



Ames Research Center



1
00:00:04,166 --> 00:00:07,000
[music playing]

2
00:00:16,166 --> 00:00:17,666
- Welcome, everyone.

3
00:00:17,666 --> 00:00:20,700
It's great to see
such a good turnout today.

4
00:00:20,700 --> 00:00:22,233
I think you all know by now

5
00:00:22,233 --> 00:00:24,666
there is a lot going on
at the center today,

6
00:00:24,666 --> 00:00:28,133
and this is one of a few
real keynote events

7
00:00:28,133 --> 00:00:31,866
that I hope you'll all be able
to take advantage of.

8
00:00:31,866 --> 00:00:34,233
We've got students
all over the center.

9
00:00:34,233 --> 00:00:37,400
We've got a poster session
later today, free lunch,

10
00:00:37,400 --> 00:00:41,033
and a diversity
and inclusion day.

11
00:00:41,033 --> 00:00:44,133
So let me start

by sharing with you

12

00:00:44,133 --> 00:00:47,200
the lament of a senior manager:

13

00:00:47,200 --> 00:00:49,500
that there are many things
that I get to start,

14

00:00:49,500 --> 00:00:51,833
and few that I get to finish.

15

00:00:51,833 --> 00:00:56,400
And so although it's not
my style or my preference,

16

00:00:56,400 --> 00:01:00,066
I am starting things today
for you,

17

00:01:00,066 --> 00:01:03,433
but I need to go and start
some other things too.

18

00:01:03,433 --> 00:01:07,833
And so I need to excuse myself
as soon as I finish this.

19

00:01:07,833 --> 00:01:10,066
I really wish I could stay,

20

00:01:10,066 --> 00:01:12,500
because this is
a fascinating subject

21

00:01:12,500 --> 00:01:15,333
that I really look forward
to hearing about,

22

00:01:15,333 --> 00:01:17,633
and I'll have to find
some other way to catch up

23

00:01:17,633 --> 00:01:21,466
and learn the message
from today.

24

00:01:21,466 --> 00:01:24,366
So with that aside,
let me tell you a little bit

25

00:01:24,366 --> 00:01:25,900
about our speaker today.

26

00:01:25,900 --> 00:01:28,900
Some of you already know him.

27

00:01:28,900 --> 00:01:30,600
The presentation is entitled,

28

00:01:30,600 --> 00:01:33,700
"Exploration of Pluto
by New Horizons."

29

00:01:33,700 --> 00:01:37,566
And our speaker today
is Dr. Alan Stern,

30

00:01:37,566 --> 00:01:41,966
who is the Principal
Investigator of this mission.

31

00:01:41,966 --> 00:01:46,033
But he's also a familiar face
to many of us at NASA,

32

00:01:46,033 --> 00:01:49,000
because from 2007 to 2008,

33

00:01:49,000 --> 00:01:51,166

he was the Associate
Administrator

34

00:01:51,166 --> 00:01:52,500

at NASA headquarters,

35

00:01:52,500 --> 00:01:54,466

and the Science Mission
Directorate.

36

00:01:54,466 --> 00:01:56,833

And under that tenure,

37

00:01:56,833 --> 00:01:59,233

he is known for having sponsored

38

00:01:59,233 --> 00:02:04,166

a number of very successful
accomplishments and missions,

39

00:02:04,166 --> 00:02:07,500

one of which was our very own
LADEE during that time

40

00:02:07,500 --> 00:02:09,466

that he was
Associate Administrator.

41

00:02:09,466 --> 00:02:12,633

So we're deeply appreciative
of the support for that mission,

42

00:02:12,633 --> 00:02:17,133

and some others that took place
during that tenure

43

00:02:17,133 --> 00:02:21,100

featured the first woman

Principal Investigator

44

00:02:21,100 --> 00:02:22,533
for a number of missions.

45

00:02:22,533 --> 00:02:23,933
One of them was

46

00:02:23,933 --> 00:02:27,533
the Discovery-class mission
for GRAIL.

47

00:02:27,533 --> 00:02:30,366
Another one was an
Explorer-class mission

48

00:02:30,366 --> 00:02:32,300
for NuSTAR.

49

00:02:32,300 --> 00:02:34,700
And finally,
Living With a Star,

50

00:02:34,700 --> 00:02:38,433
the Star Geospace Mission of
Opportunity, the BARREL mission.

51

00:02:38,433 --> 00:02:42,833
So that was really a pioneering
set of historic events too

52

00:02:42,833 --> 00:02:46,100
that took place
while he was with NASA.

53

00:02:46,100 --> 00:02:50,000
He's been involved
with 27 suborbital, orbital,

54

00:02:50,000 --> 00:02:52,000
and planetary space missions,

55

00:02:52,000 --> 00:02:55,100
including eight for which he was
the Principal Investigator

56

00:02:55,100 --> 00:02:57,033
on the mission.

57

00:02:57,033 --> 00:02:59,633
It all started,
I might point out,

58

00:02:59,633 --> 00:03:02,966
as a summer intern
at Johnson Space Center.

59

00:03:02,966 --> 00:03:05,466
And the year that
that took place has been omitted

60

00:03:05,466 --> 00:03:07,966
for the sake of the innocent.

61

00:03:07,966 --> 00:03:10,066
But needless to say,

62

00:03:10,066 --> 00:03:13,666
it's a very strong endorsement
of student internships

63

00:03:13,666 --> 00:03:15,800
and the value that they create

64

00:03:15,800 --> 00:03:19,600
for individuals
in their careers.

65

00:03:19,600 --> 00:03:23,833
Dr. Stern completed two Master's
degrees in aerospace engineering

66
00:03:23,833 --> 00:03:25,800
and atmospheric sciences,

67
00:03:25,800 --> 00:03:28,666
and Bachelor's degrees
in physics and astronomy

68
00:03:28,666 --> 00:03:31,133
from the University of Texas.

69
00:03:31,133 --> 00:03:35,500
Dr. Stern earned his PhD in 1989
in astrophysics

70
00:03:35,500 --> 00:03:39,333
and planetary science
from the University of Colorado.

71
00:03:39,333 --> 00:03:42,733
He has published
over 250 technical papers

72
00:03:42,733 --> 00:03:45,200
and 40 popular articles,

73
00:03:45,200 --> 00:03:47,766
and has received
numerous awards,

74
00:03:47,766 --> 00:03:51,433
including the American
Astronomical Society 2016

75
00:03:51,433 --> 00:03:53,166
Carl Sagan Award.

76

00:03:53,166 --> 00:03:55,900

And very recently
he paid us a visit,

77

00:03:55,900 --> 00:03:58,133

just a month ago,
to receive

78

00:03:58,133 --> 00:04:02,300

the NASA Distinguished
Public Service Medal.

79

00:04:02,300 --> 00:04:06,933

In 2007 and 2016,
Dr. Stern was listed

80

00:04:06,933 --> 00:04:10,866

among TIME Magazine's 100 most
influential people in the world.

81

00:04:10,866 --> 00:04:13,500

So I hope you are
equally influenced

82

00:04:13,500 --> 00:04:16,100

by everything
that he has to say today.

83

00:04:16,100 --> 00:04:19,566

And please help me in giving a
warm welcome to Dr. Alan Stern.

84

00:04:19,566 --> 00:04:22,566

[applause]

85

00:04:28,133 --> 00:04:31,433

- Well, thank you for that
very generous introduction.

86

00:04:31,433 --> 00:04:33,566

And that didn't raise the bar
at all, so...

87

00:04:33,566 --> 00:04:35,566

[laughs]

88

00:04:35,566 --> 00:04:38,000

I want to say thank you
for having me out to Ames.

89

00:04:38,000 --> 00:04:40,633

It's always great
to come out here.

90

00:04:40,633 --> 00:04:42,733

I see a lot of people
in the audience,

91

00:04:42,733 --> 00:04:46,500

but it's very hard with
the lights to see who's where.

92

00:04:46,500 --> 00:04:48,600

One of the great things
about New Horizons

93

00:04:48,600 --> 00:04:50,233

is it's a team.

94

00:04:50,233 --> 00:04:53,833

And coming out here to Ames,
I want to point out

95

00:04:53,833 --> 00:04:56,533

for those of you
that don't know it,

96

00:04:56,533 --> 00:04:59,233

Ames plays a big role

in New Horizons.

97

00:04:59,233 --> 00:05:02,133

Dr. Dale Cruikshank, who I know
is sitting over there,

98

00:05:02,133 --> 00:05:04,066

is one of our co-investigators.

99

00:05:04,066 --> 00:05:07,400

I know that there are
quite a number of collaborators

100

00:05:07,400 --> 00:05:11,366

on the New Horizons science team
that are here today.

101

00:05:11,366 --> 00:05:14,866

We have other co-investigators
from Ames like Jeff Moore,

102

00:05:14,866 --> 00:05:16,166

who's not here today.

103

00:05:16,166 --> 00:05:18,433

But I was with Jeff
in Arizona earlier this week.

104

00:05:18,433 --> 00:05:21,966

He runs our geology--
geophysics imaging team.

105

00:05:21,966 --> 00:05:24,166

We have co-investigators
at the SETI Institute,

106

00:05:24,166 --> 00:05:25,533

and at Stanford.

107

00:05:25,533 --> 00:05:28,933

And so the whole Bay Area
is really very well represented

108

00:05:28,933 --> 00:05:30,433

on New Horizons.

109

00:05:30,433 --> 00:05:35,666

Now for today, I'm gonna give
a sort of soup-to-nuts talk

110

00:05:35,666 --> 00:05:40,300

about how we got to do this,
what it was all about,

111

00:05:40,300 --> 00:05:42,766

and some of the discoveries
that we've made.

112

00:05:42,766 --> 00:05:46,100

And then I'll connect it
to a couple of other things

113

00:05:46,100 --> 00:05:47,733

at the tail end.

114

00:05:47,733 --> 00:05:50,033

And so let's just go ahead
and get started.

115

00:05:50,033 --> 00:05:51,600

I'm going to do most of this
with a clicker.

116

00:05:51,600 --> 00:05:53,200

And there you go.

117

00:05:53,200 --> 00:05:54,766

Meet Pluto.

118

00:05:54,766 --> 00:05:58,766

I suspect most of you have
seen this natural color image

119

00:05:58,766 --> 00:06:01,366

of this distant little
dwarf planet

120

00:06:01,366 --> 00:06:04,833

over 3 billion miles away.

121

00:06:04,833 --> 00:06:10,366

This is an image mosaic
made by New Horizons data,

122

00:06:10,366 --> 00:06:12,800

showing the close encounter
hemisphere

123

00:06:12,800 --> 00:06:15,900

that we explored in detail
last July.

124

00:06:15,900 --> 00:06:18,900

But prior to last July,
this was the best image of Pluto

125

00:06:18,900 --> 00:06:21,400

that had ever been made.

126

00:06:21,400 --> 00:06:25,233

This is as good as it got
for almost 85 years,

127

00:06:25,233 --> 00:06:26,566

from the time
of Pluto's discovery

128

00:06:26,566 --> 00:06:28,600

until we sent
a spacecraft there.

129

00:06:28,600 --> 00:06:31,800

This image was made
with the Hubble Space Telescope.

130

00:06:31,800 --> 00:06:34,166

And you just can't do better,
because it's defraction limited

131

00:06:34,166 --> 00:06:36,566

and above the Earth's
atmosphere.

132

00:06:36,566 --> 00:06:38,566

And I have to tell you,
embarrassingly,

133

00:06:38,566 --> 00:06:41,466

because I was the PI
of the Hubble program

134

00:06:41,466 --> 00:06:42,900

that took this image,

135

00:06:42,900 --> 00:06:46,300

that we wrote lots of papers
about that.

136

00:06:46,300 --> 00:06:48,933

[audience laughter]

137

00:06:48,933 --> 00:06:50,866

Even though we knew
that what you really need

138

00:06:50,866 --> 00:06:53,566

are data like this
to understand a planet.

139

00:06:53,566 --> 00:06:54,766

Right?

140

00:06:54,766 --> 00:06:57,200

In fact,

141

00:06:57,200 --> 00:06:58,733

if you take this image
of the Earth,

142

00:06:58,733 --> 00:07:00,166

from which you can do
real science

143

00:07:00,166 --> 00:07:03,233

if you had been doing
your first flyby of the Earth,

144

00:07:03,233 --> 00:07:06,666

and pixelate it
to the same resolution

145

00:07:06,666 --> 00:07:09,166

as that image of Pluto,

146

00:07:09,166 --> 00:07:12,633

which I had one of our
New Horizons postdocs,

147

00:07:12,633 --> 00:07:16,200

Amanda Zangari, do,
this is what you get.

148

00:07:16,200 --> 00:07:19,500

So, what could you learn about
the Earth at that resolution?

149

00:07:19,500 --> 00:07:21,533

It's not very much.

150

00:07:21,533 --> 00:07:23,866

You can't even tell that there
are continents and oceans

151

00:07:23,866 --> 00:07:26,266

on the planet.

152

00:07:26,266 --> 00:07:28,700

In fact, you know,
this is the reason

153

00:07:28,700 --> 00:07:31,866

that we send spacecraft
far away,

154

00:07:31,866 --> 00:07:35,700

is to get close
so we can do real science.

155

00:07:35,700 --> 00:07:38,400

And I would like to drive
that home a little further

156

00:07:38,400 --> 00:07:40,033

by showing this picture

157

00:07:40,033 --> 00:07:42,233

and asking if anyone
in the first couple of rows

158

00:07:42,233 --> 00:07:44,166

wants to guess
what we're looking at.

159

00:07:45,800 --> 00:07:47,433

Well, it might be Mars,
but it's not.

160
00:07:47,433 --> 00:07:49,133
[audience laughter]

161
00:07:49,133 --> 00:07:51,533
Which just makes the point.

162
00:07:51,533 --> 00:07:54,600
Now, New Horizons
was a big project.

163
00:07:54,600 --> 00:07:57,900
2,500 men and women worked on it
at one point or another

164
00:07:57,900 --> 00:08:00,466
to build it and to launch it,

165
00:08:00,466 --> 00:08:03,800
and then a very small team
flew it across the solar system.

166
00:08:03,800 --> 00:08:07,200
It's the first mission in NASA's

167
00:08:07,200 --> 00:08:11,500
Science Mission Directorate
New Frontiers program,

168
00:08:11,500 --> 00:08:15,200
which flies approximately
billion-dollar-class missions.

169
00:08:15,200 --> 00:08:17,666
Juno, which just entered orbit
around Jupiter,

170
00:08:17,666 --> 00:08:19,800
is the second mission
in that sequence.

171

00:08:19,800 --> 00:08:21,566

And the third one,
called OSIRIS-REx,

172

00:08:21,566 --> 00:08:23,833

which will sample
a near-Earth asteroid,

173

00:08:23,833 --> 00:08:25,800

is gonna launch next month.

174

00:08:27,100 --> 00:08:30,866

And you might wonder,
how did we get to do this?

175

00:08:30,866 --> 00:08:32,833

Right?
To explore the farthest worlds

176

00:08:32,833 --> 00:08:34,600

that humans have ever explored,

177

00:08:34,600 --> 00:08:37,100

to win a mission to Pluto,

178

00:08:37,100 --> 00:08:39,900

and then get to build it
and fly it,

179

00:08:39,900 --> 00:08:42,566

and then have lots of fun
with the data.

180

00:08:42,566 --> 00:08:45,666

I have to say, it took a while.

181

00:08:45,666 --> 00:08:50,833

I first got the bug to be a part

of something like this in 1989.

182

00:08:52,466 --> 00:08:55,466

And NASA conducted
the first real study

183

00:08:55,466 --> 00:08:57,233

of how to do a Pluto mission

184

00:08:57,233 --> 00:09:00,066

just after Voyager
had flown by Neptune,

185

00:09:00,066 --> 00:09:03,300

finishing its exploration
of the giant planets.

186

00:09:03,300 --> 00:09:05,733

That was called Pluto 350,

187

00:09:05,733 --> 00:09:11,033

because that spacecraft
was gonna weigh 350 kilograms.

188

00:09:11,033 --> 00:09:13,466

But that project never got legs.

189

00:09:13,466 --> 00:09:15,566

It was cancelled
in favor of the idea

190

00:09:15,566 --> 00:09:17,900

of something called
Pluto Mariner Mark 2,

191

00:09:17,900 --> 00:09:21,533

which was the idea of taking
the Cassini line--

192

00:09:21,533 --> 00:09:23,300

Cassini is a Saturn orbiter--

193

00:09:23,300 --> 00:09:24,933

and flying more of them,

194

00:09:24,933 --> 00:09:27,700

one of them the size

of a houseboat,

195

00:09:27,700 --> 00:09:29,733

to Pluto.

196

00:09:29,733 --> 00:09:32,000

And then that turned out

to be too expensive

197

00:09:32,000 --> 00:09:33,966

for what the budget

could afford.

198

00:09:33,966 --> 00:09:36,666

So we looked at--we went

from houseboats to hamsters.

199

00:09:36,666 --> 00:09:39,266

And the next iteration

was called Pluto Fast Flyby,

200

00:09:39,266 --> 00:09:42,933

and it was gonna weigh 35 kilos,

including fuel.

201

00:09:42,933 --> 00:09:45,933

One-tenth Pluto 350.

202

00:09:45,933 --> 00:09:48,166

That didn't turn out

to work at all.

203

00:09:48,166 --> 00:09:53,833

By the time...

it got a good, hard look,

204

00:09:53,833 --> 00:09:56,133

the spacecraft kept growing

and growing in mass,

205

00:09:56,133 --> 00:09:58,300

and growing and growing in cost.

206

00:09:58,300 --> 00:09:59,766

And so it got canceled,

207

00:09:59,766 --> 00:10:01,833

and they rebooted

as Pluto Express.

208

00:10:01,833 --> 00:10:03,200

And I won't go through

all the steps,

209

00:10:03,200 --> 00:10:05,000

but you see it there

listed in time.

210

00:10:05,000 --> 00:10:08,366

New Horizons

was the sixth iteration.

211

00:10:08,366 --> 00:10:11,633

The sixth attempt

to get a spacecraft

212

00:10:11,633 --> 00:10:14,000

all the way out

to the Pluto system.

213

00:10:14,000 --> 00:10:15,766

And I'm saying this

214

00:10:15,766 --> 00:10:17,466
primarily for the students
in the audience,

215

00:10:17,466 --> 00:10:18,900
the interns,

216

00:10:18,900 --> 00:10:21,800
because one of the things
that it takes in space flight--

217

00:10:21,800 --> 00:10:23,566
and if you talk to people
in other projects,

218

00:10:23,566 --> 00:10:25,566
even Earth-orbital projects,

219

00:10:25,566 --> 00:10:28,633
human space flight
as well as robotic,

220

00:10:28,633 --> 00:10:30,233
and it's true in research too--

221

00:10:30,233 --> 00:10:31,966
it takes persistence.

222

00:10:31,966 --> 00:10:33,233
You've got to really want it.

223

00:10:33,233 --> 00:10:35,500
The scientific community
stuck with this

224

00:10:35,500 --> 00:10:37,566
and kept going back

to the agency

225

00:10:37,566 --> 00:10:39,100
and the advisory committees.

226

00:10:39,100 --> 00:10:44,333
And every time, a Pluto mission
fell apart for some reason.

227

00:10:44,333 --> 00:10:46,166
Sometimes costs,
sometimes technical,

228

00:10:46,166 --> 00:10:48,700
sometimes the management team
wasn't right.

229

00:10:48,700 --> 00:10:50,000
Whatever.

230

00:10:50,000 --> 00:10:53,633
The community picked itself up
off the floor and said,

231

00:10:53,633 --> 00:10:55,800
"Let's start again."

232

00:10:55,800 --> 00:10:58,500
And not just two or three times.
Half a dozen different times.

233

00:10:58,500 --> 00:11:02,433
Now, to get the funding
to do something like this...

234

00:11:05,233 --> 00:11:07,966
Is a significant activity
in and of itself.

235

00:11:07,966 --> 00:11:10,500
And ultimately
in the United States,

236
00:11:10,500 --> 00:11:13,033
things like this
have to rise through

237
00:11:13,033 --> 00:11:16,766
an independent review process
called a decadal survey.

238
00:11:16,766 --> 00:11:19,433
In the case of Pluto,

239
00:11:19,433 --> 00:11:21,500
and flying a mission
to the Pluto system,

240
00:11:21,500 --> 00:11:24,100
we were making the case
all through the '90s

241
00:11:24,100 --> 00:11:26,266
to advisory committees

242
00:11:26,266 --> 00:11:29,866
that we knew many interesting
things about Pluto,

243
00:11:29,866 --> 00:11:35,000
and that it promised to get
a lot of bang, scientifically,

244
00:11:35,000 --> 00:11:38,566
for the bucks that were
gonna be involved.

245
00:11:38,566 --> 00:11:42,766
At the top is an infrared

reflectance spectrum

246

00:11:42,766 --> 00:11:46,366
of the surface of Pluto,
actually made in the 1990s.

247

00:11:46,366 --> 00:11:49,766
Dale Cruikshank may have
actually been the observer.

248

00:11:49,766 --> 00:11:51,466
He's saying yes.
So Dale--

249

00:11:51,466 --> 00:11:53,566
this is Dale's spectrum.

250

00:11:53,566 --> 00:11:57,300
And you can see that there are
quite a number of molecules

251

00:11:57,300 --> 00:12:01,133
whose absorption features
are seen there.

252

00:12:01,133 --> 00:12:02,633
The interesting thing
is all three

253

00:12:02,633 --> 00:12:04,800
of the primary constituents
that you see--

254

00:12:04,800 --> 00:12:08,233
the methane bands,
the molecular nitrogen bands,

255

00:12:08,233 --> 00:12:10,900
and the carbon monoxide--
are all molecules

256

00:12:10,900 --> 00:12:14,933

that are capable of being mobile
on Pluto's surface

257

00:12:14,933 --> 00:12:17,766

at the relevant surface
temperatures way out there.

258

00:12:17,766 --> 00:12:19,600

35 or 40 Kelvin.

259

00:12:19,600 --> 00:12:22,733

And so those molecules
all play analogous roles,

260

00:12:22,733 --> 00:12:26,100

because they can go from solid
state to vapor phase and back,

261

00:12:26,100 --> 00:12:28,533

and therefore transport
around the surface

262

00:12:28,533 --> 00:12:30,800

that water plays on the Earth,

263

00:12:30,800 --> 00:12:33,733

or that CO₂,
carbon dioxide and water,

264

00:12:33,733 --> 00:12:35,233

play on Mars.

265

00:12:35,233 --> 00:12:37,600

So this promised
very interesting

266

00:12:37,600 --> 00:12:39,866

surface atmosphere interactions

267

00:12:39,866 --> 00:12:43,366
and a very complex interaction,
we thought,

268

00:12:43,366 --> 00:12:46,933
between the geology
and volatile transport.

269

00:12:46,933 --> 00:12:48,900
These three molecules
being called volatile

270

00:12:48,900 --> 00:12:50,800
because they can
transport around.

271

00:12:50,800 --> 00:12:52,833
We also knew that Pluto
had an atmosphere.

272

00:12:52,833 --> 00:12:56,866
In the lower left
is a trace of an occultation,

273

00:12:56,866 --> 00:13:00,166
an event in which a star
was observed in the late 1980s

274

00:13:00,166 --> 00:13:02,800
by the Kuiper Airborne
Observatory,

275

00:13:02,800 --> 00:13:05,800
the precursory to SOFIA
that Ames runs,

276

00:13:05,800 --> 00:13:08,400
to disappear

behind Pluto's limb.

277

00:13:08,400 --> 00:13:11,233

And because the starlight
gradually dimmed

278

00:13:11,233 --> 00:13:15,466

over a period of tens of seconds
instead of just winking out,

279

00:13:15,466 --> 00:13:20,366

that team could determine
that Pluto has an atmosphere

280

00:13:20,366 --> 00:13:23,433

that was causing
a refractive effect.

281

00:13:23,433 --> 00:13:26,066

Many other things were learned
back in that era

282

00:13:26,066 --> 00:13:28,033

that also promised
it would be interesting.

283

00:13:28,033 --> 00:13:30,800

One is that Pluto's
big satellite, Charon,

284

00:13:30,800 --> 00:13:32,000

was not only discovered,

285

00:13:32,000 --> 00:13:33,266

but we got
the first good estimates

286

00:13:33,266 --> 00:13:35,033

of its size and its mass.

287

00:13:35,033 --> 00:13:37,133

And it turns out
to be a double system.

288

00:13:37,133 --> 00:13:41,000

The satellite is half as big
as the planet.

289

00:13:41,000 --> 00:13:43,833

And we learned, from knowing
the sizes of the two objects

290

00:13:43,833 --> 00:13:46,466

and measuring
the barycentric wobble

291

00:13:46,466 --> 00:13:49,066

due to the tug of Charon
on Pluto,

292

00:13:49,066 --> 00:13:51,800

what their individual
masses were.

293

00:13:51,800 --> 00:13:55,166

And from that, we could
determine that density of Pluto

294

00:13:55,166 --> 00:13:56,566

for the first time.

295

00:13:56,566 --> 00:13:59,966

And it turned out
that despite being way out

296

00:13:59,966 --> 00:14:02,566

on the edge of the solar system,
so far from the sun

297

00:14:02,566 --> 00:14:06,900
and covered in ice that it's not
actually an icy planet.

298

00:14:06,900 --> 00:14:11,933
It's actually about 70% rock
on the inside,

299

00:14:11,933 --> 00:14:13,666
which was a big surprise
at the time.

300

00:14:13,666 --> 00:14:17,333
So all these things
and others were arguments

301

00:14:17,333 --> 00:14:21,100
that were being made
to review panels

302

00:14:21,100 --> 00:14:22,800
and to advisory groups

303

00:14:22,800 --> 00:14:24,933
why we should
send a mission to Pluto

304

00:14:24,933 --> 00:14:26,966
instead of all the other
good things you could be doing.

305

00:14:26,966 --> 00:14:28,400
And you know what?

306

00:14:28,400 --> 00:14:30,100
That kept getting
on the A-list.

307

00:14:30,100 --> 00:14:33,700
And that's part of the reason

that we kept getting

308

00:14:33,700 --> 00:14:35,766

new studies each time
one would fail.

309

00:14:35,766 --> 00:14:39,400

The case was good enough
that we'd start again.

310

00:14:39,400 --> 00:14:41,900

Let me tell you what put it
at the top of the A-list.

311

00:14:41,900 --> 00:14:44,300

And I have to start
with a diagram

312

00:14:44,300 --> 00:14:46,866

of the solar system
as we used to know it

313

00:14:46,866 --> 00:14:48,300

in the 20th century.

314

00:14:48,300 --> 00:14:51,633

And probably most people in this
room saw something like this

315

00:14:51,633 --> 00:14:52,866

even in grade school,

316

00:14:52,866 --> 00:14:55,000

when you first learned a little
about the planets.

317

00:14:55,000 --> 00:14:57,600

There you see the way
that we used to think

318

00:14:57,600 --> 00:14:59,400

the solar system was laid out:

319

00:14:59,400 --> 00:15:02,766

with four little rocky
terrestrial planets--

320

00:15:02,766 --> 00:15:05,633

Mercury, Venus, Earth and Mars--
on the inside,

321

00:15:05,633 --> 00:15:07,100

the asteroid belt,

322

00:15:07,100 --> 00:15:10,566

and then four gargantuan
gas giants on the outside,

323

00:15:10,566 --> 00:15:13,133

and then Pluto in a funny orbit
and very tiny

324

00:15:13,133 --> 00:15:15,633

compared to any of those
other eight.

325

00:15:15,633 --> 00:15:18,066

Kind of a misfit.

326

00:15:18,066 --> 00:15:21,066

But as it turns out,
that was a myopic view.

327

00:15:21,066 --> 00:15:23,733

It was limited
by our technology--

328

00:15:23,733 --> 00:15:28,266

our telescope technology

and our detector technology.

329

00:15:28,266 --> 00:15:31,733

In planetary science,
everything that we see

330

00:15:31,733 --> 00:15:33,033

is in reflection.

331

00:15:33,033 --> 00:15:37,666

And so the R-squared diminution
of light with distance

332

00:15:37,666 --> 00:15:40,566

isn't the problem.

333

00:15:40,566 --> 00:15:42,033

The problem is in reflection.

334

00:15:42,033 --> 00:15:44,333

It's R-squared going out
and R-squared coming back.

335

00:15:44,333 --> 00:15:46,066

And so that's
R to the fourth.

336

00:15:46,066 --> 00:15:48,100

And so every time you try
and look a little further,

337

00:15:48,100 --> 00:15:50,700

it's dramatically harder.

338

00:15:50,700 --> 00:15:52,933

And Clyde Tombaugh
discovered Pluto in 1930,

339

00:15:52,933 --> 00:15:55,400

and people went looking
for farther things

340
00:15:55,400 --> 00:15:57,166
in the '30s
and '40s and '50s

341
00:15:57,166 --> 00:15:59,233
and '60s and '70s and '80s.

342
00:15:59,233 --> 00:16:00,733
And they didn't
find a thing until,

343
00:16:00,733 --> 00:16:03,766
in the 1990s--
and we'll start this video,

344
00:16:03,766 --> 00:16:05,800
which should not have sound.

345
00:16:05,800 --> 00:16:08,333
And there's--
or very low sound.

346
00:16:08,333 --> 00:16:10,700
There's Pluto
rolling along its orbit.

347
00:16:10,700 --> 00:16:13,633
And all those dots that
are popping up are cohorts

348
00:16:13,633 --> 00:16:16,600
in that new third zone
of the solar system

349
00:16:16,600 --> 00:16:19,566
we call the Kuiper Belt today.

350

00:16:19,566 --> 00:16:22,000

And you'll notice
all those are real objects,

351

00:16:22,000 --> 00:16:23,933

and some of them
are pretty big.

352

00:16:23,933 --> 00:16:27,233

They're not just tiny little
things the size of counties

353

00:16:27,233 --> 00:16:28,866

or New England states,

354

00:16:28,866 --> 00:16:32,933

but they're the size
of objects like Pluto.

355

00:16:32,933 --> 00:16:36,166

So this was really a revolution
in planetary science.

356

00:16:36,166 --> 00:16:38,033

The solar system
didn't have two zones--

357

00:16:38,033 --> 00:16:40,500

the inner planets
and the giant planets--

358

00:16:40,500 --> 00:16:44,766

but a third zone where
all the orbits are puffed up.

359

00:16:44,766 --> 00:16:47,200

And most of them are eccentric
like Pluto's.

360

00:16:47,200 --> 00:16:49,466

But we didn't know about it
for a very long time.

361

00:16:49,466 --> 00:16:52,566

So, you know, I used to say,
well, who's the misfit now?

362

00:16:52,566 --> 00:16:55,600

There are more dwarf planets
discovered in the Kuiper Belt

363

00:16:55,600 --> 00:16:58,300

than the giant planets and the
terrestrial planets combined.

364

00:16:58,300 --> 00:17:03,233

And here, you can see a
collection of cohorts to Pluto,

365

00:17:03,233 --> 00:17:05,733

and Pluto itself.

366

00:17:05,733 --> 00:17:08,466

And you'll see that they are
very heterogeneous

367

00:17:08,466 --> 00:17:10,700

in their appearance
on this chart.

368

00:17:10,700 --> 00:17:12,933

But they're heterogeneous
in real life.

369

00:17:12,933 --> 00:17:15,133

They're not only different
in their colors

370

00:17:15,133 --> 00:17:17,266

but the number of satellites,

371

00:17:17,266 --> 00:17:19,266

whether they have
atmospheres or not.

372

00:17:19,266 --> 00:17:23,633

There are some that have much
higher, much rockier densities

373

00:17:23,633 --> 00:17:25,033

than even Pluto.

374

00:17:25,033 --> 00:17:26,866

And some that are much lower.

375

00:17:26,866 --> 00:17:28,966

Some have volatiles
on their surface,

376

00:17:28,966 --> 00:17:31,733

and some just have water ice,
which is as good as a rock

377

00:17:31,733 --> 00:17:34,933

at those temperatures.

378

00:17:34,933 --> 00:17:38,066

And why we have this diversity
is a great problem

379

00:17:38,066 --> 00:17:40,333

that we have not explained
in planetary science.

380

00:17:40,333 --> 00:17:43,333

But an even bigger problem is,
who knew the solar system

381

00:17:43,333 --> 00:17:44,800
was so good at making planets,

382

00:17:44,800 --> 00:17:47,566
and that most of them
are nothing like the Earth

383

00:17:47,566 --> 00:17:51,200
or any of the eight that we
thought were the typical ones?

384

00:17:51,200 --> 00:17:54,200
So it was this realization--

385

00:17:54,200 --> 00:17:56,733
and, in fact, by the National
Academy of Sciences--

386

00:17:56,733 --> 00:18:00,400
that rocketed the priority
to go do a Pluto mission

387

00:18:00,400 --> 00:18:02,533
from just being on the A-list

388

00:18:02,533 --> 00:18:05,600
to being at the very top
of the A-list,

389

00:18:05,600 --> 00:18:08,466
because it was realized
that by studying Pluto system,

390

00:18:08,466 --> 00:18:09,700
we weren't just gonna learn

391

00:18:09,700 --> 00:18:11,933
about the fascinating
Pluto system.

392

00:18:11,933 --> 00:18:16,333

But this was the first
of a new class of worlds

393

00:18:16,333 --> 00:18:19,000

in the outer solar system
that we had not touched

394

00:18:19,000 --> 00:18:21,700

in 40 years
of space exploration.

395

00:18:21,700 --> 00:18:24,933

So NASA called for proposals
for teams to form

396

00:18:24,933 --> 00:18:28,433

and write proposals
to compete to fly this mission

397

00:18:28,433 --> 00:18:32,400

within a fixed amount of time,
to fly it before the year 2020--

398

00:18:32,400 --> 00:18:35,900

I'm sorry, to arrive at Pluto
before 2020.

399

00:18:35,900 --> 00:18:38,733

And to do it on a fixed budget
that was tiny

400

00:18:38,733 --> 00:18:40,466

compared to the budget
for Voyager.

401

00:18:40,466 --> 00:18:42,300

About two dimes on the dollar.

402

00:18:42,300 --> 00:18:44,666
And five teams formed.

403
00:18:44,666 --> 00:18:47,600
And one of them
was New Horizons.

404
00:18:47,600 --> 00:18:50,900
And fortunately for us, we won.

405
00:18:50,900 --> 00:18:52,866
It was a very tough competition.

406
00:18:52,866 --> 00:18:54,400
It lasted about a year

407
00:18:54,400 --> 00:18:56,466
with a typical two-stage,

408
00:18:56,466 --> 00:18:58,100
just like Discovery
is going through now.

409
00:18:58,100 --> 00:19:00,566
And New Frontiers
is about to start a new round

410
00:19:00,566 --> 00:19:02,300
for New Frontiers 4.

411
00:19:02,300 --> 00:19:07,233
We got notified that we had won
in November of 2001,

412
00:19:07,233 --> 00:19:10,766
and the timing and geometry

413
00:19:10,766 --> 00:19:13,700
to get a Jupiter gravity assist

to speed us

414

00:19:13,700 --> 00:19:16,533
meant that we only had
four years and two months

415

00:19:16,533 --> 00:19:19,633
to pull it all together
and get to the launch pad.

416

00:19:19,633 --> 00:19:22,333
And so I'm also saying this
for the interns.

417

00:19:22,333 --> 00:19:25,000
This is the core team
for New Horizons,

418

00:19:25,000 --> 00:19:29,200
representing the 2,5000 people
that worked on the project.

419

00:19:29,200 --> 00:19:33,866
This is a picture taken
at our prime mission partner,

420

00:19:33,866 --> 00:19:35,633
Johns Hopkins
Applied Physics Lab,

421

00:19:35,633 --> 00:19:37,933
in one of their
conference rooms.

422

00:19:37,933 --> 00:19:40,766
And I just want to say, we could
not have pulled this off

423

00:19:40,766 --> 00:19:44,200
without a really

spectacular team of people.

424

00:19:44,200 --> 00:19:47,033

When we recruited the team
for New Horizons,

425

00:19:47,033 --> 00:19:49,933

I know at APL,
because they had not done--

426

00:19:49,933 --> 00:19:52,400

they'd only done one planetary
mission at that point,

427

00:19:52,400 --> 00:19:55,066

and no outer planets missions.

428

00:19:55,066 --> 00:19:57,200

People were crawling
all over themselves,

429

00:19:57,200 --> 00:20:00,033

all over each other,
to get onboard this mission.

430

00:20:00,033 --> 00:20:01,966

And so we had
the pick of the litter.

431

00:20:01,966 --> 00:20:05,566

And we did also, I think--
our science team,

432

00:20:05,566 --> 00:20:08,366

our team at Southwest Research
where I work,

433

00:20:08,366 --> 00:20:10,200

people really wanted
to be a part

434

00:20:10,200 --> 00:20:11,466
of what we used to call

435

00:20:11,466 --> 00:20:14,200
the first mission
to the last planet.

436

00:20:14,200 --> 00:20:17,433
And, you know, in the '60s
and the '70s and the '80s,

437

00:20:17,433 --> 00:20:20,633
it was a primo thing
to get to be aboard

438

00:20:20,633 --> 00:20:23,400
an early Mariner mission
to Mars or Venus.

439

00:20:23,400 --> 00:20:25,933
Or Pioneer,
the first to Jupiter.

440

00:20:25,933 --> 00:20:28,366
Or Voyager, you know,
the most storied

441

00:20:28,366 --> 00:20:31,366
of all of the early
exploration missions.

442

00:20:31,366 --> 00:20:34,166
And it was something like that
for New Horizons.

443

00:20:34,166 --> 00:20:37,366
And we asked people, we said,
this is gonna be hard.

444
00:20:37,366 --> 00:20:40,300
We're gonna have a lot
less money and a lot less time,

445
00:20:40,300 --> 00:20:42,333
and we might just fail
at this.

446
00:20:42,333 --> 00:20:44,700
So we're gonna ask you
to work nights and weekends

447
00:20:44,700 --> 00:20:46,533
for years on end.

448
00:20:46,533 --> 00:20:49,700
And still people crawled all
over each other to get on it.

449
00:20:49,700 --> 00:20:51,933
And it really worked.

450
00:20:51,933 --> 00:20:55,700
And I will say the reasons
New Horizons succeeded

451
00:20:55,700 --> 00:20:59,800
is in large measure
because it's such a great team.

452
00:20:59,800 --> 00:21:02,933
And then we spent four years
and two months

453
00:21:02,933 --> 00:21:06,166
to design, build,
and test New Horizons.

454
00:21:06,166 --> 00:21:09,966

And we had many, many problems
along the way.

455

00:21:09,966 --> 00:21:12,933

Technical problems,
budget problems,

456

00:21:12,933 --> 00:21:15,000

schedule problems.

457

00:21:15,000 --> 00:21:16,833

Problems at every level.

458

00:21:16,833 --> 00:21:18,400

We had the secret sauce

459

00:21:18,400 --> 00:21:21,066

for how to build
ultra-stable oscillators

460

00:21:21,066 --> 00:21:25,033

for our radio science experiment
that only resided in one place.

461

00:21:25,033 --> 00:21:29,600

And the two gentlemen who had
been doing that for 20 years

462

00:21:29,600 --> 00:21:31,800

died together in a plane crash

463

00:21:31,800 --> 00:21:33,866

one month after
we were selected.

464

00:21:35,366 --> 00:21:37,500

We were canceled
after we were selected,

465

00:21:37,500 --> 00:21:42,200
and had to get restarted in a
new presidential administration.

466
00:21:42,200 --> 00:21:43,666
We had normal human errors,

467
00:21:43,666 --> 00:21:45,933
where people dropped
some hardware.

468
00:21:45,933 --> 00:21:48,666
We had an entire shutdown
of Los Alamos National Lab

469
00:21:48,666 --> 00:21:50,666
that was preparing
the plutonium

470
00:21:50,666 --> 00:21:52,933
that fueled our nuclear
power generator.

471
00:21:52,933 --> 00:21:54,333
And they were shut down
for months,

472
00:21:54,333 --> 00:21:56,400
and we didn't think we could get
enough plutonium

473
00:21:56,400 --> 00:21:57,800
to fly the mission.

474
00:21:57,800 --> 00:21:59,666
And there were lots
of other problems.

475
00:21:59,666 --> 00:22:02,666
But we did it.

We built this little spacecraft.

476

00:22:02,666 --> 00:22:04,100

And it's intentionally small.

477

00:22:04,100 --> 00:22:06,366

If you go to the Air and Space
Museum and check it out,

478

00:22:06,366 --> 00:22:08,433

it's in that same hall
where Voyager is,

479

00:22:08,433 --> 00:22:11,000

and boy, is it small
compared to Voyager.

480

00:22:11,000 --> 00:22:14,766

We wanted to build it small so
that it could travel very fast

481

00:22:14,766 --> 00:22:17,433

by being launched on
a really large launch vehicle.

482

00:22:17,433 --> 00:22:20,300

Here you can see--and I think
this pointer will work,

483

00:22:20,300 --> 00:22:21,833

so excuse me for turning away.

484

00:22:21,833 --> 00:22:23,366

That's the high-gain antenna.

485

00:22:23,366 --> 00:22:27,700

This is the nuclear power source
that powers the spacecraft.

486

00:22:27,700 --> 00:22:29,966

It's filled
with plutonium dioxide.

487

00:22:29,966 --> 00:22:31,966

This is the spacecraft bus
that contains

488

00:22:31,966 --> 00:22:35,366

propulsion guidance
and navigation,

489

00:22:35,366 --> 00:22:38,400

command and data handling,
solid state recorders,

490

00:22:38,400 --> 00:22:40,900

thermal control,
all the subsystems.

491

00:22:40,900 --> 00:22:43,766

And on New Horizons,
they're all redundant.

492

00:22:43,766 --> 00:22:46,566

Fortunately, we're ten years now
after launch,

493

00:22:46,566 --> 00:22:50,900

and we're still only using--
nothing's failed.

494

00:22:50,900 --> 00:22:52,900

It's all in great shape.

495

00:22:54,466 --> 00:22:57,033

And I like this picture in part
because you can actually see

496

00:22:57,033 --> 00:22:59,600

the structure of the spacecraft,
which is made of aluminum.

497

00:22:59,600 --> 00:23:02,600

Not all of the multi-layer
insulation has been put on it.

498

00:23:02,600 --> 00:23:04,533

This is down at the Cape
about two months before launch,

499

00:23:04,533 --> 00:23:05,966

in Florida.

500

00:23:05,966 --> 00:23:07,533

And you can see,
because of all the people,

501

00:23:07,533 --> 00:23:08,833

just how small it is.

502

00:23:08,833 --> 00:23:10,933

It's about the size
of a baby grand piano.

503

00:23:10,933 --> 00:23:12,433

It weighs about
a thousand pounds,

504

00:23:12,433 --> 00:23:15,000

or 480 kilos when it's fueled.

505

00:23:15,000 --> 00:23:16,833

It carries seven
scientific instruments.

506

00:23:16,833 --> 00:23:18,600

The inset names them.

507

00:23:18,600 --> 00:23:21,166

So there are eight imagers
aboard.

508

00:23:21,166 --> 00:23:22,900

Eight monochromatic imagers.

509

00:23:22,900 --> 00:23:24,633

Some are very wide band,

510

00:23:24,633 --> 00:23:26,400

basically the entire visible.

511

00:23:26,400 --> 00:23:29,966

Others, individual colors,
like a red channel

512

00:23:29,966 --> 00:23:33,266

and a near-infrared channel.

513

00:23:33,266 --> 00:23:34,733

And a blue channel,
for that matter.

514

00:23:34,733 --> 00:23:39,166

And narrow channels to image in,
like, the methane band.

515

00:23:39,166 --> 00:23:43,433

And also panchromatic channels

516

00:23:43,433 --> 00:23:46,566

that we have several of.

517

00:23:46,566 --> 00:23:48,233

And then there are
spectrometers,

518

00:23:48,233 --> 00:23:51,266

both an ultraviolet spectrometer
to study Pluto's atmosphere

519

00:23:51,266 --> 00:23:53,333

and search for an atmosphere
around its moon, Charon.

520

00:23:53,333 --> 00:23:56,333

And an infrared spectrometer
to do the same kind of thing

521

00:23:56,333 --> 00:23:58,633

that Dale Cruikshank's chart
was showing you,

522

00:23:58,633 --> 00:24:00,700

except instead of showing you
an average

523

00:24:00,700 --> 00:24:02,433

for the entire surface,

524

00:24:02,433 --> 00:24:05,700

to be able to look in each
and every place.

525

00:24:05,700 --> 00:24:07,900

In fact, the infrared
spectrometer that we flew

526

00:24:07,900 --> 00:24:11,933

can take 64,000 locations
simultaneously

527

00:24:11,933 --> 00:24:14,566

and deliver a spectrum
in a matter of seconds.

528

00:24:14,566 --> 00:24:16,800

So, amazing technology.

529

00:24:16,800 --> 00:24:19,266

There are also two plasma instruments onboard

530

00:24:19,266 --> 00:24:21,300

to study the interaction of the solar wind

531

00:24:21,300 --> 00:24:23,966

and charged particles with Pluto's environment.

532

00:24:23,966 --> 00:24:25,833

A dust counter built by students.

533

00:24:25,833 --> 00:24:28,533

The first ever student-built instrument to fly

534

00:24:28,533 --> 00:24:30,133

on a planetary mission.

535

00:24:30,133 --> 00:24:33,166

Radio science.

536

00:24:33,166 --> 00:24:34,833

Total of seven different instruments

537

00:24:34,833 --> 00:24:36,566

with eight different sensors,

538

00:24:36,566 --> 00:24:39,366

and together they weigh 30--

539

00:24:39,366 --> 00:24:41,400

I'm sorry, they weigh less

than the camera on Cassini,

540

00:24:41,400 --> 00:24:44,433
and they only draw 30 watts
combined.

541

00:24:44,433 --> 00:24:45,666
All seven.

542

00:24:45,666 --> 00:24:47,500
And that miniaturization
was where we put

543

00:24:47,500 --> 00:24:50,100
a lot of the advanced technology
development money

544

00:24:50,100 --> 00:24:51,900
for this mission.

545

00:24:51,900 --> 00:24:53,833
Because prior to New Horizons,

546

00:24:53,833 --> 00:24:56,400
typical instruments
weighed more

547

00:24:56,400 --> 00:24:59,800
than our whole payload of seven.

548

00:24:59,800 --> 00:25:02,166
This is a picture of the
spacecraft in the launch shroud.

549

00:25:02,166 --> 00:25:03,800
And I'm in front of it.

550

00:25:03,800 --> 00:25:06,333
And this is the day

that we fueled the RTG:

551

00:25:06,333 --> 00:25:08,766

the Radioactive
Thermoelectric Generator.

552

00:25:08,766 --> 00:25:11,200

And New Horizons came alive.

553

00:25:11,200 --> 00:25:12,933

And our mission control
started operating it,

554

00:25:12,933 --> 00:25:14,700

even though it hadn't
been launched.

555

00:25:14,700 --> 00:25:19,200

This is Friday the 13th
in January of 2006.

556

00:25:19,200 --> 00:25:21,033

Our lucky day.

557

00:25:21,033 --> 00:25:26,200

And I show this picture
because when we fueled the RTG,

558

00:25:26,200 --> 00:25:28,533

of course it was radioactive
at that point.

559

00:25:28,533 --> 00:25:30,533

And so they didn't want
people around it

560

00:25:30,533 --> 00:25:34,166

until they closed the hatch
that has a radiation shield.

561
00:25:34,166 --> 00:25:36,166
But they let five of us
get our picture taken,

562
00:25:36,166 --> 00:25:39,066
and I asked to be last as PI,

563
00:25:39,066 --> 00:25:41,166
because I knew this would be
the last picture ever taken

564
00:25:41,166 --> 00:25:43,200
of New Horizons.

565
00:25:43,200 --> 00:25:44,800
So I'm very proud
of that picture

566
00:25:44,800 --> 00:25:48,433
and all the work
that those 2,500 people put in

567
00:25:48,433 --> 00:25:50,533
to build this launch vehicle
and this spacecraft,

568
00:25:50,533 --> 00:25:55,500
and to get it tested in--
basically in record time.

569
00:25:55,500 --> 00:25:59,233
And then we put it up on top

570
00:25:59,233 --> 00:26:02,766
of an enormous Atlas 5
launch vehicle,

571
00:26:02,766 --> 00:26:04,600
built by Lockheed Martin

and Boeing

572

00:26:04,600 --> 00:26:07,333
which have since amalgamated
in the launch vehicle business

573

00:26:07,333 --> 00:26:09,800
to be ULA,
the United Launch Alliance.

574

00:26:09,800 --> 00:26:12,033
And NASA did
what I never could do

575

00:26:12,033 --> 00:26:14,533
as a kid building
Estes model rockets,

576

00:26:14,533 --> 00:26:17,100
and they got the decal on
without a single crease.

577

00:26:17,100 --> 00:26:19,633
[audience laughter]

578

00:26:19,633 --> 00:26:23,133
And then we launched it,
six days after we fueled it

579

00:26:23,133 --> 00:26:26,400
on the 19th of January, 2006.

580

00:26:26,400 --> 00:26:28,100
Now, this is a very big
launch vehicle,

581

00:26:28,100 --> 00:26:29,400
and I imagine some people,

582

00:26:29,400 --> 00:26:30,666

particularly some
of the interns,

583

00:26:30,666 --> 00:26:33,733

have never been to a launch
of a big launch vehicle.

584

00:26:33,733 --> 00:26:37,033

This one's over 220 feet tall.

585

00:26:37,033 --> 00:26:39,533

And I'll tell you,
as a kid that used to buy

586

00:26:39,533 --> 00:26:41,900

Estes model rockets
on a very limited allowance

587

00:26:41,900 --> 00:26:43,633

and a lot of car washes,

588

00:26:43,633 --> 00:26:45,966

it was so much fun
to pick this guy out,

589

00:26:45,966 --> 00:26:48,566

because I had the budget
to trick it out

590

00:26:48,566 --> 00:26:51,433

with everything Lockheed Martin
could offer.

591

00:26:51,433 --> 00:26:53,633

The most number
of solid rocket boosters,

592

00:26:53,633 --> 00:26:55,566

the lightest-weight nose cone.

593

00:26:55,566 --> 00:26:56,933

Everything.

594

00:26:56,933 --> 00:27:00,633

And then we put this very tiny spacecraft on top.

595

00:27:00,633 --> 00:27:04,500

This launch vehicle was built to launch very large satellites,

596

00:27:04,500 --> 00:27:06,366

the size of a school bus.

597

00:27:06,366 --> 00:27:08,133

But we put something on,

598

00:27:08,133 --> 00:27:10,066

you know,

larger than this podium,

599

00:27:10,066 --> 00:27:11,900

but only a few times larger.

600

00:27:11,900 --> 00:27:16,333

So we basically took the biggest launch vehicle we could buy,

601

00:27:16,333 --> 00:27:19,700

tricked it out and launched it essentially empty.

602

00:27:19,700 --> 00:27:23,233

And the end result is that it lifted off the pad

603

00:27:23,233 --> 00:27:26,966

at 2 Gs of acceleration,

it was so light.

604

00:27:26,966 --> 00:27:29,333

And it was in Earth orbit
eight minutes later.

605

00:27:29,333 --> 00:27:31,266

And I never get tired
of watching this launch,

606

00:27:31,266 --> 00:27:32,533

so you get to watch it.

607

00:27:32,533 --> 00:27:33,866

And this does have sound.

608

00:27:33,866 --> 00:27:35,266

So I'll mostly be quiet.

609

00:27:35,266 --> 00:27:37,100

I think I have to start it.

610

00:27:38,500 --> 00:27:40,200

And it only runs
about 90 seconds.

611

00:27:40,200 --> 00:27:41,766

- Go, Atlas.
- Watch how fast

612

00:27:41,766 --> 00:27:42,966

this baby goes up.

613

00:27:42,966 --> 00:27:44,966

When it cross the cloud break,

614

00:27:44,966 --> 00:27:48,766

it's at 10,000 feet
only seconds after launch.

615

00:27:48,766 --> 00:27:51,866

- Six, five, four,

616

00:27:51,866 --> 00:27:54,666

three, two, one.

617

00:27:54,666 --> 00:27:57,133

We have ignition,

618

00:27:57,133 --> 00:28:00,333

and liftoff at NASA's

New Horizon spacecraft

619

00:28:00,333 --> 00:28:04,000

on a decade-long voyage

to visit the planet Pluto

620

00:28:04,000 --> 00:28:05,800

and then beyond.

621

00:28:05,800 --> 00:28:10,133

[upbeat music]

622

00:28:10,133 --> 00:28:11,766

Plus 15 seconds.

623

00:28:11,766 --> 00:28:13,400

Everything continues

to look good,

624

00:28:13,400 --> 00:28:16,066

as the Atlas 5 vehicle

climbs away

625

00:28:16,066 --> 00:28:17,666

from Florida's east coast.

626

00:28:17,666 --> 00:28:19,633

The five solid rocket
strap-on boosters

627

00:28:19,633 --> 00:28:21,033

are burning just fine,

628

00:28:21,033 --> 00:28:24,066

sending the New Horizon
spacecraft on its way

629

00:28:24,066 --> 00:28:26,933

to the very edge
of our solar system.

630

00:28:26,933 --> 00:28:32,933

[upbeat music]

631

00:28:33,933 --> 00:28:35,366

- Coming up is the staging,

632

00:28:35,366 --> 00:28:38,566

where the solid rocket motors
separate,

633

00:28:38,566 --> 00:28:40,133

because they're finished.

634

00:28:40,133 --> 00:28:41,366

They've spent all their fuel.

635

00:28:41,366 --> 00:28:44,266

You'll see them come off
in two groups.

636

00:28:44,266 --> 00:28:48,633

First, I think three come off,
and then two.

637

00:28:48,633 --> 00:28:50,466
Or it's two and then three.

638
00:28:50,466 --> 00:28:54,366
There you go.

639
00:28:54,366 --> 00:28:57,400
And there it went,
off into orbit.

640
00:28:57,400 --> 00:29:01,666
We flew halfway around the Earth
that afternoon

641
00:29:01,666 --> 00:29:03,700
to the injection point,

642
00:29:03,700 --> 00:29:05,500
to accelerate out
towards Jupiter

643
00:29:05,500 --> 00:29:07,200
for that gravity assist.

644
00:29:07,200 --> 00:29:09,366
It reignited
the Centaur Upper Stage,

645
00:29:09,366 --> 00:29:10,900
burned it to depletion.

646
00:29:10,900 --> 00:29:13,933
Then the solid rocket motor
built by Boeing fired.

647
00:29:13,933 --> 00:29:15,233
New Horizons is so light

648
00:29:15,233 --> 00:29:17,966

that at the end of that solid
rocket motor firing,

649

00:29:17,966 --> 00:29:20,900

the spacecraft
was pulling 14 Gs.

650

00:29:20,900 --> 00:29:23,633

And it became the fastest
spacecraft ever launched.

651

00:29:23,633 --> 00:29:27,433

As a comparison point,
New Horizons--

652

00:29:27,433 --> 00:29:28,966

well, Apollo missions
used to launch

653

00:29:28,966 --> 00:29:30,533

at 25,000 miles an hour,

654

00:29:30,533 --> 00:29:32,500

and took three days
to reach the moon.

655

00:29:32,500 --> 00:29:35,033

New Horizons did it
in nine hours.

656

00:29:35,033 --> 00:29:37,933

That's right.

657

00:29:37,933 --> 00:29:41,233

And we flew across the solar
system in record time too.

658

00:29:41,233 --> 00:29:43,800

First, to Jupiter
in just over a year.

659

00:29:43,800 --> 00:29:46,133

Now recognize Galileo

Jupiter orbiter

660

00:29:46,133 --> 00:29:47,700

took six years

to get to Jupiter.

661

00:29:47,700 --> 00:29:50,066

Cassini, which was flying by,

took four.

662

00:29:50,066 --> 00:29:51,900

Thirteen months

we were at Jupiter

663

00:29:51,900 --> 00:29:53,166

for that gravity assist,

664

00:29:53,166 --> 00:29:55,066

and then we flew all the way

across the solar system.

665

00:29:55,066 --> 00:29:57,566

So I'm going to skip

about nine years,

666

00:29:57,566 --> 00:30:00,500

between 2006 and 2015,

667

00:30:00,500 --> 00:30:03,966

except to say that during

the flight to Jupiter,

668

00:30:03,966 --> 00:30:05,933

we had to get the spacecraft,

669

00:30:05,933 --> 00:30:08,200

all the prime and redundant
systems checked out,

670

00:30:08,200 --> 00:30:10,000

all seven instruments
up and running,

671

00:30:10,000 --> 00:30:12,133

calibrated
for the Jupiter flyby,

672

00:30:12,133 --> 00:30:16,033

and navigate to the very precise
window in space

673

00:30:16,033 --> 00:30:18,566

where a Jupiter flyby
will take you to Pluto

674

00:30:18,566 --> 00:30:20,466

and not somewhere else.

675

00:30:20,466 --> 00:30:22,866

We thought that was
kind of important.

676

00:30:22,866 --> 00:30:24,733

And we did that right.

677

00:30:24,733 --> 00:30:26,200

The gravity assist
was successful.

678

00:30:26,200 --> 00:30:29,133

This was kind of a stress test
for our spacecraft.

679

00:30:29,133 --> 00:30:32,400

We planned hundreds
of scientific observations.

680

00:30:32,400 --> 00:30:33,766

We were not the first mission
to Jupiter.

681

00:30:33,766 --> 00:30:35,366

In fact, we were the eighth.

682

00:30:35,366 --> 00:30:37,633

Juno is now the ninth.

683

00:30:37,633 --> 00:30:40,633

But we produced a lot of science
as a result.

684

00:30:40,633 --> 00:30:42,300

And we got a great
shakedown cruise.

685

00:30:42,300 --> 00:30:43,766

Thank you, because this was
the only thing

686

00:30:43,766 --> 00:30:45,466

we passed along the way.

687

00:30:45,466 --> 00:30:49,466

And then...

688

00:30:49,466 --> 00:30:51,233

we flew it across the rest
of the solar system.

689

00:30:51,233 --> 00:30:53,233

I hope I can start this video.

690

00:30:53,233 --> 00:30:54,633

There you go.

691
00:30:54,633 --> 00:30:57,500
From Jupiter, across the orbits
of Saturn in 2008,

692
00:30:57,500 --> 00:31:00,100
Uranus in 2011.

693
00:31:00,100 --> 00:31:02,566
Now, Saturn, Uranus, and Neptune
were nowhere near

694
00:31:02,566 --> 00:31:04,266
where we crossed their orbits,
by the way.

695
00:31:04,266 --> 00:31:05,833
And then off towards Pluto.

696
00:31:05,833 --> 00:31:07,166
And there the video ends.

697
00:31:07,166 --> 00:31:09,166
And it looks like we missed,
but we didn't.

698
00:31:09,166 --> 00:31:10,933
[audience laughter]

699
00:31:10,933 --> 00:31:13,566
And then we started
a two-year flight operation

700
00:31:13,566 --> 00:31:16,400
that's still continuing,
which is our flyby.

701
00:31:16,400 --> 00:31:18,166
Started in January
of last year--

702

00:31:18,166 --> 00:31:20,666
thank you on the timing.

703

00:31:20,666 --> 00:31:22,633
And began
with approach phase imaging

704

00:31:22,633 --> 00:31:24,066
looking for hazards,

705

00:31:24,066 --> 00:31:27,733
navigating to the aim point
between Pluto

706

00:31:27,733 --> 00:31:29,433
and its big moon, Charon.

707

00:31:29,433 --> 00:31:31,933
Then the flyby itself,
all the close approach stuff

708

00:31:31,933 --> 00:31:33,166
was in July.

709

00:31:33,166 --> 00:31:35,900
And then we started
downlinking the data.

710

00:31:35,900 --> 00:31:39,800
And for comparison,
we took 250 times as much data

711

00:31:39,800 --> 00:31:42,266
as Voyager did
on its Neptune flyby.

712

00:31:42,266 --> 00:31:45,366
And we took 5,000 times

as much data

713

00:31:45,366 --> 00:31:47,333
as the first mission to Mars.

714

00:31:47,333 --> 00:31:52,733
So that combined with
the low cost of New Horizons

715

00:31:52,733 --> 00:31:56,066
meant that it would take a
long time to get the data back.

716

00:31:56,066 --> 00:32:01,000
And here we are
in August of 2016,

717

00:32:01,000 --> 00:32:04,500
13 months after the flyby,
we're still sending data back.

718

00:32:04,500 --> 00:32:07,966
And it will continue until about
November 1st, or late October.

719

00:32:07,966 --> 00:32:10,066
There's a lot of data
up there still

720

00:32:10,066 --> 00:32:11,900
that we haven't seen.

721

00:32:11,900 --> 00:32:13,533
And we share
the Deep Space Network.

722

00:32:13,533 --> 00:32:14,933
And so it takes a while.

723

00:32:14,933 --> 00:32:17,200

So now let me tell you
about flyby results.

724

00:32:17,200 --> 00:32:19,366

And I'd just like to start
by showing our project manager,

725

00:32:19,366 --> 00:32:21,733

Glen Fountain,
who led this project

726

00:32:21,733 --> 00:32:24,800

from the time of our
critical designer view

727

00:32:24,800 --> 00:32:27,233

until just earlier this year,
when he retired.

728

00:32:27,233 --> 00:32:28,966

And there's our mission control

729

00:32:28,966 --> 00:32:30,933

and one of our
flight controllers.

730

00:32:30,933 --> 00:32:32,900

And here's the Pluto system

731

00:32:32,900 --> 00:32:35,566

as viewed by New Horizons
on approach.

732

00:32:35,566 --> 00:32:36,966

And you can see Pluto.

733

00:32:36,966 --> 00:32:40,433

And that's the encounter
hemisphere with the heart on it.

734

00:32:40,433 --> 00:32:42,833

It's about roughly the width
of the United States.

735

00:32:42,833 --> 00:32:45,433

Somewhat smaller,
but that's the scale there.

736

00:32:45,433 --> 00:32:49,700

Next to the upper left
is the big moon, called Charon,

737

00:32:49,700 --> 00:32:52,733

which looks distinctly different
from Pluto,

738

00:32:52,733 --> 00:32:56,100

and is about
17,000 kilometers away.

739

00:32:56,100 --> 00:32:59,433

And then two of the four small
satellites are shown there.

740

00:32:59,433 --> 00:33:02,633

Those are the two larger ones,
called Nix and Hydra.

741

00:33:02,633 --> 00:33:04,700

Here are the four small
satellites in more detail,

742

00:33:04,700 --> 00:33:07,966

as seen by New Horizons
in a montage,

743

00:33:07,966 --> 00:33:10,666

as if they were above the limb
of the big one, Charon.

744

00:33:10,666 --> 00:33:13,300

So you can get a relative size.

And these are--

745

00:33:13,300 --> 00:33:16,200

the four of them--

Styx, Nix, Kerberos, and Hydra.

746

00:33:16,200 --> 00:33:19,633

are shown in order

of their distance outward.

747

00:33:19,633 --> 00:33:22,466

And you'll notice there's

a little one and a big one,

748

00:33:22,466 --> 00:33:24,166

and a little one and a big one.

749

00:33:24,166 --> 00:33:26,100

And we're not sure if that's

telling us something important

750

00:33:26,100 --> 00:33:27,700

about how the satellite system

formed

751

00:33:27,700 --> 00:33:30,066

or if it's just a coincidence,

because there's only four.

752

00:33:30,066 --> 00:33:32,233

There aren't that many ways

to arrange them.

753

00:33:32,233 --> 00:33:33,866

But it is very interesting.

754

00:33:33,866 --> 00:33:35,800
These are four space rocks,

755
00:33:35,800 --> 00:33:39,266
the smallest of which
is about 15 kilometers

756
00:33:39,266 --> 00:33:41,600
and the largest of which,
70 kilometers.

757
00:33:41,600 --> 00:33:45,433
So these are like asteroids that
we've had flyby missions of,

758
00:33:45,433 --> 00:33:49,300
whereas Pluto and Charon
are literally small planets.

759
00:33:49,300 --> 00:33:51,000
They have been rounded
by self-gravity.

760
00:33:51,000 --> 00:33:52,800
They're in hydrostatic
equilibrium.

761
00:33:52,800 --> 00:33:54,166
This is the binary.

762
00:33:54,166 --> 00:33:57,566
This is the pair that all four
of the small ones orbit,

763
00:33:57,566 --> 00:34:00,066
shown in exaggerated color,

764
00:34:00,066 --> 00:34:01,933
where we, in the computer,
stretch the colors

765

00:34:01,933 --> 00:34:03,600

so you can see
the color boundaries

766

00:34:03,600 --> 00:34:05,033

much more easily.

767

00:34:05,033 --> 00:34:07,166

But we stretch the color
for the whole image.

768

00:34:07,166 --> 00:34:10,433

And so you can see that Pluto is
much more colorful and diverse

769

00:34:10,433 --> 00:34:13,133

than its big satellite Charon.

770

00:34:13,133 --> 00:34:16,433

And it's also brighter.
It's much more reflective.

771

00:34:16,433 --> 00:34:19,933

Some parts of its surface
are almost 100% reflective.

772

00:34:19,933 --> 00:34:24,166

Other parts are as dark as dirt,
literally.

773

00:34:24,166 --> 00:34:26,833

Only perhaps 10% reflective.

774

00:34:26,833 --> 00:34:30,100

But the satellite Charon
is uniformly much darker,

775

00:34:30,100 --> 00:34:32,400

and has much less
color diversity.

776

00:34:32,400 --> 00:34:34,666

Here's Charon in more detail.

777

00:34:34,666 --> 00:34:36,200

It looks like a typical
icy satellite

778

00:34:36,200 --> 00:34:38,166

of one of the giant planets.

779

00:34:38,166 --> 00:34:41,133

It's about 1,400 kilometers
in diameter.

780

00:34:41,133 --> 00:34:42,900

I think you will notice
immediately

781

00:34:42,900 --> 00:34:45,633

that it's got a lot of craters
on its surface.

782

00:34:45,633 --> 00:34:47,800

And you'll notice in a minute
when I show you Pluto

783

00:34:47,800 --> 00:34:49,933

a very different situation.

784

00:34:49,933 --> 00:34:53,633

But this is because
Charon's internal engine

785

00:34:53,633 --> 00:34:55,033

ran out a long time ago,

786

00:34:55,033 --> 00:34:57,533
and Charon has
no sensible atmosphere.

787
00:34:57,533 --> 00:35:00,333
In fact, we looked very hard
and set very high--

788
00:35:00,333 --> 00:35:01,833
very strong upper limits.

789
00:35:01,833 --> 00:35:03,900
And the combination
of those two things

790
00:35:03,900 --> 00:35:06,500
means that this is
an ancient surface

791
00:35:06,500 --> 00:35:10,400
that's been collecting craters
as they've rained down

792
00:35:10,400 --> 00:35:11,733
over 4 billion years.

793
00:35:11,733 --> 00:35:14,066
In fact, we age-date it
to that age.

794
00:35:14,066 --> 00:35:18,366
You can see across the equator
that big canyon system.

795
00:35:18,366 --> 00:35:20,466
It's an extensional
tectonic belt

796
00:35:20,466 --> 00:35:25,266
that's probably the largest one

in the entire solar system.

797

00:35:25,266 --> 00:35:26,933

And it's probably caused
by the fact

798

00:35:26,933 --> 00:35:29,766

that early in Charon's history
when it was much warmer,

799

00:35:29,766 --> 00:35:31,333

the water ice on the inside
was liquid,

800

00:35:31,333 --> 00:35:32,866

and then it froze and expanded,

801

00:35:32,866 --> 00:35:34,666

and that expansion
cracked the surface

802

00:35:34,666 --> 00:35:37,800

across this vast scale.

803

00:35:37,800 --> 00:35:39,800

And you'll also notice
that the north pole,

804

00:35:39,800 --> 00:35:41,033

which is at the top,

805

00:35:41,033 --> 00:35:44,200

has that funny red stain
of a color.

806

00:35:44,200 --> 00:35:48,166

Anybody that works in 245
or in Dale Cruikshank's group

807

00:35:48,166 --> 00:35:49,733
knows about tholins.

808
00:35:49,733 --> 00:35:53,700
Those are the radiation
processing products

809
00:35:53,700 --> 00:35:57,900
of things like methane
and nitrogen and carbon monoxide

810
00:35:57,900 --> 00:35:59,200
that we see on Pluto's surface,

811
00:35:59,200 --> 00:36:01,400
but we don't have
any evidence of on Charon.

812
00:36:01,400 --> 00:36:06,933
So we hypothesized that Pluto's
escaping atmosphere,

813
00:36:06,933 --> 00:36:10,266
some fraction of it
lands on Charon,

814
00:36:10,266 --> 00:36:12,666
because Charon's in the way
of some of the atmosphere

815
00:36:12,666 --> 00:36:14,366
as it's trying to leave.

816
00:36:14,366 --> 00:36:16,433
And at the poles
where it's coldest,

817
00:36:16,433 --> 00:36:17,700
it can condense out.

818

00:36:17,700 --> 00:36:19,066

And then, over time,

819

00:36:19,066 --> 00:36:21,633

ultraviolet and charged particle
radiation

820

00:36:21,633 --> 00:36:23,366

can turn those raw materials,

821

00:36:23,366 --> 00:36:25,933

like nitrogen

and carbon monoxide and methane,

822

00:36:25,933 --> 00:36:27,533

into these tholins that,

823

00:36:27,533 --> 00:36:31,400

when Dale produces them

in the lab on a cold finger,

824

00:36:31,400 --> 00:36:34,666

are just this color and have
just the same kind of spectrum.

825

00:36:34,666 --> 00:36:38,366

And there's now a paper in press
at Nature on this topic

826

00:36:38,366 --> 00:36:39,866

where you can read

a lot more about it.

827

00:36:39,866 --> 00:36:41,366

That paper's by Will Grundy,

828

00:36:41,366 --> 00:36:43,500

who runs our surface
composition team.

829

00:36:43,500 --> 00:36:45,133

We learned a lot of other things
about Charon,

830

00:36:45,133 --> 00:36:46,600

but I'm running out of time.

831

00:36:46,600 --> 00:36:48,500

So I'll take questions
about Charon if you like,

832

00:36:48,500 --> 00:36:50,433

and I'll just move on.

833

00:36:50,433 --> 00:36:51,933

Pluto is the star of the show,

834

00:36:51,933 --> 00:36:55,033

and I notice that
this view graph doesn't work.

835

00:36:55,033 --> 00:36:56,633

You're just seeing blankness.

836

00:36:56,633 --> 00:36:58,100

So I'll go right to this one

837

00:36:58,100 --> 00:37:04,033

that shows not only very rugged
terrain on the surface.

838

00:37:04,033 --> 00:37:05,366

That told us immediately

839

00:37:05,366 --> 00:37:07,600

that all those materials
we'd seen from Earth

840

00:37:07,600 --> 00:37:09,966

which are structurally weak
like nitrogen,

841

00:37:09,966 --> 00:37:11,266

molecular nitrogen,

842

00:37:11,266 --> 00:37:13,266

had to only be a veneer
on the surface.

843

00:37:13,266 --> 00:37:15,833

That there's something stronger,
namely water ice,

844

00:37:15,833 --> 00:37:17,866

that makes up the crust
of Pluto.

845

00:37:17,866 --> 00:37:19,633

And you can also see.

846

00:37:19,633 --> 00:37:21,233

You don't have to have
a spectrum to see it.

847

00:37:21,233 --> 00:37:23,766

You can see Pluto's atmosphere
in this image,

848

00:37:23,766 --> 00:37:26,400

which was made 15 minutes
after closest approach,

849

00:37:26,400 --> 00:37:28,700

because you can see
the haze layers

850

00:37:28,700 --> 00:37:32,666

that are very good at scattering
the sunlight

851

00:37:32,666 --> 00:37:36,333

forward to the spacecraft that
was on the far side of Pluto.

852

00:37:36,333 --> 00:37:38,533

We studied Pluto's atmosphere
in detail.

853

00:37:38,533 --> 00:37:40,533

We used our ultraviolet
spectrometer, called Alice,

854

00:37:40,533 --> 00:37:42,933

to do that,
to study its air glow,

855

00:37:42,933 --> 00:37:45,433

to get the vertical structure,

856

00:37:45,433 --> 00:37:46,900

temperature
and pressure structure

857

00:37:46,900 --> 00:37:48,233

of the upper atmosphere

858

00:37:48,233 --> 00:37:49,933

through a solar occultation.

859

00:37:49,933 --> 00:37:51,566

We determined the pressure
at the surface

860

00:37:51,566 --> 00:37:54,133

with the REX Radio
Science Instrument.

861

00:37:54,133 --> 00:37:56,333

It's about 11 microbars.

862

00:37:56,333 --> 00:37:59,233

We found that the atmospheric escape rate was much lower

863

00:37:59,233 --> 00:38:02,300

than all the Earth-based studies that indicate.

864

00:38:02,300 --> 00:38:04,633

And those mountains that we saw on the surface

865

00:38:04,633 --> 00:38:06,433

that you saw two images back

866

00:38:06,433 --> 00:38:09,333

not only are prevalent across the surface--

867

00:38:09,333 --> 00:38:10,566

and they're very high.

868

00:38:10,566 --> 00:38:12,900

They're typically three to five kilometers.

869

00:38:12,900 --> 00:38:14,166

So they're taller than the Alps.

870

00:38:14,166 --> 00:38:16,800

They're like the tallest of the Rockies.

871

00:38:16,800 --> 00:38:21,633

They're also, in some cases,

covered with snows of methane.

872

00:38:21,633 --> 00:38:23,200

That bright material--

873

00:38:23,200 --> 00:38:27,866

by the way, this image is about
the scale of western Colorado.

874

00:38:27,866 --> 00:38:31,600

And so those mountain ranges
are like ranges in the Rockies.

875

00:38:31,600 --> 00:38:34,000

And as I say, they're about
the same altitudes.

876

00:38:34,000 --> 00:38:35,366

And they have snowcaps,

877

00:38:35,366 --> 00:38:38,200

which I just think is just
a fantastic sci-fi thought,

878

00:38:38,200 --> 00:38:39,466

because we don't find snowcaps

879

00:38:39,466 --> 00:38:41,233

very many places
in the solar system.

880

00:38:41,233 --> 00:38:42,800

And to find snowcaps
in the Kuiper Belt

881

00:38:42,800 --> 00:38:45,000

on the first time you visit
the Kuiper Belt,

882

00:38:45,000 --> 00:38:49,000

I just think is one
of the coolest things

883

00:38:49,000 --> 00:38:50,733

that we found.

884

00:38:50,733 --> 00:38:54,533

But scientifically even cooler
is that that big heart

885

00:38:54,533 --> 00:38:57,266

on the surface turns out
to be enormous glacier,

886

00:38:57,266 --> 00:38:59,200

with a million
square kilometers.

887

00:38:59,200 --> 00:39:02,300

And this is the northwest
quadrant of that glacier,

888

00:39:02,300 --> 00:39:04,500

which we informally call
Sputnik Planum,

889

00:39:04,500 --> 00:39:06,133

after Sputnik,
the first satellite.

890

00:39:06,133 --> 00:39:08,633

That's where we are on the disc,
in that green box.

891

00:39:08,633 --> 00:39:12,433

These are mountain ranges
that ring Sputnik Planum.

892

00:39:12,433 --> 00:39:15,166

And here's where
the ice field abuts it.

893

00:39:15,166 --> 00:39:17,500

And if you look carefully,
you'll find that our geologist--

894

00:39:17,500 --> 00:39:19,766

you'll find that the same thing
that our geologist found:

895

00:39:19,766 --> 00:39:22,066

that there are flow patterns
in the ice

896

00:39:22,066 --> 00:39:23,433

wherever there are obstacles,

897

00:39:23,433 --> 00:39:25,400

like those islands
that are sticking up.

898

00:39:25,400 --> 00:39:27,533

This glacier is alive.

899

00:39:27,533 --> 00:39:29,133

And I don't mean
that it's biologically alive.

900

00:39:29,133 --> 00:39:31,066

It's geologically alive.

901

00:39:31,066 --> 00:39:34,600

And when we look at it carefully
to count craters,

902

00:39:34,600 --> 00:39:36,166

we can't find any,

903

00:39:36,166 --> 00:39:39,500
which tells us that this glacier
is very young.

904
00:39:39,500 --> 00:39:40,866
The best estimate of its age

905
00:39:40,866 --> 00:39:43,266
is that it's less
than 10 million years old,

906
00:39:43,266 --> 00:39:47,466
which is a lot older than
anything in San Francisco.

907
00:39:47,466 --> 00:39:51,233
But super young compared
to the age of Pluto:

908
00:39:51,233 --> 00:39:52,666
4 1/2 billion years old.

909
00:39:52,666 --> 00:39:55,533
And we can age-date some units
on the surface of Pluto

910
00:39:55,533 --> 00:39:57,566
that are 4 1/2 billion
years old.

911
00:39:57,566 --> 00:40:01,033
We also see other evidence
of dynamics on the surface.

912
00:40:01,033 --> 00:40:04,600
Here, in the northeast part
of Sputnik,

913
00:40:04,600 --> 00:40:07,866
we see a giant ice fall that--

maybe an avalanche

914

00:40:07,866 --> 00:40:09,766
that came out of these mountains

915

00:40:09,766 --> 00:40:11,700
thousands of feet
above the plain,

916

00:40:11,700 --> 00:40:13,333
and came out and pooled
right there

917

00:40:13,333 --> 00:40:16,733
over a scale about the size
of the San Francisco Bay.

918

00:40:16,733 --> 00:40:19,433
So this is a lot
of ice moving.

919

00:40:19,433 --> 00:40:21,700
And very recently, again,
no craters on it.

920

00:40:21,700 --> 00:40:24,033
So in Pluto's recent past,

921

00:40:24,033 --> 00:40:26,700
there's been a lot
of geologic activity.

922

00:40:26,700 --> 00:40:29,400
In fact, we believe--and this
made the cover of Nature.

923

00:40:29,400 --> 00:40:31,633
Bill McKinnon
on our science team

924
00:40:31,633 --> 00:40:33,700
published this paper.

925
00:40:33,700 --> 00:40:35,500
That ice is convecting.

926
00:40:35,500 --> 00:40:36,966
There's a heat source below it.

927
00:40:36,966 --> 00:40:38,766
We're not sure
what that heat source is.

928
00:40:38,766 --> 00:40:41,033
We're surprised that after
4 1/2 billion years

929
00:40:41,033 --> 00:40:43,633
a small planet can generate
that kind of heat.

930
00:40:43,633 --> 00:40:46,100
And we see lots
of other weirdness.

931
00:40:46,100 --> 00:40:47,833
We call this bladed terrain.

932
00:40:47,833 --> 00:40:49,866
Some people call it
snakeskin terrain.

933
00:40:49,866 --> 00:40:52,966
These are aligned ridges
of methane ice,

934
00:40:52,966 --> 00:40:54,733
a thousand feet high
individually,

935

00:40:54,733 --> 00:40:56,800
stretching over hundreds
of kilometers

936

00:40:56,800 --> 00:40:59,033
in a terrain type
that's never been seen

937

00:40:59,033 --> 00:41:00,900
anywhere else
in the solar system.

938

00:41:00,900 --> 00:41:02,900
Elsewhere on Pluto,
we see what looked like

939

00:41:02,900 --> 00:41:05,833
giant shield volcanoes,
like on Mars,

940

00:41:05,833 --> 00:41:08,700
a hundred kilometers
or more across.

941

00:41:08,700 --> 00:41:11,900
Nothing like this has been seen
in the deep outer solar system,

942

00:41:11,900 --> 00:41:13,300
except on Pluto.

943

00:41:13,300 --> 00:41:15,600
It's much more Earth-like
or Mars-like

944

00:41:15,600 --> 00:41:17,733
in this respect
than several others.

945

00:41:17,733 --> 00:41:21,566

We see places like,
if you look carefully up here

946

00:41:21,566 --> 00:41:26,833

where we see what the geologists
call dendritic networks

947

00:41:26,833 --> 00:41:29,133

that could be the result
of fluid flow

948

00:41:29,133 --> 00:41:31,533

in the past on the surface.

949

00:41:31,533 --> 00:41:33,466

We see things that look,
for all the world,

950

00:41:33,466 --> 00:41:36,600

like frozen lakes
on the surface of Pluto.

951

00:41:36,600 --> 00:41:38,366

That can't happen now.

952

00:41:38,366 --> 00:41:40,500

There's not enough
atmospheric pressure

953

00:41:40,500 --> 00:41:44,400

to make liquid nitrogen
or anything else possible

954

00:41:44,400 --> 00:41:45,933

on the surface.

955

00:41:45,933 --> 00:41:48,400

We're below the triple point.

956

00:41:48,400 --> 00:41:50,700

You needed pressures that were
orders of magnitude higher

957

00:41:50,700 --> 00:41:52,266

in the ancient past.

958

00:41:52,266 --> 00:41:55,800

But this seems to be evidence
for a very different Pluto,

959

00:41:55,800 --> 00:41:58,166

with a much thicker atmosphere
long ago.

960

00:41:58,166 --> 00:42:00,733

I'm gonna skip some evidence--

961

00:42:00,733 --> 00:42:02,866

I'm out of time--

I don't want to talk about.

962

00:42:02,866 --> 00:42:06,300

But I will say there
are lots more data sets.

963

00:42:06,300 --> 00:42:10,100

These are composition maps in
three different molecular bands.

964

00:42:10,100 --> 00:42:14,200

These are plots that show us
that we can age-date

965

00:42:14,200 --> 00:42:15,666

individual surface units,

966

00:42:15,666 --> 00:42:19,033

and we find not only are some
surface units ancient--

967

00:42:19,033 --> 00:42:21,333

billions of years old,
4 billion years old,

968

00:42:21,333 --> 00:42:25,266

and Sputnik is very young,
about 10 million years--

969

00:42:25,266 --> 00:42:28,566

but we found units
that are in between.

970

00:42:28,566 --> 00:42:29,766

So Pluto's been active

971

00:42:29,766 --> 00:42:32,133

throughout its history,
we've learned.

972

00:42:32,133 --> 00:42:34,366

We've learned from counting
craters on Pluto's surface

973

00:42:34,366 --> 00:42:37,166

a lot about the impacter
population in the Kuiper Belt

974

00:42:37,166 --> 00:42:40,866

at size scales that you can't
probe with any telescope.

975

00:42:40,866 --> 00:42:42,266

Even any telescope
that's planned,

976

00:42:42,266 --> 00:42:43,600

like the 30-meter telescope,

977

00:42:43,600 --> 00:42:46,233
that'll become operational
in the '20s,

978

00:42:46,233 --> 00:42:49,033
or James Webb could not see
down to these sizes.

979

00:42:49,033 --> 00:42:52,366
But by counting the craters
and measuring their sizes,

980

00:42:52,366 --> 00:42:54,366
we can determine how big
the impacters are.

981

00:42:54,366 --> 00:42:57,266
And we've ruled out some models
in the Kuiper Belt.

982

00:42:57,266 --> 00:42:59,766
My next-to-last little bit
on Pluto

983

00:42:59,766 --> 00:43:03,100
is to show you
this image sequence,

984

00:43:03,100 --> 00:43:06,866
which is a mosaic created from
New Horizons imagery,

985

00:43:06,866 --> 00:43:09,233
in that it extended color.

986

00:43:09,233 --> 00:43:12,066
And this is as if--
how do I start this?

987
00:43:15,400 --> 00:43:17,033
No...

988
00:43:18,700 --> 00:43:20,966
There we go.
Yeah, great.

989
00:43:20,966 --> 00:43:22,266
Because this is a lot of fun.

990
00:43:22,266 --> 00:43:23,800
We're going to zoom down
over the surface,

991
00:43:23,800 --> 00:43:26,266
use our highest resolution
imagery.

992
00:43:26,266 --> 00:43:28,100
You'll see the rectangle
of the region.

993
00:43:28,100 --> 00:43:30,666
Starting out at the limb,
we'll come down onto Sputnik.

994
00:43:30,666 --> 00:43:32,600
This is about 70 meters
per pixel,

995
00:43:32,600 --> 00:43:34,433
starting out at the limb.

996
00:43:34,433 --> 00:43:35,633
You'll see lots of craters.

997
00:43:35,633 --> 00:43:37,533
You can see structure
inside the surface.

998

00:43:37,533 --> 00:43:38,766

Stratigraphy.

999

00:43:38,766 --> 00:43:40,800

You can see
some linear features

1000

00:43:40,800 --> 00:43:43,133

that start appearing
right about now on the surface

1001

00:43:43,133 --> 00:43:46,366

that might be the result
of atmospheric phenomena

1002

00:43:46,366 --> 00:43:47,666

interacting with the surface.

1003

00:43:47,666 --> 00:43:51,300

And then this hilly region
that transforms

1004

00:43:51,300 --> 00:43:53,233

into bigger and bigger
mountain blocks--

1005

00:43:53,233 --> 00:43:55,800

individually,
30 to 50 kilometers across

1006

00:43:55,800 --> 00:43:58,733

and in excess
of 10,000 feet high.

1007

00:43:58,733 --> 00:44:00,900

And then off onto the shoreline
of Sputnik Planum,

1008

00:44:00,900 --> 00:44:04,066

you can see convection cells
in the glacier.

1009

00:44:04,066 --> 00:44:06,500

If you find any craters,
let me know.

1010

00:44:06,500 --> 00:44:07,700

[chuckles]

1011

00:44:07,700 --> 00:44:09,933

Lots of other
interesting detail.

1012

00:44:09,933 --> 00:44:11,933

And all of this is available
on the Web.

1013

00:44:11,933 --> 00:44:14,000

And a lot of it's already
in the planetary data system.

1014

00:44:14,000 --> 00:44:15,833

So you can have at it yourself.

1015

00:44:15,833 --> 00:44:18,500

This is my absolutely favorite
picture of the entire flyby

1016

00:44:18,500 --> 00:44:22,266

as a guy that worked on this
for 26 years,

1017

00:44:22,266 --> 00:44:24,133

because it's an image
of sunlight

1018

00:44:24,133 --> 00:44:26,000

filtering through

Pluto's atmosphere,

1019

00:44:26,000 --> 00:44:28,866

and can only be taken
from the far side of Pluto.

1020

00:44:28,866 --> 00:44:31,666

So it's my "we did it" image.

1021

00:44:31,666 --> 00:44:34,500

It's in actual color,
not exaggerated color.

1022

00:44:34,500 --> 00:44:37,933

The skies of Pluto are,
in fact, blue to your eye

1023

00:44:37,933 --> 00:44:40,266

if you were to see them
from this vantage point.

1024

00:44:40,266 --> 00:44:42,800

And then I'm going to close
by saying just a couple things

1025

00:44:42,800 --> 00:44:44,566

to put this in perspective.

1026

00:44:44,566 --> 00:44:46,700

These are two
New York Times covers.

1027

00:44:46,700 --> 00:44:50,600

The one on the left
is July the 16th, 2015.

1028

00:44:50,600 --> 00:44:53,933

The one on the right
is July the 16th, 1965,

1029

00:44:53,933 --> 00:44:56,866

50 years before
to the very day.

1030

00:44:56,866 --> 00:44:58,633

It's the first flyby of Pluto
on the left,

1031

00:44:58,633 --> 00:45:00,433

and the first flyby of Mars.

1032

00:45:00,433 --> 00:45:02,233

Fifty years.

1033

00:45:02,233 --> 00:45:05,000

There are probably people
working at Ames

1034

00:45:05,000 --> 00:45:09,900

that were young engineers
or scientists then.

1035

00:45:09,900 --> 00:45:12,400

And in the space
of just that amount of time,

1036

00:45:12,400 --> 00:45:16,233

NASA was first to every planet
in the solar system.

1037

00:45:16,233 --> 00:45:19,000

It's pretty impressive.
And that's it.

1038

00:45:19,000 --> 00:45:20,466

You can only be first once.

1039

00:45:20,466 --> 00:45:23,333

And across the entirety

of the solar system,

1040

00:45:23,333 --> 00:45:25,533

it's our space agency
that did all of it,

1041

00:45:25,533 --> 00:45:27,033

from Mercury to Pluto.

1042

00:45:27,033 --> 00:45:28,766

Now many other space agencies

1043

00:45:28,766 --> 00:45:30,733

have done many other
spectacular things,

1044

00:45:30,733 --> 00:45:34,166

and we love having partners
in planetary exploration,

1045

00:45:34,166 --> 00:45:36,333

but it's also important

1046

00:45:36,333 --> 00:45:39,800

that over all those congresses
and administrations,

1047

00:45:39,800 --> 00:45:43,666

this space agency was supported
and had the technical talent

1048

00:45:43,666 --> 00:45:45,466

to go and do all those things.

1049

00:45:45,466 --> 00:45:48,266

And we were really proud,
as the New Horizons team,

1050

00:45:48,266 --> 00:45:50,600

to run that anchor leg
in the relay

1051

00:45:50,600 --> 00:45:54,533
of the nine planets known at
the beginning of the Space Age.

1052

00:45:54,533 --> 00:45:56,733
For all of us that worked
on New Horizons,

1053

00:45:56,733 --> 00:45:58,766
this was super emotional.

1054

00:45:58,766 --> 00:46:00,733
And we don't usually talk
about things that way,

1055

00:46:00,733 --> 00:46:04,466
but having worked on this
a long time, we got to Pluto--

1056

00:46:04,466 --> 00:46:08,200
this is a live picture taken
by a professional photographer

1057

00:46:08,200 --> 00:46:09,966
who we asked
to stand in the room

1058

00:46:09,966 --> 00:46:12,566
when the first high-resolution
image was shown

1059

00:46:12,566 --> 00:46:15,833
to the science team
just after it got to the ground.

1060

00:46:15,833 --> 00:46:17,966
It's just amazing what

this meant to all the people

1061

00:46:17,966 --> 00:46:19,833

that worked on it.

1062

00:46:19,833 --> 00:46:22,733

But it also meant a lot
to people around the country,

1063

00:46:22,733 --> 00:46:24,066

and even around the world.

1064

00:46:24,066 --> 00:46:25,500

Thousands of people came

1065

00:46:25,500 --> 00:46:27,166

to where our mission control is
in Maryland.

1066

00:46:27,166 --> 00:46:28,933

There they are on flyby day.

1067

00:46:28,933 --> 00:46:31,633

That's part of them, but...

1068

00:46:31,633 --> 00:46:34,333

you know, I'm sure you saw
a lot of this,

1069

00:46:34,333 --> 00:46:36,400

because you're all
in the space program.

1070

00:46:36,400 --> 00:46:38,900

People got really wrapped up
in what we did.

1071

00:46:38,900 --> 00:46:40,333

And we weren't sure they would,

1072

00:46:40,333 --> 00:46:42,300
because nothing like it
had happened in a generation,

1073

00:46:42,300 --> 00:46:43,766
since Voyager.

1074

00:46:43,766 --> 00:46:46,400
But we got the Google doodle.
I mean, how do you beat that?

1075

00:46:46,400 --> 00:46:48,266
We were on the covers--
NASA counted--

1076

00:46:48,266 --> 00:46:52,900
458 newspapers, front page,
on the same day.

1077

00:46:52,900 --> 00:46:57,066
Our website had over
a billion visitors in a day,

1078

00:46:57,066 --> 00:46:59,133
ten times the previous record
for NASA.

1079

00:46:59,133 --> 00:47:01,333
And countless magazine covers.

1080

00:47:01,333 --> 00:47:04,700
It was just crazy
what the public response is.

1081

00:47:04,700 --> 00:47:07,200
And continues to this day.

1082

00:47:07,200 --> 00:47:09,033

We've given hundreds
of public talks

1083

00:47:09,033 --> 00:47:12,600
between our science team members
and our engineering team.

1084

00:47:12,600 --> 00:47:14,266
And people are still asking.

1085

00:47:14,266 --> 00:47:17,533
We get about ten requests
for public talks every week.

1086

00:47:17,533 --> 00:47:21,433
And radio interviews
and TV shows.

1087

00:47:21,433 --> 00:47:25,700
And I'll go back to my favorite
image of Pluto to end this.

1088

00:47:27,133 --> 00:47:29,166
People love exploration.

1089

00:47:29,166 --> 00:47:31,333
I don't think they can
get enough of it.

1090

00:47:31,333 --> 00:47:33,000
I think it's just wonderful.

1091

00:47:33,000 --> 00:47:37,666
And I think--and for this agency
that is at the earliest stages

1092

00:47:37,666 --> 00:47:39,966
of beginning a journey to Mars--

1093

00:47:39,966 --> 00:47:43,333

if one little robot
the size of a baby grand

1094

00:47:43,333 --> 00:47:46,966

can generate this much interest
by going to a frozen,

1095

00:47:46,966 --> 00:47:48,966

remote planet
3 billion miles away,

1096

00:47:48,966 --> 00:47:52,900

can you imagine the inspiration
it will be

1097

00:47:52,900 --> 00:47:57,133

to send our fellows,
men and women, to Mars?

1098

00:47:57,133 --> 00:47:58,766

Thank you very much.

1099

00:47:58,766 --> 00:48:02,066

[applause]

1100

00:48:02,066 --> 00:48:04,000

- Excellent. Great.
Perfect.

1101

00:48:04,000 --> 00:48:05,433

- Just out of time.
It was too late.

1102

00:48:05,433 --> 00:48:09,333

- Yeah, no more time.

1103

00:48:09,333 --> 00:48:11,166

So we have time
for a few questions.

1104

00:48:11,166 --> 00:48:13,300

Please raise your hand.

Wait for the mic.

1105

00:48:13,300 --> 00:48:16,766

There's only one runner.

It's one question only.

1106

00:48:16,766 --> 00:48:19,533

Stand up.

Thank you.

1107

00:48:19,533 --> 00:48:21,666

- Hi. Great talk.

I was wondering,

1108

00:48:21,666 --> 00:48:24,500

what got the fire burning

in your belly for doing this?

1109

00:48:24,500 --> 00:48:27,866

Because you've been on this

for 26, 27 years.

1110

00:48:27,866 --> 00:48:29,433

So, I mean,

that takes a lot

1111

00:48:29,433 --> 00:48:31,400

of perseverance and passion

to do this.

1112

00:48:31,400 --> 00:48:34,233

So why--what was it

that kind of, like,

1113

00:48:34,233 --> 00:48:36,366

set you on this course

to do this?

1114

00:48:36,366 --> 00:48:39,600

- Ah, well, three things,
I would say.

1115

00:48:39,600 --> 00:48:42,033

One is I was really interested
in the science.

1116

00:48:42,033 --> 00:48:43,833

I did my master's thesis

1117

00:48:43,833 --> 00:48:46,666

with some computer models
of Pluto's atmosphere,

1118

00:48:46,666 --> 00:48:49,900

and just was all wrapped up
in the mystery of the place.

1119

00:48:49,900 --> 00:48:51,466

Part of it was a chance to be

1120

00:48:51,466 --> 00:48:54,266

on the last train
to Clarksville, you know?

1121

00:48:54,266 --> 00:48:57,333

You know, I was too young
to get on Voyager.

1122

00:48:57,333 --> 00:48:59,800

And I was--you know,
Mariner missions were--

1123

00:48:59,800 --> 00:49:01,366

you know,
I was sucking my thumb.

1124

00:49:01,366 --> 00:49:03,866

This was a chance
to be a part of, you know,

1125

00:49:03,866 --> 00:49:05,266

as I said,
what we used to call

1126

00:49:05,266 --> 00:49:06,933

the first mission
to the last planet.

1127

00:49:06,933 --> 00:49:08,500

And then part of it, honestly--

1128

00:49:08,500 --> 00:49:10,500

and a few people in this room
know me--

1129

00:49:10,500 --> 00:49:14,533

a part of it was that after
we got started, we got canceled.

1130

00:49:14,533 --> 00:49:17,700

I was kind of upset about that.

1131

00:49:17,700 --> 00:49:19,766

And then we got canceled
a second and a third time.

1132

00:49:19,766 --> 00:49:21,200

And the more we got canceled,

1133

00:49:21,200 --> 00:49:22,933

the more I wanted
to make it happen.

1134

00:49:22,933 --> 00:49:24,800

And so that's true
of a lot of us that were on it.

1135

00:49:24,800 --> 00:49:26,866

And I think that combination
of things--

1136

00:49:26,866 --> 00:49:28,666

it didn't seem like
26 years doing it,

1137

00:49:28,666 --> 00:49:30,000

at least not most days.

1138

00:49:30,000 --> 00:49:31,700

[laughs]

1139

00:49:31,700 --> 00:49:33,233

But it does take
a little persistence.

1140

00:49:33,233 --> 00:49:34,633

Thank you for that question.

1141

00:49:34,633 --> 00:49:36,533

Who's next?

1142

00:49:36,533 --> 00:49:38,866

I think the runner
is in charge of who's next.

1143

00:49:41,666 --> 00:49:45,933

- Hi. Very interesting talk.
Thank you very much.

1144

00:49:47,433 --> 00:49:50,400

Two weeks before
the New Horizons flyby,

1145

00:49:50,400 --> 00:49:56,633

the SOFIA telescope observed

the atmosphere of Pluto

1146

00:49:56,633 --> 00:49:58,600
from New Zealand.

1147

00:49:58,600 --> 00:50:02,033
Could you comment
on how significant

1148

00:50:02,033 --> 00:50:04,033
these observations were for you?

1149

00:50:04,033 --> 00:50:06,566
- Absolutely. That was,
I believe, on the 29th of June.

1150

00:50:06,566 --> 00:50:09,600
There was a very bright
stellar occultation.

1151

00:50:09,600 --> 00:50:12,800
The kind of event that actually
discovered Pluto's atmosphere.

1152

00:50:12,800 --> 00:50:14,800
And SOFIA accepted

1153

00:50:14,800 --> 00:50:16,800
a peer-reviewed proposal
by others--

1154

00:50:16,800 --> 00:50:19,066
not directly
the New Horizons team--

1155

00:50:19,066 --> 00:50:20,533
to go fly way down
to the southern hemisphere

1156

00:50:20,533 --> 00:50:22,000
and observe that.

1157
00:50:22,000 --> 00:50:23,400
And that was very important.

1158
00:50:23,400 --> 00:50:25,466
In fact, I wrote a letter
of support for that proposal,

1159
00:50:25,466 --> 00:50:29,600
because for 85 years Pluto was
an astronomer's planet.

1160
00:50:29,600 --> 00:50:33,433
We were observing it from SOFIA,
and Kuiper Airborne Observatory,

1161
00:50:33,433 --> 00:50:35,366
and the Hubble,
and telescopes on the Earth,

1162
00:50:35,366 --> 00:50:38,100
and other NASA observatories.

1163
00:50:38,100 --> 00:50:42,966
And then for about a month it
was a New Horizons data collect.

1164
00:50:42,966 --> 00:50:46,200
And then we're back
to the astronomical era again.

1165
00:50:46,200 --> 00:50:49,366
So having a tie point
for the atmosphere,

1166
00:50:49,366 --> 00:50:52,766
where we saw it from the Earth
at the resolution

1167

00:50:52,766 --> 00:50:55,066
and spectral resolution
that we can get from the Earth,

1168

00:50:55,066 --> 00:50:58,000
at the very time a spacecraft
was doing the in situ

1169

00:50:58,000 --> 00:51:02,333
and the high-resolution work
grounds us

1170

00:51:02,333 --> 00:51:04,666
for all the decades
going forward,

1171

00:51:04,666 --> 00:51:08,933
with James Webb and SOFIA and
large ground-based telescopes

1172

00:51:08,933 --> 00:51:10,366
for studying its atmosphere.

1173

00:51:10,366 --> 00:51:11,566
And at the same time,

1174

00:51:11,566 --> 00:51:13,033
we put an entire
campaign together,

1175

00:51:13,033 --> 00:51:16,000
so there were also ground-based
observations of the surface

1176

00:51:16,000 --> 00:51:18,100
and of the satellites
and other things,

1177

00:51:18,100 --> 00:51:20,333
because we knew we wanted
to anchor everything in time

1178
00:51:20,333 --> 00:51:22,533
at the time New Horizons
was going by

1179
00:51:22,533 --> 00:51:25,200
as a fiducial,
as a reference point.

1180
00:51:25,200 --> 00:51:27,666
So I consider it
really important.

1181
00:51:27,666 --> 00:51:29,200
Who's next?

1182
00:51:29,200 --> 00:51:32,233
- You had a couple pictures
of convection cells

1183
00:51:32,233 --> 00:51:34,100
in the glacier.

1184
00:51:34,100 --> 00:51:37,533
It's kind of hard for me to
imagine convection in a solid,

1185
00:51:37,533 --> 00:51:40,366
and I was surprised
not to see more, like,

1186
00:51:40,366 --> 00:51:42,133
crumbling at the edges
of the cells.

1187
00:51:42,133 --> 00:51:45,100
Can you comment how that works?

1188

00:51:45,100 --> 00:51:48,033

- As much as I can,
because I'm not a geologist.

1189

00:51:48,033 --> 00:51:50,766

So I'm going to play one on TV
for a minute,

1190

00:51:50,766 --> 00:51:53,900

because this is
going to be on YouTube.

1191

00:51:53,900 --> 00:51:58,200

So...

1192

00:51:58,200 --> 00:52:02,766

the convection happens when
you have a buoyancy-driven flow.

1193

00:52:02,766 --> 00:52:07,766

And depending upon the gravity
and the viscosity of the ice,

1194

00:52:07,766 --> 00:52:10,266

and the temperature,
and the temperature differential

1195

00:52:10,266 --> 00:52:14,400

from the surface down
to the bottom of the glacier,

1196

00:52:14,400 --> 00:52:15,900

you'll have different
characteristics

1197

00:52:15,900 --> 00:52:17,300

of the convection.

1198

00:52:17,300 --> 00:52:19,533
You could do the same experiment
if you put a little oil

1199
00:52:19,533 --> 00:52:22,366
in a pan of water
and heat it up.

1200
00:52:22,366 --> 00:52:24,100
Different oils
with different viscosities

1201
00:52:24,100 --> 00:52:26,933
or different amounts of heat
or different-sized pans

1202
00:52:26,933 --> 00:52:29,566
will produce different
convection cell patterns.

1203
00:52:29,566 --> 00:52:32,066
And Bill McKinnon,
who led that paper,

1204
00:52:32,066 --> 00:52:34,900
actually took the patterns
that are seen there--

1205
00:52:34,900 --> 00:52:37,500
the scales of the individual
cells, for example.

1206
00:52:37,500 --> 00:52:41,100
And by knowing something
about the height

1207
00:52:41,100 --> 00:52:44,266
of the way the surfaces bowed,

1208
00:52:44,266 --> 00:52:46,466

and by knowing
some other things,

1209

00:52:46,466 --> 00:52:49,900
he could model the temperature
difference that must take place

1210

00:52:49,900 --> 00:52:51,966
from the bottom
to the top of the glacier,

1211

00:52:51,966 --> 00:52:55,200
derive how strong
the energy source takes

1212

00:52:55,200 --> 00:52:57,933
to generate that heat
differential.

1213

00:52:57,933 --> 00:53:00,466
And as he showed
in that paper in Nature--

1214

00:53:00,466 --> 00:53:02,966
and others have as well,
in fact, in Nature,

1215

00:53:02,966 --> 00:53:04,766
another paper,

1216

00:53:04,766 --> 00:53:08,633
has shown that convection
is a very good explanation.

1217

00:53:08,633 --> 00:53:10,900
But then that begs
the question:

1218

00:53:10,900 --> 00:53:13,733
what's driving

that energy source?

1219

00:53:13,733 --> 00:53:16,233

And there are a bunch
of ideas out there.

1220

00:53:16,233 --> 00:53:18,466

And I don't know
if any of them are right.

1221

00:53:18,466 --> 00:53:20,266

Or one of them's right.

1222

00:53:20,266 --> 00:53:23,600

My favorite is that we also have
pretty good evidence

1223

00:53:23,600 --> 00:53:25,800

that Pluto has
an internal ocean

1224

00:53:25,800 --> 00:53:30,133

like Enceladus and like Europa
and other worlds,

1225

00:53:30,133 --> 00:53:32,633

and that that ocean
is slowly freezing over time,

1226

00:53:32,633 --> 00:53:35,033

which reduces the latent heat

1227

00:53:35,033 --> 00:53:38,100

resultant from that freezing.

1228

00:53:38,100 --> 00:53:41,000

And that acts like a battery
that's still powering Pluto

1229

00:53:41,000 --> 00:53:42,966
and is driving the convection.

1230
00:53:42,966 --> 00:53:44,600
Now that's my favorite idea.

1231
00:53:44,600 --> 00:53:47,700
We'll see which one, over time,
pans out to be correct,

1232
00:53:47,700 --> 00:53:49,533
whether it's that one
or another.

1233
00:53:49,533 --> 00:53:51,533
Okay, next question,
if there's time.

1234
00:53:51,533 --> 00:53:56,300
- You know, it's so fascinating
that you've got now

1235
00:53:56,300 --> 00:54:01,600
an $n=2$ sample
of the Kuiper Belt.

1236
00:54:01,600 --> 00:54:06,000
And Charon and Pluto
are so different in some ways.

1237
00:54:06,000 --> 00:54:08,066
I mean, obviously
the tholin issue

1238
00:54:08,066 --> 00:54:10,933
and the internal heating
potential and stuff.

1239
00:54:10,933 --> 00:54:13,500
Do you have any sense

about whether or not

1240

00:54:13,500 --> 00:54:18,366
we're gonna see more Charons
or more Pluto-like things

1241

00:54:18,366 --> 00:54:22,200
as we eventually begin
to interrogate the Kuiper Belt

1242

00:54:22,200 --> 00:54:23,400
in greater numbers?

1243

00:54:23,400 --> 00:54:24,833
- Well, that's a great question.

1244

00:54:24,833 --> 00:54:27,433
And I would say we have
an $n=6$

1245

00:54:27,433 --> 00:54:29,133
because we have
the four little satellites

1246

00:54:29,133 --> 00:54:31,966
and we're going on
in an extended mission now to--

1247

00:54:31,966 --> 00:54:35,833
both have another flyby
of a small KBO in 2019.

1248

00:54:35,833 --> 00:54:38,933
And we'll study a lot of them
at relatively close range.

1249

00:54:38,933 --> 00:54:41,433
But as far as planet-sized KBOs,

1250

00:54:41,433 --> 00:54:43,133

New Horizons can't reach
any of them.

1251

00:54:43,133 --> 00:54:44,733

They're too few and far between.

1252

00:54:44,733 --> 00:54:46,300

And as I said at the outset,

1253

00:54:46,300 --> 00:54:47,733

we already know
from ground-based

1254

00:54:47,733 --> 00:54:49,433

that they have different colors,

1255

00:54:49,433 --> 00:54:51,466

different surface compositions,
different densities.

1256

00:54:51,466 --> 00:54:54,266

We see this
heterogeneous population.

1257

00:54:54,266 --> 00:54:55,866

Some of them
do look like Charon.

1258

00:54:55,866 --> 00:54:57,066

They're water ice covered,

1259

00:54:57,066 --> 00:54:59,000

and they have similar densities
to Charon.

1260

00:54:59,000 --> 00:55:01,100

Some of them look a lot more
like Pluto,

1261

00:55:01,100 --> 00:55:03,600

and some just look
completely different.

1262

00:55:03,600 --> 00:55:07,266

And so as PI of New Horizons,
I'd be the first to get in line

1263

00:55:07,266 --> 00:55:09,433

to say we ought to fly
more flyby missions

1264

00:55:09,433 --> 00:55:10,633

out in the Kuiper Belt,

1265

00:55:10,633 --> 00:55:12,200

because we've got
a lot to learn.

1266

00:55:12,200 --> 00:55:14,766

Not just about the ones
that look like Pluto and Charon,

1267

00:55:14,766 --> 00:55:18,500

but also the ones that are
different or more exotic.

1268

00:55:18,500 --> 00:55:20,300

So I think we have our work
cut out for us

1269

00:55:20,300 --> 00:55:21,666

in the Kuiper Belt.

1270

00:55:21,666 --> 00:55:23,800

Fortunately,
the 21st century is young.

1271

00:55:23,800 --> 00:55:26,833

Yeah.
Who's next?

1272
00:55:26,833 --> 00:55:29,800
- With that, please join me
in thanking Dr. Alan Stern

1273
00:55:29,800 --> 00:55:31,700
for an excellent talk.

1274
00:55:31,700 --> 00:55:32,966
- Thanks.
- Thank you again.

1275
00:55:32,966 --> 00:55:36,133
[applause]