
Ames Research Center

1
00:00:02,800 --> 00:00:05,800
[music playing]

2
00:00:18,800 --> 00:00:23,666
- Welcome to the 2016 NASA
Ames Summer Series.

3
00:00:25,200 --> 00:00:28,100
Humans are evolutionary

4
00:00:28,100 --> 00:00:31,766
successful species

5
00:00:31,766 --> 00:00:34,400
due to our inherent drive

6
00:00:34,400 --> 00:00:37,933
to explore and migrate.

7
00:00:37,933 --> 00:00:42,466
This, in part, is due
to our ability

8
00:00:42,466 --> 00:00:44,233
to invent tools

9
00:00:44,233 --> 00:00:47,366
and adapt them for the purpose

10
00:00:47,366 --> 00:00:51,466
of surviving new environments.

11
00:00:51,466 --> 00:00:53,300
Today's talk, entitled

12
00:00:53,300 --> 00:00:56,066
"Planetary Exploration
Reinvented,"

13
00:00:56,066 --> 00:00:59,133
will be given by
Dr. Terry Fong.

14
00:01:01,133 --> 00:01:03,900
He received a bachelor's
in science

15
00:01:03,900 --> 00:01:07,433
in aeronautics and astronautics
from MIT,

16
00:01:07,433 --> 00:01:09,966
and then followed with an MS

17
00:01:09,966 --> 00:01:14,066
in aeronautics
and astronautics also at MIT.

18
00:01:14,066 --> 00:01:16,800
He then came to Ames

19
00:01:16,800 --> 00:01:20,966
from 1991 to 1994

20
00:01:20,966 --> 00:01:25,166
and decided
to go and do a PhD.

21
00:01:25,166 --> 00:01:27,833
So he went and started a PhD

22
00:01:27,833 --> 00:01:30,233
and received a PhD

23
00:01:30,233 --> 00:01:32,333
from...

24
00:01:33,833 --> 00:01:34,833
In computer science

25
00:01:34,833 --> 00:01:36,900
from Carnegie
Mellon University.

26
00:01:36,900 --> 00:01:38,333
During that time,

27
00:01:38,333 --> 00:01:41,133
he also cofounded

28
00:01:41,133 --> 00:01:43,233
a company, Fourth Planet,

29
00:01:43,233 --> 00:01:45,200
producer of interactive tools

30
00:01:45,200 --> 00:01:49,266
for real-time
information visualization.

31
00:01:51,200 --> 00:01:55,266
In 2004, he came back to Ames,

32
00:01:55,266 --> 00:01:58,266
so all of you that are here
for the first time,

33
00:01:58,266 --> 00:02:02,366
maybe we'll see most
of you back here.

34
00:02:02,366 --> 00:02:06,066
He has numerous
publications and awards.

35

00:02:06,066 --> 00:02:09,966
Please join me
in welcoming Dr. Terry Fong.

36
00:02:09,966 --> 00:02:12,966
[applause]

37
00:02:15,800 --> 00:02:17,000
- Thanks very much, Jacob.

38
00:02:17,000 --> 00:02:19,233
Good morning.
It still is morning, I think.

39
00:02:19,233 --> 00:02:22,633
I'm really glad to see
so many people here.

40
00:02:22,633 --> 00:02:24,400
Quick show of hands,
how many of you are here

41
00:02:24,400 --> 00:02:26,866
just for the summer,
at least for now?

42
00:02:26,866 --> 00:02:28,700
Wow, so that's
almost all of you.

43
00:02:28,700 --> 00:02:29,833
So that's great.

44
00:02:29,833 --> 00:02:32,100
That means I can go rag on
all the people

45
00:02:32,100 --> 00:02:34,666
who are here all the time
who didn't come to see me

46
00:02:34,666 --> 00:02:37,466
although they were
encouraged to.

47
00:02:37,466 --> 00:02:39,333
Let's see.
As Jessica said,

48
00:02:39,333 --> 00:02:41,133
there will be some
questions at the end,

49
00:02:41,133 --> 00:02:42,766
but because you get
to grill me at the end,

50
00:02:42,766 --> 00:02:43,766
I'm going to start off
by grilling

51
00:02:43,766 --> 00:02:45,000
all of you to start with.

52
00:02:45,000 --> 00:02:46,766
So quick show of hands,

53
00:02:46,766 --> 00:02:49,233
how many of you were born

54
00:02:49,233 --> 00:02:52,933
after December 1972?

55
00:02:52,933 --> 00:02:54,866
Wow, almost all of you again.

56
00:02:54,866 --> 00:02:57,300
Can any of you tell me
why December 1972,

57
00:02:57,300 --> 00:02:58,866
and specifically December 7,

58
00:02:58,866 --> 00:03:01,200
1972 is important?

59
00:03:03,100 --> 00:03:04,233
Not yet, so stay tuned.

60
00:03:04,233 --> 00:03:05,400
I'm not going to answer
that right away,

61
00:03:05,400 --> 00:03:06,866
but just keep that in mind.

62
00:03:06,866 --> 00:03:09,000
Next question, how many
of you work in

63
00:03:09,000 --> 00:03:12,366
planetary exploration
or space sciences?

64
00:03:12,366 --> 00:03:13,466
So only a few.

65
00:03:13,466 --> 00:03:16,166
So hopefully that means

66
00:03:16,166 --> 00:03:17,700
a lot of what I'm gonna tell you
will be new to you,

67
00:03:17,700 --> 00:03:19,233
and you won't just go to sleep

68

00:03:19,233 --> 00:03:21,466
and then, you know,
come apologize afterwards.

69
00:03:21,466 --> 00:03:24,766
So let me tell you what
I'm going to describe today,

70
00:03:24,766 --> 00:03:26,433
is some of the work
we've been doing here at

71
00:03:26,433 --> 00:03:28,966
NASA Ames for the past
decade in my group,

72
00:03:28,966 --> 00:03:30,233
the Intelligent Robotics Group,

73
00:03:30,233 --> 00:03:32,766
to try to come up
with new tools, new techniques,

74
00:03:32,766 --> 00:03:35,400
new ways of doing
planetary exploration.

75
00:03:35,400 --> 00:03:37,333
A lot of what we care
about at NASA,

76
00:03:37,333 --> 00:03:38,433
across the board, of course,

77
00:03:38,433 --> 00:03:40,266
is learning more
about the universe,

78
00:03:40,266 --> 00:03:42,033
learning more about

the solar system,

79
00:03:42,033 --> 00:03:43,400
understanding,

80
00:03:43,400 --> 00:03:46,500
you know, differences
of the Moon, Mars,

81
00:03:46,500 --> 00:03:48,733
and other places
compared to the Earth,

82
00:03:48,733 --> 00:03:51,333
and doing so really
helps us better understand

83
00:03:51,333 --> 00:03:53,166
how we all came to be here,

84
00:03:53,166 --> 00:03:54,500
and to also think
about the future

85
00:03:54,500 --> 00:03:57,033
of how we can perhaps
expand human presence

86
00:03:57,033 --> 00:03:58,200
from where we are today

87
00:03:58,200 --> 00:04:00,800
to where we would like
to be in the future.

88
00:04:00,800 --> 00:04:03,233
So maybe what I'll start with is
trying to answer the question

89

00:04:03,233 --> 00:04:05,133
I just asked you about
why December

90
00:04:05,133 --> 00:04:06,966
1972 is so important.

91
00:04:06,966 --> 00:04:09,200
And the reason is,
that was the very last time

92
00:04:09,200 --> 00:04:12,433
that humans went
beyond lower orbit.

93
00:04:12,433 --> 00:04:15,466
That was and still is today
the state-of-the-art

94
00:04:15,466 --> 00:04:17,033
of human planetary exploration.

95
00:04:17,033 --> 00:04:19,000
1972, December 1972,

96
00:04:19,000 --> 00:04:21,300
is when Apollo 17
went to the Moon,

97
00:04:21,300 --> 00:04:23,700
and in particular,
this image to me,

98
00:04:23,700 --> 00:04:25,766
it really sort of summarizes

99
00:04:25,766 --> 00:04:28,733
where we are still more
than 44--well,

100
00:04:28,733 --> 00:04:30,533
coming up on 44 years later

101
00:04:30,533 --> 00:04:33,333
in terms of the state-of-the-art
of human planetary exploration.

102
00:04:33,333 --> 00:04:36,800
This is a picture
of Jack Schmitt, astronaut,

103
00:04:36,800 --> 00:04:39,900
geologist, on the surface
of the moon with his car,

104
00:04:39,900 --> 00:04:41,466
the Lunar Roving Vehicle,

105
00:04:41,466 --> 00:04:44,400
doing fieldwork
with handheld tools,

106
00:04:44,400 --> 00:04:47,100
shovels, sample collection bags,

107
00:04:47,100 --> 00:04:49,566
walking inside of
a pressure suit

108
00:04:49,566 --> 00:04:51,033
on the surface of the Moon.

109
00:04:51,033 --> 00:04:52,433
When you think about it,
you know,

110
00:04:52,433 --> 00:04:55,200
that's both really exciting,
the fact that, you know,

111
00:04:55,200 --> 00:04:57,500
we did get out beyond
low Earth orbit,

112
00:04:57,500 --> 00:04:59,900
that there was exploration
of the surface of the moon.

113
00:04:59,900 --> 00:05:01,800
At the same time, it's a little
sad if you think about it.

114
00:05:01,800 --> 00:05:04,266
That was 44 years ago,

115
00:05:04,266 --> 00:05:05,666
and a lot has
changed since then.

116
00:05:05,666 --> 00:05:07,200
Which means that part
of the question is,

117
00:05:07,200 --> 00:05:09,533
well, can we
do things differently?

118
00:05:09,533 --> 00:05:10,900
Can we do things better?

119
00:05:10,900 --> 00:05:12,566
Or perhaps are there
other ways to think

120
00:05:12,566 --> 00:05:14,766
about planetary exploration?

121
00:05:14,766 --> 00:05:18,400

In particular, a lot has evolved
over the past 40-some years

122
00:05:18,400 --> 00:05:21,433
in terms of our ability
to use tools,

123
00:05:21,433 --> 00:05:24,233
especially things like orbiters.

124
00:05:24,233 --> 00:05:25,433
You see in the top row there,
there are

125
00:05:25,433 --> 00:05:27,500
a number of different
satellite systems

126
00:05:27,500 --> 00:05:29,033
that have been
back to the moon.

127
00:05:29,033 --> 00:05:31,233
The Japanese, the Indians,

128
00:05:31,233 --> 00:05:34,366
NASA have sent probes
to orbit the moon

129
00:05:34,366 --> 00:05:36,233
and collect
high-resolution images,

130
00:05:36,233 --> 00:05:37,533
and to use other instruments

131
00:05:37,533 --> 00:05:40,466
to measure the properties
of the lunar surface.

132
00:05:40,466 --> 00:05:42,600
We've learned how to live
and work in space.

133
00:05:42,600 --> 00:05:43,900
The Space Station's
been up there

134
00:05:43,900 --> 00:05:45,533
for more than a decade now

135
00:05:45,533 --> 00:05:47,833
where people routinely
conduct experiments,

136
00:05:47,833 --> 00:05:50,166
they do work onboard
Space Station.

137
00:05:50,166 --> 00:05:52,700
They learn a lot about
what it's like to live

138
00:05:52,700 --> 00:05:56,900
and work in a really unnatural
environment for humans.

139
00:05:56,900 --> 00:05:58,333
And, of course,
NASA has been

140
00:05:58,333 --> 00:06:00,600
very fortunate
over the past few decades

141
00:06:00,600 --> 00:06:02,000
to be able to send,
you know,

142

00:06:02,000 --> 00:06:05,366
our robotic explorers
far beyond Earth orbit.

143
00:06:05,366 --> 00:06:08,500
We've sent landers
such as Phoenix to Mars.

144
00:06:08,500 --> 00:06:11,133
We've used Mars rovers
to explore the surface

145
00:06:11,133 --> 00:06:14,166
of the third--I'm sorry,
the fourth planet.

146
00:06:14,166 --> 00:06:16,133
And over the past,
you know, few years,

147
00:06:16,133 --> 00:06:18,600
we've been doing a lot of
experimentation on Space Station

148
00:06:18,600 --> 00:06:19,966
with robots like Robonaut 2

149
00:06:19,966 --> 00:06:21,866
as well as here on Earth
with a variety

150
00:06:21,866 --> 00:06:23,200
of robots to understand

151
00:06:23,200 --> 00:06:25,333
how robots can be
used productively

152
00:06:25,333 --> 00:06:27,600
for planetary exploration.

153
00:06:27,600 --> 00:06:30,666
But, you know, if we look at
where NASA is headed,

154
00:06:30,666 --> 00:06:33,433
we're trying to embark
upon a journey to Mars.

155
00:06:33,433 --> 00:06:35,766
We're trying to go
from where we are today,

156
00:06:35,766 --> 00:06:38,633
which is a lot of work
on the Earth or in Earth orbit

157
00:06:38,633 --> 00:06:41,366
to a future
where we do have humans,

158
00:06:41,366 --> 00:06:43,233
you know,
on the Moon again,

159
00:06:43,233 --> 00:06:46,600
at Mars, in Mars orbit,
on the surface of Mars,

160
00:06:46,600 --> 00:06:49,700
and being able to carry out
these missions requires us

161
00:06:49,700 --> 00:06:51,566
to do a lot of development,

162
00:06:51,566 --> 00:06:54,100
a lot of thinking of how do
we really make that possible.

163
00:06:54,100 --> 00:06:56,200
These missions, as we're looking
to go further

164
00:06:56,200 --> 00:06:58,400
and further away from Earth,
are more complex,

165
00:06:58,400 --> 00:07:01,100
they are longer duration,
they require new technology,

166
00:07:01,100 --> 00:07:03,200
they require new tools.

167
00:07:03,200 --> 00:07:04,966
A variety of different things
we have to worry about

168
00:07:04,966 --> 00:07:07,633
include robotics,

169
00:07:07,633 --> 00:07:10,133
deep space habitation,
spacesuits,

170
00:07:10,133 --> 00:07:11,966
communications, propulsions,

171
00:07:11,966 --> 00:07:14,100
lots of different things
that we today

172
00:07:14,100 --> 00:07:16,166
still don't quite have
all the answers.

173
00:07:16,166 --> 00:07:18,066
And so, one of the challenges

for all of you,

174
00:07:18,066 --> 00:07:20,733
if you're interested,
is to try to help NASA

175
00:07:20,733 --> 00:07:22,933
answer some of the questions
of how do you create

176
00:07:22,933 --> 00:07:24,500
the tools and the techniques,

177
00:07:24,500 --> 00:07:26,700
the methods that we need
for doing future exploration,

178
00:07:26,700 --> 00:07:28,766
at least future
human exploration

179
00:07:28,766 --> 00:07:30,633
of deep space?

180
00:07:30,633 --> 00:07:32,133
So what I'm going
to talk to you about today

181
00:07:32,133 --> 00:07:34,100
are three of the things that
we've been doing here

182
00:07:34,100 --> 00:07:37,566
at NASA Ames in my group
to really try to expand

183
00:07:37,566 --> 00:07:40,133
and try to reinvent
in some way the way

184
00:07:40,133 --> 00:07:42,733
that planetary explanation
can be conceived of,

185
00:07:42,733 --> 00:07:44,800
can be performed.

186
00:07:44,800 --> 00:07:47,566
Three parts,
so a three-part act today.

187
00:07:47,566 --> 00:07:50,133
The first one in terms of robots
for human exploration.

188
00:07:50,133 --> 00:07:52,333
How can we use robots
to improve the way

189
00:07:52,333 --> 00:07:54,700
that humans live
and work in space?

190
00:07:54,700 --> 00:07:56,366
Number two is
an interesting area

191
00:07:56,366 --> 00:07:57,800
called neo-geography.

192
00:07:57,800 --> 00:07:59,100
There's been a real revolution

193
00:07:59,100 --> 00:08:01,433
in the past couple of decades

194
00:08:01,433 --> 00:08:05,000
of how we think
about using maps, and images,

195
00:08:05,000 --> 00:08:07,200
and combining maps
and images together.

196
00:08:07,200 --> 00:08:08,900
So I'll talk a little
bit about that.

197
00:08:08,900 --> 00:08:12,000
And the third is in terms of
Exploration Ground Data System,

198
00:08:12,000 --> 00:08:13,733
which is a fancy way
of saying how do you

199
00:08:13,733 --> 00:08:15,833
organize the information

200
00:08:15,833 --> 00:08:17,666
that you're using to plan

201
00:08:17,666 --> 00:08:19,700
and carry out
exploration missions

202
00:08:19,700 --> 00:08:21,200
through software
in particular?

203
00:08:21,200 --> 00:08:23,900
Do you do that on a laptop,
is it on a tablet,

204
00:08:23,900 --> 00:08:25,900
is it with a giant
ground control team

205

00:08:25,900 --> 00:08:28,966
like we've routinely
done here at NASA?

206
00:08:28,966 --> 00:08:30,966
So we'll go into each of these
in a little bit,

207
00:08:30,966 --> 00:08:33,333
and hopefully this will
give you some, you know,

208
00:08:33,333 --> 00:08:35,066
insight of some
of the different ways

209
00:08:35,066 --> 00:08:37,500
to perhaps explore
in the future.

210
00:08:37,500 --> 00:08:39,300
So I'll start off
with the robots

211
00:08:39,300 --> 00:08:40,900
for human exploration.

212
00:08:40,900 --> 00:08:42,566
This is the topic
that's been near and dear

213
00:08:42,566 --> 00:08:44,300
to my heart for many years now,

214
00:08:44,300 --> 00:08:45,833
and the reason that it's really,

215
00:08:45,833 --> 00:08:47,633
I think, interesting is
this whole notion

216
00:08:47,633 --> 00:08:49,300
of how you combine humans

217
00:08:49,300 --> 00:08:51,833
and robots together
into an effective team.

218
00:08:51,833 --> 00:08:53,700
NASA has had a long history

219
00:08:53,700 --> 00:08:56,400
of using robots
for deep-space exploration.

220
00:08:56,400 --> 00:08:57,966
We've had a long history,

221
00:08:57,966 --> 00:09:00,333
although some of it
is quite historical now,

222
00:09:00,333 --> 00:09:03,000
of using humans to do
exploration in space,

223
00:09:03,000 --> 00:09:04,466
but the question looking forward

224
00:09:04,466 --> 00:09:06,766
is how do you combine humans
and robots together?

225
00:09:06,766 --> 00:09:09,166
Are there effective ways
to create teams,

226
00:09:09,166 --> 00:09:12,366
robots that can

complement and supplement

227
00:09:12,366 --> 00:09:13,733
the activities of humans?

228
00:09:13,733 --> 00:09:15,400
You know, and
how do you do that?

229
00:09:15,400 --> 00:09:17,333
So one of the things

230
00:09:17,333 --> 00:09:18,566
that we've been
doing here at Ames

231
00:09:18,566 --> 00:09:21,100
is trying to look at
the whole trade space.

232
00:09:21,100 --> 00:09:22,566
You know, how do you
combine humans

233
00:09:22,566 --> 00:09:24,900
and robots
in an effective manner?

234
00:09:24,900 --> 00:09:27,133
And I like to point out to
people that human-robot teaming

235
00:09:27,133 --> 00:09:29,333
is not just what you
might see in the movies.

236
00:09:29,333 --> 00:09:32,466
It's not just, you know,
Luke Skywalker and R2-D2

237
00:09:32,466 --> 00:09:34,133
just being closely--you know,

238
00:09:34,133 --> 00:09:37,433
walking hand-in-hand
or hand-in-gripper or whatever,

239
00:09:37,433 --> 00:09:40,733
but it's a broader
set of configurations.

240
00:09:40,733 --> 00:09:42,000
It's the idea
that you can have

241
00:09:42,000 --> 00:09:44,000
robots working before humans,

242
00:09:44,000 --> 00:09:45,533
or robots working in parallel

243
00:09:45,533 --> 00:09:46,900
or supporting humans,

244
00:09:46,900 --> 00:09:48,500
and of course
robots working afterwards.

245
00:09:48,500 --> 00:09:51,966
So the whole notion of before,
in parallel or supporting,

246
00:09:51,966 --> 00:09:53,733
and after is
an interesting twist

247
00:09:53,733 --> 00:09:55,700
on the idea
of human-robot teaming.

248
00:09:55,700 --> 00:09:57,400
It's not just
about hand-in-hand.

249
00:09:57,400 --> 00:09:59,900
It's really the whole idea
of looking at

250
00:09:59,900 --> 00:10:01,900
how they can be complementary
over a broad range

251
00:10:01,900 --> 00:10:04,100
of space and time

252
00:10:04,100 --> 00:10:06,033
and not going off to lunch

253
00:10:06,033 --> 00:10:08,900
when we go back up here.

254
00:10:08,900 --> 00:10:11,800
So one of the things
that we did a few years ago

255
00:10:11,800 --> 00:10:14,933
was conduct an experiment called
the robotic recon experiment.

256
00:10:14,933 --> 00:10:18,133
This was an experiment
that we ran to understand

257
00:10:18,133 --> 00:10:21,100
a little bit better
how having robots working

258
00:10:21,100 --> 00:10:23,433

ahead of humans
might really improve

259
00:10:23,433 --> 00:10:25,600
the overall productivity
of the exploration,

260
00:10:25,600 --> 00:10:29,500
make it more productive,
make it more effective.

261
00:10:29,500 --> 00:10:31,566
To do this, you know,
we set up an experiment

262
00:10:31,566 --> 00:10:34,833
where we--we tested exploration
of an unknown area--

263
00:10:34,833 --> 00:10:37,266
I'll get into the details
in a minute here--both with

264
00:10:37,266 --> 00:10:39,333
and without the benefit
of having robots

265
00:10:39,333 --> 00:10:40,900
working in advance.

266
00:10:40,900 --> 00:10:43,133
And we tried to use
this experiment

267
00:10:43,133 --> 00:10:45,133
to better understand
what are the requirements,

268
00:10:45,133 --> 00:10:47,200
the kinds of things

that are needed to carry out

269
00:10:47,200 --> 00:10:50,033
this kind of joint
human-and-robot activity

270
00:10:50,033 --> 00:10:51,266
in terms
of the instrumentation

271
00:10:51,266 --> 00:10:53,533
the robots have to carry,
the communications,

272
00:10:53,533 --> 00:10:55,533
the navigation,
the planning,

273
00:10:55,533 --> 00:10:58,100
how do we understand
the coordination

274
00:10:58,100 --> 00:11:01,500
between robot activity
and human activity,

275
00:11:01,500 --> 00:11:03,833
all these kinds
of questions are things

276
00:11:03,833 --> 00:11:05,466
that we tried to look at,

277
00:11:05,466 --> 00:11:07,100
and if any of you
are really interested

278
00:11:07,100 --> 00:11:08,933
in the detailed results,

279
00:11:08,933 --> 00:11:12,100
there's a nice paper
that my deputy wrote,

280
00:11:12,100 --> 00:11:14,433
Maria Bualat,
published back in 2011.

281
00:11:14,433 --> 00:11:17,566
I'm happy to give you
the reference afterwards

282
00:11:17,566 --> 00:11:19,133
so you can look at it
on YouTube,

283
00:11:19,133 --> 00:11:22,400
so you don't have to try to
scribble it down right now.

284
00:11:22,400 --> 00:11:24,000
But to motivate this,
let me tell you a little bit

285
00:11:24,000 --> 00:11:27,833
about why recon or scouting
in general is useful,

286
00:11:27,833 --> 00:11:29,200
and to do that I'm going
to tell you a little bit

287
00:11:29,200 --> 00:11:30,566
about Apollo 17.

288
00:11:30,566 --> 00:11:34,166
As I mentioned, Apollo 17
happened in December 1972.

289

00:11:34,166 --> 00:11:36,166
It was the last Apollo mission,

290
00:11:36,166 --> 00:11:37,533
and it was the only mission

291
00:11:37,533 --> 00:11:40,733
where one of the astronauts
was a trained scientist.

292
00:11:40,733 --> 00:11:43,100
Jack Schmitt,
geologist by training,

293
00:11:43,100 --> 00:11:45,866
was kind of a last-minute
replacement,

294
00:11:45,866 --> 00:11:49,033
but he was a member of the crew
who had training,

295
00:11:49,033 --> 00:11:50,933
a background in field geology.

296
00:11:50,933 --> 00:11:54,200
That is, he was used to going
out and doing fieldwork,

297
00:11:54,200 --> 00:11:56,233
walking around,

298
00:11:56,233 --> 00:11:59,633
trying to understand
multiple hypotheses

299
00:11:59,633 --> 00:12:02,766
at the time about the way that
the environment was constructed.

300
00:12:02,766 --> 00:12:04,300
What are the different
geologic units?

301
00:12:04,300 --> 00:12:06,966
How do they fit together?
Where do they come from?

302
00:12:06,966 --> 00:12:09,700
And one of the things
that Jack did

303
00:12:09,700 --> 00:12:12,833
was he was part of
a number of sorties,

304
00:12:12,833 --> 00:12:17,233
a number of EVA activities
on the surface of the moon.

305
00:12:17,233 --> 00:12:19,566
The second of those,
EVA-2,

306
00:12:19,566 --> 00:12:22,333
uh, started off
from the landing site,

307
00:12:22,333 --> 00:12:24,200
and they went out along

308
00:12:24,200 --> 00:12:26,933
and followed the blue lines
towards the South Massif,

309
00:12:26,933 --> 00:12:28,133
and then they worked their way
back out

310

00:12:28,133 --> 00:12:29,533
on the upper part there

311
00:12:29,533 --> 00:12:32,266
to what was termed Station 4.

312
00:12:32,266 --> 00:12:34,533
It's a location
called Shorty Crater.

313
00:12:34,533 --> 00:12:36,733
You can see by the map here
it's about 3/4

314
00:12:36,733 --> 00:12:39,400
of the way through the sortie,

315
00:12:39,400 --> 00:12:41,633
about 75% of the time through,

316
00:12:41,633 --> 00:12:44,633
and at that location,
Jack Schmitt, walking around,

317
00:12:44,633 --> 00:12:49,033
a trained field geologist
discovered orange soil.

318
00:12:49,033 --> 00:12:51,733
It actually turns out to be
this pyroclastic material.

319
00:12:51,733 --> 00:12:54,666
You can see here, this volcanic
material in orange.

320
00:12:54,666 --> 00:12:55,933
It was really exciting.

321

00:12:55,933 --> 00:13:00,533
It was perhaps the most exciting
discovery of Apollo 17.

322
00:13:00,533 --> 00:13:03,733
But it happened 3/4 of the way
through this traverse,

323
00:13:03,733 --> 00:13:06,100
and as you can imagine,
they were running short on time.

324
00:13:06,100 --> 00:13:08,300
They were running
short on oxygen.

325
00:13:08,300 --> 00:13:11,000
They couldn't stay
there very long.

326
00:13:11,000 --> 00:13:12,900
And so they quickly
grabbed some samples,

327
00:13:12,900 --> 00:13:14,166
and they went back.

328
00:13:14,166 --> 00:13:15,466
And you think about it,

329
00:13:15,466 --> 00:13:16,900
perhaps the most
important scientific

330
00:13:16,900 --> 00:13:19,300
discovery of Apollo 17,

331
00:13:19,300 --> 00:13:23,300
and didn't really have a
whole lot of time to study it.

332
00:13:23,300 --> 00:13:25,266
So you think about
how could you, you know,

333
00:13:25,266 --> 00:13:27,366
perhaps do better than that.

334
00:13:27,366 --> 00:13:29,800
And of course the obvious answer
is well, if we had known

335
00:13:29,800 --> 00:13:31,366
that Shorty Crater
was an important place,

336
00:13:31,366 --> 00:13:33,000
maybe we would have
gone there first

337
00:13:33,000 --> 00:13:34,866
or maybe would have
sped up the traverse

338
00:13:34,866 --> 00:13:36,400
so we could spend
more time there.

339
00:13:36,400 --> 00:13:39,466
But the only way you can do that
is by having better information.

340
00:13:39,466 --> 00:13:41,800
So you need to do scouting,
you need to do recon

341
00:13:41,800 --> 00:13:43,433
to make that determination.

342

00:13:43,433 --> 00:13:45,566
So for us, it was
an interesting question, okay.

343
00:13:45,566 --> 00:13:49,266
So if we want to think
about reimagining Apollo 17,

344
00:13:49,266 --> 00:13:51,433
how do we do this and how
would you carry this out

345
00:13:51,433 --> 00:13:52,966
by using a robot?

346
00:13:52,966 --> 00:13:54,366
That was the background
for this experiment

347
00:13:54,366 --> 00:13:56,633
we did back in 2009

348
00:13:56,633 --> 00:13:59,400
where we went through
a sequence of steps.

349
00:13:59,400 --> 00:14:01,800
We did a pre-recon,
sort of planning

350
00:14:01,800 --> 00:14:04,166
phase for this combination

351
00:14:04,166 --> 00:14:06,966
robot followed
by human mission.

352
00:14:06,966 --> 00:14:09,466
The first phase
in terms of pre-recon

353
00:14:09,466 --> 00:14:11,300
looked at using
satellite images.

354
00:14:11,300 --> 00:14:13,233
We did some planning
with a geologic map

355
00:14:13,233 --> 00:14:14,800
we developed
to try to lay out

356
00:14:14,800 --> 00:14:17,366
where we would want
to do scouting ahead of time,

357
00:14:17,366 --> 00:14:19,833
scouting carried out
by planetary rover.

358
00:14:19,833 --> 00:14:22,133
And the second phase,
and what you see here,

359
00:14:22,133 --> 00:14:25,800
is the K10 planetary
rover under control

360
00:14:25,800 --> 00:14:28,166
by a ground control
team followed up

361
00:14:28,166 --> 00:14:30,733
by some secondary planning
with a--

362
00:14:30,733 --> 00:14:32,333
for a human mission

363
00:14:32,333 --> 00:14:33,700
and then ultimately carried out

364
00:14:33,700 --> 00:14:35,500
as a simulated
astronaut mission.

365
00:14:35,500 --> 00:14:37,500
This was an experiment
that we carried out

366
00:14:37,500 --> 00:14:41,566
over the course of a number
of months in 2009.

367
00:14:41,566 --> 00:14:45,233
We did this at a place
called Black Point Lava Flow.

368
00:14:45,233 --> 00:14:48,533
How many of you have ever heard
of Black Point Lava Flow?

369
00:14:48,533 --> 00:14:51,133
Let's see, one,
maybe two people, three people.

370
00:14:51,133 --> 00:14:54,966
So Black Point Lava Flow is 65
kilometers north of Flagstaff.

371
00:14:54,966 --> 00:14:56,300
It's in Arizona.

372
00:14:56,300 --> 00:14:58,966
It's what we consider
to be a planetary analog,

373
00:14:58,966 --> 00:15:00,766

that it has some characteristics

374
00:15:00,766 --> 00:15:03,100
that are similar,
in this case,

375
00:15:03,100 --> 00:15:05,633
to a feature on the moon
called the Straight Wall.

376
00:15:05,633 --> 00:15:08,966
It's a large lava flow,
a fairly old lava flow.

377
00:15:08,966 --> 00:15:11,400
It's a basaltic, volcanic rock.

378
00:15:11,400 --> 00:15:13,933
It's a lot of different
geologic units

379
00:15:13,933 --> 00:15:15,000
that has different areas

380
00:15:15,000 --> 00:15:17,733
that have very different
characteristics.

381
00:15:17,733 --> 00:15:19,233
And we were interested
in studying this because

382
00:15:19,233 --> 00:15:20,800
it was
a very large structure,

383
00:15:20,800 --> 00:15:23,633
15 kilometers wide east to west,

384

00:15:23,633 --> 00:15:25,433
about 5 kilometers
north to south,

385
00:15:25,433 --> 00:15:27,166
a large area to cover

386
00:15:27,166 --> 00:15:29,900
if you're gonna try
to do exploration

387
00:15:29,900 --> 00:15:31,833
in the style
that was done during Apollo,

388
00:15:31,833 --> 00:15:33,466
which I said is still
the state-of-the-art today

389
00:15:33,466 --> 00:15:36,133
for human exploration.

390
00:15:36,133 --> 00:15:38,266
- Two NASA robots are exploring

391
00:15:38,266 --> 00:15:41,666
the dusty and rocky terrain
of the Arizona desert

392
00:15:41,666 --> 00:15:44,533
to simulate
a scouting mission on the moon.

393
00:15:44,533 --> 00:15:46,633
The robots, known as K10 Black

394
00:15:46,633 --> 00:15:50,000
and K10 Red, are using
their onboard cameras

395
00:15:50,000 --> 00:15:51,566
and 3D laser scanners

396
00:15:51,566 --> 00:15:54,000
to take images
and map the terrain.

397
00:15:54,000 --> 00:15:57,166
- We're looking at using
a smaller robot like K10

398
00:15:57,166 --> 00:15:59,400
to explore the area
ahead of time

399
00:15:59,400 --> 00:16:03,466
to make the astronauts' time
more efficient on the moon.

400
00:16:03,466 --> 00:16:05,966
- The data is transmitted
to mission managers

401
00:16:05,966 --> 00:16:07,633
at the Ames Research Center

402
00:16:07,633 --> 00:16:10,200
where the robots are
remotely controlled.

403
00:16:10,200 --> 00:16:12,400
Robotic scouting missions
to the Moon

404
00:16:12,400 --> 00:16:15,066
will provide astronauts
a lunar road map

405
00:16:15,066 --> 00:16:16,600

that will improve the quality

406
00:16:16,600 --> 00:16:18,066
and amount of science data

407
00:16:18,066 --> 00:16:21,066
collected during their stay
on the lunar surface.

408
00:16:21,066 --> 00:16:23,333
Information
gathered from the K10s

409
00:16:23,333 --> 00:16:26,000
will be used to plan
a simulated astronaut mission

410
00:16:26,000 --> 00:16:27,700
to the moon this August.

411
00:16:27,700 --> 00:16:30,466
And that's this week at NASA.

412
00:16:30,466 --> 00:16:34,600
- Or at least that was this week
at NASA back in 2009.

413
00:16:34,600 --> 00:16:37,500
The video is interesting
in a couple of respects.

414
00:16:37,500 --> 00:16:39,133
One is you saw
a planetary rover

415
00:16:39,133 --> 00:16:40,433
that was being interactively

416
00:16:40,433 --> 00:16:43,966

controlled by
a science operation team.

417
00:16:43,966 --> 00:16:45,400
They were using
a number of instruments

418
00:16:45,400 --> 00:16:48,800
onboard the robot:
cameras, 3D scanning,

419
00:16:48,800 --> 00:16:52,400
lidar, to better
understand the environment.

420
00:16:52,400 --> 00:16:53,533
But the primary purpose,
of course,

421
00:16:53,533 --> 00:16:55,966
was not moving the robot
from point A to point B.

422
00:16:55,966 --> 00:16:57,866
I mean, that's sort of
a secondary effect.

423
00:16:57,866 --> 00:17:00,200
Roboticists or operators
care about, you know,

424
00:17:00,200 --> 00:17:01,933
making sure the robot is safe.

425
00:17:01,933 --> 00:17:03,966
But the primary purpose
was of course

426
00:17:03,966 --> 00:17:05,500
to use the robot

to gather information

427
00:17:05,500 --> 00:17:08,100
that's necessary
for improving the planning

428
00:17:08,100 --> 00:17:11,666
of what comes next,
which is the human mission.

429
00:17:11,666 --> 00:17:14,333
And so one of the key
questions was, you know,

430
00:17:14,333 --> 00:17:16,600
how should you carry
out that mission?

431
00:17:16,600 --> 00:17:18,533
What sort of data
should you collect?

432
00:17:18,533 --> 00:17:21,300
Scouting is a nontrivial thing.

433
00:17:21,300 --> 00:17:23,166
The goal is not
to go out there and spend

434
00:17:23,166 --> 00:17:25,866
every possible hour
doing a super-detailed,

435
00:17:25,866 --> 00:17:27,600
comprehensive study
of the environment,

436
00:17:27,600 --> 00:17:29,066
because you just
never have the time.

437
00:17:29,066 --> 00:17:30,933
In fact, you don't have
the resources either.

438
00:17:30,933 --> 00:17:32,666
And so the question is,
how can you be smart

439
00:17:32,666 --> 00:17:34,766
about going to
different locations

440
00:17:34,766 --> 00:17:38,366
to gather the most important
information that will be,

441
00:17:38,366 --> 00:17:41,666
you know, useful for planning
what comes next?

442
00:17:41,666 --> 00:17:43,100
One of the things
we did, of course, was

443
00:17:43,100 --> 00:17:45,233
we used a number of different
instruments on that robot.

444
00:17:45,233 --> 00:17:48,200
As I said, it had
laser scanners, it has cameras.

445
00:17:48,200 --> 00:17:51,700
We also happened to have a
panoramic imager called GigaPan

446
00:17:51,700 --> 00:17:54,700
which allowed us to create
very high-resolution panoramas.

447
00:17:54,700 --> 00:17:57,433
And we collected
a lot of recon data,

448
00:17:57,433 --> 00:17:59,633
8 1/2 gigabytes of data

449
00:17:59,633 --> 00:18:02,000
over 52 hours
of remote operations.

450
00:18:02,000 --> 00:18:03,600
And you can see here
it was spread out

451
00:18:03,600 --> 00:18:05,300
over a fairly large area.

452
00:18:05,300 --> 00:18:08,433
We had an area to the west,
in blue there,

453
00:18:08,433 --> 00:18:10,733
and an area
to the--what we consider

454
00:18:10,733 --> 00:18:12,000
to be the north section,

455
00:18:12,000 --> 00:18:14,066
and a fairly large amount
of data collected

456
00:18:14,066 --> 00:18:17,066
in the center here,
a lot of data.

457
00:18:17,066 --> 00:18:19,300

This data was important because
it really helped complement

458
00:18:19,300 --> 00:18:20,933
some of the data
that we started out with.

459
00:18:20,933 --> 00:18:23,366
As I told you earlier,
we began this whole experiment

460
00:18:23,366 --> 00:18:24,900
by starting off
with satellite imagery,

461
00:18:24,900 --> 00:18:26,800
the kind of imagery
we would get today

462
00:18:26,800 --> 00:18:29,266
if we were to go back
to the Moon or go to Mars.

463
00:18:29,266 --> 00:18:31,466
This is an example
of orbital data.

464
00:18:31,466 --> 00:18:33,600
This comes from Digital Globe.

465
00:18:33,600 --> 00:18:35,900
It was a QuickBird image
at the time,

466
00:18:35,900 --> 00:18:37,166
60 centimeters per pixel.

467
00:18:37,166 --> 00:18:38,366
You can do better
than that today.

468
00:18:38,366 --> 00:18:40,400
It was a commercially available

469
00:18:40,400 --> 00:18:43,333
state-of-the-art orbital image.

470
00:18:43,333 --> 00:18:45,600
And if I tell you a little bit
more about this image,

471
00:18:45,600 --> 00:18:48,100
such as, "Well,
here's the location

472
00:18:48,100 --> 00:18:49,566
and here's the time of day,"

473
00:18:49,566 --> 00:18:51,866
and you do a little bit of math
based on where the sun was,

474
00:18:51,866 --> 00:18:53,566
you could probably look
at this area

475
00:18:53,566 --> 00:18:55,666
highlighted in red and figure
out "Oh, this area

476
00:18:55,666 --> 00:18:58,100
where you see
some dark area,

477
00:18:58,100 --> 00:19:01,366
this kind of dark shadow,

478
00:19:01,366 --> 00:19:03,000
is actually a cast shadow."

479
00:19:03,000 --> 00:19:05,533
You could infer that
on the bottom of the image,

480
00:19:05,533 --> 00:19:06,933
that section of the ground

481
00:19:06,933 --> 00:19:08,766
is higher than
what's inside the box.

482
00:19:08,766 --> 00:19:11,900
And so the shadow is cast.
It's falling into that area.

483
00:19:11,900 --> 00:19:13,266
And so what you're really
looking at here

484
00:19:13,266 --> 00:19:15,900
is not an area that has
different colored materials

485
00:19:15,900 --> 00:19:19,966
but rather is a basin
or something is lower.

486
00:19:19,966 --> 00:19:21,466
That's the kind of thing
that you can, you know,

487
00:19:21,466 --> 00:19:22,666
glean from this image.

488
00:19:22,666 --> 00:19:24,100
And of course
that might help you

489

00:19:24,100 --> 00:19:25,666
in terms of planning
for navigation.

490
00:19:25,666 --> 00:19:27,300
Because you know, "Well,
I don't want to start

491
00:19:27,300 --> 00:19:28,600
on the bottom edge
and just drive straight

492
00:19:28,600 --> 00:19:30,633
because I'll probably
fall off of a cliff."

493
00:19:30,633 --> 00:19:32,333
But it doesn't tell you
more than that.

494
00:19:32,333 --> 00:19:33,733
It doesn't tell you
in particular, you know,

495
00:19:33,733 --> 00:19:35,800
why are there
some differences in there

496
00:19:35,800 --> 00:19:37,733
and why is that area--
which kind of looks

497
00:19:37,733 --> 00:19:40,633
a little bit like, I guess,
North America--in white?

498
00:19:40,633 --> 00:19:42,900
You know, what is that?
Why is it so white?

499

00:19:42,900 --> 00:19:44,433
How is that different
from this very,

500
00:19:44,433 --> 00:19:45,933
very deep black area?

501
00:19:45,933 --> 00:19:49,000
And if in fact that black area
is shadow, what's in there?

502
00:19:49,000 --> 00:19:50,866
And so one of the frustrations

503
00:19:50,866 --> 00:19:52,100
we have of using even

504
00:19:52,100 --> 00:19:54,100
this high-resolution
satellite imaging

505
00:19:54,100 --> 00:19:55,466
is that it doesn't
give us enough information

506
00:19:55,466 --> 00:19:58,200
to really plan
surface activities.

507
00:19:58,200 --> 00:20:00,466
Well, contrast
this kind of data,

508
00:20:00,466 --> 00:20:01,800
which comes from satellites

509
00:20:01,800 --> 00:20:04,066
from orbit,
with this kind of data,

510
00:20:04,066 --> 00:20:06,600
which is what we gathered
with our robot.

511
00:20:06,600 --> 00:20:09,866
This is information
gathered with imagers.

512
00:20:09,866 --> 00:20:12,366
We have, for example,
this top panorama

513
00:20:12,366 --> 00:20:14,833
inside that exact same area,
the same basin.

514
00:20:14,833 --> 00:20:17,100
And now you can see well,
yes, it is a wall.

515
00:20:17,100 --> 00:20:19,833
So we definitely do not want
to drive off of that.

516
00:20:19,833 --> 00:20:21,733
But more interesting,
of course, is you can zoom in

517
00:20:21,733 --> 00:20:24,433
and take a look at, you know,
from an oblique angle,

518
00:20:24,433 --> 00:20:25,900
and understand well,

519
00:20:25,900 --> 00:20:28,933
in this case, you know,
the wall looks like this.

520

00:20:28,933 --> 00:20:30,466
We can look down close
to the ground

521
00:20:30,466 --> 00:20:32,233
and very high-resolution
because here, of course,

522
00:20:32,233 --> 00:20:33,800
you can have high-resolution

523
00:20:33,800 --> 00:20:35,333
imaging on the surface

524
00:20:35,333 --> 00:20:36,800
and determine whether
or not it's important

525
00:20:36,800 --> 00:20:38,200
to go to this area

526
00:20:38,200 --> 00:20:41,633
or if it's just
a feature to avoid.

527
00:20:41,633 --> 00:20:42,800
The other interesting
thing, of course,

528
00:20:42,800 --> 00:20:44,700
is that if you do have
these sensors that are,

529
00:20:44,700 --> 00:20:48,100
you know, on the surface,
you can have very close up,

530
00:20:48,100 --> 00:20:50,333
very--extremely high-resolution
detailed measurements

531
00:20:50,333 --> 00:20:52,966
that are just impossible
to acquire from orbit.

532
00:20:52,966 --> 00:20:56,900
This is an example
of a camera image

533
00:20:56,900 --> 00:20:59,633
that we also managed
to image with our

534
00:20:59,633 --> 00:21:01,566
3D-scanning laser system here.

535
00:21:01,566 --> 00:21:04,866
Very high-resolution,
3-millimeter depth resolution.

536
00:21:04,866 --> 00:21:07,100
The kind of information
that makes it really,

537
00:21:07,100 --> 00:21:09,833
I think, effective if
you're trying to plan

538
00:21:09,833 --> 00:21:13,066
whether or not you should go
to an area, collect samples,

539
00:21:13,066 --> 00:21:16,100
or, you know,
merely take a look at it,

540
00:21:16,100 --> 00:21:18,266
you know, from a distance.

541

00:21:18,266 --> 00:21:20,766
What we did after
that robotic mission, of course,

542
00:21:20,766 --> 00:21:22,866
is we--we took a look at

543
00:21:22,866 --> 00:21:24,266
how we could use
that information

544
00:21:24,266 --> 00:21:26,466
and plan a follow-up
human mission.

545
00:21:26,466 --> 00:21:28,900
The mission that we carried out
at that time was done

546
00:21:28,900 --> 00:21:31,900
with some of our friends
at NASA Johnson,

547
00:21:31,900 --> 00:21:34,166
who, back in the 2009 period,

548
00:21:34,166 --> 00:21:36,100
were developing a vehicle called

549
00:21:36,100 --> 00:21:37,500
the Space Exploration Vehicle.

550
00:21:37,500 --> 00:21:39,366
This was meant to be,
I don't know,

551
00:21:39,366 --> 00:21:42,633
the far descendent of

552

00:21:42,633 --> 00:21:44,466
the Lunar Roving Vehicle
that I started off with

553
00:21:44,466 --> 00:21:46,533
talking about from Apollo 17.

554
00:21:46,533 --> 00:21:48,833
In this case here,
it's a vehicle where the idea

555
00:21:48,833 --> 00:21:52,100
is that you keep the spacesuits
outside of the vehicle.

556
00:21:52,100 --> 00:21:54,333
You can see in the bottom
image there, these spacesuits

557
00:21:54,333 --> 00:21:58,666
that are mounted through
a mechanism we call a suit port.

558
00:21:58,666 --> 00:22:01,633
And so the astronauts would live
inside this vehicle

559
00:22:01,633 --> 00:22:03,833
in a nice shirt sleeve,
clean environment.

560
00:22:03,833 --> 00:22:05,500
When they needed to go
outside and do fieldwork,

561
00:22:05,500 --> 00:22:08,100
they would step into
the spacesuits and detach,

562
00:22:08,100 --> 00:22:11,400

and be able to then work
outside the vehicle.

563
00:22:11,400 --> 00:22:14,666
This helps, you know,
minimize the amount of dust

564
00:22:14,666 --> 00:22:17,366
and other materials
that you might bring in

565
00:22:17,366 --> 00:22:20,100
and contaminate the clean
living environment.

566
00:22:20,100 --> 00:22:21,900
It also allows us
to be very efficient

567
00:22:21,900 --> 00:22:24,633
at being able to quickly go in
and out of a place

568
00:22:24,633 --> 00:22:26,566
which is, you know,
comfortable for living

569
00:22:26,566 --> 00:22:28,066
to have to go work
on the outside,

570
00:22:28,066 --> 00:22:31,200
rather than go through
a very long process and airlocks

571
00:22:31,200 --> 00:22:32,866
and all these
kinds of things.

572
00:22:32,866 --> 00:22:34,666

What we did
during our experiment

573
00:22:34,666 --> 00:22:38,200
was we divided up
a set of astronauts,

574
00:22:38,200 --> 00:22:39,533
or at least
simulated astronauts here.

575
00:22:39,533 --> 00:22:40,933
I shouldn't say "simulated,"
because actually,

576
00:22:40,933 --> 00:22:43,433
two of our test subjects,
Mike Gernhardt

577
00:22:43,433 --> 00:22:45,133
and Andy Thomas are,
in fact, astronauts

578
00:22:45,133 --> 00:22:46,900
that have been
on the Space Station.

579
00:22:46,900 --> 00:22:49,433
We combined them along with

580
00:22:49,433 --> 00:22:50,900
Brent Garry
and Jake Bleacher,

581
00:22:50,900 --> 00:22:52,100
who are field geologists,

582
00:22:52,100 --> 00:22:53,700
practicing geologists,
that work for NASA.

583
00:22:53,700 --> 00:22:55,633
They routinely go out
and do fieldwork.

584
00:22:55,633 --> 00:22:59,033
We had them carry out
a number of different traverses

585
00:22:59,033 --> 00:23:02,166
to do sampling, do fieldwork.

586
00:23:02,166 --> 00:23:03,600
And what we did, of course,

587
00:23:03,600 --> 00:23:05,600
is we took the data

588
00:23:05,600 --> 00:23:07,633
from the robotic recon mission

589
00:23:07,633 --> 00:23:09,066
that we had carried
out ahead of time,

590
00:23:09,066 --> 00:23:11,233
and we used that information,
and we gave that information

591
00:23:11,233 --> 00:23:12,833
only to one of the crews.

592
00:23:12,833 --> 00:23:14,433
And the other crew, we said,
"Well, we're gonna try

593
00:23:14,433 --> 00:23:16,666
to pretend like
you're just Apollo.

594
00:23:16,666 --> 00:23:17,933
You only have the benefit

595
00:23:17,933 --> 00:23:21,533
of satellite imaging,
orbital data."

596
00:23:21,533 --> 00:23:24,233
And then we'll see what are
the effects of working with

597
00:23:24,233 --> 00:23:26,866
and without surface information.

598
00:23:26,866 --> 00:23:29,200
So here's a short video
just to give you an idea

599
00:23:29,200 --> 00:23:32,266
of what the Space
Exploration Vehicle looks like.

600
00:23:32,266 --> 00:23:35,200
Large, six-wheeled vehicle.

601
00:23:36,533 --> 00:23:39,533
[engine humming]

602
00:23:49,300 --> 00:23:51,966
You can see here
the astronauts are now

603
00:23:51,966 --> 00:23:53,566
into their simulated spacesuits,

604
00:23:53,566 --> 00:23:55,400
and they're going out
to do fieldwork.

605
00:23:55,400 --> 00:23:56,566
What was interesting, of course,

606
00:23:56,566 --> 00:24:00,066
is that, you know, our focus was
on using robots.

607
00:24:00,066 --> 00:24:02,966
We didn't try to optimize
the use of hand tools.

608
00:24:02,966 --> 00:24:05,333
And so the tools
that they used were very similar

609
00:24:05,333 --> 00:24:07,933
to what was used back
during Apollo 17.

610
00:24:07,933 --> 00:24:10,000
This idea of using shovels

611
00:24:10,000 --> 00:24:13,900
and collection bags
to collect samples.

612
00:24:15,433 --> 00:24:18,000
Let's go ahead--in the interest
of time, we'll move on here.

613
00:24:18,000 --> 00:24:20,833
Some of the results
that we got from this study

614
00:24:20,833 --> 00:24:23,566
is that in the area,
the western area,

615

00:24:23,566 --> 00:24:26,133
the pre-recon plan
that was designed--and again,

616
00:24:26,133 --> 00:24:27,966
this was based purely
on satellite information--

617
00:24:27,966 --> 00:24:29,933
was designed to be
very Apollo-like.

618
00:24:29,933 --> 00:24:32,333
That is, if you think
of what was done during Apollo,

619
00:24:32,333 --> 00:24:34,733
they tried to do
very rapid area coverage

620
00:24:34,733 --> 00:24:36,133
because you only had
a single visit.

621
00:24:36,133 --> 00:24:38,433
You had to try to maximize
the area covered,

622
00:24:38,433 --> 00:24:40,200
trying to visit, you know,

623
00:24:40,200 --> 00:24:42,166
as many different
geologic units as possible

624
00:24:42,166 --> 00:24:44,266
because you don't have
a chance to go back there.

625
00:24:44,266 --> 00:24:45,700

What we found, of course,

626
00:24:45,700 --> 00:24:47,566
is then--and maybe
this is all common sense--

627
00:24:47,566 --> 00:24:51,600
is that with the benefit
of surface recon information,

628
00:24:51,600 --> 00:24:53,566
our plan was
significantly different

629
00:24:53,566 --> 00:24:55,000
because we decided
that, you know,

630
00:24:55,000 --> 00:24:57,166
the things which look
radically different from orbit,

631
00:24:57,166 --> 00:24:59,166
the things which appeared
to be, you know,

632
00:24:59,166 --> 00:25:01,000
incredibly important
to go look at

633
00:25:01,000 --> 00:25:02,933
this unit versus another,
turns out well,

634
00:25:02,933 --> 00:25:04,300
actually, they're
very similar on the ground,

635
00:25:04,300 --> 00:25:05,766
so we don't really

need to do that.

636
00:25:05,766 --> 00:25:08,200
And as a result,
our pre-recon plan

637
00:25:08,200 --> 00:25:11,000
and our post-recon plan
are significantly different.

638
00:25:11,000 --> 00:25:14,166
So one of the impacts
of having scouting information

639
00:25:14,166 --> 00:25:15,433
is that we were able to,
you know,

640
00:25:15,433 --> 00:25:17,133
really improve
the prioritization

641
00:25:17,133 --> 00:25:19,633
and the targeting of the work
being done by humans.

642
00:25:19,633 --> 00:25:21,966
Seems, you know,
fairly self-evident.

643
00:25:21,966 --> 00:25:23,533
The more information
you have, the better.

644
00:25:23,533 --> 00:25:25,566
But, you know,
other interesting results

645
00:25:25,566 --> 00:25:28,166
were that well, just having

information is not enough.

646
00:25:28,166 --> 00:25:30,500
'Cause part of the question
is how do you coordinate

647
00:25:30,500 --> 00:25:33,200
the activities done
by humans versus robots?

648
00:25:33,200 --> 00:25:34,700
I mean, if you're going
to send a robot out

649
00:25:34,700 --> 00:25:35,966
for scouting in advance,

650
00:25:35,966 --> 00:25:39,100
where do you go, how do you
carry out that scouting?

651
00:25:39,100 --> 00:25:40,466
And then how do you
take that information

652
00:25:40,466 --> 00:25:42,866
and then pass it
over to humans?

653
00:25:42,866 --> 00:25:44,166
Do you provide humans,
for example,

654
00:25:44,166 --> 00:25:46,266
with the data that was
collected by the robots,

655
00:25:46,266 --> 00:25:47,800
because of course the robots
are going to locations

656
00:25:47,800 --> 00:25:49,200
that maybe you're not
gonna send humans.

657
00:25:49,200 --> 00:25:52,133
Is that helpful or not?

658
00:25:52,133 --> 00:25:53,666
It was a real
interesting experiment

659
00:25:53,666 --> 00:25:54,933
'cause it really
started opening our eyes

660
00:25:54,933 --> 00:25:56,900
to this whole notion
of coordination

661
00:25:56,900 --> 00:25:58,333
between humans and robots,

662
00:25:58,333 --> 00:26:01,400
something that was not
really evident to us

663
00:26:01,400 --> 00:26:03,233
is--was a key driver.

664
00:26:03,233 --> 00:26:06,566
But it turns out to be
extremely important.

665
00:26:06,566 --> 00:26:08,833
So that was the robotic
recon experiment.

666
00:26:08,833 --> 00:26:10,500

You know, after
we finished that one,

667
00:26:10,500 --> 00:26:12,666
of course, we were sitting
around thinking, "Well,

668
00:26:12,666 --> 00:26:14,100
what's a natural follow-up?"

669
00:26:14,100 --> 00:26:15,566
And someone in my group said,
"Well, you know,

670
00:26:15,566 --> 00:26:17,733
we should just write a proposal
to do the opposite.

671
00:26:17,733 --> 00:26:21,200
We should go write a robotic
follow-up experiment."

672
00:26:21,200 --> 00:26:23,200
And so we did.
And it's, of course,

673
00:26:23,200 --> 00:26:25,100
a nice thing to do if
you're out there writing grants.

674
00:26:25,100 --> 00:26:27,300
You know, you do some work,
and then your second grant,

675
00:26:27,300 --> 00:26:29,066
you just take what you just did
and you flip it on its head,

676
00:26:29,066 --> 00:26:31,033
and you can go get some more

funding to do that.

677
00:26:31,033 --> 00:26:33,233
So we did another experiment

678
00:26:33,233 --> 00:26:35,633
called the Robotic
Follow-up Experiment.

679
00:26:35,633 --> 00:26:37,500
And this was meant to look
at solving the problem

680
00:26:37,500 --> 00:26:39,400
that we have when
we're out doing fieldwork

681
00:26:39,400 --> 00:26:42,400
in that we never,
ever have enough time.

682
00:26:42,400 --> 00:26:43,533
If you're in the field,

683
00:26:43,533 --> 00:26:46,400
oftentimes you run out
of resources,

684
00:26:46,400 --> 00:26:50,266
or your field experiment
just runs short,

685
00:26:50,266 --> 00:26:51,700
and you get back home,
and you think, "Boy,

686
00:26:51,700 --> 00:26:52,900
if I'd only have more time.

687

00:26:52,900 --> 00:26:54,366
I could've done
more observations,

688
00:26:54,366 --> 00:26:56,100
collected more samples,

689
00:26:56,100 --> 00:26:59,300
I could have
done additional work.

690
00:26:59,300 --> 00:27:02,433
Now that I'm sitting at home,
sitting in my office, boy,

691
00:27:02,433 --> 00:27:05,533
if I'd just gone to this
location," but you can't.

692
00:27:05,533 --> 00:27:07,566
And so one question was well,

693
00:27:07,566 --> 00:27:10,866
what if you combine
human activity with robots,

694
00:27:10,866 --> 00:27:12,733
and you leave the robots behind

695
00:27:12,733 --> 00:27:14,166
so that after you get home,

696
00:27:14,166 --> 00:27:16,266
you can actually use
the robots to follow-up

697
00:27:16,266 --> 00:27:18,400
and do the things that you
would've liked to have done

698
00:27:18,400 --> 00:27:21,366
if you could've stayed
in the field longer.

699
00:27:21,366 --> 00:27:23,300
Now, of course,
why is follow-up useful?

700
00:27:23,300 --> 00:27:25,400
I'll show you this slide,
and you probably recognize this,

701
00:27:25,400 --> 00:27:27,000
since I showed it
a few minutes ago.

702
00:27:27,000 --> 00:27:30,333
Except before it said,
"Why Is Recon Useful?"

703
00:27:30,333 --> 00:27:32,400
Apollo 17, same sort of problem.

704
00:27:32,400 --> 00:27:34,733
As you recall, out here
at Shorty Crater,

705
00:27:34,733 --> 00:27:37,066
not enough time to really
collect all the samples

706
00:27:37,066 --> 00:27:39,333
you want, not enough time to do
all the detailed fieldwork.

707
00:27:39,333 --> 00:27:42,500
Well, what if you had left
the Lunar Roving Vehicle behind,

708

00:27:42,500 --> 00:27:45,100
but it was
a self-driving car today,

709
00:27:45,100 --> 00:27:47,866
and it could carry out
its own set of activities?

710
00:27:47,866 --> 00:27:49,966
Well, that's fine.
You know, humans can go home,

711
00:27:49,966 --> 00:27:51,500
leave the robots behind,

712
00:27:51,500 --> 00:27:52,933
and then you could use
those robots to do

713
00:27:52,933 --> 00:27:55,700
some detailed systematic
work afterwards.

714
00:27:55,700 --> 00:27:57,333
It was an interesting idea,

715
00:27:57,333 --> 00:27:58,833
something which I fully believe

716
00:27:58,833 --> 00:28:00,166
is likely to happen
in the future

717
00:28:00,166 --> 00:28:02,700
because these days,
when we build things,

718
00:28:02,700 --> 00:28:04,866
they all have software in them,

719
00:28:04,866 --> 00:28:07,866
whether it's a tool
or a vehicle or a robot.

720
00:28:07,866 --> 00:28:09,366
It's very likely in the future

721
00:28:09,366 --> 00:28:12,200
that as humans go
to planetary environments,

722
00:28:12,200 --> 00:28:13,300
whether that's the Moon or Mars,

723
00:28:13,300 --> 00:28:14,766
they're going to
leave things behind.

724
00:28:14,766 --> 00:28:18,333
And then afterwards, we're
gonna operate them robotically.

725
00:28:18,333 --> 00:28:21,000
So to try to understand
what are the benefits of this,

726
00:28:21,000 --> 00:28:22,866
we went out to
a different analog site.

727
00:28:22,866 --> 00:28:24,400
This was a place
in the Canadian Arctic

728
00:28:24,400 --> 00:28:25,900
called Haughton Crater.

729
00:28:25,900 --> 00:28:29,800
Haughton Crater is about

74 degrees north.

730
00:28:29,800 --> 00:28:31,800
It's in the high
Canadian Arctic.

731
00:28:31,800 --> 00:28:34,800
And here's a trivia--bit of
trivia knowledge for all of you.

732
00:28:34,800 --> 00:28:37,000
What's the largest
uninhabited island on Earth?

733
00:28:37,000 --> 00:28:38,766
And the answer
is Devon Island,

734
00:28:38,766 --> 00:28:40,300
which is where
Haughton Crater is located.

735
00:28:40,300 --> 00:28:41,933
If anybody asks you, you know,

736
00:28:41,933 --> 00:28:43,800
where should you go
to get away from everybody?

737
00:28:43,800 --> 00:28:46,933
This is a great place for that.
[laughs]

738
00:28:46,933 --> 00:28:48,600
Devon Island
is an interesting place

739
00:28:48,600 --> 00:28:50,366
because it's snowbound
most of the year.

740
00:28:50,366 --> 00:28:52,633
There's about a six-week
period in the summer

741
00:28:52,633 --> 00:28:55,266
where the snow's all gone
at least on the surface.

742
00:28:55,266 --> 00:28:57,033
There is permafrost,

743
00:28:57,033 --> 00:28:59,000
a lot of interesting

744
00:28:59,000 --> 00:29:01,000
subsurface features
that persist year-round

745
00:29:01,000 --> 00:29:03,533
because of the very cold,
arid climate.

746
00:29:03,533 --> 00:29:05,733
And we went there because
Haughton Crater--

747
00:29:05,733 --> 00:29:08,533
this is a picture of it here,
in the far north here--

748
00:29:08,533 --> 00:29:10,800
is an analog for one
of the most interesting places

749
00:29:10,800 --> 00:29:12,466
on the Moon called
Shackleton Crater.

750

00:29:12,466 --> 00:29:14,700
They're both polar
impact structures,

751
00:29:14,700 --> 00:29:17,100
about 20 kilometers in diameter.

752
00:29:17,100 --> 00:29:20,133
Haughton Crater
has subsurface water ice.

753
00:29:20,133 --> 00:29:22,200
Shackleton Crater, we believe,
in many places,

754
00:29:22,200 --> 00:29:24,933
has subsurface water
ice as well.

755
00:29:24,933 --> 00:29:28,100
They are remote, isolated,
difficult to access.

756
00:29:28,100 --> 00:29:29,233
Interesting location for us

757
00:29:29,233 --> 00:29:31,866
to go try to do
some experimentation.

758
00:29:31,866 --> 00:29:33,433
And so what we did back in 2009

759
00:29:33,433 --> 00:29:35,300
was we carried out
a crew mission

760
00:29:35,300 --> 00:29:36,633
by first having humans

761
00:29:36,633 --> 00:29:38,933
go explore very much
in Apollo style.

762
00:29:38,933 --> 00:29:41,666
They used this Humvee as a proxy

763
00:29:41,666 --> 00:29:43,800
for a future vehicle,

764
00:29:43,800 --> 00:29:45,966
and they carried out
a couple of different surveys.

765
00:29:45,966 --> 00:29:47,533
One in terms
of geologic mapping,

766
00:29:47,533 --> 00:29:50,666
which is a classical way
that field geologists go out

767
00:29:50,666 --> 00:29:53,566
to try to document
the history of an area,

768
00:29:53,566 --> 00:29:55,933
try to examine
the structural geometry,

769
00:29:55,933 --> 00:29:57,066
the major units of an area.

770
00:29:57,066 --> 00:29:59,600
And the second was
a geophysical survey

771
00:29:59,600 --> 00:30:01,833
using handheld, or at least

hand-deployed,

772
00:30:01,833 --> 00:30:03,366
ground-penetrating radar

773
00:30:03,366 --> 00:30:07,266
to examine the 3D
subsurface structure.

774
00:30:07,266 --> 00:30:08,766
Here are some example images.

775
00:30:08,766 --> 00:30:10,700
These were collected
by Mark Helper,

776
00:30:10,700 --> 00:30:13,000
one of our field geologists
who we sent up

777
00:30:13,000 --> 00:30:14,466
to Haughton Crater.

778
00:30:14,466 --> 00:30:17,666
He collected these images
with a handheld camera

779
00:30:17,666 --> 00:30:20,666
and identified afterwards
different contacts

780
00:30:20,666 --> 00:30:22,766
between different carbonates.

781
00:30:22,766 --> 00:30:25,100
You can see a variety
of different sediments

782
00:30:25,100 --> 00:30:26,800

and different views

783
00:30:26,800 --> 00:30:29,633
of the Haughton
impact structure.

784
00:30:29,633 --> 00:30:31,133
Here are some examples
of the

785
00:30:31,133 --> 00:30:33,000
ground-penetrating radar data.

786
00:30:33,000 --> 00:30:34,466
This was collected
by Essam Heggy,

787
00:30:34,466 --> 00:30:36,766
who at the time worked at JPL,

788
00:30:36,766 --> 00:30:39,066
and what he was able to identify

789
00:30:39,066 --> 00:30:41,200
was the presence
of subsurface ice wedges,

790
00:30:41,200 --> 00:30:44,033
locations where the ice
in the subsurface

791
00:30:44,033 --> 00:30:46,033
is pushing up
in little peaks

792
00:30:46,033 --> 00:30:48,566
towards the surface.

793
00:30:48,566 --> 00:30:50,466

Based on that,
we then sat down and said,

794
00:30:50,466 --> 00:30:52,600
"Well, how can we follow up
with this with a robot?

795
00:30:52,600 --> 00:30:55,400
You know, where should we send
robots to do additional work,

796
00:30:55,400 --> 00:30:57,766
complementary work to what
was done by our humans?"

797
00:30:57,766 --> 00:30:59,600
And we decided to create

798
00:30:59,600 --> 00:31:02,400
a number of different plans
in these various sites.

799
00:31:02,400 --> 00:31:03,933
Some of these are traverses

800
00:31:03,933 --> 00:31:05,966
where you're going
from point-to-point-to-point.

801
00:31:05,966 --> 00:31:08,000
Others are systematic surveys
where you might be

802
00:31:08,000 --> 00:31:09,400
following a raster or,
you know,

803
00:31:09,400 --> 00:31:11,933
lawnmower kind of pattern
to get detailed information

804
00:31:11,933 --> 00:31:14,166
about that site.

805
00:31:14,166 --> 00:31:16,000
And here's an image--or sorry,

806
00:31:16,000 --> 00:31:17,966
a movie of one our rovers.

807
00:31:17,966 --> 00:31:19,900
This is the K10 rover

808
00:31:19,900 --> 00:31:21,666
that we sent to Haughton Crater.

809
00:31:21,666 --> 00:31:23,833
It turns out it was the same
rover that was in

810
00:31:23,833 --> 00:31:26,000
Black Point Lava Flow
in Arizona as well.

811
00:31:26,000 --> 00:31:28,533
But this time, we added
some different instrumentation.

812
00:31:28,533 --> 00:31:29,800
On the bottom of the chassis

813
00:31:29,800 --> 00:31:31,766
there's a
ground-penetrating radar.

814
00:31:31,766 --> 00:31:33,533
This was meant
to complement the work

815
00:31:33,533 --> 00:31:35,166
that was done
with the handheld tool.

816
00:31:35,166 --> 00:31:38,500
There's also an XRF
device on the back.

817
00:31:38,500 --> 00:31:41,633
There's a high-resolution

818
00:31:41,633 --> 00:31:43,266
3D-scanning lidar on the top.

819
00:31:43,266 --> 00:31:45,966
This is a robotic--
a GigaPan system

820
00:31:45,966 --> 00:31:48,066
that we're using
for panoramic imaging.

821
00:31:48,066 --> 00:31:51,633
And we use these to conduct
the follow-up work.

822
00:31:51,633 --> 00:31:53,300
Now, one of the interesting
things about this,

823
00:31:53,300 --> 00:31:55,066
of course, is that
we were trying to understand

824
00:31:55,066 --> 00:31:56,500
the impact of using robots.

825
00:31:56,500 --> 00:31:59,200
So we didn't want to just

have the robots replace humans.

826
00:31:59,200 --> 00:32:00,666
We wanted to try to understand
how the robots

827
00:32:00,666 --> 00:32:02,866
could function in ways
that are complementary.

828
00:32:02,866 --> 00:32:05,566
So this robot, for example,
is very autonomous.

829
00:32:05,566 --> 00:32:07,233
It's able to drive and navigate

830
00:32:07,233 --> 00:32:08,833
from point to point by itself.

831
00:32:08,833 --> 00:32:10,933
All the steering of the wheels
you're seeing here

832
00:32:10,933 --> 00:32:12,766
are being done fully
autonomously by the robot.

833
00:32:12,766 --> 00:32:14,966
It's making its own decisions
of how to drive,

834
00:32:14,966 --> 00:32:16,933
which places to avoid,

835
00:32:16,933 --> 00:32:18,600
you know, when to acquire images

836
00:32:18,600 --> 00:32:20,333

based on high-level guidance

837
00:32:20,333 --> 00:32:22,866
provided by the planning team.

838
00:32:25,166 --> 00:32:28,000
Some of the results
from this is that we found

839
00:32:28,000 --> 00:32:29,433
that using robots

840
00:32:29,433 --> 00:32:31,566
in sort of a follow-up
mode was very useful

841
00:32:31,566 --> 00:32:35,200
because you could verify
and amend the data

842
00:32:35,200 --> 00:32:36,800
that was collected by humans.

843
00:32:36,800 --> 00:32:40,266
In some places, you were able
to go back and confirm

844
00:32:40,266 --> 00:32:43,300
some of the hypotheses
that the human team had

845
00:32:43,300 --> 00:32:46,066
when they were carrying out
the work by themselves.

846
00:32:46,066 --> 00:32:48,833
And particularly in terms
of the geophysical survey,

847

00:32:48,833 --> 00:32:50,233
we were able to correlate,

848
00:32:50,233 --> 00:32:53,133
in a very high-resolution way,

849
00:32:53,133 --> 00:32:54,833
surface and subsurface features

850
00:32:54,833 --> 00:32:56,233
because the robots
were able to acquire

851
00:32:56,233 --> 00:32:57,933
a lot more detailed information

852
00:32:57,933 --> 00:32:59,866
in a very precise manner.

853
00:32:59,866 --> 00:33:02,566
You know, robots, of course,
are very, very easy to track.

854
00:33:02,566 --> 00:33:03,933
We use positioning systems.

855
00:33:03,933 --> 00:33:05,500
We knew exactly
where they were.

856
00:33:05,500 --> 00:33:08,533
Bit harder to do
that with humans.

857
00:33:08,533 --> 00:33:10,866
However, we learned a number
of interesting things.

858
00:33:10,866 --> 00:33:13,166

One is that
it's really nontrivial

859
00:33:13,166 --> 00:33:15,200
trying to plan the coordination

860
00:33:15,200 --> 00:33:17,466
between human activity
and robot activity.

861
00:33:17,466 --> 00:33:19,733
If you send humans
out and tell them,

862
00:33:19,733 --> 00:33:21,633
"Well, robots are gonna
come along afterwards,"

863
00:33:21,633 --> 00:33:23,833
it's really hard for those
humans to think, "Well,

864
00:33:23,833 --> 00:33:25,733
can the robot actually come here

865
00:33:25,733 --> 00:33:27,000
or go to that location

866
00:33:27,000 --> 00:33:29,266
that's far away
that I'd like to send it?"

867
00:33:29,266 --> 00:33:30,933
Because one of the problems
that we have as humans

868
00:33:30,933 --> 00:33:32,833
is it's difficult
for us to understand

869
00:33:32,833 --> 00:33:34,833
in detail what are
the performance limits.

870
00:33:34,833 --> 00:33:37,300
What are the capabilities
of those robots?

871
00:33:37,300 --> 00:33:39,466
You know, can we make them
go to the place

872
00:33:39,466 --> 00:33:40,800
where we really want to?

873
00:33:40,800 --> 00:33:42,166
That's an important thing,
because, of course,

874
00:33:42,166 --> 00:33:44,066
if you're depending
upon somebody else,

875
00:33:44,066 --> 00:33:45,666
whether it's a human teammate

876
00:33:45,666 --> 00:33:47,333
or a robot
to follow-up after you,

877
00:33:47,333 --> 00:33:49,666
you need to understand
what their capabilities are.

878
00:33:49,666 --> 00:33:51,033
And you have to take
that into consideration

879
00:33:51,033 --> 00:33:53,133

when you're planning
because otherwise, you know,

880
00:33:53,133 --> 00:33:54,433
when you hand off
a plan and say,

881
00:33:54,433 --> 00:33:57,366
"Hey, go do this," you know,
at the end of the day,

882
00:33:57,366 --> 00:33:59,500
you're not going to get
the results that you wanted.

883
00:33:59,500 --> 00:34:02,166
So one of the things
that we learned from this work

884
00:34:02,166 --> 00:34:04,400
of having robots
working before and after

885
00:34:04,400 --> 00:34:06,066
is that it's really
critically important

886
00:34:06,066 --> 00:34:08,500
to think about
human-robot teaming,

887
00:34:08,500 --> 00:34:10,166
and thinking about
what that means.

888
00:34:10,166 --> 00:34:11,933
Coordination
is clearly important.

889
00:34:11,933 --> 00:34:13,566

Understanding
the capabilities of each,

890
00:34:13,566 --> 00:34:16,366
whether the human
or the robot, is important.

891
00:34:16,366 --> 00:34:19,566
Understanding, you know,
how do you transfer information?

892
00:34:19,566 --> 00:34:23,066
The way that humans
acquire data with our senses

893
00:34:23,066 --> 00:34:24,800
and interpret that is very,

894
00:34:24,800 --> 00:34:27,400
very different than the way
that robots do that.

895
00:34:27,400 --> 00:34:28,533
These are the kind of issues

896
00:34:28,533 --> 00:34:29,766
that I think are
critically important

897
00:34:29,766 --> 00:34:32,000
if we really want
to depend upon robots

898
00:34:32,000 --> 00:34:34,366
for future planetary exploration

899
00:34:34,366 --> 00:34:36,633
when they're working,
you know, before, or in support,

900
00:34:36,633 --> 00:34:39,966
or after human teammates.

901
00:34:39,966 --> 00:34:42,066
Any case, that was part one,

902
00:34:42,066 --> 00:34:45,166
talking about robots
for human exploration.

903
00:34:45,166 --> 00:34:46,800
I think when we get
to the end of this talk

904
00:34:46,800 --> 00:34:48,166
if any of you have questions
about that,

905
00:34:48,166 --> 00:34:50,066
you know, please keep in mind
there's this whole idea

906
00:34:50,066 --> 00:34:51,900
of robots before,
in parallel, and after.

907
00:34:51,900 --> 00:34:53,500
It's a really interesting area,
and I think

908
00:34:53,500 --> 00:34:55,900
that's fundamentally something
that's gonna help reinvent

909
00:34:55,900 --> 00:34:58,466
the way that humans
explore planets.

910
00:34:58,466 --> 00:35:01,666

But let me switch now and talk
about a different set of tools,

911
00:35:01,666 --> 00:35:04,800
another way of thinking of
how can we change the way

912
00:35:04,800 --> 00:35:06,466
that we're doing
planetary exploration.

913
00:35:06,466 --> 00:35:09,333
And that's in terms
of a whole domain that's

914
00:35:09,333 --> 00:35:11,600
over the past decade been
called neo-geography,

915
00:35:11,600 --> 00:35:13,900
or, you know, a sort of
reinvention of the way

916
00:35:13,900 --> 00:35:17,266
that we think
about the use of maps.

917
00:35:17,266 --> 00:35:18,966
How many of you
in the past, say,

918
00:35:18,966 --> 00:35:22,233
six months or so has relied
upon a digital map,

919
00:35:22,233 --> 00:35:25,466
Google Maps, or Bing,
or what's on your phone?

920
00:35:25,466 --> 00:35:29,266

I think it's, like, every
single person in this room.

921
00:35:29,266 --> 00:35:30,833
Now, what's fascinating
is if you go back

922
00:35:30,833 --> 00:35:32,100
and you ask,
you know, like,

923
00:35:32,100 --> 00:35:34,566
your parents or your
grandparents that same question

924
00:35:34,566 --> 00:35:35,900
and the answer will probably be,

925
00:35:35,900 --> 00:35:37,700
"No, we didn't do that,"
or at best,

926
00:35:37,700 --> 00:35:39,066
"we used a paper map."

927
00:35:39,066 --> 00:35:40,600
Some of you are old enough--

928
00:35:40,600 --> 00:35:42,133
I'm going to date myself now--

929
00:35:42,133 --> 00:35:43,633
to know what a triptik is.

930
00:35:43,633 --> 00:35:45,166
This is a thing
that came from the AAA.

931
00:35:45,166 --> 00:35:46,566

People are like, "AAA?
What's the AAA?"

932
00:35:46,566 --> 00:35:48,733
Well, that's a whole
nother question

933
00:35:48,733 --> 00:35:50,066
or topic of discussion.

934
00:35:50,066 --> 00:35:52,900
But the point is that
over the past decade,

935
00:35:52,900 --> 00:35:55,200
we've come to rely
increasingly upon the use

936
00:35:55,200 --> 00:35:57,700
of geographic
information systems

937
00:35:57,700 --> 00:35:59,533
that are online,
that are real-time,

938
00:35:59,533 --> 00:36:02,400
that have a lot to do
with mapping.

939
00:36:02,400 --> 00:36:05,033
And so, what's important
for us here at NASA

940
00:36:05,033 --> 00:36:07,133
is to understand
how can we do the same

941
00:36:07,133 --> 00:36:08,933
for planetary exploration?

942
00:36:08,933 --> 00:36:11,366
I mean, here on Earth,
we really have, you know,

943
00:36:11,366 --> 00:36:15,133
gleaned a lot of benefits
from the existence of GPS

944
00:36:15,133 --> 00:36:17,966
and satellite data
and online maps.

945
00:36:17,966 --> 00:36:20,900
How can we do the same
for planetary exploration?

946
00:36:20,900 --> 00:36:23,100
Well, probably doesn't
surprise you that

947
00:36:23,100 --> 00:36:24,700
over the past few decades,

948
00:36:24,700 --> 00:36:26,766
NASA and other space
agencies have gotten

949
00:36:26,766 --> 00:36:30,766
increasingly good at acquiring
high-resolution data from orbit.

950
00:36:30,766 --> 00:36:32,166
You know, as I mentioned,
from the Moon, we've had

951
00:36:32,166 --> 00:36:34,466
a lot of orbiters
acquire information

952
00:36:34,466 --> 00:36:37,033
over the past several years.

953
00:36:37,033 --> 00:36:39,133
And the question is then,
based on that information,

954
00:36:39,133 --> 00:36:41,133
how can you use that
to improve the way

955
00:36:41,133 --> 00:36:43,700
that you carry out
scientific investigation?

956
00:36:43,700 --> 00:36:45,033
How do you use that
to improve the way

957
00:36:45,033 --> 00:36:47,366
that you plan future
exploration missions,

958
00:36:47,366 --> 00:36:48,633
whether those are
orbital missions

959
00:36:48,633 --> 00:36:51,700
or ones on the surface?

960
00:36:51,700 --> 00:36:53,333
I think one of the reasons
why this is important

961
00:36:53,333 --> 00:36:56,233
is that we have, you know,
found ways

962
00:36:56,233 --> 00:36:58,766

of acquiring more and more
planetary data.

963
00:36:58,766 --> 00:37:01,366
And at the same time,
it's not just an exciting thing.

964
00:37:01,366 --> 00:37:02,966
It's also a real problem.

965
00:37:02,966 --> 00:37:05,366
Over the past few decades,

966
00:37:05,366 --> 00:37:08,366
the number of images
of the Moon and Mars

967
00:37:08,366 --> 00:37:11,300
has grown at a greater than
exponential rate

968
00:37:11,300 --> 00:37:14,200
in terms of the amount
of data we acquire.

969
00:37:14,200 --> 00:37:17,266
We are really great
at getting that information.

970
00:37:17,266 --> 00:37:18,466
What we're not so great
at is being able

971
00:37:18,466 --> 00:37:19,866
to find ways of processing

972
00:37:19,866 --> 00:37:22,500
and using that information
because we have a lot of data.

973
00:37:22,500 --> 00:37:24,600
And it's not just the number
of images acquired.

974
00:37:24,600 --> 00:37:27,666
It has to deal with the size
and scale of these images.

975
00:37:27,666 --> 00:37:30,633
We have really, really
big images these days.

976
00:37:30,633 --> 00:37:32,300
Images, for example,

977
00:37:32,300 --> 00:37:35,500
from the Mars camera
called HiRISE,

978
00:37:35,500 --> 00:37:38,133
which was carried by
the Mars Reconnaissance Orbiter.

979
00:37:38,133 --> 00:37:41,266
20K by 40K images
are routine.

980
00:37:41,266 --> 00:37:44,433
These are huge pieces of data,

981
00:37:44,433 --> 00:37:45,800
and if you think about it,

982
00:37:45,800 --> 00:37:48,533
trying to process these
in a manual manner,

983
00:37:48,533 --> 00:37:50,166
the way that we've done

for many decades,

984
00:37:50,166 --> 00:37:52,966
the way that's traditional
in the space science world,

985
00:37:52,966 --> 00:37:55,233
which is human-intensive
cartography,

986
00:37:55,233 --> 00:37:57,100
is really, really limiting.

987
00:37:57,100 --> 00:37:58,700
There's only so much
that humans can do,

988
00:37:58,700 --> 00:38:01,500
no matter how many humans
you might have,

989
00:38:01,500 --> 00:38:03,733
because really there aren't
that many skilled cartographers

990
00:38:03,733 --> 00:38:06,400
in the world to be able
to process this data.

991
00:38:06,400 --> 00:38:08,266
And so the question is,
how can you make use

992
00:38:08,266 --> 00:38:10,200
of this in a faster way?

993
00:38:10,200 --> 00:38:12,000
Well, one way of doing
that is doing

994
00:38:12,000 --> 00:38:14,533
automated stereo processing.

995
00:38:14,533 --> 00:38:17,600
We can use computer systems

996
00:38:17,600 --> 00:38:19,266
to take pairs of images,

997
00:38:19,266 --> 00:38:22,833
and we can reconstruct 3D
terrain by processing these.

998
00:38:22,833 --> 00:38:24,466
NASA has done this
for a long time,

999
00:38:24,466 --> 00:38:27,933
although traditionally
with manual tools.

1000
00:38:27,933 --> 00:38:29,866
We can now apply
computer software

1001
00:38:29,866 --> 00:38:31,500
to do the same sort of thing.

1002
00:38:31,500 --> 00:38:32,933
Here in my group,
we've developed

1003
00:38:32,933 --> 00:38:34,566
a map-processing pipeline

1004
00:38:34,566 --> 00:38:36,733
that takes data from lots
of different sources,

1005
00:38:36,733 --> 00:38:39,700
runs it through a variety
of computer vision algorithms

1006
00:38:39,700 --> 00:38:42,100
that we may run on, say,
the supercomputer here,

1007
00:38:42,100 --> 00:38:44,733
and output that
in different ways.

1008
00:38:44,733 --> 00:38:47,300
We've created lots
of models of Mars.

1009
00:38:47,300 --> 00:38:49,433
We've worked with a number
of different imagers.

1010
00:38:49,433 --> 00:38:50,933
We've done the same
thing of the Moon.

1011
00:38:50,933 --> 00:38:53,066
And some of the work we've done
is actually with historic data,

1012
00:38:53,066 --> 00:38:56,566
where we've taken scans
of the original Apollo films

1013
00:38:56,566 --> 00:38:58,666
from the Apollo panoramic
and metric camera

1014
00:38:58,666 --> 00:39:01,966
and created these
high-resolution 3D models.

1015
00:39:01,966 --> 00:39:03,866
We've used that to create
these high-resolution

1016
00:39:03,866 --> 00:39:05,200
3D maps of the Moon.

1017
00:39:05,200 --> 00:39:07,366
For example, we've created
a digital elevation map,

1018
00:39:07,366 --> 00:39:11,300
a 3D terrain model of a large
mosaic of 4,000 images.

1019
00:39:11,300 --> 00:39:14,633
They've been all registered
and adjusted together.

1020
00:39:14,633 --> 00:39:16,300
And then, of course,
you can reconstruct this

1021
00:39:16,300 --> 00:39:19,833
and project this back
out to the moon.

1022
00:39:19,833 --> 00:39:21,933
And the reason why
this is exciting is that

1023
00:39:21,933 --> 00:39:23,466
once you have this data
in digital format

1024
00:39:23,466 --> 00:39:25,233
is you can not only process it,

1025
00:39:25,233 --> 00:39:26,566

but then you can
visualize it in ways

1026
00:39:26,566 --> 00:39:27,866
that are really different.

1027
00:39:27,866 --> 00:39:29,966
One of the great tools
that was created over

1028
00:39:29,966 --> 00:39:32,300
the past decade
was a tool called Google Earth.

1029
00:39:32,300 --> 00:39:34,066
I'm sure most of you
have probably played with it

1030
00:39:34,066 --> 00:39:37,133
at some point in your life.

1031
00:39:37,133 --> 00:39:38,500
I'm not sure how many, though,

1032
00:39:38,500 --> 00:39:39,766
are aware that Google Earth

1033
00:39:39,766 --> 00:39:42,666
actually has a Mars
mode and a Moon mode.

1034
00:39:42,666 --> 00:39:44,933
If you go back to your desktop
computer or your laptop

1035
00:39:44,933 --> 00:39:48,033
and you launch it after this
talk, click on the toolbar.

1036

00:39:48,033 --> 00:39:49,266
There's a little Saturn icon.

1037
00:39:49,266 --> 00:39:50,866
And if you click on
the Saturn icon,

1038
00:39:50,866 --> 00:39:52,200
you can flip to these
other modes.

1039
00:39:52,200 --> 00:39:55,433
And you can find data
that we created and then worked

1040
00:39:55,433 --> 00:39:57,966
with Google to push out
to the broad public,

1041
00:39:57,966 --> 00:40:00,766
of both Mars and the Moon.

1042
00:40:00,766 --> 00:40:03,300
- From Earth to the Moon
in Google Earth,

1043
00:40:03,300 --> 00:40:06,000
go to the top toolbar
and select "Moon."

1044
00:40:06,000 --> 00:40:07,766
Now you'll be able
to explore the Moon

1045
00:40:07,766 --> 00:40:11,533
and Moon-related content
in the left panel layers.

1046
00:40:11,533 --> 00:40:12,966
With historical charts,

1047
00:40:12,966 --> 00:40:14,566
you can explore actual
planning charts

1048
00:40:14,566 --> 00:40:17,333
of the Moon
from the Apollo missions.

1049
00:40:17,333 --> 00:40:18,766
These high-resolution maps

1050
00:40:18,766 --> 00:40:20,200
were used for astronaut training

1051
00:40:20,200 --> 00:40:23,666
and by Mission Control
during the lunar missions.

1052
00:40:23,666 --> 00:40:25,633
Clicking the human artifacts
layer displays

1053
00:40:25,633 --> 00:40:27,633
those objects humans
have left on the moon,

1054
00:40:27,633 --> 00:40:30,933
including 3D
models of spacecraft.

1055
00:40:30,933 --> 00:40:32,700
In the left panel,
you will see links

1056
00:40:32,700 --> 00:40:35,633
to the six Apollo
landing sites on the moon.

1057

00:40:35,633 --> 00:40:39,866
Double-click Apollo 11 and zoom
in and see it in more detail.

1058
00:40:39,866 --> 00:40:43,200
Once you arrive,
you can watch video clips

1059
00:40:43,200 --> 00:40:45,333
of Neil Armstrong's
first steps on the moon

1060
00:40:45,333 --> 00:40:48,100
and many other significant
mission moments,

1061
00:40:48,100 --> 00:40:50,066
view 3D models
of mission spacecraft

1062
00:40:50,066 --> 00:40:53,366
like the Apollo 11
lunar module "Eagle,"

1063
00:40:53,366 --> 00:40:54,933
and see panoramic imagery taken

1064
00:40:54,933 --> 00:40:58,366
by the astronauts themselves
of the Moon's surface.

1065
00:40:58,366 --> 00:40:59,833
- Let me flip over and show you

1066
00:40:59,833 --> 00:41:01,633
one of the other interesting
things that's embedded

1067
00:41:01,633 --> 00:41:04,033
within Moon and Mars

in Google Earth,

1068
00:41:04,033 --> 00:41:05,500
and that is guided tours.

1069
00:41:05,500 --> 00:41:08,100
So if you want to go
and explore the Moon,

1070
00:41:08,100 --> 00:41:09,966
you don't have
to just look at it

1071
00:41:09,966 --> 00:41:11,466
by navigating yourself,

1072
00:41:11,466 --> 00:41:13,433
but you can actually
take a tour with,

1073
00:41:13,433 --> 00:41:14,800
for example, Jack Schmitt.

1074
00:41:14,800 --> 00:41:17,966
- I'm Jack Schmitt, Apollo 17
astronaut and geologist,

1075
00:41:17,966 --> 00:41:22,066
flew on the Apollo 17 mission
in December of 1972.

1076
00:41:22,066 --> 00:41:25,400
The crew of Apollo 17
was an aggregate

1077
00:41:25,400 --> 00:41:29,333
of two backup crews
of Apollo 14 and 15.

1078

00:41:29,333 --> 00:41:31,566
I replaced Joe Engle
on that crew,

1079
00:41:31,566 --> 00:41:34,466
and Gene Cernan
would be the commander.

1080
00:41:34,466 --> 00:41:37,100
And Ron Evans
was going to continue

1081
00:41:37,100 --> 00:41:38,800
as the command module pilot.

1082
00:41:38,800 --> 00:41:41,333
Gene Cernan got out
of the spacecraft first,

1083
00:41:41,333 --> 00:41:44,300
and I followed him

1084
00:41:44,300 --> 00:41:46,166
fairly quickly afterwards.

1085
00:41:46,166 --> 00:41:47,366
We were in a valley,

1086
00:41:47,366 --> 00:41:49,400
deeper than the Grand Canyon
of the Colorado.

1087
00:41:49,400 --> 00:41:52,133
The mountains on either side
with 2,100 meters,

1088
00:41:52,133 --> 00:41:54,000
or about 7,000 feet high.

1089

00:41:54,000 --> 00:41:56,300
The Sun was as brilliant
as any sun

1090
00:41:56,300 --> 00:41:57,833
that you can imagine.

1091
00:41:57,833 --> 00:42:02,333
Even more impressive
was the Earth,

1092
00:42:02,333 --> 00:42:04,866
which was hanging over
one of the mountains

1093
00:42:04,866 --> 00:42:08,133
and stayed hanging over that
mountain, the South Massif.

1094
00:42:08,133 --> 00:42:10,633
And that was really
a magnificent sight for me,

1095
00:42:10,633 --> 00:42:13,033
and that's what I remember
as being sort of my first

1096
00:42:13,033 --> 00:42:16,333
real impressions of the valley
of Taurus-Littrow.

1097
00:42:16,333 --> 00:42:19,133
- So the interesting thing,
of course, is the fact

1098
00:42:19,133 --> 00:42:22,400
that we have these tools now
that allow anyone,

1099
00:42:22,400 --> 00:42:25,800

not just, you know,
a trained planetary scientist,

1100
00:42:25,800 --> 00:42:27,466
not just someone
who works at NASA

1101
00:42:27,466 --> 00:42:30,833
or another space agency,
but anyone, you,

1102
00:42:30,833 --> 00:42:32,466
your best friend,
your grandmother,

1103
00:42:32,466 --> 00:42:35,033
to go explore
these other environments,

1104
00:42:35,033 --> 00:42:37,266
these different planets.

1105
00:42:37,266 --> 00:42:39,133
We've also done some work
not just with Google,

1106
00:42:39,133 --> 00:42:40,266
but with Microsoft.

1107
00:42:40,266 --> 00:42:42,700
Microsoft had another
piece of software

1108
00:42:42,700 --> 00:42:44,166
called Worldwide Telescope

1109
00:42:44,166 --> 00:42:48,466
that we worked to help
add planetary data to.

1110
00:42:48,466 --> 00:42:51,466
[music playing]

1111
00:43:02,933 --> 00:43:04,600
- Couple years ago,
in working

1112
00:43:04,600 --> 00:43:06,000
with Chris Kemp from NASA,

1113
00:43:06,000 --> 00:43:08,633
we started thinking
how we could bring together

1114
00:43:08,633 --> 00:43:10,333
the features
and the functionality

1115
00:43:10,333 --> 00:43:12,600
that we had
in Worldwide Telescope

1116
00:43:12,600 --> 00:43:14,666
to some of the planetary
data sets.

1117
00:43:14,666 --> 00:43:17,033
And we really wanted to focus
on a unique asset,

1118
00:43:17,033 --> 00:43:19,266
the HiRISE imagery
that Mars had.

1119
00:43:19,266 --> 00:43:21,566
And so we started working
and collaborating to figure out

1120
00:43:21,566 --> 00:43:25,866

how we could bring to the public
and get it in their hands.

1121
00:43:25,866 --> 00:43:28,033
The HiRISE imagery
is a one-of-a-kind camera

1122
00:43:28,033 --> 00:43:29,600
that's onboard one
of the satellites

1123
00:43:29,600 --> 00:43:30,866
that goes around Mars

1124
00:43:30,866 --> 00:43:33,500
and takes really
high-resolution images

1125
00:43:33,500 --> 00:43:36,466
of the planet's surface.

1126
00:43:36,466 --> 00:43:38,466
- We have complete
base maps of Mars

1127
00:43:38,466 --> 00:43:40,700
as well as very
high-resolution data

1128
00:43:40,700 --> 00:43:43,233
that are actually
higher-resolution

1129
00:43:43,233 --> 00:43:45,033
than most of
the satellite data

1130
00:43:45,033 --> 00:43:47,433
that is publicly
available of Earth.

1131
00:43:47,433 --> 00:43:48,833
And so we can
actually see Mars

1132
00:43:48,833 --> 00:43:50,900
in better detail in some areas

1133
00:43:50,900 --> 00:43:54,100
than we can see Earth.

1134
00:43:55,533 --> 00:43:59,466
- This project leverages
several teams within NASA

1135
00:43:59,466 --> 00:44:02,333
and then also, of course,
teams at Microsoft.

1136
00:44:02,333 --> 00:44:04,400
And, really,
it's bringing together

1137
00:44:04,400 --> 00:44:06,633
some of the kind of
cutting-edge technologies

1138
00:44:06,633 --> 00:44:08,800
in both institutions

1139
00:44:08,800 --> 00:44:12,166
to do something which has not
been possible before.

1140
00:44:12,166 --> 00:44:14,333
- People can go
for a walk on Mars now

1141
00:44:14,333 --> 00:44:17,266

and actually see the craters,
see the cliffs,

1142
00:44:17,266 --> 00:44:19,766
and get appreciation
of the scale in a way

1143
00:44:19,766 --> 00:44:22,833
that they could never
have done before.

1144
00:44:22,833 --> 00:44:25,666
- Mars is a big place.
By making this raw data,

1145
00:44:25,666 --> 00:44:27,066
this full high-resolution

1146
00:44:27,066 --> 00:44:28,933
data available at
Worldwide Telescope,

1147
00:44:28,933 --> 00:44:31,500
we're just going to open
all of that up to classrooms

1148
00:44:31,500 --> 00:44:32,933
across America,
across the world,

1149
00:44:32,933 --> 00:44:34,733
and connect with
the public in a way

1150
00:44:34,733 --> 00:44:37,333
we've never
been able to before.

1151
00:44:37,333 --> 00:44:40,366
So if we can really put projects

like Worldwide Telescope

1152
00:44:40,366 --> 00:44:42,700
and data sets like the Mars
HiRISE data set,

1153
00:44:42,700 --> 00:44:45,033
I think we could inspire
the next generation of Americans

1154
00:44:45,033 --> 00:44:47,900
like Apollo inspired
this generation of Americans

1155
00:44:47,900 --> 00:44:50,100
to really be innovators,
be thought leaders,

1156
00:44:50,100 --> 00:44:52,100
and be leaders in the world.

1157
00:44:55,833 --> 00:44:57,500
- In the interest of time,
I'm going to skip ahead

1158
00:44:57,500 --> 00:45:00,233
and just take us to the last bit
I want to tell you about,

1159
00:45:00,233 --> 00:45:03,566
which is Exploration
Ground Data System.

1160
00:45:03,566 --> 00:45:05,300
You all know--
you've probably seen on TV--

1161
00:45:05,300 --> 00:45:07,033
that when NASA
operates missions,

1162
00:45:07,033 --> 00:45:08,600
we typically have
large control rooms

1163
00:45:08,600 --> 00:45:11,466
of very excited people
trying to figure out

1164
00:45:11,466 --> 00:45:13,766
how do we operate
a robot or a spacecraft,

1165
00:45:13,766 --> 00:45:15,800
how do we work with humans
on the Space Station?

1166
00:45:15,800 --> 00:45:18,566
These are large teams,
and one of the key questions

1167
00:45:18,566 --> 00:45:21,066
is how do you coordinate
the activity of those teams

1168
00:45:21,066 --> 00:45:23,100
on the ground
supporting those things

1169
00:45:23,100 --> 00:45:24,566
which are not on the ground?

1170
00:45:24,566 --> 00:45:26,900
Things that are in space, things
that are on other planets.

1171
00:45:26,900 --> 00:45:28,433
Traditionally, we spent
a lot of time

1172
00:45:28,433 --> 00:45:30,066
creating one-off systems.

1173
00:45:30,066 --> 00:45:31,900
That is, we'll create a mission,

1174
00:45:31,900 --> 00:45:34,400
and we'll staff up a whole team
and build a very expensive,

1175
00:45:34,400 --> 00:45:36,433
very large software system

1176
00:45:36,433 --> 00:45:38,933
that's used just for
that single mission.

1177
00:45:38,933 --> 00:45:40,533
And that's been
an effective way for us

1178
00:45:40,533 --> 00:45:42,300
because we don't have
that many missions.

1179
00:45:42,300 --> 00:45:44,600
I mean, there are frankly
a number of missions

1180
00:45:44,600 --> 00:45:47,666
out there that take decades

1181
00:45:47,666 --> 00:45:50,033
or maybe a whole career
to put together.

1182
00:45:50,033 --> 00:45:51,333
But if you think about it,

1183
00:45:51,333 --> 00:45:53,133
the world doesn't operate
that way anymore.

1184
00:45:53,133 --> 00:45:56,166
Software is something
that changes very rapidly,

1185
00:45:56,166 --> 00:45:58,733
whether it's on your phone,
on your desktop, your laptop.

1186
00:45:58,733 --> 00:46:00,433
It's something
which is distributed.

1187
00:46:00,433 --> 00:46:02,933
We don't have large systems
in our offices.

1188
00:46:02,933 --> 00:46:05,233
In fact, most of us
may not even use an office.

1189
00:46:05,233 --> 00:46:07,566
We may exist
by working in cafes.

1190
00:46:07,566 --> 00:46:09,000
And so the question is,

1191
00:46:09,000 --> 00:46:11,066
how do we try to catch up

1192
00:46:11,066 --> 00:46:14,033
in terms of the world
of software for the way

1193
00:46:14,033 --> 00:46:15,466

that we operate
these missions?

1194
00:46:15,466 --> 00:46:18,966
So here we've been
trying to figure out

1195
00:46:18,966 --> 00:46:21,266
how to create web-based systems

1196
00:46:21,266 --> 00:46:23,166
to help plan, monitor,

1197
00:46:23,166 --> 00:46:26,066
and ultimately explore,
whether we're using robots

1198
00:46:26,066 --> 00:46:28,400
or humans to carry
out activities.

1199
00:46:28,400 --> 00:46:29,600
And this, of course,

1200
00:46:29,600 --> 00:46:31,366
as I was saying,
just with the robots before,

1201
00:46:31,366 --> 00:46:33,433
is the kind of thing
that can be done before,

1202
00:46:33,433 --> 00:46:35,766
so in a planning phase,
during the mission,

1203
00:46:35,766 --> 00:46:37,733
and when you're carrying
something out,

1204
00:46:37,733 --> 00:46:39,866
human or robot,
and afterwards,

1205
00:46:39,866 --> 00:46:41,866
the idea that you can use
the same sort of software

1206
00:46:41,866 --> 00:46:44,366
to support your analysis.

1207
00:46:44,366 --> 00:46:45,766
We've been looking
at a number of different

1208
00:46:45,766 --> 00:46:47,433
exploration missions,

1209
00:46:47,433 --> 00:46:48,800
so these future
mission concepts,

1210
00:46:48,800 --> 00:46:50,866
some of those
involving humans in, say,

1211
00:46:50,866 --> 00:46:53,066
the Space Exploration
Vehicle in the center there.

1212
00:46:53,066 --> 00:46:55,300
Some using robots
as you've seen before

1213
00:46:55,300 --> 00:46:58,200
with the K10
planetary rovers,

1214
00:46:58,200 --> 00:47:00,600

and other cases
that we've tested out

1215
00:47:00,600 --> 00:47:02,433
over the past several years.

1216
00:47:02,433 --> 00:47:04,700
NASA carries out,
on pretty much

1217
00:47:04,700 --> 00:47:06,000
a yearly basis,
a number of different

1218
00:47:06,000 --> 00:47:08,300
of these planetary
analog field campaigns.

1219
00:47:08,300 --> 00:47:09,700
We try to support these.

1220
00:47:09,700 --> 00:47:11,700
In fact, there's one that
just wrapped up last week

1221
00:47:11,700 --> 00:47:13,700
that was at the Crater
of the Moons in Idaho

1222
00:47:13,700 --> 00:47:15,066
where we were trying
to use our software

1223
00:47:15,066 --> 00:47:18,066
to support exploration.

1224
00:47:18,066 --> 00:47:19,400
The system we've developed
here in my group

1225
00:47:19,400 --> 00:47:21,266
is called the Exploration
Ground Data System,

1226
00:47:21,266 --> 00:47:23,133
and like all good NASA projects,

1227
00:47:23,133 --> 00:47:24,833
has a nice acronym, xGDS,

1228
00:47:24,833 --> 00:47:27,466
which is only meaningful
to the developers.

1229
00:47:27,466 --> 00:47:30,600
But xGDS is a system--it's
a web-based system

1230
00:47:30,600 --> 00:47:33,966
that allows us to combine
these maps and data,

1231
00:47:33,966 --> 00:47:36,666
like I just showed you
in the previous segment here,

1232
00:47:36,666 --> 00:47:39,233
in a way that allows people
to interactively browse,

1233
00:47:39,233 --> 00:47:41,166
without a whole lot of training,

1234
00:47:41,166 --> 00:47:42,633
and be able to use
that to carry out

1235
00:47:42,633 --> 00:47:44,266
these exploration missions.

1236
00:47:44,266 --> 00:47:46,800
For those of you who are
the geeks in the room

1237
00:47:46,800 --> 00:47:49,766
and really want to know
about the details underneath it,

1238
00:47:49,766 --> 00:47:51,366
it's a web-based system.

1239
00:47:51,366 --> 00:47:54,733
It uses Django and MySQL,
pulls together

1240
00:47:54,733 --> 00:47:56,433
a lot of different
kind of data interfaces,

1241
00:47:56,433 --> 00:47:59,866
different user interfaces
including Google Earth,

1242
00:47:59,866 --> 00:48:02,000
Open Street Map, web browsers,

1243
00:48:02,000 --> 00:48:04,100
and all kinds of data.
If you're interested,

1244
00:48:04,100 --> 00:48:06,033
I can point you to a couple
papers about this.

1245
00:48:06,033 --> 00:48:07,666
Or if you're interested
in coming to work on this,

1246

00:48:07,666 --> 00:48:09,966
come see me afterwards,
and we can talk about that.

1247
00:48:09,966 --> 00:48:13,333
But what we use this tool for is

1248
00:48:13,333 --> 00:48:15,566
to have a nice way to quickly

1249
00:48:15,566 --> 00:48:18,600
and rapidly and flexibly
support different people

1250
00:48:18,600 --> 00:48:20,566
who care
about science operations

1251
00:48:20,566 --> 00:48:22,400
for field exploration missions.

1252
00:48:22,400 --> 00:48:25,033
We serve maps, we serve data

1253
00:48:25,033 --> 00:48:26,433
that we use
for planning purposes,

1254
00:48:26,433 --> 00:48:28,000
for laying out traverses,

1255
00:48:28,000 --> 00:48:30,000
we can track, in real-time,

1256
00:48:30,000 --> 00:48:32,166
people and human--
people and human--

1257
00:48:32,166 --> 00:48:35,466

people and robots
as they're acquiring data.

1258
00:48:35,466 --> 00:48:36,866
We can represent
the data products

1259
00:48:36,866 --> 00:48:38,666
that are acquired,
either real,

1260
00:48:38,666 --> 00:48:40,066
live, raw data,

1261
00:48:40,066 --> 00:48:42,700
or the derived products
after processing.

1262
00:48:42,700 --> 00:48:44,333
We can show raster plots

1263
00:48:44,333 --> 00:48:47,500
so you can actually look
at signals over time,

1264
00:48:47,500 --> 00:48:49,000
information that's
very important if you're trying

1265
00:48:49,000 --> 00:48:50,833
to look at time-varying signals

1266
00:48:50,833 --> 00:48:52,833
or things which
are really driven

1267
00:48:52,833 --> 00:48:55,000
by where you are
at a certain moment.

1268
00:48:55,000 --> 00:48:57,366
We can turn that information
into raster maps

1269
00:48:57,366 --> 00:48:59,966
and show a different coloring

1270
00:48:59,966 --> 00:49:03,233
of how various parameters
of the environment,

1271
00:49:03,233 --> 00:49:05,066
varying characteristics change

1272
00:49:05,066 --> 00:49:08,300
over spatial regions.

1273
00:49:08,300 --> 00:49:12,033
We can log different information
in real-time.

1274
00:49:12,033 --> 00:49:13,700
So this is sort of like
a stenographer function

1275
00:49:13,700 --> 00:49:14,933
where you're trying
to log information.

1276
00:49:14,933 --> 00:49:16,866
And we can cross-link
those with images

1277
00:49:16,866 --> 00:49:18,600
and geographic data.

1278
00:49:18,600 --> 00:49:20,500
And, of course, then you can
take all that information

1279
00:49:20,500 --> 00:49:22,933
and provide tools to help people
browse this information.

1280
00:49:22,933 --> 00:49:24,866
These are the kinds
of flexible tools

1281
00:49:24,866 --> 00:49:27,833
that we all are used to today
in our everyday life,

1282
00:49:27,833 --> 00:49:29,800
but which we've never had before

1283
00:49:29,800 --> 00:49:31,500
in terms of real-time
mission operations,

1284
00:49:31,500 --> 00:49:34,266
especially for
exploration missions.

1285
00:49:34,266 --> 00:49:36,200
We've done this work in
a number of different projects.

1286
00:49:36,200 --> 00:49:38,366
One of those is the Pavilion
Lake Research Project.

1287
00:49:38,366 --> 00:49:39,966
It's an interesting project
that's led

1288
00:49:39,966 --> 00:49:41,733
by Darlene Lim here at NASA Ames

1289

00:49:41,733 --> 00:49:43,266
where they use
these one-man submersibles

1290
00:49:43,266 --> 00:49:47,100
to map out
microbialite formations

1291
00:49:47,100 --> 00:49:50,366
in a lake a little bit
north of Vancouver in Canada.

1292
00:49:50,366 --> 00:49:53,400
This is actually
a video of Darlene

1293
00:49:53,400 --> 00:49:54,800
having a fun day at work

1294
00:49:54,800 --> 00:49:57,566
where she's out doing
some exploration

1295
00:49:57,566 --> 00:49:59,933
in this one-man submersible.

1296
00:49:59,933 --> 00:50:02,100
These are the kind of images

1297
00:50:02,100 --> 00:50:05,666
that are collected by the pilots
as they are flying

1298
00:50:05,666 --> 00:50:07,766
around underwater
in Pavilion Lake here.

1299
00:50:07,766 --> 00:50:10,400
And they're making real-time
observations,

1300
00:50:10,400 --> 00:50:13,300
commentary that is streamed up
along with this

1301
00:50:13,300 --> 00:50:16,866
high-definition video that we're
recording and then putting into

1302
00:50:16,866 --> 00:50:20,600
our Exploration Ground Data
System in an effort

1303
00:50:20,600 --> 00:50:23,233
to try to understand
the formation

1304
00:50:23,233 --> 00:50:26,000
of these really
interesting areas

1305
00:50:26,000 --> 00:50:28,533
within Pavilion Lake.

1306
00:50:28,533 --> 00:50:30,166
We've used all that information,
put it together

1307
00:50:30,166 --> 00:50:31,666
into these different tools,

1308
00:50:31,666 --> 00:50:33,866
and that's really
helped us figure out

1309
00:50:33,866 --> 00:50:35,600
how we can better support

1310
00:50:35,600 --> 00:50:37,666

distributed science operations

1311
00:50:37,666 --> 00:50:39,300
as we're looking
for future missions.

1312
00:50:39,300 --> 00:50:41,566
The kind of thing
that we feel is important

1313
00:50:41,566 --> 00:50:43,633
to be more flexible,
more extensible,

1314
00:50:43,633 --> 00:50:45,166
and ultimately more reusable

1315
00:50:45,166 --> 00:50:46,966
if we're going to
carry out missions

1316
00:50:46,966 --> 00:50:48,733
that are not
just one-offs,

1317
00:50:48,733 --> 00:50:50,966
and missions that are not just,
you know, one per career,

1318
00:50:50,966 --> 00:50:52,566
but missions
that happen routinely

1319
00:50:52,566 --> 00:50:55,400
throughout the lives
of the people involved.

1320
00:50:55,400 --> 00:50:57,133
I'm just going
to wrap up right now

1321
00:50:57,133 --> 00:50:59,066
since I see we're running
a bit short of time here

1322
00:50:59,066 --> 00:51:01,533
and just point out to you
that I've told you

1323
00:51:01,533 --> 00:51:03,300
about three different ways

1324
00:51:03,300 --> 00:51:05,633
of perhaps reinventing
planetary exploration.

1325
00:51:05,633 --> 00:51:08,566
The idea of using robots
with human explorers,

1326
00:51:08,566 --> 00:51:10,933
robots that work before,
in parallel, or after.

1327
00:51:10,933 --> 00:51:13,400
Very important,
interesting challenges in terms

1328
00:51:13,400 --> 00:51:16,166
of how do you coordinate
human and robot activity.

1329
00:51:16,166 --> 00:51:19,400
Secondly, in the fact
that today the world relies

1330
00:51:19,400 --> 00:51:21,833
upon geography in ways

1331

00:51:21,833 --> 00:51:23,600
that we never thought
were gonna be critical

1332
00:51:23,600 --> 00:51:25,033
to our everyday lives

1333
00:51:25,033 --> 00:51:26,600
but fundamentally
are also important,

1334
00:51:26,600 --> 00:51:28,133
I think, for planetary
exploration.

1335
00:51:28,133 --> 00:51:30,133
And finally, this whole notion
that it's important to think

1336
00:51:30,133 --> 00:51:33,033
about how we reinvent software
to make it more flexible,

1337
00:51:33,033 --> 00:51:36,700
more distributed,
more web-based, lighter-weight,

1338
00:51:36,700 --> 00:51:37,900
to really support the way

1339
00:51:37,900 --> 00:51:40,533
that we can carry out
exploration tasks.

1340
00:51:40,533 --> 00:51:42,833
But in essence,
all of that's really

1341
00:51:42,833 --> 00:51:44,500
just meant to be

a starting point

1342
00:51:44,500 --> 00:51:47,400
for trying to reinvent the way
that we explore outer space.

1343
00:51:47,400 --> 00:51:49,366
It's something that I would
challenge all of you,

1344
00:51:49,366 --> 00:51:51,266
each and every one of you,
to think about.

1345
00:51:51,266 --> 00:51:54,400
How can we take the tools today
and make them better?

1346
00:51:54,400 --> 00:51:56,066
How can we create new tools

1347
00:51:56,066 --> 00:51:58,600
and go further than
we've ever gone before?

1348
00:51:58,600 --> 00:52:01,166
But with that, I'll wrap up
and, uh,

1349
00:52:01,166 --> 00:52:03,200
turn it back over to Jacob.

1350
00:52:03,200 --> 00:52:04,866
[applause]

1351
00:52:04,866 --> 00:52:07,200
- Thank you very much.
Very good.

1352

00:52:09,633 --> 00:52:11,966
So we have time
for a few questions.

1353
00:52:11,966 --> 00:52:14,666
If you have a question,
please raise your hand,

1354
00:52:14,666 --> 00:52:17,733
wait for the microphone,
and ask one question only.

1355
00:52:17,733 --> 00:52:19,733
Thank you.

1356
00:52:21,800 --> 00:52:23,800
- Hmm?

1357
00:52:26,833 --> 00:52:30,133
- Hi there.
Thanks for the amazing talk.

1358
00:52:30,133 --> 00:52:32,700
Can you actually see
any kind of difference,

1359
00:52:32,700 --> 00:52:36,466
main differences
for a combined mission,

1360
00:52:36,466 --> 00:52:38,633
robotic-human,

1361
00:52:38,633 --> 00:52:41,166
between the Moon and Mars?

1362
00:52:41,166 --> 00:52:43,700
- So I think that one
of the things

1363
00:52:43,700 --> 00:52:45,133
that NASA
cares about today

1364
00:52:45,133 --> 00:52:48,366
is understanding
how do we get to Mars?

1365
00:52:48,366 --> 00:52:51,300
The agency is focused really

1366
00:52:51,300 --> 00:52:52,966
on this whole journey to Mars,

1367
00:52:52,966 --> 00:52:55,266
and that involves
the development of tools

1368
00:52:55,266 --> 00:52:57,933
and systems that can be
tested out on the Moon

1369
00:52:57,933 --> 00:53:00,600
and used ultimately on Mars.

1370
00:53:00,600 --> 00:53:02,166
And one of the areas
that the agency

1371
00:53:02,166 --> 00:53:04,433
really is putting
a lot of effort into right now

1372
00:53:04,433 --> 00:53:06,633
is understanding how do robots,

1373
00:53:06,633 --> 00:53:08,200
you know, support that?

1374
00:53:08,200 --> 00:53:09,700
One of the things
that we do know

1375
00:53:09,700 --> 00:53:12,033
is that we are going
to need robots

1376
00:53:12,033 --> 00:53:14,866
to carry out a lot of activities
when humans aren't present,

1377
00:53:14,866 --> 00:53:17,700
because we can't keep humans
in space indefinitely.

1378
00:53:17,700 --> 00:53:19,366
And then even when
humans are present,

1379
00:53:19,366 --> 00:53:21,266
something I didn't
talk about today

1380
00:53:21,266 --> 00:53:22,800
is that we have
to be able to use

1381
00:53:22,800 --> 00:53:25,133
these robots to help
support humans.

1382
00:53:25,133 --> 00:53:27,733
On the Space Station,
for example, right now exists

1383
00:53:27,733 --> 00:53:30,366
because not only the people
onboard the Space Station,

1384
00:53:30,366 --> 00:53:33,500
but for the fact that we have a
very large mission control team

1385
00:53:33,500 --> 00:53:35,866
that's in continuous
tight communications

1386
00:53:35,866 --> 00:53:37,800
with the people
on the Space Station.

1387
00:53:37,800 --> 00:53:39,466
Well, think of what happens
when you take those people

1388
00:53:39,466 --> 00:53:41,566
and you put them
far out at Mars,

1389
00:53:41,566 --> 00:53:44,000
perhaps 20 to 40-minute
round-trip communication delay,

1390
00:53:44,000 --> 00:53:46,166
and they're no longer
tightly coupled.

1391
00:53:46,166 --> 00:53:47,533
Well, in those situations,

1392
00:53:47,533 --> 00:53:48,766
when you need to take care
of the vehicle,

1393
00:53:48,766 --> 00:53:50,700
basic housekeeping
and things like that,

1394

00:53:50,700 --> 00:53:54,000
you're going to need robots
to help support, you know,

1395
00:53:54,000 --> 00:53:57,200
the humans that are trying to
live and work there.

1396
00:54:01,466 --> 00:54:03,300
- All right, I guess
you just kind of--

1397
00:54:03,300 --> 00:54:05,100
I'm Morgan from Florida Tech.

1398
00:54:05,100 --> 00:54:07,600
I guess you just sort of talked
a little bit about that,

1399
00:54:07,600 --> 00:54:10,300
but how do you see robots
working in the future

1400
00:54:10,300 --> 00:54:12,533
to, like,
build habitation for humans,

1401
00:54:12,533 --> 00:54:15,066
and how do you see human

1402
00:54:15,066 --> 00:54:16,766
and robotic teams
working together

1403
00:54:16,766 --> 00:54:19,066
from, like,
long-distance environments?

1404
00:54:19,066 --> 00:54:21,333
- Yeah, that's a great question.

1405
00:54:21,333 --> 00:54:23,700
I think that if we are going
to send people

1406
00:54:23,700 --> 00:54:25,200
to live in some place,

1407
00:54:25,200 --> 00:54:28,333
whether that's on the Moon
or Mars or other destinations,

1408
00:54:28,333 --> 00:54:31,900
we have to find ways of
building the infrastructure

1409
00:54:31,900 --> 00:54:34,900
and maintaining it even
when they're not present.

1410
00:54:34,900 --> 00:54:36,400
And in particular, part of that
is that we can't

1411
00:54:36,400 --> 00:54:38,266
just launch every single thing

1412
00:54:38,266 --> 00:54:39,700
that we need from Earth.

1413
00:54:39,700 --> 00:54:43,933
It's incredibly difficult
to launch large structures.

1414
00:54:43,933 --> 00:54:46,233
It's incredibly difficult
to supply all the information,

1415
00:54:46,233 --> 00:54:47,533

all the infrastructure,

1416
00:54:47,533 --> 00:54:50,800
and all the consumables
that you need to continuously,

1417
00:54:50,800 --> 00:54:52,366
you know,
keep those things running.

1418
00:54:52,366 --> 00:54:54,300
And so one of the things
that we have to do is figure out

1419
00:54:54,300 --> 00:54:56,266
how do we use robots for that?

1420
00:54:56,266 --> 00:54:58,400
Are they just
to assemble things?

1421
00:54:58,400 --> 00:55:01,600
Do they support other things
such as collecting resources

1422
00:55:01,600 --> 00:55:04,233
and processing those resources?

1423
00:55:04,233 --> 00:55:06,433
Ames, for example, is working
on a--developing

1424
00:55:06,433 --> 00:55:10,033
a future planetary mission
called Resource Prospector,

1425
00:55:10,033 --> 00:55:11,800
where we're interested
in going to the Moon

1426
00:55:11,800 --> 00:55:13,933
and looking--
and characterizing

1427
00:55:13,933 --> 00:55:17,800
the presence of hydrogen
in the subsurface.

1428
00:55:17,800 --> 00:55:19,866
And if we can really
determine that yes,

1429
00:55:19,866 --> 00:55:23,233
this is a resource we can mine
and then process,

1430
00:55:23,233 --> 00:55:25,700
well, now we don't need
to bring fuel along from Earth,

1431
00:55:25,700 --> 00:55:28,033
or we don't need
to bring water.

1432
00:55:28,033 --> 00:55:32,200
We can actually mine it
and use it on the Moon.

1433
00:55:32,200 --> 00:55:33,500
And of course,
that's not something

1434
00:55:33,500 --> 00:55:35,133
that we would rely
on humans to do.

1435
00:55:35,133 --> 00:55:36,933
We'd carry that out
purely robotically.

1436
00:55:36,933 --> 00:55:38,566
Those are the kinds of things
I think are really important

1437
00:55:38,566 --> 00:55:42,600
as we're looking
towards the future.

1438
00:55:42,600 --> 00:55:45,366
- Okay.
So please join me in thanking

1439
00:55:45,366 --> 00:55:47,266
Dr. Fong
for an excellent seminar.

1440
00:55:47,266 --> 00:55:49,033
Thank you very much.

1441
00:55:49,033 --> 00:55:51,433
[applause]