> 00:41:16,006

They could've been  
massive enough

884

00:41:16,006 --> 00:41:18,775

to have survived the  
micro-meteoroid bombardment

885

00:41:18,775 --> 00:41:22,246

and erosion that took place  
to be there 'til today.

886

00:41:22,246 --> 00:41:24,615

Less massive, they  
must be young.

887

00:41:24,615 --> 00:41:26,350

Perhaps only 100  
million years old,

888

00:41:26,350 --> 00:41:29,886

a small fraction of the  
age of the solar system,

889

00:41:29,886 --> 00:41:32,489  
perhaps forming from a comet  
or a moon that got too close,

890

00:41:32,489 --> 00:41:34,525  
Saturn's gravity  
ripped it apart,

891

00:41:34,525 --> 00:41:37,361  
those pieces went  
on to form the ring.

892

00:41:37,361 --> 00:41:39,796  
We still hope to get the  
composition of the rings,

893

00:41:39,796 --> 00:41:41,764  
we just have to  
get a ring particle

894

00:41:41,764 --> 00:41:44,167  
into our cosmic dust analyzer.

895

00:41:44,167 --> 00:41:46,269  
Then for the planet itself  
and also for the rings,

896

00:41:46,269 --> 00:41:47,971  
we get some of the  
best pictures ever

897

00:41:47,971 --> 00:41:50,841  
of the hexagon, of the  
storms at the poles,

898

00:41:50,841 --> 00:41:53,477  
you've seen one swath,  
we're gonna do that again,

899

00:41:53,477 --> 00:41:55,412

perhaps get some color,

900

00:41:55,412 --> 00:41:57,581

exquisite pictures

of those inner rings,

901

00:41:57,581 --> 00:42:01,351

who knows what we'll find

when we take a closer look.

902

00:42:01,351 --> 00:42:03,753

Then of course on

the last five orbits,

903

00:42:03,753 --> 00:42:07,491

we're literally dipping our

toe into Saturn's atmosphere,

904

00:42:07,491 --> 00:42:09,259

and our ion and neutral

mass spectrometer

905

00:42:09,259 --> 00:42:12,229

will be tasting the composition.

906

00:42:12,229 --> 00:42:14,265

It's mostly hydrogen, but

there are other things

907

00:42:14,265 --> 00:42:15,498

there as well.

908

00:42:15,498 --> 00:42:17,801

And so for the first

time directly sampling

909

00:42:17,801 --> 00:42:20,637

the upper atmosphere

of the planet.

910

00:42:20,637 --> 00:42:22,005

There's a radiation belt there.

911

00:42:22,005 --> 00:42:23,773

We know from Saturn  
orbit insertion

912

00:42:23,773 --> 00:42:25,575

there's a very weak  
radiation belt,

913

00:42:25,575 --> 00:42:28,345

not nearly as strong as the  
main belt outside of the rings,

914

00:42:28,345 --> 00:42:30,447

so we hope to characterize  
the radiation belt

915

00:42:30,447 --> 00:42:33,784

and the plasma  
environment in that gap

916

00:42:33,784 --> 00:42:36,386

between the planet  
and the rings.

917

00:42:36,386 --> 00:42:38,355

Then of course we're gonna  
study the magnetic field,

918

00:42:38,355 --> 00:42:42,693

these blue lines coming out  
from Saturn in exquisite detail.

919

00:42:42,693 --> 00:42:44,027

One of the things  
we still don't know

920

00:42:44,027 --> 00:42:45,662  
is the length of a Saturn day.

921

00:42:45,662 --> 00:42:48,832  
How fast does Saturn  
rotate on its interior,

922

00:42:48,832 --> 00:42:49,933  
because when you  
look at the outside,

923

00:42:49,933 --> 00:42:51,435  
all you see are clouds.

924

00:42:51,435 --> 00:42:53,704  
And different latitudes  
rotate at different rates,

925

00:42:53,704 --> 00:42:55,839  
and so we want to know  
what's the rate of rotation.

926

00:42:55,839 --> 00:42:59,075  
It's around 10 hours,  
maybe 10 hours 20 minutes.

927

00:42:59,075 --> 00:43:00,577  
What is it?

928

00:43:00,577 --> 00:43:02,646  
And we're hoping if the  
magnetometer data shows us

929

00:43:02,646 --> 00:43:04,815  
the magnetic field is  
tilted just a little bit,

930

00:43:04,815 --> 00:43:08,017

it'll swivel around  
like a giant lighthouse,

931  
00:43:08,017 --> 00:43:10,554  
giving us the length of a day.

932  
00:43:10,554 --> 00:43:11,855  
We also want to know

933  
00:43:11,855 --> 00:43:13,523  
where does the magnetic  
field originate?

934  
00:43:13,523 --> 00:43:15,024  
The atmosphere is  
gas at the top,

935  
00:43:15,024 --> 00:43:18,628  
that hydrogen compresses to be  
a molecular hydrogen liquid,

936  
00:43:18,628 --> 00:43:21,231  
compresses some more  
until it becomes metallic,

937  
00:43:21,231 --> 00:43:24,067  
it's metallic in a phase  
where currents can flow

938  
00:43:24,067 --> 00:43:25,502  
and generate a magnetic field.

939  
00:43:25,502 --> 00:43:28,271  
We think it's about  
half a Saturn radius in,

940  
00:43:28,271 --> 00:43:30,540  
about a million  
atmospheres of pressure.

941  
00:43:30,540 --> 00:43:32,576  
That's what our models tell us.

942  
00:43:32,576 --> 00:43:34,277  
So we'll get a  
chance to find out,

943  
00:43:34,277 --> 00:43:36,947  
see what the inside  
of the planet is like.

944  
00:43:36,947 --> 00:43:39,149  
We'll study the  
aurora in more detail,

945  
00:43:39,149 --> 00:43:40,917  
particles come in  
along the field lines,

946  
00:43:40,917 --> 00:43:43,120  
crash into that  
area, create aurora,

947  
00:43:43,120 --> 00:43:45,222  
and they're pink,  
pink and purple,

948  
00:43:45,222 --> 00:43:47,591  
because it's hydrogen  
that's glowing and emitting

949  
00:43:47,591 --> 00:43:50,427  
in the aurora on Saturn.

950  
00:43:50,427 --> 00:43:53,363  
And then finally, looking  
at the interior itself,

951  
00:43:53,363 --> 00:43:55,065

with our gravity measurements,

952

00:43:55,065 --> 00:43:58,202

the size of a rocky core,  
is it one Earth in size?

953

00:43:58,202 --> 00:43:59,736

Two Earths in size?

954

00:43:59,736 --> 00:44:01,205

What's the boundary like?

955

00:44:01,205 --> 00:44:02,672

How deep do the winds go?

956

00:44:02,672 --> 00:44:05,208

Is it 300 miles, 3000 miles?

957

00:44:05,208 --> 00:44:08,245

When do you start to  
feel the winds peter out?

958

00:44:08,245 --> 00:44:10,781

And we think with the gravity  
measurement irregularities

959

00:44:10,781 --> 00:44:15,318

we'll be able to pin down  
the location of those winds.

960

00:44:15,318 --> 00:44:18,188

Then of course on  
that final orbit,

961

00:44:18,188 --> 00:44:20,123

we go into Saturn.

962

00:44:20,123 --> 00:44:22,525

And that's gonna be

really I think a tough,

963

00:44:22,525 --> 00:44:25,461

a tough day, to say  
goodbye to this spacecraft

964

00:44:25,461 --> 00:44:26,963

that's been around for so long.

965

00:44:26,963 --> 00:44:28,464

And when you think about it,

966

00:44:28,464 --> 00:44:31,335

with Cassini's final heartbeat,

967

00:44:31,335 --> 00:44:34,637

that's humankind's  
last intimate,

968

00:44:34,637 --> 00:44:36,373

personal connection with Saturn,

969

00:44:36,373 --> 00:44:39,042

that connection will be cut.

970

00:44:39,042 --> 00:44:40,744

And we'll no longer be able to

971

00:44:40,744 --> 00:44:42,245

see those little tiny moons

972

00:44:42,245 --> 00:44:45,549

that I showed you pictures of  
tonight, or Saturn's F ring,

973

00:44:45,549 --> 00:44:49,119

because you see, they'll  
be lost in the glare

974  
00:44:49,119 --> 00:44:50,687  
of Saturn and its rings.

975  
00:44:50,687 --> 00:44:53,656  
Except for once every 15 years

976  
00:44:53,656 --> 00:44:56,860  
when the rings are  
edge-on to the sun

977  
00:44:56,860 --> 00:44:58,662  
and the rings go dark.

978  
00:44:58,662 --> 00:45:01,264  
Then we'll get a chance  
to catch a glimpse

979  
00:45:01,264 --> 00:45:05,101  
of these little tiny worlds  
that Cassini revealed.

980  
00:45:05,101 --> 00:45:08,539  
But we have 20 more  
dives through that gap

981  
00:45:10,274 --> 00:45:11,708  
before we get to the end.

982  
00:45:11,708 --> 00:45:14,311  
So we have a lot  
more new, exciting,

983  
00:45:14,311 --> 00:45:16,546  
incredible science ahead.

984  
00:45:16,546 --> 00:45:19,749  
So join us, check our web page,

985

00:45:19,749 --> 00:45:21,584

look at the great  
pictures coming down,

986

00:45:21,584 --> 00:45:24,554

and enjoy these final heady days

987

00:45:24,554 --> 00:45:26,724

of Cassini's grand finale.

988

00:45:27,858 --> 00:45:29,159

Thank you very much.

989

00:45:29,159 --> 00:45:31,562

(applauding)

990

00:45:41,871 --> 00:45:43,573

Earl and I would be  
happy to take questions

991

00:45:43,573 --> 00:45:45,342

if you wouldn't  
mind please using

992

00:45:45,342 --> 00:45:47,010

the microphone in the back,

993

00:45:47,010 --> 00:45:48,611

and that way everyone  
will be able to hear you,

994

00:45:48,611 --> 00:45:51,448

so if you can go in the  
back and use the microphone,

995

00:45:51,448 --> 00:45:53,117

that would be great.

996

00:45:58,789 --> 00:45:59,990

Go ahead.

997

00:45:59,990 --> 00:46:01,791

- Yeah, in the early '70s,

998

00:46:01,791 --> 00:46:04,761

I along with two now retired  
colleagues developed the model

999

00:46:04,761 --> 00:46:06,897

for the gravitational  
attraction of a disk,

1000

00:46:06,897 --> 00:46:09,799

which a Voyager navigator  
said was rather critical

1001

00:46:09,799 --> 00:46:12,635

to Voyager actually  
to go to Uranus

1002

00:46:12,635 --> 00:46:15,038

instead of some random place.

1003

00:46:15,038 --> 00:46:16,907

I'm kind of surprised that

1004

00:46:16,907 --> 00:46:19,276

partial derivatives  
of your trajectory

1005

00:46:19,276 --> 00:46:21,978

with respect to the  
mass of the rings

1006

00:46:21,978 --> 00:46:24,548

using that model don't  
give you better information

1007

00:46:24,548 --> 00:46:27,284  
than 100 percent  
of an error bar.

1008  
00:46:28,652 --> 00:46:30,220  
- Well sort of the  
question is, you know,

1009  
00:46:30,220 --> 00:46:32,022  
you needed to know  
the mass of the rings

1010  
00:46:32,022 --> 00:46:33,790  
to have sent Voyager  
on to Uranus,

1011  
00:46:33,790 --> 00:46:36,759  
so why don't we know them  
better from our navigation data?

1012  
00:46:36,759 --> 00:46:39,529  
Well, if you look at it,  
the mass of the rings

1013  
00:46:39,529 --> 00:46:44,267  
compared to the mass of  
Saturn is absolutely tiny.

1014  
00:46:44,267 --> 00:46:46,002  
So in a certain sense, you know,

1015  
00:46:46,002 --> 00:46:47,570  
the rings are kind  
of in the noise

1016  
00:46:47,570 --> 00:46:49,839  
because Saturn is so massive.

1017  
00:46:49,839 --> 00:46:51,574  
So even after all, you know,

1018

00:46:51,574 --> 00:46:55,178

we have it down much  
more precisely than  
we had for Voyager,

1019

00:46:55,178 --> 00:46:58,748

but it's still a  
large error bar.

1020

00:46:58,748 --> 00:47:00,751

- Another question also,

1021

00:47:00,751 --> 00:47:04,821

I assume that when the line  
of sight between the Earth

1022

00:47:04,821 --> 00:47:07,390

and the spacecraft  
passes through Saturn,

1023

00:47:07,390 --> 00:47:09,259

that you are getting information

1024

00:47:09,259 --> 00:47:13,063

of the atmospheric composition  
using microspectrometry.

1025

00:47:13,063 --> 00:47:14,297

- Right, right.

1026

00:47:14,297 --> 00:47:15,531

That's a very good point.

1027

00:47:15,531 --> 00:47:17,033

There are other kinds  
of things we'll be doing

1028

00:47:17,033 --> 00:47:19,269

with the spacecraft, we can  
actually use the radio signal

1029

00:47:19,269 --> 00:47:21,905  
occulted by Saturn to get  
occultations of the atmosphere,

1030

00:47:21,905 --> 00:47:25,809  
of the rings themselves, and  
do a lot of other science

1031

00:47:25,809 --> 00:47:27,610  
focused on Saturn as well.

1032

00:47:27,610 --> 00:47:29,045  
We'll actually get  
radar in the rings

1033

00:47:29,045 --> 00:47:30,547  
for the first time too.

1034

00:47:30,547 --> 00:47:32,148  
And we've been doing that  
throughout the mission,

1035

00:47:32,148 --> 00:47:34,717  
using the radio beam or  
stars to get occultations

1036

00:47:34,717 --> 00:47:37,287  
of the planet and of the rings.

1037

00:47:39,689 --> 00:47:41,992  
- Hey, I'm curious if you  
could talk at all about

1038

00:47:41,992 --> 00:47:44,628  
how you made the determination  
that it was gonna be safe

1039

00:47:44,628 --> 00:47:46,362

to pass between the  
rings and Saturn.

1040

00:47:46,362 --> 00:47:47,897

I know you talked  
a little bit about

1041

00:47:47,897 --> 00:47:50,333

the ring scientists did a  
lot of work in determining

1042

00:47:50,333 --> 00:47:52,702

that the dust environment  
would be low enough

1043

00:47:52,702 --> 00:47:53,970

Cassini could survive,

1044

00:47:53,970 --> 00:47:55,571

but since it had never  
been explored before,

1045

00:47:55,571 --> 00:47:57,941

how could you make that  
with enough confidence

1046

00:47:57,941 --> 00:48:00,943

to say yeah, we'll  
risk it and let's go?

1047

00:48:00,943 --> 00:48:03,380

- Well we had a model,  
and what we did is,

1048

00:48:03,380 --> 00:48:05,582

Earl showed it earlier,  
we took a picture

1049

00:48:05,582 --> 00:48:07,250  
of the innermost  
part of the rings

1050  
00:48:07,250 --> 00:48:10,320  
with Saturn's shadow  
going across it.

1051  
00:48:10,320 --> 00:48:12,922  
And we know the shadow was  
very black and very dark,

1052  
00:48:12,922 --> 00:48:15,458  
we looked at our image,  
we stretched it to see

1053  
00:48:15,458 --> 00:48:18,828  
where that boundary went  
relative to the shadow.

1054  
00:48:18,828 --> 00:48:22,565  
But in the images, all you see  
are the tiny dust particles.

1055  
00:48:22,565 --> 00:48:25,735  
So we felt we understood  
the dust very well.

1056  
00:48:25,735 --> 00:48:28,672  
But the bigger particles, if  
there aren't very many of them,

1057  
00:48:28,672 --> 00:48:29,939  
you don't see them.

1058  
00:48:29,939 --> 00:48:31,774  
So we were just  
sort of assuming,

1059  
00:48:31,774 --> 00:48:33,677

okay, let's assume  
it's sort of like

1060  
00:48:33,677 --> 00:48:36,145  
when we go through the  
E ring or the G ring,

1061  
00:48:36,145 --> 00:48:39,082  
just little particles  
and extrapolate in.

1062  
00:48:39,082 --> 00:48:41,651  
Our extrapolations told us  
we should have less dust

1063  
00:48:41,651 --> 00:48:44,520  
than we saw in the E ring  
or the ring grazing orbits,

1064  
00:48:44,520 --> 00:48:47,090  
but there was nothing  
in the model to say

1065  
00:48:47,090 --> 00:48:49,025  
there'd be no dust.

1066  
00:48:49,025 --> 00:48:50,861  
So but part of it,  
the bigger particles,

1067  
00:48:50,861 --> 00:48:52,929  
that was a risk.

1068  
00:48:52,929 --> 00:48:55,531  
A risk though worth taking.

1069  
00:48:55,531 --> 00:48:56,533  
- Thank you.

1070

00:48:58,468 --> 00:49:00,203  
- Thanks for the great talk.

1071  
00:49:00,203 --> 00:49:02,872  
I had a question  
for each of you.

1072  
00:49:02,872 --> 00:49:05,542  
First question, on the animation

1073  
00:49:06,943 --> 00:49:10,947  
depicting Cassini's first  
travel through the ring plane,

1074  
00:49:10,947 --> 00:49:13,115  
it appeared that the mag boom

1075  
00:49:13,115 --> 00:49:16,386  
was rotated towards the D ring,

1076  
00:49:16,386 --> 00:49:18,221  
is that accurate?

1077  
00:49:18,221 --> 00:49:20,924  
And would there be  
any difference between

1078  
00:49:20,924 --> 00:49:23,560  
particulate risk on  
either orientation?

1079  
00:49:23,560 --> 00:49:24,728  
- No.

1080  
00:49:24,728 --> 00:49:26,395  
When you're pointing  
into the ram,

1081  
00:49:26,395 --> 00:49:29,766

you know, the mag boom  
is equally exposed,

1082  
00:49:29,766 --> 00:49:31,734  
and so that was a  
preferential attitude

1083  
00:49:31,734 --> 00:49:34,471  
for the magnetometer itself.

1084  
00:49:34,471 --> 00:49:36,406  
- Yeah, if you look at the  
Cassini model over here,

1085  
00:49:36,406 --> 00:49:38,808  
you can see the mag boom,  
that big golden boom,

1086  
00:49:38,808 --> 00:49:41,277  
it doesn't matter how  
you point the space...

1087  
00:49:41,277 --> 00:49:43,113  
Well, for the high gain antenna

1088  
00:49:43,113 --> 00:49:44,547  
protecting the rest  
of the spacecraft,

1089  
00:49:44,547 --> 00:49:47,083  
the mag boom was  
hanging out there.

1090  
00:49:47,083 --> 00:49:48,618  
Yeah.

1091  
00:49:48,618 --> 00:49:51,487  
- Second question, on the  
equinox slide that you had,

1092

00:49:51,487 --> 00:49:54,791

there's a lot of  
vertical perturbations,

1093

00:49:54,791 --> 00:49:58,061

and it looked like they were  
all 90 degrees from ring plane.

1094

00:49:58,061 --> 00:50:00,564

What are the  
mechanics behind that?

1095

00:50:00,564 --> 00:50:02,665

- In that image I  
showed from equinox,

1096

00:50:02,665 --> 00:50:07,070

the sun direction was shining  
from above, shining down,

1097

00:50:07,070 --> 00:50:09,572

and so that small piece  
of the rings that you saw,

1098

00:50:09,572 --> 00:50:11,207

it made them look  
like, you know,

1099

00:50:11,207 --> 00:50:14,210

all the shadows were going  
out in a single direction.

1100

00:50:14,210 --> 00:50:16,712

Why the clumps happened to  
be at the edge of the B ring,

1101

00:50:16,712 --> 00:50:19,115

there's a resonance keeping  
the edge from spreading

1102

00:50:19,115 --> 00:50:21,784

and maybe the clumping,  
there's a lot of clumping

1103

00:50:21,784 --> 00:50:24,153

that happens in that  
region as the particles,

1104

00:50:24,153 --> 00:50:26,423

like a crowded freeway,  
they're trying to merge over

1105

00:50:26,423 --> 00:50:28,891

and they can't, so they're  
starting to clump together.

1106

00:50:28,891 --> 00:50:30,559

- But the main question was on

1107

00:50:30,559 --> 00:50:32,529

the vertical extension of that.

1108

00:50:32,529 --> 00:50:36,666

If a moon is traveling by,  
and caused perturbation,

1109

00:50:36,666 --> 00:50:39,002

wouldn't that be  
bent or inclined

1110

00:50:39,002 --> 00:50:41,471

as opposed to straight  
out of ring plane?

1111

00:50:41,471 --> 00:50:43,406

- Well, everything  
pretty much with Saturn,

1112

00:50:43,406 --> 00:50:44,908

that's a very  
interesting question,

1113  
00:50:44,908 --> 00:50:46,676  
the rings on average are  
only about 10 feet thick,

1114  
00:50:46,676 --> 00:50:49,779  
and Saturn's oblateness  
tends to keep everything

1115  
00:50:49,779 --> 00:50:51,915  
very very coplanar.

1116  
00:50:51,915 --> 00:50:54,717  
So they don't tend to  
have inclined orbits.

1117  
00:50:54,717 --> 00:50:56,620  
There are other places in the  
rings with inclined orbits,

1118  
00:50:56,620 --> 00:50:58,054  
bending waves, et cetera,

1119  
00:50:58,054 --> 00:51:00,589  
but not generally  
across the rings

1120  
00:51:00,589 --> 00:51:02,458  
not at the edge of the B ring.

1121  
00:51:02,458 --> 00:51:03,293  
- Thank you.

1122  
00:51:03,293 --> 00:51:04,127  
- Yeah.

1123  
00:51:05,295 --> 00:51:08,331

- Yes, all the orbits  
of the spacecraft

1124

00:51:08,331 --> 00:51:11,434

that I saw here, it looked  
extremely elliptical.

1125

00:51:11,434 --> 00:51:14,638

Is there a way that you could've  
obtained a circular orbit,

1126

00:51:14,638 --> 00:51:18,040

and if so, could you have  
continued the mission

1127

00:51:18,040 --> 00:51:22,878

by attaining the circular  
orbit within the ring gap,

1128

00:51:22,878 --> 00:51:24,113

considering now that you know

1129

00:51:24,113 --> 00:51:25,648

that there's very few  
particles in there,

1130

00:51:25,648 --> 00:51:28,385

and then you wouldn't have  
run into much resistance,

1131

00:51:28,385 --> 00:51:30,286

and if it eventually  
decayed its orbit

1132

00:51:30,286 --> 00:51:31,921

like a satellite around Earth,

1133

00:51:31,921 --> 00:51:34,124

it would just crash  
into the planet anyway,

1134

00:51:34,124 --> 00:51:37,493

and it wouldn't present  
any hazard to the moons.

1135

00:51:37,493 --> 00:51:40,096

- Well, I think a circular  
orbit's always an option,

1136

00:51:40,096 --> 00:51:43,366

but not a very scientifically  
interesting one.

1137

00:51:43,366 --> 00:51:46,202

One of the things we really  
did have to, you know,

1138

00:51:46,202 --> 00:51:49,806

if you're going to use  
Titan as a circularizer,

1139

00:51:49,806 --> 00:51:51,541

and that's really the only  
way we could've done it,

1140

00:51:51,541 --> 00:51:53,309

you're gonna have to  
come back to Titan,

1141

00:51:53,309 --> 00:51:54,577

there's no way to avoid it,

1142

00:51:54,577 --> 00:51:56,179

so you're essentially  
going to be

1143

00:51:56,179 --> 00:51:58,148

in some sort of  
Titan-like orbit,

1144

00:51:58,148 --> 00:52:00,383

and if you're going  
to be doing that,

1145

00:52:00,383 --> 00:52:02,552

you're eventually  
gonna have to deal with

1146

00:52:02,552 --> 00:52:03,853

the fact that you're  
out of propellant

1147

00:52:03,853 --> 00:52:06,155

and in an orbit you  
don't want to be in,

1148

00:52:06,155 --> 00:52:07,857

with Titan messing with you.

1149

00:52:07,857 --> 00:52:09,325

There were some other options

1150

00:52:09,325 --> 00:52:13,129

for very large elliptical  
orbits that were also stable,

1151

00:52:13,129 --> 00:52:15,899

but the scientific  
value of those

1152

00:52:17,267 --> 00:52:20,670

relative to these grand  
finale orbits was so marginal

1153

00:52:20,670 --> 00:52:24,173

that they were dismissed  
almost immediately.

1154

00:52:24,173 --> 00:52:25,941

- Right, in fact, the  
scientists kind of looked down

1155  
00:52:25,941 --> 00:52:27,810  
this table of options  
of what we could do

1156  
00:52:27,810 --> 00:52:30,179  
and they saw the grand finale  
and they said "that's it,

1157  
00:52:30,179 --> 00:52:33,083  
"end of discussion, we don't  
need to talk about it anymore,"

1158  
00:52:33,083 --> 00:52:34,517  
so they liked that.

1159  
00:52:34,517 --> 00:52:36,386  
- Yeah, granted that  
because of the way

1160  
00:52:36,386 --> 00:52:38,121  
the mission proceeded,  
it's no longer an option,

1161  
00:52:38,121 --> 00:52:41,557  
but if you'd known when  
you started the mission

1162  
00:52:41,557 --> 00:52:43,259  
what you know now, would  
it have been possible

1163  
00:52:43,259 --> 00:52:46,129  
to end the mission with the  
spacecraft in a circular orbit

1164  
00:52:46,129 --> 00:52:48,565  
within the ring gap?

1165

00:52:48,565 --> 00:52:49,999

- Oh, within the ring gap.

1166

00:52:49,999 --> 00:52:51,401

I don't think so,

1167

00:52:52,435 --> 00:52:54,904

simply because

there's, where are you,

1168

00:52:54,904 --> 00:52:57,140

you're going to have to find

something to circularize you

1169

00:52:57,140 --> 00:52:59,976

at both periapsis

and at the apoapsis,

1170

00:52:59,976 --> 00:53:02,045

and I'm not quite sure...

1171

00:53:03,480 --> 00:53:05,681

I'm not gonna stick my

neck out on that, though.

1172

00:53:05,681 --> 00:53:07,584

Again, if you're using Titan,

1173

00:53:07,584 --> 00:53:09,452

and that's really the

only thing we've got,

1174

00:53:09,452 --> 00:53:12,455

you're gonna have to end up

coming back out to Titan again.

1175

00:53:12,455 --> 00:53:13,690

- So there's no way...

1176

00:53:13,690 --> 00:53:15,091

You couldn't carry  
enough fuel to do that,

1177

00:53:15,091 --> 00:53:16,025

you'd have to--

1178

00:53:16,025 --> 00:53:16,859

- Well that would be the thing,

1179

00:53:16,859 --> 00:53:18,795

and no, I don't think...

1180

00:53:18,795 --> 00:53:21,564

Well, I'll let Linda speak  
to the scientific merits

1181

00:53:21,564 --> 00:53:23,299

of carrying that much propellant

1182

00:53:23,299 --> 00:53:25,902

and then using it to go inside  
the rings and stay there.

1183

00:53:25,902 --> 00:53:29,338

But you could, I  
mean, conceivably

1184

00:53:29,338 --> 00:53:31,140

you could take enough  
propellant to go in

1185

00:53:31,140 --> 00:53:33,876

and actually once you've  
got periapsis inside,

1186

00:53:33,876 --> 00:53:37,213

then do a braking burn to

take apoapsis in as well.

1187

00:53:37,213 --> 00:53:39,315

But that's a lot of propellant.

1188

00:53:39,315 --> 00:53:40,650

- That's a lot of propellant,

1189

00:53:40,650 --> 00:53:42,418

or you could try

aerocapture or aerobraking,

1190

00:53:42,418 --> 00:53:43,853

but until Cassini flew there,

1191

00:53:43,853 --> 00:53:45,788

we had no idea how

clear it would be.

1192

00:53:45,788 --> 00:53:47,290

- Okay, thank you.

1193

00:53:50,193 --> 00:53:51,027

- Hi.

1194

00:53:52,495 --> 00:53:56,199

I was wondering, do you use  
plutonium to power Cassini?

1195

00:54:00,303 --> 00:54:01,604

- Yes we do.

1196

00:54:01,604 --> 00:54:03,907

But we use plutonium in  
a very interesting way,

1197

00:54:03,907 --> 00:54:08,311

because plutonium,  
that's P238, is very hot.

1198

00:54:08,311 --> 00:54:10,813

And so all we're doing  
is using the heat

1199

00:54:10,813 --> 00:54:13,516

from its radioactive  
decay to fire,

1200

00:54:13,516 --> 00:54:17,086

to power little  
thermoelectric cells.

1201

00:54:17,086 --> 00:54:19,421

We have three of them  
on the spacecraft,

1202

00:54:19,421 --> 00:54:20,957

you can look at the model later

1203

00:54:20,957 --> 00:54:22,792

and see them at the bottom,  
they're these black things.

1204

00:54:22,792 --> 00:54:25,027

And so it's the  
heat from plutonium

1205

00:54:25,027 --> 00:54:26,729

that give us the electricity.

1206

00:54:26,729 --> 00:54:28,130

And that's all we use it for,

1207

00:54:28,130 --> 00:54:31,935

we actually use chemical  
rocket fuel for the propellant,

1208

00:54:31,935 --> 00:54:35,538

and the plutonium,  
well, as a good example,

1209

00:54:36,672 --> 00:54:38,575

Voyager's coming  
up on its 40th year

1210

00:54:38,575 --> 00:54:40,977

and they're still going  
fine on plutonium.

1211

00:54:40,977 --> 00:54:44,680

Cassini has lots of  
electricity, just no propellant.

1212

00:54:44,680 --> 00:54:46,149

- Yeah, if you look  
at the Voyager model,

1213

00:54:46,149 --> 00:54:48,784

that big black object  
off to one side,

1214

00:54:48,784 --> 00:54:50,987

Cassini has three of those.

1215

00:54:50,987 --> 00:54:53,056

And that's what  
contains the plutonium

1216

00:54:53,056 --> 00:54:57,227

that the heat is used to power  
Voyager and to power Cassini.

1217

00:54:59,128 --> 00:55:02,265

- Another question is  
do you have an idea

1218

00:55:02,265 --> 00:55:05,768

of what the pentagon

could be made of?

1219

00:55:05,768 --> 00:55:08,938

- Oh, what the hexagon at  
the north pole is made of?

1220

00:55:08,938 --> 00:55:11,774

Well it's a jet stream,  
so it's made of gas,

1221

00:55:11,774 --> 00:55:13,343

but going around very fast.

1222

00:55:13,343 --> 00:55:16,279

That edge of the hexagon  
is like a giant racetrack,

1223

00:55:16,279 --> 00:55:18,314

and the clouds just  
race around there faster

1224

00:55:18,314 --> 00:55:20,483

than just about any place else.

1225

00:55:20,483 --> 00:55:24,354

Why it has six sides, and  
what keeps six sides on it,

1226

00:55:24,354 --> 00:55:26,389

we have no idea.

1227

00:55:26,389 --> 00:55:27,390

- Thank you.

1228

00:55:30,126 --> 00:55:32,662

- Yeah, I was wondering  
if the ring gaps

1229

00:55:32,662 --> 00:55:37,233

seem to be always caused by  
moons that clear out the debris,

1230

00:55:37,233 --> 00:55:39,568

or maybe moons that  
were once there

1231

00:55:39,568 --> 00:55:41,137

and were ejected at some point,

1232

00:55:41,137 --> 00:55:44,506

are are they like dynamic  
and constantly changing?

1233

00:55:44,506 --> 00:55:45,808

- Well initially with the rings,

1234

00:55:45,808 --> 00:55:48,878

we thought that the  
gaps had to have moons,

1235

00:55:48,878 --> 00:55:51,347

because we saw Pan  
in the Encke gap,

1236

00:55:51,347 --> 00:55:53,683

then we discovered  
Daphnis in the Kieler gap,

1237

00:55:53,683 --> 00:55:55,318

but there are gaps  
in the C ring,

1238

00:55:55,318 --> 00:55:57,954

some of the gaps have  
ringlets inside of it,

1239

00:55:57,954 --> 00:56:00,756

and we looked, and we  
looked, and we looked,

1240

00:56:00,756 --> 00:56:05,494

we didn't find any moons in  
any of the gaps in the C ring.

1241

00:56:05,494 --> 00:56:09,032

So there's some process that  
we don't understand quite yet

1242

00:56:09,032 --> 00:56:12,735

that can keep gaps  
open without moons.

1243

00:56:12,735 --> 00:56:15,238

So if you have a good  
idea, let us know.

1244

00:56:15,238 --> 00:56:16,072

(audience laughing)

1245

00:56:16,072 --> 00:56:17,073

- Thank you.

1246

00:56:18,407 --> 00:56:19,576

- Howdy.

1247

00:56:19,576 --> 00:56:21,044

I actually had two  
really quick questions.

1248

00:56:21,044 --> 00:56:24,647

One was about Pan, that  
odd ridge-shaped feature

1249

00:56:24,647 --> 00:56:27,983

on its equator, do you know  
like the consistency of that,

1250

00:56:27,983 --> 00:56:29,418

is it more like a rocky material

1251

00:56:29,418 --> 00:56:32,054

or more of like something  
equivalent to sand?

1252

00:56:32,054 --> 00:56:35,325

- Okay, well the rings are  
made 99 percent of water ice.

1253

00:56:35,325 --> 00:56:38,227

And so, and that's  
also true of the moons.

1254

00:56:38,227 --> 00:56:40,363

And we can also,  
through some mechanisms,

1255

00:56:40,363 --> 00:56:44,200

figure out how porous, you  
know, how porous it is.

1256

00:56:44,200 --> 00:56:46,469

An ice cube would be  
not porous at all,

1257

00:56:46,469 --> 00:56:48,738

a snowball would  
be quite porous.

1258

00:56:48,738 --> 00:56:50,806

Pan is much more  
toward a snowball

1259

00:56:50,806 --> 00:56:52,675

than it is toward an ice cube.

1260

00:56:52,675 --> 00:56:55,011

There's a lot of porous  
space in between,

1261

00:56:55,011 --> 00:56:56,479

and it's water ice.

1262

00:56:56,479 --> 00:56:57,980

- Okay.

1263

00:56:57,980 --> 00:57:01,951

And my second question was in regards to the final orbit.

1264

00:57:01,951 --> 00:57:06,222

Right now the final orbit is perpendicular to the rings.

1265

00:57:06,222 --> 00:57:08,924

Was it ever considered to do a orbit

1266

00:57:08,924 --> 00:57:11,527

more parallel to the rings?

1267

00:57:11,527 --> 00:57:14,330

Was that every a consideration?

1268

00:57:14,330 --> 00:57:15,998

- Do you want to answer that, the navigator?

1269

00:57:15,998 --> 00:57:17,500

- Well...

1270

00:57:17,500 --> 00:57:18,935

- That's a good question, they did find something.

1271

00:57:18,935 --> 00:57:20,536

- It's a great question.

1272

00:57:20,536 --> 00:57:22,972

But what happened,  
actually when we

1273

00:57:22,972 --> 00:57:24,173

first started with Cassini,

1274

00:57:24,173 --> 00:57:26,075

we didn't think we could  
do what we've done.

1275

00:57:26,075 --> 00:57:29,245

So the techniques, the  
astrodynamic techniques

1276

00:57:29,245 --> 00:57:32,148

and the numerical techniques  
have been evolving,

1277

00:57:32,148 --> 00:57:33,616

and we actually do now know

1278

00:57:33,616 --> 00:57:36,385

based on some work from  
the Cassini navigation team

1279

00:57:36,385 --> 00:57:40,756

that we could have these  
so-called ring skirting orbits,

1280

00:57:40,756 --> 00:57:44,293

but by that time,  
interestingly enough,

1281

00:57:44,293 --> 00:57:47,997

we developed the Cassini  
project, the nav team developed

1282

00:57:47,997 --> 00:57:52,701

these responses more as we ran  
out of propellant too early.

1283

00:57:52,701 --> 00:57:56,473

By that time we had invested  
so much time and energy

1284

00:57:56,473 --> 00:58:00,209

and our propellant reserves  
in getting ourselves

1285

00:58:00,209 --> 00:58:02,511

into these grand finale orbits

1286

00:58:02,511 --> 00:58:04,146

that it really wasn't an option.

1287

00:58:04,146 --> 00:58:06,015

But it's out there, and  
we're actually seeing

1288

00:58:06,015 --> 00:58:08,951

maybe some mission proposals  
next time around to do that.

1289

00:58:08,951 --> 00:58:11,086

- Right, when Cassini  
launched, we had no idea

1290

00:58:11,086 --> 00:58:13,589

you could dive in between  
the rings and the planet.

1291

00:58:13,589 --> 00:58:15,791

And that just took the  
evolution of software

1292

00:58:15,791 --> 00:58:17,993

and of the right  
people to find that.

1293

00:58:17,993 --> 00:58:20,195

It's actually a group at  
Purdue first found it,

1294

00:58:20,195 --> 00:58:23,065

then people here at JPL  
were the ones that actually

1295

00:58:23,065 --> 00:58:26,302

came up with and finished  
the grand finale orbits.

1296

00:58:26,302 --> 00:58:30,072

- So it's possible that  
the next Saturn mission

1297

00:58:30,072 --> 00:58:32,441

will be more ring-focused or  
something along those lines.

1298

00:58:32,441 --> 00:58:36,311

- There's almost a ring  
hovering type mission now

1299

00:58:36,311 --> 00:58:39,315

that the astrodynamics  
allow it to happen,

1300

00:58:39,315 --> 00:58:41,851

just need to get it started.

1301

00:58:41,851 --> 00:58:43,319

- So just to sort  
of answer that,

1302

00:58:43,319 --> 00:58:44,520

the priorities if we were  
to go back to Saturn,

1303

00:58:44,520 --> 00:58:46,488

NASA has a New  
Frontiers program,

1304

00:58:46,488 --> 00:58:49,892

and in it there are three  
possible Saturn missions.

1305

00:58:49,892 --> 00:58:51,794

One is a Saturn probe,

1306

00:58:51,794 --> 00:58:54,297

send a probe deep into  
Saturn's atmosphere,

1307

00:58:54,297 --> 00:58:57,866

measure noble gases in the  
composition as you go down,

1308

00:58:57,866 --> 00:59:00,135

the next is Titan as a target,

1309

00:59:00,135 --> 00:59:04,406

orbit Titan, land on Titan,  
float in Titan's methane seas,

1310

00:59:04,406 --> 00:59:06,675

and the third is to  
go back to Enceladus.

1311

00:59:06,675 --> 00:59:09,545

So those are the  
three major targets.

1312

00:59:09,545 --> 00:59:12,081

New Frontiers is a  
much smaller budget

1313

00:59:12,081 --> 00:59:14,116

than a big flagship  
like Cassini,

1314  
00:59:14,116 --> 00:59:17,119  
but at least there's three  
of them, three possibilities.

1315  
00:59:17,119 --> 00:59:18,854  
In November they'll down select,

1316  
00:59:18,854 --> 00:59:20,923  
I think they got  
40 some proposals,

1317  
00:59:20,923 --> 00:59:22,591  
go down to three to five,

1318  
00:59:22,591 --> 00:59:24,726  
and then further down select  
probably a year after that,

1319  
00:59:24,726 --> 00:59:27,296  
so we'll see if Saturn  
is still in the mix,

1320  
00:59:27,296 --> 00:59:28,798  
going back to Saturn,

1321  
00:59:28,798 --> 00:59:31,133  
but it's still, you know, it's  
probably 30 years from now

1322  
00:59:31,133 --> 00:59:32,468  
until we get back.

1323  
00:59:32,468 --> 00:59:33,635  
It's a long trip.

1324  
00:59:33,635 --> 00:59:34,503

- Fingers crossed.

1325

00:59:34,503 --> 00:59:35,404

- Yeah.

1326

00:59:35,404 --> 00:59:36,406

- Thank you.

1327

00:59:37,472 --> 00:59:40,008

- Hi, I have a two-parter also.

1328

00:59:40,008 --> 00:59:44,614

First question is, how  
long out are you able to

1329

00:59:44,614 --> 00:59:46,182

plan for this trip?

1330

00:59:46,182 --> 00:59:48,951

Like a 30 year mission,  
how long are you able...

1331

00:59:48,951 --> 00:59:50,986

I mean, do you start off  
with like a five year plan,

1332

00:59:50,986 --> 00:59:53,422

and then you, you  
know, figure that out,

1333

00:59:53,422 --> 00:59:54,823

and then after  
another five years,

1334

00:59:54,823 --> 00:59:55,924

you do another five year plan?

1335

00:59:55,924 --> 00:59:58,695

Like how much out do you end up

1336

00:59:58,695 --> 01:00:00,229

before you're like  
re-evaluating?

1337

01:00:00,229 --> 01:00:01,764

- You pretty much  
plan end to end,

1338

01:00:01,764 --> 01:00:03,866

you plan, you know, when  
you're gonna launch,

1339

01:00:03,866 --> 01:00:05,968

how long the cruise  
is gonna take,

1340

01:00:05,968 --> 01:00:08,070

and what your prime  
mission would be like,

1341

01:00:08,070 --> 01:00:10,773

and that's part of the  
package that you put together

1342

01:00:10,773 --> 01:00:14,209

and give to NASA for the  
missions that you want to fly.

1343

01:00:14,209 --> 01:00:17,480

So when we first got,  
Cassini started in 1990,

1344

01:00:17,480 --> 01:00:20,049

we picked the instruments,  
built the spacecraft,

1345

01:00:20,049 --> 01:00:21,784

we knew it would  
launch, you know,

1346

01:00:21,784 --> 01:00:23,185

we had some launch  
slips and things,

1347

01:00:23,185 --> 01:00:24,386

but when it launched in '97,

1348

01:00:24,386 --> 01:00:27,055

we knew exactly when  
it would get to Saturn,

1349

01:00:27,055 --> 01:00:30,726

and we knew exactly what those  
four years would look like.

1350

01:00:30,726 --> 01:00:33,528

- The solstice mission  
that I showed you

1351

01:00:33,528 --> 01:00:35,898

actually was planned in 2009,

1352

01:00:35,898 --> 01:00:39,368

right down to almost  
the final set of orbits.

1353

01:00:39,368 --> 01:00:41,403

Now there are certainly some  
tweaks and modifications,

1354

01:00:41,403 --> 01:00:45,575

but we really take the long  
view on that final set.

1355

01:00:46,943 --> 01:00:50,613

- So I'm also curious, the  
crash into Saturn with Cassini,

1356

01:00:50,613 --> 01:00:54,684  
was there a plan B, and  
why wasn't plan B chosen?

1357  
01:00:56,418 --> 01:00:59,888  
- Probably plans A through  
F, maybe through H,

1358  
01:00:59,888 --> 01:01:01,723  
and again, it's the science.

1359  
01:01:01,723 --> 01:01:03,559  
- Right, yeah, the  
science drove it,

1360  
01:01:03,559 --> 01:01:05,694  
and more than that, you  
know, the fuel light's on,

1361  
01:01:05,694 --> 01:01:07,296  
it's red and it's blinking,

1362  
01:01:07,296 --> 01:01:09,465  
and it's saying, you know,  
you're almost out of gas,

1363  
01:01:09,465 --> 01:01:11,167  
in fact we don't use  
the main engines,

1364  
01:01:11,167 --> 01:01:14,036  
we use use the  
hydrazine reservoir now,

1365  
01:01:14,036 --> 01:01:15,438  
and it really was the fuel,

1366  
01:01:15,438 --> 01:01:17,940  
healthy spacecraft,  
great instruments,

1367

01:01:17,940 --> 01:01:21,243  
you know, we just need a way  
to refuel, and we'd be fine.

1368

01:01:21,243 --> 01:01:22,245  
- Thank you.

1369

01:01:23,979 --> 01:01:26,516  
- Do we understand why  
the Saturnian system

1370

01:01:26,516 --> 01:01:29,819  
is so complex compared  
with another solar system,

1371

01:01:29,819 --> 01:01:34,089  
or any other planetary  
system in our solar system?

1372

01:01:34,089 --> 01:01:36,191  
- Well the Saturn  
system looks complex,

1373

01:01:36,191 --> 01:01:37,626  
you've got the main planet,

1374

01:01:37,626 --> 01:01:39,562  
you've got the  
rings, and 62 moons,

1375

01:01:39,562 --> 01:01:42,565  
but the Jovian system has  
complexities of its own,

1376

01:01:42,565 --> 01:01:44,600  
as do the systems of  
Uranus and Neptune,

1377

01:01:44,600 --> 01:01:47,169  
we just haven't studied  
Uranus and Neptune

1378  
01:01:47,169 --> 01:01:50,139  
as well as we've studied  
the Saturn system, you know.

1379  
01:01:50,139 --> 01:01:52,308  
Saturn just has these  
great big wonderful rings,

1380  
01:01:52,308 --> 01:01:54,744  
but so do Jupiter,  
Uranus, and Neptune,

1381  
01:01:54,744 --> 01:01:56,245  
they have rings too,

1382  
01:01:56,245 --> 01:01:58,581  
they have fascinating moons,  
maybe not quite as many,

1383  
01:01:58,581 --> 01:02:02,751  
but there's a lot of complexity  
with those outer planets.

1384  
01:02:02,751 --> 01:02:04,820  
- In other words,  
it just happened.

1385  
01:02:04,820 --> 01:02:06,455  
- Yeah, we don't know,  
that's a good question.

1386  
01:02:06,455 --> 01:02:09,558  
Why the moons ended up,  
the order and the masses,

1387  
01:02:09,558 --> 01:02:11,627

that's a really good question.

1388

01:02:11,627 --> 01:02:13,996

- The same question  
for both of you,

1389

01:02:13,996 --> 01:02:16,299

there have been many  
surprises on this mission,

1390

01:02:16,299 --> 01:02:19,001

what was the biggest  
surprise for you?

1391

01:02:19,001 --> 01:02:22,471

- You take that, what's  
the biggest surprise?

1392

01:02:22,471 --> 01:02:25,308

- I guess I've still got  
to go back to Enceladus.

1393

01:02:25,308 --> 01:02:28,111

I mean there's just  
something absolutely magical

1394

01:02:28,111 --> 01:02:29,712

about this...

1395

01:02:29,712 --> 01:02:32,582

I mean, again, it's just  
totally out of the blue

1396

01:02:32,582 --> 01:02:35,317

that it would be as  
dynamic as it is,

1397

01:02:35,317 --> 01:02:37,754

and not only dynamic  
in a geological sense,

1398

01:02:37,754 --> 01:02:40,356

but to have all the  
chemistry going on as well.

1399

01:02:40,356 --> 01:02:43,292

I mean that's just  
rewritten the book.

1400

01:02:43,292 --> 01:02:46,462

It's promoted itself  
from a class zero

1401

01:02:47,863 --> 01:02:49,499

to a class three object,

1402

01:02:49,499 --> 01:02:52,334

and by those I mean  
planetary protection terms,

1403

01:02:52,334 --> 01:02:54,469

it is something that, you know,

1404

01:02:54,469 --> 01:02:56,839

once in a lifetime you'll  
be walking down the trail

1405

01:02:56,839 --> 01:02:59,107

and you find a ruby.

1406

01:02:59,107 --> 01:03:00,876

It's just amazing.

1407

01:03:00,876 --> 01:03:03,412

- Yeah, I mean, Enceladus  
was a complete surprise.

1408

01:03:03,412 --> 01:03:05,515

A moon 300 miles across,

1409

01:03:05,515 --> 01:03:08,750

we thought for certain  
it would be frozen solid.

1410

01:03:08,750 --> 01:03:11,286

And to fly by and  
see active geysers

1411

01:03:11,286 --> 01:03:14,122

coming out of four  
fractures at the south pole,

1412

01:03:14,122 --> 01:03:16,458

mostly water vapor and  
water ice particles,

1413

01:03:16,458 --> 01:03:20,295

but you found organics,  
you found carbon dioxide,

1414

01:03:20,295 --> 01:03:23,999

methane, ammonia,  
then the global ocean

1415

01:03:23,999 --> 01:03:26,034

that was round the rocky core,

1416

01:03:26,034 --> 01:03:28,203

hydrothermal vents  
on the sea floor,

1417

01:03:28,203 --> 01:03:30,572

that hydrogen coming  
out has enough energy

1418

01:03:30,572 --> 01:03:33,042

in combination with methane,

1419

01:03:33,042 --> 01:03:35,244  
in fact the scientists  
did a calculation,

1420  
01:03:35,244 --> 01:03:36,812  
there's enough  
hydrogen coming out,

1421  
01:03:36,812 --> 01:03:38,980  
the energy there  
is the equivalent

1422  
01:03:38,980 --> 01:03:41,917  
of 300 cheese pizzas per hour

1423  
01:03:41,917 --> 01:03:43,085  
(audience laughing)

1424  
01:03:43,085 --> 01:03:44,586  
coming out of, you  
know, out of Enceladus.

1425  
01:03:44,586 --> 01:03:47,356  
If you wanted microbes, you  
had a lot of hungry microbes.

1426  
01:03:47,356 --> 01:03:49,826  
You have a lot of food  
there for them to eat.

1427  
01:03:49,826 --> 01:03:52,628  
So basically, I think  
one of Cassini's legacies

1428  
01:03:52,628 --> 01:03:54,363  
will be we've changed  
the way we look

1429  
01:03:54,363 --> 01:03:56,164  
at where you can find life.

1430

01:03:56,164 --> 01:03:58,801

It doesn't have to be  
in that Goldilocks zone

1431

01:03:58,801 --> 01:04:00,235

where the Earth is,  
where you can have

1432

01:04:00,235 --> 01:04:01,704

liquid water on the surface.

1433

01:04:01,704 --> 01:04:04,907

It could be beneath the icy  
crusts of worlds like Enceladus,

1434

01:04:04,907 --> 01:04:08,010

Europa, Titan, and  
perhaps other worlds,

1435

01:04:08,010 --> 01:04:09,812

so I think that's  
probably the biggest

1436

01:04:09,812 --> 01:04:13,648

shift in our thinking, where  
do you go to look for life.

1437

01:04:13,648 --> 01:04:16,385

And if we found life  
in Enceladus's ocean,

1438

01:04:16,385 --> 01:04:17,953

it would be remarkable,

1439

01:04:17,953 --> 01:04:20,822

to think that life could form  
underneath the icy crust,

1440

01:04:20,822 --> 01:04:22,924

it would be totally  
a different path

1441

01:04:22,924 --> 01:04:25,461

from the life that we  
took on our planet,

1442

01:04:25,461 --> 01:04:27,697

and by the same token  
if we didn't find life

1443

01:04:27,697 --> 01:04:31,267

in Enceladus's ocean, that  
would be remarkable as well,

1444

01:04:31,267 --> 01:04:33,802

because it would show you  
here you have this habitat,

1445

01:04:33,802 --> 01:04:37,405

you have these ingredients, and  
yet life didn't get started.

1446

01:04:37,405 --> 01:04:39,975

And so maybe life on  
the Earth is special.

1447

01:04:39,975 --> 01:04:43,245

So either way, whatever the  
answer to that question,

1448

01:04:43,245 --> 01:04:44,947

whether it's  
Enceladus or Europa,

1449

01:04:44,947 --> 01:04:48,383

it will be remarkable,  
whatever that answer.

1450

01:04:48,383 --> 01:04:49,385

- Thank you.

1451

01:04:52,154 --> 01:04:53,889

- Two questions.

1452

01:04:53,889 --> 01:04:56,992

One, is there a contingency plan

1453

01:04:56,992 --> 01:05:00,596

if any of these last orbits

throw a wrench in the works

1454

01:05:00,596 --> 01:05:03,098

or a surprise, sort of

like not finding dust,

1455

01:05:03,098 --> 01:05:05,234

maybe you find something

you weren't expecting,

1456

01:05:05,234 --> 01:05:06,902

and the second question is,

1457

01:05:06,902 --> 01:05:10,239

in the sort of

contingency planning,

1458

01:05:10,239 --> 01:05:13,642

is there any thought

or imagination

1459

01:05:13,642 --> 01:05:15,944

as to what happens when you

put a little bit of plutonium

1460

01:05:15,944 --> 01:05:19,581

on a planet that probably

didn't have it to begin with?

1461

01:05:19,581 --> 01:05:20,883

- You want to take  
the first part,

1462

01:05:20,883 --> 01:05:21,884

I'll take the second part.

1463

01:05:21,884 --> 01:05:23,118

- Sorry, I got--

1464

01:05:23,118 --> 01:05:24,286

- Oh, okay, the  
contingency plans.

1465

01:05:24,286 --> 01:05:27,422

Once we got the  
final flyby of Titan,

1466

01:05:27,422 --> 01:05:29,225

127th flyby,

1467

01:05:29,225 --> 01:05:31,993

we were pointed to what we  
call a ballistic trajectory,

1468

01:05:31,993 --> 01:05:33,996

and if something  
happened to Cassini,

1469

01:05:33,996 --> 01:05:37,699

the bits and pieces or  
whatever or the damaged Cassini

1470

01:05:37,699 --> 01:05:39,702

would follow the same orbits,

1471

01:05:39,702 --> 01:05:42,705

ending up in Saturn  
on September 15th.

1472

01:05:42,705 --> 01:05:44,105

So we don't have to  
do anything else,

1473

01:05:44,105 --> 01:05:46,408

and that's why NASA's  
planetary protection

1474

01:05:46,408 --> 01:05:48,677

really liked this set of orbits.

1475

01:05:48,677 --> 01:05:50,513

We could get in  
there, take the risk,

1476

01:05:50,513 --> 01:05:54,917

something happens, the mission  
is still gonna end with that.

1477

01:05:54,917 --> 01:05:57,519

As far as putting  
plutonium into Saturn,

1478

01:05:57,519 --> 01:05:59,621

if you look at the  
mass of Cassini

1479

01:05:59,621 --> 01:06:03,025

compared to the mass of  
Saturn, it's pretty tiny.

1480

01:06:03,025 --> 01:06:04,827

And one thing that's  
kinda cool to think about,

1481

01:06:04,827 --> 01:06:07,963

we're putting a little  
piece of Earth into Saturn.

1482

01:06:07,963 --> 01:06:10,399

So yeah, and we're  
going really fast,

1483

01:06:10,399 --> 01:06:11,933

and it's gonna be very hot,

1484

01:06:11,933 --> 01:06:13,535

so if we do have  
any microbes there,

1485

01:06:13,535 --> 01:06:14,737

they're gonna be toast.

1486

01:06:14,737 --> 01:06:17,039

(audience laughing)

1487

01:06:17,039 --> 01:06:18,040

- Thank you.

1488

01:06:19,975 --> 01:06:21,877

- I have two more questions.

1489

01:06:21,877 --> 01:06:23,679

(audience laughing)

1490

01:06:23,679 --> 01:06:27,015

One question would  
be what would you do

1491

01:06:27,015 --> 01:06:30,019

if you lost connection  
with Cassini?

1492

01:06:31,419 --> 01:06:32,287

- You want to take that, Earl?

1493

01:06:32,287 --> 01:06:33,722

- We would keep looking.

1494

01:06:33,722 --> 01:06:35,190  
(audience laughing)

1495

01:06:35,190 --> 01:06:38,894  
Cassini, and I don't mean to  
be glib, but what happens if...

1496

01:06:38,894 --> 01:06:42,798  
Cassini has a tremendous  
amount of what we call

1497

01:06:42,798 --> 01:06:45,701  
fall protection  
software built into it.

1498

01:06:45,701 --> 01:06:48,537  
So if we were to lose  
contact with Cassini,

1499

01:06:48,537 --> 01:06:51,506  
we have to talk to Cassini  
and Cassini has to talk to us.

1500

01:06:51,506 --> 01:06:54,042  
If for example we lost contact

1501

01:06:54,042 --> 01:06:56,444  
and Cassini didn't hear from us,

1502

01:06:56,444 --> 01:06:58,581  
it would start  
looking for the Earth,

1503

01:06:58,581 --> 01:07:01,016  
and meanwhile we're starting  
to look for Cassini,

1504

01:07:01,016 --> 01:07:03,652  
so we'd go through days and  
days and potentially weeks

1505  
01:07:03,652 --> 01:07:07,956  
of allowing Cassini to  
turn on different hardware,

1506  
01:07:07,956 --> 01:07:10,859  
different radios, point  
its antenna different ways,

1507  
01:07:10,859 --> 01:07:13,595  
meanwhile we're using all the  
antennas all over the Earth

1508  
01:07:13,595 --> 01:07:15,130  
to try to re-command it.

1509  
01:07:15,130 --> 01:07:19,301  
So if indeed it happened because  
Cassini failed in some way,

1510  
01:07:20,803 --> 01:07:22,871  
then we of course  
wouldn't hear back,

1511  
01:07:22,871 --> 01:07:26,241  
but it would be a long  
time before we gave up.

1512  
01:07:26,241 --> 01:07:28,077  
- We probably wouldn't  
give up 'til the end.

1513  
01:07:28,077 --> 01:07:30,445  
(audience laughing)

1514  
01:07:30,445 --> 01:07:32,214  
- My second question is,

1515

01:07:32,214 --> 01:07:36,385

are you going to start another mission after Cassini ends?

1516

01:07:37,719 --> 01:07:40,055

- Well, there's another mission in the works to Europa.

1517

01:07:40,055 --> 01:07:41,790

It's called the Europa Clipper.

1518

01:07:41,790 --> 01:07:43,759

And so NASA has selected to go back

1519

01:07:43,759 --> 01:07:45,961

to this other ocean world

1520

01:07:45,961 --> 01:07:48,697

and to study it and learn more about it,

1521

01:07:48,697 --> 01:07:51,066

for possible future missions there's even a proposal

1522

01:07:51,066 --> 01:07:54,035

for a Europa lander, to find a place where there might be

1523

01:07:54,035 --> 01:07:57,038

plumes on Europa, put a lander down on the surface,

1524

01:07:57,038 --> 01:08:01,109

and sample and look for life coming from that plume.

1525

01:08:01,109 --> 01:08:02,611

So that's sort of  
next on the books.

1526

01:08:02,611 --> 01:08:03,846

I hope there's a lot more.

1527

01:08:03,846 --> 01:08:05,280

I want to go back to  
Uranus and Neptune

1528

01:08:05,280 --> 01:08:07,882

and back to Saturn  
and Enceladus, so.

1529

01:08:07,882 --> 01:08:09,217

Hopefully there's a lot more.

1530

01:08:09,217 --> 01:08:10,219

- Thank you.

1531

01:08:11,753 --> 01:08:14,756

- Do you want to read some  
of the questions there?

1532

01:08:14,756 --> 01:08:16,124

- Thank you.

1533

01:08:16,124 --> 01:08:18,327

Following the goodbye kiss,

1534

01:08:18,327 --> 01:08:21,230

will you have control  
over the angle of descent

1535

01:08:21,230 --> 01:08:23,332

into Saturn's atmosphere?

1536

01:08:24,700 --> 01:08:27,369

You're saying no, you won't  
really know the angle?

1537

01:08:27,369 --> 01:08:29,705

- Well, we'll know  
this one thing,

1538

01:08:29,705 --> 01:08:31,239

'til the very last second,

1539

01:08:31,239 --> 01:08:33,842

we'll be pointing the high  
gain antenna at the Earth.

1540

01:08:33,842 --> 01:08:36,078

And that's our goal, and  
then while we do that,

1541

01:08:36,078 --> 01:08:38,280

the other axis is pointing

1542

01:08:38,280 --> 01:08:39,948

the ion and neutral  
mass spectrometer

1543

01:08:39,948 --> 01:08:41,983

in the direction of  
Saturn's atmosphere.

1544

01:08:41,983 --> 01:08:44,620

So we have picked  
that orientation.

1545

01:08:44,620 --> 01:08:47,589

Send back the most data,  
the longest possible time.

1546

01:08:47,589 --> 01:08:49,924

- The spacecraft will be  
controlling its attitude

1547

01:08:49,924 --> 01:08:52,528  
until it can't, and so  
we will know it's...

1548

01:08:52,528 --> 01:08:54,329  
And it will not only  
be controlling it,

1549

01:08:54,329 --> 01:08:55,931  
it'll be telling us what it is.

1550

01:08:55,931 --> 01:08:57,298  
Again, until it can't.

1551

01:08:57,298 --> 01:08:59,167  
- Would the hope be  
that it goes in maybe

1552

01:08:59,167 --> 01:09:00,869  
a little more  
shallow than steep,

1553

01:09:00,869 --> 01:09:02,071  
just to give you a  
few more seconds?

1554

01:09:02,071 --> 01:09:03,272  
- No, it's going in.

1555

01:09:03,272 --> 01:09:04,540  
It's going in.

1556

01:09:04,540 --> 01:09:06,842  
It's not gonna skip out,  
it's not gonna skip out.

1557

01:09:06,842 --> 01:09:09,344  
- If it comes out, we're

gonna be both very embarrassed

1558

01:09:09,344 --> 01:09:11,647  
and having to deal with a  
very damaged spacecraft.

1559

01:09:11,647 --> 01:09:12,647  
(audience laughing)

1560

01:09:12,647 --> 01:09:13,649  
- Thank you.

1561

01:09:16,552 --> 01:09:19,188  
- I'm not quite sure how to  
ask this question, but...

1562

01:09:19,188 --> 01:09:20,422  
- Great shirt, by the way.

1563

01:09:20,422 --> 01:09:21,257  
- Oh, thanks.

1564

01:09:21,257 --> 01:09:22,090  
- Absolutely.

1565

01:09:22,090 --> 01:09:24,426  
Thumbs up on the shirt.

1566

01:09:24,426 --> 01:09:26,061  
- How do I say this?

1567

01:09:26,061 --> 01:09:29,731  
So there's a lot of  
talk about the science,

1568

01:09:29,731 --> 01:09:32,334  
but what I'm curious  
to know is that

1569

01:09:32,334 --> 01:09:36,004

this is technology that we  
had 20 years ago, right?

1570

01:09:36,004 --> 01:09:39,541

When it launched,  
and so now it's 2017,

1571

01:09:39,541 --> 01:09:43,211

and so, and it  
feels like Cassini,

1572

01:09:43,211 --> 01:09:47,515

the analogy that I think  
of is like a jazz musician.

1573

01:09:47,515 --> 01:09:50,052

It feels like you're  
just kind of riffing.

1574

01:09:50,052 --> 01:09:52,120

And you're kinda  
just going around

1575

01:09:52,120 --> 01:09:53,989

and not necessarily  
making it up,

1576

01:09:53,989 --> 01:09:56,091

but you have like a hunch  
and you kinda go for it.

1577

01:09:56,091 --> 01:09:58,660

Knowing what we  
know now, you know,

1578

01:09:58,660 --> 01:10:01,997

like what will we bring to  
the next jam session, I guess?

1579

01:10:01,997 --> 01:10:05,434

Like what technology  
has evolved, or what  
have we learned,

1580

01:10:05,434 --> 01:10:07,536

or what kind of technology  
do we wish we had

1581

01:10:07,536 --> 01:10:11,507

on Cassini that we'll have  
for Europa Clipper, I suppose.

1582

01:10:11,507 --> 01:10:12,774

- Right, right.

1583

01:10:12,774 --> 01:10:15,944

Certainly had we known  
the potential for life

1584

01:10:15,944 --> 01:10:18,013

in Enceladus's ocean, if  
we knew it had an ocean,

1585

01:10:18,013 --> 01:10:21,316

we would've carried more  
capable mass spectrometers.

1586

01:10:21,316 --> 01:10:23,485

That we have mass  
spectrometers kind of like

1587

01:10:23,485 --> 01:10:27,990

100 atomic mass units,  
100 protons' worth  
of molecular size,

1588

01:10:27,990 --> 01:10:30,658

that's not nearly enough  
to look for fatty acids,

1589

01:10:30,658 --> 01:10:32,861  
amino acids, evidence for life.

1590

01:10:32,861 --> 01:10:34,863  
So you would carry  
mass spectrometers,

1591

01:10:34,863 --> 01:10:36,731  
instruments that  
could do the sampling

1592

01:10:36,731 --> 01:10:38,266  
that could help answer the...

1593

01:10:38,266 --> 01:10:40,168  
You're getting free samples,  
so take advantage, you know,

1594

01:10:40,168 --> 01:10:42,404  
and check it out, and who knows

1595

01:10:42,404 --> 01:10:44,339  
with the camera  
technologies, you know,

1596

01:10:44,339 --> 01:10:45,940  
our cameras may not be as good

1597

01:10:45,940 --> 01:10:47,342  
as the cell phone  
cameras of today.

1598

01:10:47,342 --> 01:10:49,410  
So you could do a lot  
more with the cameras,

1599

01:10:49,410 --> 01:10:52,914  
the spectrometers, all

## kinds of instruments

1600

01:10:52,914 --> 01:10:54,415  
with the technologies today,

1601

01:10:54,415 --> 01:10:57,052  
and we'd have a lot of  
more orbit choice, too,

1602

01:10:57,052 --> 01:10:59,021  
we could do, you know,  
skim across the rings,

1603

01:10:59,021 --> 01:11:00,522  
finding this unique orbit,

1604

01:11:00,522 --> 01:11:02,390  
maybe go inside  
and come back out,

1605

01:11:02,390 --> 01:11:04,025  
now that we know it's clear.

1606

01:11:04,025 --> 01:11:06,328  
You know, we could do maybe  
a lot of things differently.

1607

01:11:06,328 --> 01:11:08,797  
Carry two probes, maybe a  
Titan orbiter, you know,

1608

01:11:08,797 --> 01:11:10,766  
a lot you could do.

1609

01:11:10,766 --> 01:11:12,000  
- Okay, great.

1610

01:11:12,000 --> 01:11:14,069  
Thank you so much.

1611

01:11:14,069 --> 01:11:15,570

- Do you want to, okay.

1612

01:11:15,570 --> 01:11:17,005

After this, we're gonna ask a couple question from online,

1613

01:11:17,005 --> 01:11:18,506

yeah.

1614

01:11:18,506 --> 01:11:22,011

- One of the objectives that you named for this final dive

1615

01:11:23,245 --> 01:11:25,780

is to keep Titan pristine,

1616

01:11:25,780 --> 01:11:28,383

but Huygens has already gone into Titan.

1617

01:11:28,383 --> 01:11:31,753

So how, was there special protection done?

1618

01:11:31,753 --> 01:11:33,555

Or was it done on the assumption

1619

01:11:33,555 --> 01:11:35,957

that we weren't going to find as much as we did there?

1620

01:11:35,957 --> 01:11:37,859

- You know, I think that's a fair comment,

1621

01:11:37,859 --> 01:11:41,797

and we really have to

be very careful about

1622

01:11:41,797 --> 01:11:43,932

Titan's classification.

1623

01:11:43,932 --> 01:11:47,936

It still is, and was what  
we call a category two,

1624

01:11:47,936 --> 01:11:52,540

which means that the  
probability of contamination

1625

01:11:52,540 --> 01:11:56,978

influencing future  
investigations is very very low.

1626

01:11:56,978 --> 01:12:01,383

But nonetheless, you  
know, Huygens soft-landed,

1627

01:12:01,383 --> 01:12:02,684

you're absolutely right,

1628

01:12:02,684 --> 01:12:05,187

it wasn't cleaned any  
more than Cassini was,

1629

01:12:05,187 --> 01:12:06,989

it wasn't decontaminated,

1630

01:12:06,989 --> 01:12:09,724

and so it could've potentially  
left microbes on the surface,

1631

01:12:09,724 --> 01:12:11,993

but again, we're  
bringing plutonium,

1632

01:12:11,993 --> 01:12:14,529

lots of it onto the  
surface, potentially,

1633

01:12:14,529 --> 01:12:18,032

and again, it's something  
that we need to take

1634

01:12:18,032 --> 01:12:20,869

every reasonable  
precaution to avoid.

1635

01:12:20,869 --> 01:12:25,040

But Enceladus went from a  
category one or even maybe zero

1636

01:12:26,674 --> 01:12:29,744

to category three, which means  
that the probability of us,

1637

01:12:29,744 --> 01:12:31,246

our requirements  
on the probability

1638

01:12:31,246 --> 01:12:34,048

of inadvertently striking  
it are much more stringent,

1639

01:12:34,048 --> 01:12:36,017

and that's really the driver.

1640

01:12:36,017 --> 01:12:39,121

Titan, at the time  
it seemed fine,

1641

01:12:39,121 --> 01:12:41,957

and you know, you  
can't undo what we did,

1642

01:12:41,957 --> 01:12:43,492

and the classification  
hasn't changed,

1643  
01:12:43,492 --> 01:12:46,061  
but it still looks  
different now than it did.

1644  
01:12:46,061 --> 01:12:48,196  
- Right, you could  
still land on Titan,

1645  
01:12:48,196 --> 01:12:49,664  
the way it's categorized now.

1646  
01:12:49,664 --> 01:12:53,668  
In part, the icy crust is so  
thick above the ocean of Titan,

1647  
01:12:53,668 --> 01:12:57,338  
which is where we'd worry  
about Earth kinds of life,

1648  
01:12:57,338 --> 01:12:59,007  
but that is, you  
know, so that's why

1649  
01:12:59,007 --> 01:13:00,875  
it's stayed a category two.

1650  
01:13:00,875 --> 01:13:02,177  
And there's no direct contact,

1651  
01:13:02,177 --> 01:13:04,246  
we don't see any  
geysers or you know,

1652  
01:13:04,246 --> 01:13:07,048  
jets or anything coming  
out from Titan's surface.

1653

01:13:07,048 --> 01:13:08,416

- Okay, thank you.

1654

01:13:08,416 --> 01:13:12,487

- We've got a few questions  
from the internet.

1655

01:13:12,487 --> 01:13:15,990

Ocean McIntire, and  
this is for you Linda,

1656

01:13:15,990 --> 01:13:18,259

are there any suspected  
reasons for the lack,

1657

01:13:18,259 --> 01:13:19,594

in fact they're all for you.

1658

01:13:19,594 --> 01:13:21,797

Any suspected reasons  
for the lack of dust

1659

01:13:21,797 --> 01:13:23,531

within the ring gap?

1660

01:13:23,531 --> 01:13:24,733

- Wow, that's a great question.

1661

01:13:24,733 --> 01:13:26,167

Why no dust?

1662

01:13:26,167 --> 01:13:29,003

That's a really good  
question, we don't know.

1663

01:13:29,003 --> 01:13:31,439

We're hoping with  
a few more orbits,

1664

01:13:31,439 --> 01:13:33,008

we can, and a little bit  
more time, figure that out.

1665

01:13:33,008 --> 01:13:34,276

But a complete surprise,

1666

01:13:34,276 --> 01:13:36,244

of all the things we  
would have guessed,

1667

01:13:36,244 --> 01:13:39,948

no dust was not even  
on the list, so.

1668

01:13:39,948 --> 01:13:43,518

- And then the dynamics  
for polar activity,

1669

01:13:43,518 --> 01:13:45,787

or inactivity look impressive.

1670

01:13:45,787 --> 01:13:47,922

Can you elaborate?

1671

01:13:47,922 --> 01:13:50,658

- Okay, for polar activity.

1672

01:13:50,658 --> 01:13:52,460

- Yeah, about polar activity.

1673

01:13:52,460 --> 01:13:54,963

- Okay, I think we're probably  
talking about the hexagon

1674

01:13:54,963 --> 01:13:58,066

and the vortices,  
the hurricane-like  
vortices at the poles.

1675

01:13:58,066 --> 01:14:00,869

You know, Saturn is  
spinning, it's mostly gas,

1676

01:14:00,869 --> 01:14:03,438

we know hurricanes on  
Earth tend to migrate,

1677

01:14:03,438 --> 01:14:05,140

you know, toward the poles,

1678

01:14:05,140 --> 01:14:06,941

they don't ever make it there  
because they're out of energy,

1679

01:14:06,941 --> 01:14:09,811

but we have those two  
hurricane-like features

1680

01:14:09,811 --> 01:14:12,580

right at the poles, and the  
energy source for the hexagon

1681

01:14:12,580 --> 01:14:15,384

for that jet stream, that's  
a really good question.

1682

01:14:15,384 --> 01:14:17,585

We're hoping our  
pictures and new data

1683

01:14:17,585 --> 01:14:19,054

will help us figure that out.

1684

01:14:19,054 --> 01:14:20,455

- I think that must be  
the inactivity references

1685

01:14:20,455 --> 01:14:22,724  
to the stability  
of that hexagon.

1686  
01:14:22,724 --> 01:14:24,126  
- Right, it's been  
there at least 30 years,

1687  
01:14:24,126 --> 01:14:25,126  
Voyager discovered it, so.

1688  
01:14:25,126 --> 01:14:26,561  
- And then here's a fine one,

1689  
01:14:26,561 --> 01:14:28,696  
here's a good fitting question.

1690  
01:14:28,696 --> 01:14:31,366  
AJ asks, will there  
be a followup mission

1691  
01:14:31,366 --> 01:14:33,001  
to Saturn in the future?

1692  
01:14:33,001 --> 01:14:34,436  
- Oh, I certainly hope so.

1693  
01:14:34,436 --> 01:14:37,539  
To Saturn, to Enceladus,  
to Saturn, Titan,

1694  
01:14:37,539 --> 01:14:38,973  
there's so much we've left,

1695  
01:14:38,973 --> 01:14:41,643  
so many questions  
that we now have open

1696  
01:14:41,643 --> 01:14:42,977

for a future mission.

1697

01:14:42,977 --> 01:14:44,813

So thank you very much,  
thank you for coming.

1698

01:14:44,813 --> 01:14:47,249

(applauding)