1
00:00:00,533 --> 00:00:02,101
(techno-chime melody)

2
00:00:02,101 --> 00:00:05,605
[Announcer] NASA's Jet
Propulsion Laboratory presents:

3
00:00:05,605 --> 00:00:06,972
the von Karman Lecture.

4
00:00:06,972 --> 00:00:08,975
A series of talks by scientists

5
00:00:08,975 --> 00:00:11,944
and engineers who are
exploring our planet,

6
00:00:11,944 --> 00:00:15,448
our solar system and
all that lies beyond.

7
00:00:26,659 --> 00:00:28,260
- Hey, good evening
ladies and gentlemen.

8
00:00:28,260 --> 00:00:29,929
How's everyone doing tonight?

9
00:00:29,929 --> 00:00:31,163
(various positive
responses from audience)

10
00:00:31,163 --> 00:00:32,264
Excellent.
(applause)

11
00:00:32,264 --> 00:00:33,533
That's what we love to hear.

12
00:00:33,533 --> 00:00:35,100
Thanks so much for
comin' out tonight.

13
00:00:35,100 --> 00:00:37,536
So, Rosetta has been one
of the most difficult

14
00:00:37,536 --> 00:00:39,472
space missions ever attempted.

15
00:00:39,472 --> 00:00:41,841
After 10 years of flight,
it caught up with a comet

16
00:00:41,841 --> 00:00:45,110
speeding at 55,000
kilometers per hour

17
00:00:45,110 --> 00:00:47,513
and dropped a lander
on its surface.

18
00:00:47,513 --> 00:00:49,148
Then, the mother-craft
orbited the comet

19
00:00:49,148 --> 00:00:50,650
for another year and a half,

20
00:00:50,650 --> 00:00:53,353
coming as close as six
kilometers to the surface.

21
00:00:53,353 --> 00:00:56,222
In September of 2016,
this very mother-ship,

22
00:00:56,222 --> 00:00:59,592

not designed for landing,
will touch down onto the comet

23
00:00:59,592 --> 00:01:01,127
to end the mission.

24
00:01:01,127 --> 00:01:03,095
Tonight we have two guests
who will not only describe

25
00:01:03,095 --> 00:01:05,865
this upcoming landing
but will also talk

26
00:01:05,865 --> 00:01:08,635
about what we learned
from Rosetta, about comets

27
00:01:08,635 --> 00:01:11,170
and the formation
of our solar system.

28
00:01:11,170 --> 00:01:14,640
Art B. Chmielewski has a
very difficult last name,

29
00:01:14,640 --> 00:01:17,877
but thankfully,
easy initials: ABC.

30
00:01:17,877 --> 00:01:21,013
ABC got his education at
the University of Michigan,

31
00:01:21,013 --> 00:01:24,984
USC, and UCLA, which makes
being a college football

32
00:01:24,984 --> 00:01:28,621
and basketball fan,

well, challenging.

33
00:01:28,621 --> 00:01:30,957
He has been at JPL for
36 years and participated

34
00:01:30,957 --> 00:01:35,161
in 15 space missions, including
Galileo, Ulysses, Cassini,

35
00:01:35,161 --> 00:01:38,297
Deep Space 1, the Mars
Telecommunications Orbiter,

36
00:01:38,297 --> 00:01:42,034
Space Technology 6,
and Space Technology 8.

37
00:01:42,034 --> 00:01:43,470
Pardon me.

38
00:01:43,470 --> 00:01:45,904
Currently he is the
Rosetta US Project Manager,

39
00:01:45,904 --> 00:01:49,274
a job that, as he describes
it, requires doing everything

40
00:01:49,274 --> 00:01:52,512
that the scientists
are not willing to do.

41
00:01:52,512 --> 00:01:55,081
Dr. Bonnie Buratti is a
Senior Research Scientist

42
00:01:55,081 --> 00:01:57,250
at JPL with expertise
on the structure

43
00:01:57,250 --> 00:02:00,286
and evolution of icy moons
and other small bodies.

44
00:02:00,286 --> 00:02:04,190
She holds degrees from MIT
and Cornell in astronomy

45
00:02:04,190 --> 00:02:06,625
and is currently serving
on the Science teams

46
00:02:06,625 --> 00:02:09,128
for both the Cassini and
New Horizons missions

47
00:02:09,128 --> 00:02:11,130
as well as being the
NASA Project Scientist

48
00:02:11,130 --> 00:02:12,665
for the Rosetta Mission.

49
00:02:12,665 --> 00:02:16,169
The author or co-author of
over 200 scientific papers,

50
00:02:16,169 --> 00:02:19,004
she was awarded the NASA
Exceptional Achievement Medal

51
00:02:19,004 --> 00:02:21,907
and the International
Astronomical Union
recognized her work

52
00:02:21,907 --> 00:02:24,377
by naming an asteroid after her.

53
00:02:24,377 --> 00:02:26,179
Ladies and gentlemen,
first up tonight,

54
00:02:26,179 --> 00:02:27,647
Dr. Bonnie Buratti,

55
00:02:27,647 --> 00:02:29,916
(applause)

56
00:02:35,354 --> 00:02:36,555
- Thank you so much, Marc.

57
00:02:36,555 --> 00:02:37,490
Can everybody hear me?

58
00:02:37,490 --> 00:02:38,490
I guess so.
- Yes

59
00:02:38,490 --> 00:02:40,159
and thank you all for coming.

60
00:02:40,159 --> 00:02:44,097
It's just wonderful
to see everyone so
interested in comets.

61
00:02:44,097 --> 00:02:46,199
I'm gonna start with a
little bit of history,

62
00:02:46,199 --> 00:02:49,234
because comets, you know,
other than the major planets

63
00:02:49,234 --> 00:02:50,503
that we can see
with our naked eye,

64
00:02:50,503 --> 00:02:52,805
they're the things that
the ancients have really

65
00:02:52,805 --> 00:02:55,775
wondered about and
kind of awed over.

66
00:02:55,775 --> 00:02:57,276
So this is, are we gonna
turn the lights down

67
00:02:57,276 --> 00:02:59,278
or keep them up or whatever?

68
00:02:59,278 --> 00:03:00,980
Okay, so this is an image,

69
00:03:00,980 --> 00:03:04,316
this is kind of an
iconic image of a comet.

70
00:03:04,316 --> 00:03:08,821
And it shows you what comets
are all about: the tail.

71
00:03:08,821 --> 00:03:12,292
Most comets have a
nucleus, a rocky center.

72
00:03:12,292 --> 00:03:15,761
In fact, Fred Whipple, who
was one of the grandfathers

73
00:03:15,761 --> 00:03:18,797
of modern astronomy,
a Harvard professor,

74

00:03:18,797 --> 00:03:20,499
once called them,
"Dirty ice balls."

75
00:03:20,499 --> 00:03:22,602
And that is in
effect, what they are.

76
00:03:22,602 --> 00:03:25,771
They're lots of frozen,
what we call volatiles,

77
00:03:25,771 --> 00:03:28,474
which is a fancy word
for gases and dust.

78
00:03:28,474 --> 00:03:31,043
But the thing that we see,
that we think of comets,

79
00:03:31,043 --> 00:03:34,113
as being just so beautiful
and awesome, are the tail.

80
00:03:34,113 --> 00:03:36,249
And I really like this image
here, it's a French image

81
00:03:36,249 --> 00:03:37,517
from 1858.

82
00:03:37,517 --> 00:03:41,420
It's Donati's Comet of
1858 I believe it was.

83
00:03:41,420 --> 00:03:44,623
It shows the two types of
tails: the dust tail here

84
00:03:44,623 --> 00:03:46,125

and the ion tail.

85
00:03:46,125 --> 00:03:48,427
This is just dust and
this is charged particles,

86
00:03:48,427 --> 00:03:51,029
coming from this
very small comet.

87
00:03:51,029 --> 00:03:53,766
They're typically just
a mile or so in size

88
00:03:53,766 --> 00:03:56,435
and if you are an astronomy
fan, you'll notice

89
00:03:56,435 --> 00:03:57,937
the Big Dipper and Arcturus.

90
00:03:57,937 --> 00:03:59,339
So this picture is accurate.

91
00:03:59,339 --> 00:04:00,673
It's over Paris.

92
00:04:01,841 --> 00:04:03,942
And here's another
iconic image, here.

93
00:04:03,942 --> 00:04:07,513
This is of Halley's Comet,
during the last appearance

94
00:04:07,513 --> 00:04:08,781
or apparition.

95
00:04:08,781 --> 00:04:11,083

That's a fancy word
that astronomers use

96
00:04:11,083 --> 00:04:12,084
to mean an appearance,

97
00:04:12,084 --> 00:04:14,420
This was the one in 1986.

98
00:04:14,420 --> 00:04:16,054
How many people saw it?

99
00:04:16,054 --> 00:04:18,390
It wasn't a very good
appearance, apparition.

100
00:04:18,390 --> 00:04:19,592
This is by Bill Liller.

101
00:04:19,592 --> 00:04:22,261
It's a photograph
that he took for NASA

102
00:04:22,261 --> 00:04:25,798
and you can see the two
tails, the dust tail here

103
00:04:25,798 --> 00:04:27,333
and the ion tail.

104
00:04:27,333 --> 00:04:30,269
And we'll be talking about ions
and dust a little bit later.

105
00:04:30,269 --> 00:04:32,004
But one of the
things about comets

106
00:04:32,004 --> 00:04:36,642

that has really been pretty
consistent in history:

107
00:04:36,642 --> 00:04:38,678
they have been
harbingers of doom.

108
00:04:38,678 --> 00:04:41,114
They've been an omen for
bad things in the future,

109
00:04:41,114 --> 00:04:42,047
almost always.

110
00:04:42,047 --> 00:04:43,982
This is pretty cross-cultural.

111
00:04:43,982 --> 00:04:46,819
Every civilization you
see has that feeling

112
00:04:46,819 --> 00:04:50,123
that comets somehow
foretell doom.

113
00:04:50,123 --> 00:04:53,626
So here are two images,
just two examples.

114
00:04:53,626 --> 00:04:57,529
Although one is not doom, but
this from the Bayeax Tapestry,

115
00:04:57,529 --> 00:05:00,399
which was embroidered in 1066.

116
00:05:00,399 --> 00:05:04,570
That was the year before the
fall of the last Norman King,

117
00:05:05,537 --> 00:05:06,539
King Harold.

118
00:05:08,107 --> 00:05:11,243
And you see up there's this
little expression in Latin.

119
00:05:11,243 --> 00:05:12,611
And if you did study
Latin, you'll notice

120
00:05:12,611 --> 00:05:14,413
there are some grammatical
errors in here.

121
00:05:14,413 --> 00:05:17,549
(reads Latin phrase)

122
00:05:17,549 --> 00:05:19,118
It should be (corrects
Latin), okay?

123
00:05:19,118 --> 00:05:22,288
But whatever, it means
these are, these men,

124
00:05:22,288 --> 00:05:26,058
they are marveling at
the star and here we have

125
00:05:26,058 --> 00:05:28,260
an embroidery of a comet, okay?

126
00:05:28,260 --> 00:05:30,329
And it turns out that
there was an appearance

127
00:05:30,329 --> 00:05:31,964
of Halley's Comet.

128
00:05:31,964 --> 00:05:35,534
It comes back every,
about 75 or 76 years.

129
00:05:35,534 --> 00:05:38,204
There was an appearance
in that year in 1066.

130
00:05:38,204 --> 00:05:41,040
And if you see here,
there's a fleet of boats

131
00:05:41,040 --> 00:05:43,275
and of the Norman conquest.

132
00:05:43,275 --> 00:05:46,345
And here we, on this side,
you see the King, Harold

133
00:05:46,345 --> 00:05:48,714
over there and he's
seeing the armies come in

134
00:05:48,714 --> 00:05:50,650
to overthrow the empire.

135
00:05:51,884 --> 00:05:55,188
Now on this side
here, this is a fresco

136
00:05:55,188 --> 00:05:56,656
in the church.

137
00:05:56,656 --> 00:05:59,058
There's a little church
in Padova, Padua Italy,

138
00:05:59,058 --> 00:06:00,292

which I've acutally
been to 'cause

139
00:06:00,292 --> 00:06:01,961
there was a scientific
meeting there, once.

140
00:06:01,961 --> 00:06:03,929
This is by Giotto,
the Italian artist.

141
00:06:03,929 --> 00:06:06,732
This was made in about 1320.

142
00:06:06,732 --> 00:06:10,503
And here we see, this is a
very common devotional theme

143
00:06:10,503 --> 00:06:12,738
called the Adoration
of the Magi.

144
00:06:12,738 --> 00:06:15,675
The Zoroastrian
priests from Persia

145
00:06:16,876 --> 00:06:19,812
and it shows Halley's
Comet here as the star

146
00:06:19,812 --> 00:06:21,180
of Bethlehem.

147
00:06:21,180 --> 00:06:23,916
Now we know that the
star of Bethlehem

148
00:06:23,916 --> 00:06:25,751
could not have
been Halley's Comet

149
00:06:25,751 --> 00:06:27,820
because the apparition
or the appearance

150
00:06:27,820 --> 00:06:31,057
didn't come anywhere
near the birth of Jesus.

151
00:06:31,057 --> 00:06:33,792
But, again, here, it is
shown as the foretelling

152
00:06:33,792 --> 00:06:38,464
or an apparition or
appearance of a prediction

153
00:06:38,464 --> 00:06:40,299
of the birth of Jesus.

154
00:06:41,633 --> 00:06:44,603
So we think that Giotto
actually viewed the apparition,

155
00:06:44,603 --> 00:06:48,341
the appearance in 1301 and
that's where he got the idea.

156
00:06:48,341 --> 00:06:49,508
Okay, moving along.

157
00:06:49,508 --> 00:06:51,510
Here is a pretty
extreme cartoon.

158
00:06:51,510 --> 00:06:54,479
This is also French, of a comet

159
00:06:54,479 --> 00:06:56,882

actually destroying the Earth.

160
00:06:56,882 --> 00:06:58,884
It's pretty vivid.

161
00:06:58,884 --> 00:07:02,854
And I was saying that
this idea of comets

162
00:07:02,854 --> 00:07:06,525
just as being destroyers is
pretty common in all cultures.

163
00:07:06,525 --> 00:07:10,363
This is Montezuma and
this was a 16th-century,

164
00:07:11,864 --> 00:07:14,967
just drawing, a
watercolor and it was

165
00:07:14,967 --> 00:07:18,604
So Montezuma was
overthrown in 1520.

166
00:07:18,604 --> 00:07:21,373
This was not anytime near
one of the appearances

167
00:07:21,373 --> 00:07:24,543
of Halley's Comet but there
apparently was another comet

168
00:07:24,543 --> 00:07:27,413
the year he was, you
know, assassinated

169
00:07:27,413 --> 00:07:29,448
by the conquistadors.

170
00:07:29,448 --> 00:07:30,583
And Pissaro, I think.

171
00:07:30,583 --> 00:07:31,784
Was it Pissaro?

172
00:07:31,784 --> 00:07:34,052
Wait, you don't, whatever.

173
00:07:34,052 --> 00:07:38,224
So this is seen as an omen of
the overthrow of Montezuma.

174
00:07:39,658 --> 00:07:43,161
It's also true the Chinese
tracked appearances

175
00:07:43,161 --> 00:07:46,999
of Halley's Comet back
to about 400 years BCE.

176
00:07:48,433 --> 00:07:51,470
It turns out that they never
realized that it was periodic.

177
00:07:51,470 --> 00:07:53,005
It wasn't really until
Halley that we realized

178
00:07:53,005 --> 00:07:54,673
that some of these
comets come back.

179
00:07:54,673 --> 00:07:57,409
They get captured by the
sun and are periodic.

180
00:07:57,409 --> 00:08:01,947
But, again, when Halley's

Comet appeared in 276 BCE,

181
00:08:01,947 --> 00:08:06,118
it was said the next year, the
empress dowager passed away.

182
00:08:07,019 --> 00:08:08,454
So again.

183
00:08:08,454 --> 00:08:10,622
But why should we really
care about comets?

184
00:08:10,622 --> 00:08:12,758
You know, why do
they really matter?

185
00:08:12,758 --> 00:08:14,861
Well, here are
three big reasons:

186
00:08:14,861 --> 00:08:18,764
the first one is that they
are remnants left over

187
00:08:18,764 --> 00:08:22,401
from the very earliest
stages of the solar system.

188
00:08:22,401 --> 00:08:25,671
They are what we
call planitesimals,
the building-blocks

189
00:08:25,671 --> 00:08:27,939
that came together
to form the planets.

190
00:08:27,939 --> 00:08:29,508
And research from

Rosetta has shown

191
00:08:29,508 --> 00:08:32,345
they really are
leftover remnants.

192
00:08:32,345 --> 00:08:34,346
They supply the Earth
with some water.

193
00:08:34,346 --> 00:08:36,749
Probably not all of
it but a lot of it,

194
00:08:36,749 --> 00:08:39,251
and organic material.

195
00:08:39,251 --> 00:08:42,955
It's possible that most
of the prebiotic material

196
00:08:42,955 --> 00:08:45,023
that led to the origin
of life on Earth came

197
00:08:45,023 --> 00:08:47,993
from the outer solar
system fed by comets.

198
00:08:47,993 --> 00:08:50,295
These are key to the
formation of life.

199
00:08:50,295 --> 00:08:51,497
And the final reason is,

200
00:08:51,497 --> 00:08:54,500
they are really
potential destroyers.

201
00:08:54,500 --> 00:08:56,235
So, here's a NASA
artist's conception

202
00:08:56,235 --> 00:08:58,570
of what the early solar
system looked like.

203
00:08:58,570 --> 00:09:01,040
You can see the sun and
the planets forming.

204
00:09:01,040 --> 00:09:04,043
But all these little
planetesimals came together

205
00:09:04,043 --> 00:09:05,744
to form the planets.

206
00:09:05,744 --> 00:09:08,680
And as you'll see when we
actually look at images

207
00:09:08,680 --> 00:09:12,852
and all the data on the
comet that Rosetta explored,

208
00:09:16,755 --> 00:09:18,958
it will actually look
like these planetesimals

209
00:09:18,958 --> 00:09:20,225
coming together.

210
00:09:20,225 --> 00:09:23,095
It will look like
two planetesimals.

211
00:09:23,095 --> 00:09:26,165

Okay, so where are
all these comets, now?

212
00:09:26,165 --> 00:09:29,100
So all that debris that you
see here is still around.

213
00:09:29,100 --> 00:09:31,636
But it kinda got shuffled around

214
00:09:31,636 --> 00:09:34,140
and is now in two major areas.

215
00:09:35,307 --> 00:09:37,509
Okay, so first what
we have to think big.

216
00:09:37,509 --> 00:09:39,878
A lot of these comets
were kinda flung out

217
00:09:39,878 --> 00:09:43,048
of the solar system and
all collected in this area

218
00:09:43,048 --> 00:09:44,183
called the oort cloud.

219
00:09:44,183 --> 00:09:45,551
It was named after Jan Oort

220
00:09:45,551 --> 00:09:48,454
who was a Dutch
astronomer, actually.

221
00:09:48,454 --> 00:09:49,654
He's since passed away.

222
00:09:49,654 --> 00:09:51,323

But it's really
immense, it's huge.

223
00:09:51,323 --> 00:09:52,791
If you look at this,

224
00:09:52,791 --> 00:09:56,828
it's about 100,000 astronomical
units, AU, is the distance.

225
00:09:56,828 --> 00:09:58,830
An astronomical
unit is the distance

226
00:09:58,830 --> 00:10:00,632
between the Earth and the sun.

227
00:10:00,632 --> 00:10:02,267
It's about 93 million miles.

228
00:10:02,267 --> 00:10:04,003
So this is immense, it's huge.

229
00:10:04,003 --> 00:10:07,205
It's like a large fraction of
the distance to the next star.

230
00:10:07,205 --> 00:10:09,575
And the very center
there, like a little dot,

231
00:10:09,575 --> 00:10:10,943
is the solar system.

232
00:10:10,943 --> 00:10:13,412
I have it expanded
there 500 times.

233
00:10:13,412 --> 00:10:14,813

And this is the Kuiper Belt.

234
00:10:14,813 --> 00:10:17,349
This is this debris, sometimes
called the third zone,

235
00:10:17,349 --> 00:10:20,252
debris outside the orbit, this
is the orbit of Pluto, here,

236
00:10:20,252 --> 00:10:21,487
and Neptune.

237
00:10:21,487 --> 00:10:23,655
That Pluto is a body
that New Horizons

238
00:10:23,655 --> 00:10:26,225
made this first encounter with.

239
00:10:26,225 --> 00:10:27,993
Some of the comets
come from there.

240
00:10:27,993 --> 00:10:30,396
Churyumov-Gerasimenko does come,

241
00:10:30,396 --> 00:10:32,797
which we will call
67P from now on

242
00:10:32,797 --> 00:10:35,534
because it is not pronounceable.

243
00:10:35,534 --> 00:10:37,736
(laughter)

244
00:10:37,736 --> 00:10:40,973
Okay, so 67P comes

from the Kuiper Belt,

245
00:10:40,973 --> 00:10:44,543
which is where the
Jupiter-family comets come from.

246
00:10:44,543 --> 00:10:46,278
But some of the
long-period comets

247
00:10:46,278 --> 00:10:49,448
and these comets
that come pristine,

248
00:10:49,448 --> 00:10:51,817
from the outer, outside
the solar system,

249
00:10:51,817 --> 00:10:52,985
come from the Oort cloud.

250
00:10:52,985 --> 00:10:55,354
Now, don't forget,
there's also asteroids,

251
00:10:55,354 --> 00:10:56,755
which are in this little,

252
00:10:56,755 --> 00:10:58,156
the asteroid belt's this little,

253
00:10:58,156 --> 00:11:00,158
but that's also stuff left over

254
00:11:00,158 --> 00:11:02,494
from the origins
of the solar system

255
00:11:02,494 --> 00:11:04,330

although it's not quite
as pristine as comets.

256
00:11:04,330 --> 00:11:06,098
That's just in that
little area there.

257
00:11:06,098 --> 00:11:08,868
So that's kind of
the background.

258
00:11:10,035 --> 00:11:11,703
But sometimes these
comets are flung,

259
00:11:11,703 --> 00:11:15,574
comets and asteroids are flung
into the inner solar system.

260
00:11:15,574 --> 00:11:16,808
And this is an example:

261
00:11:16,808 --> 00:11:19,144
another NASA artist
has shown this picture

262
00:11:19,144 --> 00:11:22,047
of an asteroid or a
comet hitting the Earth.

263
00:11:22,047 --> 00:11:25,851
And there are some that even
believe that the extinction,

264
00:11:25,851 --> 00:11:30,022
the great extinction, when
the dinosaurs became extinct,

265
00:11:31,356 --> 00:11:33,492
at the end of the

cretacious geologic period,

266
00:11:33,492 --> 00:11:36,128
that it may have actually
been a comet that came

267
00:11:36,128 --> 00:11:39,398
and impacted the Earth
and blew up all this dust

268
00:11:39,398 --> 00:11:42,468
which caused kind
of a global winter.

269
00:11:42,468 --> 00:11:45,270
And eventually, that's the
demise of the dinosaurs.

270
00:11:45,270 --> 00:11:48,006
And a lot of other species.

271
00:11:48,006 --> 00:11:52,044
Okay, so, Art is gonna
talk about missions,

272
00:11:52,044 --> 00:11:55,147
but before, about
the mission itself,

273
00:11:55,147 --> 00:11:58,216
but before he does that, I
wanna give like a 30-second

274
00:11:58,216 --> 00:12:02,054
overview of what missions
went before Rosetta.

275
00:12:03,455 --> 00:12:05,023
And I also wanna make the point

276
00:12:05,023 --> 00:12:07,692
that the data was not very good.

277
00:12:07,692 --> 00:12:09,795
Okay, I mean like,
the best picture.

278
00:12:09,795 --> 00:12:13,598
This is Wild 2, a comet
that Stardust looked at.

279
00:12:13,598 --> 00:12:15,901
And that's about the best
image we have of a comet.

280
00:12:15,901 --> 00:12:19,004
So this is Halley,
which was observed

281
00:12:19,004 --> 00:12:21,607
by the Giotto Spacecraft,
named after the artist

282
00:12:21,607 --> 00:12:25,778
who drew that picture of Halley
over the manger of Jesus.

283
00:12:26,978 --> 00:12:28,046
That was in 1985.

284
00:12:28,046 --> 00:12:30,215
NASA canceled its own mission.

285
00:12:30,215 --> 00:12:34,586
So there's an actual image
close-up of the nucleus,

286
00:12:34,586 --> 00:12:39,091
the rocky center we sometimes

call the nucleus, of Halley.

287
00:12:39,091 --> 00:12:41,260
Deep Space 1, which Art
and I actually both worked

288
00:12:41,260 --> 00:12:42,128
on that project.

289
00:12:42,128 --> 00:12:43,428
Comet Barrelli.

290
00:12:43,428 --> 00:12:44,529
And here's the scale of miles.

291
00:12:44,529 --> 00:12:46,932
These are all to scale.

292
00:12:46,932 --> 00:12:50,168
Wild 2, Stardust, which
also sent back a sample.

293
00:12:50,168 --> 00:12:51,670
And, look at these
little pits, here.

294
00:12:51,670 --> 00:12:55,374
Just notice how similar
they are to the ones on 67P.

295
00:12:55,374 --> 00:12:58,778
Tempel 1 which was
visited by Deep Impact

296
00:13:00,779 --> 00:13:03,214
and later went on
to see Hartley.

297
00:13:03,214 --> 00:13:04,749

And the thing about Deep Impact,

298
00:13:04,749 --> 00:13:06,218
this is my last
slide before we talk

299
00:13:06,218 --> 00:13:09,288
about the Rosetta
mission itself,

300
00:13:09,288 --> 00:13:13,392
actually put a cannon-ball-sized
metal projectile

301
00:13:14,827 --> 00:13:18,664
into Tempel 1's surface
and this is the explosion

302
00:13:20,031 --> 00:13:21,033
that we saw.

303
00:13:23,468 --> 00:13:27,505
And later on, the Stardust,
a kind of a revamped version

304
00:13:27,505 --> 00:13:30,175
of Stardust went by and
some scientists claim

305
00:13:30,175 --> 00:13:34,079
they could actually see a crater
that the cannon ball made.

306
00:13:34,079 --> 00:13:35,280
But I'm not gonna show that,

307
00:13:35,280 --> 00:13:36,915
'cause personally I
couldn't see the crater.

308
00:13:36,915 --> 00:13:40,485
Okay, so Art is gonna talk
about the actual mission

309
00:13:40,485 --> 00:13:43,521
and about, later on,
landing on the comet.

310
00:13:43,521 --> 00:13:45,224
And then later, I'll
come up and talk

311
00:13:45,224 --> 00:13:48,460
about some of the scientific
results from the mission.

312
00:13:48,460 --> 00:13:50,663
But Art is on with a model.

313
00:13:59,237 --> 00:14:00,072
- Hi folks.

314
00:14:00,072 --> 00:14:02,341
(applause)

315
00:14:06,211 --> 00:14:09,148
I got my applause, I
think I'm done, thank you.

316
00:14:09,148 --> 00:14:11,183
That was, that felt good.

317
00:14:11,183 --> 00:14:12,417
Any other questions?

318
00:14:12,417 --> 00:14:14,886
(laughter)

319

00:14:14,886 --> 00:14:19,090
So let tell you about the
Rosetta mission a little bit.

320
00:14:19,090 --> 00:14:23,895
I don't have any charts,
but I will use the audience

321
00:14:23,895 --> 00:14:26,431
to demonstrate the mission.

322
00:14:26,431 --> 00:14:29,768
So, first of all
how did this comet

323
00:14:29,768 --> 00:14:31,403
to which we traveled form?

324
00:14:31,403 --> 00:14:32,604
Okay?

325
00:14:32,604 --> 00:14:35,007
If we have anybody
under 15, come on down

326
00:14:35,007 --> 00:14:37,309
on the stage here, please.

327
00:14:37,309 --> 00:14:38,944
Under 15.

328
00:14:38,944 --> 00:14:41,146
Quick, quick, quick,
quick, quick, quick.

329
00:14:41,146 --> 00:14:43,515
Quick, quick quick.

330
00:14:43,515 --> 00:14:45,350

Alright, we have a
lot of cometessimals.

331
00:14:45,350 --> 00:14:47,085
(laughter)

332
00:14:47,085 --> 00:14:49,355
Come on up, hop up, up, up.

333
00:14:50,789 --> 00:14:52,958
And if you fall off this
stage and injure yourself,

334
00:14:52,958 --> 00:14:53,926
I'll kill you.

335
00:14:53,926 --> 00:14:55,427
(laughter)

336
00:14:55,427 --> 00:14:57,862
Okay, 'cause this
hasn't been checked

337
00:14:57,862 --> 00:15:01,099
with safety and
security at JPL, so.

338
00:15:01,099 --> 00:15:03,535
Okay, you guys are
all little pieces

339
00:15:03,535 --> 00:15:07,640
of dust and gas and we
are 4.6 billion years ago.

340
00:15:10,809 --> 00:15:13,912
In the beginnings of
the solar system, okay?

341

00:15:13,912 --> 00:15:18,349
So, spread out around
the stage, spread out.

342
00:15:18,349 --> 00:15:21,053
And now you just start walking,

343
00:15:21,053 --> 00:15:23,622
wherever you wanna walk, but
if you bump into somebody

344
00:15:23,622 --> 00:15:24,856
go straight.

345
00:15:24,856 --> 00:15:27,058
Then you have to grab
onto this person, okay?

346
00:15:27,058 --> 00:15:28,727
And then you have to
walk with this person.

347
00:15:28,727 --> 00:15:30,362
Just go and if you
touch somebody,

348
00:15:30,362 --> 00:15:31,897
you gotta grab onto them.

349
00:15:31,897 --> 00:15:34,199
Yeah, if you touch,
you gotta grab on.

350
00:15:34,199 --> 00:15:37,569
And now you have to be close
together, close together.

351
00:15:37,569 --> 00:15:39,037
Close together.

352
00:15:39,037 --> 00:15:42,941
If you bump into somebody,
grab 'em and keep on walking.

353
00:15:42,941 --> 00:15:45,577
You see, there is a lot of
instability in the universe.

354
00:15:45,577 --> 00:15:47,713
And we have our first comet!

355
00:15:47,713 --> 00:15:49,949
(applause)

356
00:15:53,318 --> 00:15:56,054
Okay, thank you cometessimals.

357
00:15:56,054 --> 00:15:57,856
Thank you, big hand
for cometessimals.

358
00:15:57,856 --> 00:16:00,125
(applause)

359
00:16:01,559 --> 00:16:03,995
So, this is basically, you can

360
00:16:03,995 --> 00:16:06,565
I know it's hard to leave
the stage once you get on it.

361
00:16:06,565 --> 00:16:08,867
(laughter)

362
00:16:08,867 --> 00:16:11,370
A lot of people in Los Angeles
area have this problem.

363

00:16:11,370 --> 00:16:13,505
(laughter)

364
00:16:13,505 --> 00:16:17,075
But, so, we're dealing
here with a body

365
00:16:17,075 --> 00:16:19,812
that formed very early
during the formation

366
00:16:19,812 --> 00:16:21,212
of the solar system.

367
00:16:21,212 --> 00:16:24,249
Formed out of gas, out of dust,

368
00:16:24,249 --> 00:16:28,087
very porous, very,
very, 70% of the comet

369
00:16:29,621 --> 00:16:31,056
is actually nothing.

370
00:16:31,056 --> 00:16:35,193
So we have this body
that orbits the sun.

371
00:16:35,193 --> 00:16:39,197
And it orbits it on the
elliptical orbit, right?

372
00:16:39,197 --> 00:16:42,200
So, let's, I think we need

373
00:16:42,200 --> 00:16:43,936
we need a spacecraft and a comet

374
00:16:43,936 --> 00:16:47,072

to demonstrate the
principle so, yes, please.

375
00:16:47,072 --> 00:16:48,039
And what is your name?

376
00:16:48,039 --> 00:16:48,907
Come on up.
- Noah.

377
00:16:48,907 --> 00:16:49,975
- What is it?

378
00:16:49,975 --> 00:16:51,977
- Noah
- Noah. Dr. Noah.

379
00:16:51,977 --> 00:16:52,944
(laughter)

380
00:16:52,944 --> 00:16:56,081
Yes, Dr. Noah from University--

381
00:16:56,081 --> 00:16:57,248
- Uh, nothing.

382
00:16:57,248 --> 00:16:59,284
- University of Nothing.
(laughter)

383
00:16:59,284 --> 00:17:01,286
It's a very small school

384
00:17:02,888 --> 00:17:06,124
Okay, and can we have
another volunteer?

385
00:17:06,124 --> 00:17:08,527
Okay, another volunteer, please.

386
00:17:08,527 --> 00:17:10,395
Under 80 would be good.

387
00:17:10,395 --> 00:17:11,663
(laughter)

388
00:17:11,663 --> 00:17:12,597
Yes, please, come
on up, come on up.

389
00:17:12,597 --> 00:17:15,267
Come on up and yeah, come on up.

390
00:17:16,635 --> 00:17:18,637
Kodiak. Kodiak?

391
00:17:18,637 --> 00:17:19,871
- [Kodiak] Yes.

392
00:17:19,871 --> 00:17:22,207
- Okay, and Dr.
Noah, Dr. Kodiak.

393
00:17:23,475 --> 00:17:24,309
- Wesley.

394
00:17:24,309 --> 00:17:25,143
- [Art] Doctor--

395
00:17:25,143 --> 00:17:25,978
- Wesley.

396
00:17:25,978 --> 00:17:27,012
- Doctor Wesley.

397
00:17:27,012 --> 00:17:28,714
(applause)

398
00:17:28,714 --> 00:17:31,215
From University of--

399
00:17:31,215 --> 00:17:33,652
- Awesome things, I don't know.

400
00:17:33,652 --> 00:17:37,121
- University of Awesome
Things, very good.

401
00:17:37,121 --> 00:17:38,824
And you are from University of--

402
00:17:38,824 --> 00:17:39,758
- [Kodiak] Home.

403
00:17:39,758 --> 00:17:41,159
- Oh, University of Home.

404
00:17:41,159 --> 00:17:43,729
This is the first
home-schooled university, okay?

405
00:17:43,729 --> 00:17:44,663
(laughter)

406
00:17:44,663 --> 00:17:46,097
Very good, very good.

407
00:17:46,097 --> 00:17:48,867
Okay, we have to approve
the curriculum, still.

408
00:17:48,867 --> 00:17:53,037
Okay, so now, lemme show
you what the situation is

409

00:17:53,037 --> 00:17:54,539
with catching up with the comet.

410
00:17:54,539 --> 00:17:57,175
The comet goes around
the sun, right?

411
00:17:57,175 --> 00:17:58,877
And when it goes
close to the sun,

412
00:17:58,877 --> 00:18:00,646
it puffs up and shoots
out all the smoke

413
00:18:00,646 --> 00:18:02,815
and all the dust and jets.

414
00:18:03,848 --> 00:18:05,851
So, we have you, Wesley.

415
00:18:07,052 --> 00:18:08,620
Dr. Wesley will be the sun.

416
00:18:08,620 --> 00:18:09,921
Here, you stand here.

417
00:18:09,921 --> 00:18:11,156
And the reason he's the sun,

418
00:18:11,156 --> 00:18:12,824
because you can tell
he's very bright.

419
00:18:12,824 --> 00:18:14,192
(laughter)

420
00:18:14,192 --> 00:18:15,126
Okay.

421
00:18:15,126 --> 00:18:17,195
And then we have a spacecraft

422
00:18:17,195 --> 00:18:19,297
and we're gonna
have a comet, right?

423
00:18:19,297 --> 00:18:22,668
So, you are a spacecraft, okay.

424
00:18:22,668 --> 00:18:24,336
And you are a comet.

425
00:18:25,403 --> 00:18:27,239
And, alright, alright.

426
00:18:29,374 --> 00:18:30,775
So now, okay.

427
00:18:30,775 --> 00:18:32,978
You have to land, Noah

428
00:18:32,978 --> 00:18:34,212
Noah?
- Yeah.

429
00:18:34,212 --> 00:18:35,113
- You have to land
this spacecraft

430
00:18:35,113 --> 00:18:36,815
on this comet, right?

431
00:18:36,815 --> 00:18:38,817
So now, you are a comet.

432
00:18:38,817 --> 00:18:42,154

You go around the
sun, right, like this.

433
00:18:43,654 --> 00:18:45,757
You speed up here when
you're close to the sun.

434
00:18:45,757 --> 00:18:48,026
Yeah, go, go, very
elliptical orbit.

435
00:18:48,026 --> 00:18:49,194
Come on back.

436
00:18:49,194 --> 00:18:50,862
Okay, very good.

437
00:18:50,862 --> 00:18:52,697
And you go on the same orbit.

438
00:18:52,697 --> 00:18:53,965
So what did you notice?

439
00:18:53,965 --> 00:18:56,034
How can you land, you speed up.

440
00:18:56,034 --> 00:18:56,901
(laughter)

441
00:18:56,901 --> 00:18:58,636
Spacecraft, don't cheat.

442
00:18:58,636 --> 00:19:00,872
You don't have huge boosters.

443
00:19:00,872 --> 00:19:02,707
First of all, what
did we notice, here?

444
00:19:02,707 --> 00:19:06,378
What do you have to do,
Noah, to land on the comet?

445
00:19:06,378 --> 00:19:07,212
- [Noah] I gotta
catch up with it.

446
00:19:07,212 --> 00:19:08,680
- You gotta catch up.

447
00:19:08,680 --> 00:19:11,483
And the spacecraft was trying
to catch up for ten years.

448
00:19:11,483 --> 00:19:12,984
(laughter)

449
00:19:12,984 --> 00:19:16,855
So, and I wanna have a
realistic simulation.

450
00:19:16,855 --> 00:19:17,689
So.

451
00:19:17,689 --> 00:19:19,925
(laughter)

452
00:19:23,028 --> 00:19:24,529
Okay, very well.

453
00:19:24,529 --> 00:19:25,997
Well, catch up, dammit.

454
00:19:25,997 --> 00:19:26,965
(laughter)

455
00:19:26,965 --> 00:19:27,799

(light applause)

456
00:19:27,799 --> 00:19:28,634
Okay, now.

457
00:19:31,269 --> 00:19:33,372
Thank you, Dr. Noah and
thank you, Dr. Kodiak,

458
00:19:33,372 --> 00:19:35,573
and thank you, sun.

459
00:19:35,573 --> 00:19:37,709
You are very bright, thank you.

460
00:19:37,709 --> 00:19:39,945
(applause)

461
00:19:43,114 --> 00:19:47,152
So, this was the mission,
this was the spacecraft.

462
00:19:47,152 --> 00:19:49,587
It's a, so this was
the spacecraft built

463
00:19:49,587 --> 00:19:53,759
by the European Space Agency
with instruments from NASA.

464
00:19:55,059 --> 00:19:57,396
NASA had big contribution
to this mission.

465
00:19:57,396 --> 00:19:59,998
And huge solar arrays,
they're actually the size

466
00:19:59,998 --> 00:20:02,333

of a tennis court.

467
00:20:02,333 --> 00:20:04,035
Because we're flying far away.

468
00:20:04,035 --> 00:20:05,570
And so this spacecraft,

469
00:20:05,570 --> 00:20:08,540
and then there was tiny little
lander attached to it, right?

470
00:20:08,540 --> 00:20:11,176
And we had to catch
up with the comet

471
00:20:11,176 --> 00:20:13,278
and it did take ten years

472
00:20:14,646 --> 00:20:18,950
because we had to get
some boost from Earth

473
00:20:18,950 --> 00:20:20,852
and boost from Mars.

474
00:20:20,852 --> 00:20:23,555
Amazingly difficult
thing, because the comet

475
00:20:23,555 --> 00:20:27,726
is actually going at 600,000
miles an hour, right?

476
00:20:29,428 --> 00:20:32,330
So this is more or
less like four times

477
00:20:32,330 --> 00:20:35,366

anybody from Texas is here?

478
00:20:35,366 --> 00:20:36,901
Anybody?

479
00:20:36,901 --> 00:20:41,073
Okay, well, it's like four times
the speeding bullet, right?

480
00:20:42,307 --> 00:20:44,442
So, you guys don't
know what it means,

481
00:20:44,442 --> 00:20:46,444
but yeah, you're not from Texas.

482
00:20:46,444 --> 00:20:48,246
But four times the speed.

483
00:20:48,246 --> 00:20:50,882
So, imagine you have to catch up

484
00:20:50,882 --> 00:20:54,686
with a speeding, four times
the speed of a speeding bullet

485
00:20:54,686 --> 00:20:58,957
and hop on, while this thing
is spinning on the top of it

486
00:20:58,957 --> 00:21:03,328
and shooting gas and jets
and particles, right?

487
00:21:03,328 --> 00:21:05,730
And you absolutely don't
know what the surface is.

488
00:21:05,730 --> 00:21:08,900

You don't know if it's, if
you're gonna sink in the dust

489
00:21:08,900 --> 00:21:11,903
or you're gonna land on
a jet and get blown up.

490
00:21:11,903 --> 00:21:13,037
What's goin' on?

491
00:21:13,037 --> 00:21:14,839
You know, the
mission was designed,

492
00:21:14,839 --> 00:21:17,742
this is the amazing thing:
this is truly Star Trek.

493
00:21:17,742 --> 00:21:21,880
You go there, you know,
and you explore, right?

494
00:21:21,880 --> 00:21:25,751
And so the lander was designed
by the Germans, by DLR,

495
00:21:25,751 --> 00:21:29,520
when the comet was just one
pixel on a picture, right?

496
00:21:29,520 --> 00:21:32,457
So, you know, how do you
design something like this?

497
00:21:32,457 --> 00:21:35,694
And, but we did catch
up with the comet

498
00:21:37,396 --> 00:21:40,298
and the only thing is that

we were expecting the comet

499
00:21:40,298 --> 00:21:42,534
would be, you know, like
one of these pictures,

500
00:21:42,534 --> 00:21:44,302
pretty much regular-shape.

501
00:21:44,302 --> 00:21:46,938
And it turned out that
it's a bizarre thing

502
00:21:46,938 --> 00:21:49,840
that looks like this, okay?

503
00:21:49,840 --> 00:21:52,877
And the actual size of this is,

504
00:21:52,877 --> 00:21:56,114
anybody from La Canada, here?

505
00:21:56,114 --> 00:22:00,352
Yeah, it's about maybe a
third of size of La Canada.

506
00:22:00,352 --> 00:22:03,321
So, you know, it's
actually relatively tiny.

507
00:22:03,321 --> 00:22:05,424
And it's spinning, right?

508
00:22:06,891 --> 00:22:09,795
So, and there are
gravity gradients

509
00:22:11,229 --> 00:22:13,999
because, you know, it

has this irregular shape.

510
00:22:13,999 --> 00:22:18,569
So, so now, you try to
land this tiny lander.

511
00:22:18,569 --> 00:22:20,371
And that did happen in November,

512
00:22:20,371 --> 00:22:21,673
maybe some of you were here.

513
00:22:21,673 --> 00:22:25,209
We talked about it,
about a year ago.

514
00:22:25,209 --> 00:22:29,480
The lander did land and because
it's such a low gravity,

515
00:22:29,480 --> 00:22:32,917
it, actually we
picked a spot, here.

516
00:22:32,917 --> 00:22:34,485
It was supposed to land here

517
00:22:34,485 --> 00:22:36,287
because it was a little flatter.

518
00:22:36,287 --> 00:22:39,324
And there's always this
discussion between engineers

519
00:22:39,324 --> 00:22:41,025
and scientists, right?

520
00:22:41,025 --> 00:22:43,061
So Bonnie is here, she's

a project scientist,

521
00:22:43,061 --> 00:22:44,395
I'm a project manager.

522
00:22:44,395 --> 00:22:46,431
And the reason we always
have these two people

523
00:22:46,431 --> 00:22:51,269
is because we wanna get
to the safe middle, okay?

524
00:22:51,269 --> 00:22:52,704
Because if you ask
Bonnie, it's like

525
00:22:52,704 --> 00:22:55,272
oh, we wanna land on
something exciting.

526
00:22:55,272 --> 00:22:57,475
You know, pam, this is exciting.

527
00:22:57,475 --> 00:22:59,811
This is exciting, okay.

528
00:22:59,811 --> 00:23:01,512
This is boring.

529
00:23:01,512 --> 00:23:02,747
Engineers want boring.

530
00:23:02,747 --> 00:23:04,750
Scientists want exciting, right?

531
00:23:04,750 --> 00:23:08,286
So, we ended up somewhere
in the middle, right?

532
00:23:08,286 --> 00:23:11,289
And so the spacecraft
did land here.

533
00:23:12,457 --> 00:23:15,193
And it's supposed
to fire harpoons

534
00:23:15,193 --> 00:23:17,862
because it was supposed
to hold itself down.

535
00:23:17,862 --> 00:23:19,197
Very low gravity.

536
00:23:19,197 --> 00:23:22,100
If I jump, I stay on the
ground because gravity.

537
00:23:22,100 --> 00:23:26,271
But, the harpoons didn't fire
and the spacecraft bounced

538
00:23:27,706 --> 00:23:30,708
and disappeared from our
camera and it went somewhere.

539
00:23:30,708 --> 00:23:34,479
Later, we calculated
where it's supposed to be.

540
00:23:34,479 --> 00:23:36,714
We figured it out
from basic physics.

541
00:23:36,714 --> 00:23:40,285
And it ended up going
across this crater,

542
00:23:40,285 --> 00:23:42,687
which is not a crater and
Bonnie will tell you about it.

543
00:23:42,687 --> 00:23:45,590
Bounced over one of the hills,
bounced over another hill,

544
00:23:45,590 --> 00:23:48,726
flipped over and
got stuck in a hole.

545
00:23:48,726 --> 00:23:50,128
Like a golf ball.

546
00:23:52,163 --> 00:23:54,800
And, but it did
transmit for a while.

547
00:23:54,800 --> 00:23:59,070
To the orbiter and the
orbiter was going around,

548
00:23:59,070 --> 00:24:01,172
all the time, going
around the comet.

549
00:24:01,172 --> 00:24:03,441
And it's still doing
this, right now.

550
00:24:03,441 --> 00:24:07,612
And sent some signals, seven
out of eight experiments

551
00:24:08,980 --> 00:24:12,750
on the spacecraft worked,
so we're very happy.

552

00:24:12,750 --> 00:24:15,453
Some scientists even liked
the fact that it moved.

553
00:24:15,453 --> 00:24:19,957
'Cause they got a lot of
data from different places.

554
00:24:19,957 --> 00:24:23,194
One experiment, you
know, there was a drill

555
00:24:23,194 --> 00:24:27,532
and these guys, when it fell
kind of in a strange position,

556
00:24:27,532 --> 00:24:30,201
you know, the drill went,
you know instead of,

557
00:24:30,201 --> 00:24:32,170
it was designed to
go straight down

558
00:24:32,170 --> 00:24:35,373
and drill into the
rigolet, right?

559
00:24:35,373 --> 00:24:39,277
But because the spacecraft
was sideways in a hole,

560
00:24:39,277 --> 00:24:42,213
this drill deployed and
went something like this,

561
00:24:42,213 --> 00:24:44,415
after 10 years of
flight and 10 years

562

00:24:44,415 --> 00:24:46,450
of testing and design of this.

563
00:24:46,450 --> 00:24:48,252
Some of these
scientists, you know,

564
00:24:48,252 --> 00:24:52,757
they were doctoral students
when they designed the drill.

565
00:24:52,757 --> 00:24:54,925
And the drill did
something like this:

566
00:24:54,925 --> 00:24:57,863
Do, do, do, do,
do, do, do, do, do.

567
00:25:00,532 --> 00:25:01,766
(laughter)

568
00:25:01,766 --> 00:25:03,100
And just didn't
touch the surface

569
00:25:03,100 --> 00:25:04,970
and didn't access the sample.

570
00:25:04,970 --> 00:25:08,706
But that was the first
landing and first mission.

571
00:25:08,706 --> 00:25:11,409
That's in the past,
that's November 2014.

572
00:25:11,409 --> 00:25:12,877
Later, I'll come back
and I'll tell you

573
00:25:12,877 --> 00:25:14,779
about the next landing.

574
00:25:16,180 --> 00:25:19,417
But, first we wanna tell
you more what we discovered

575
00:25:19,417 --> 00:25:21,319
the comets, so
Bonnie will be back.

576
00:25:21,319 --> 00:25:22,253
Where's Bonnie?

577
00:25:22,253 --> 00:25:23,188
- [Bonnie] I'm over here.

578
00:25:23,188 --> 00:25:24,121
Here you are, okay, good.

579
00:25:24,121 --> 00:25:26,791
- [Bonnie] Handing out prizes.

580
00:25:26,791 --> 00:25:28,059
- [Art] Let's roll
the comet back.

581
00:25:28,059 --> 00:25:30,328
(applause)

582
00:25:36,233 --> 00:25:38,302
Even lady scientists go first.

583
00:25:38,302 --> 00:25:41,706
(light audience chatter)

584
00:25:43,174 --> 00:25:44,442

Got that, okay?

585
00:25:50,215 --> 00:25:52,050
- Alright, can
everybody hear me?

586
00:25:52,050 --> 00:25:52,884
(affirmative murmurs)

587
00:25:52,884 --> 00:25:54,786
Okay, I think I

588
00:25:54,786 --> 00:25:55,720
Can you hear me now?

589
00:25:55,720 --> 00:25:57,021
- Yes.
- Okay.

590
00:25:57,021 --> 00:25:58,523
So, yeah, so you've
learned that engineers

591
00:25:58,523 --> 00:26:00,291
are a lot more fun
than scientists.

592
00:26:00,291 --> 00:26:01,726
(laughter)

593
00:26:01,726 --> 00:26:02,394
I think that's what
you've learned from this.

594
00:26:02,394 --> 00:26:03,628
(light applause)

595
00:26:03,628 --> 00:26:04,828
Okay, so yeah, and

for any young people

596
00:26:04,828 --> 00:26:06,398
here in the audience, you know,

597
00:26:06,398 --> 00:26:07,832
engineering is cool.

598
00:26:07,832 --> 00:26:10,034
I think you've learned that.

599
00:26:10,034 --> 00:26:12,704
So, I'm gonna talk about
some of the hard science

600
00:26:12,704 --> 00:26:13,938
that we learned.

601
00:26:13,938 --> 00:26:15,440
I'll try to make it as
interesting as possible.

602
00:26:15,440 --> 00:26:17,742
But I don't have any
props or anything.

603
00:26:17,742 --> 00:26:19,944
I just have a few graphs.

604
00:26:19,944 --> 00:26:22,146
Okay, so here are some
of the discoveries

605
00:26:22,146 --> 00:26:23,815
that, you know, we've
kind of picked out

606
00:26:23,815 --> 00:26:25,483
to try to emphasize.

607
00:26:26,651 --> 00:26:28,720
The first thing is,
as we were saying,

608
00:26:28,720 --> 00:26:31,356
comets are primordial,
they existed

609
00:26:31,356 --> 00:26:35,326
from the creation of the solar
system 4.6 billion years ago.

610
00:26:35,326 --> 00:26:36,861
They are the building-blocks.

611
00:26:36,861 --> 00:26:40,432
It's the debris left over from
the formation of the planets.

612
00:26:40,432 --> 00:26:44,836
And we found out that C-G or
67P as we usually call it,

613
00:26:44,836 --> 00:26:48,139
is composed of two
separate planetesimals

614
00:26:48,139 --> 00:26:49,374
and they are pristine.

615
00:26:49,374 --> 00:26:51,876
They haven't been
processed very much.

616
00:26:51,876 --> 00:26:53,778
And the activity
and water-production

617

00:26:53,778 --> 00:26:55,146
on the comet were huge.

618
00:26:55,146 --> 00:26:56,681
There were just spectacular
plumes coming out

619
00:26:56,681 --> 00:26:58,183
and I'll show some.

620
00:26:58,183 --> 00:27:01,052
And we discovered an amino
acid, glycine on the comet,

621
00:27:01,052 --> 00:27:02,954
as well as other organics,
things that are made

622
00:27:02,954 --> 00:27:06,490
of carbon, hydrogen,
oxygen and nitrogen.

623
00:27:06,490 --> 00:27:08,125
And we found layers
and these things

624
00:27:08,125 --> 00:27:09,394
that we call dinosaur eggs.

625
00:27:09,394 --> 00:27:10,761
And we think that
these dinosaur eggs

626
00:27:10,761 --> 00:27:13,864
are actually the
smallest building-blocks.

627
00:27:13,864 --> 00:27:17,035
When you saw the kids
kind of running around,

628
00:27:17,035 --> 00:27:19,704
these are the fragments
from which comets,

629
00:27:19,704 --> 00:27:22,673
and ultimately the
planets, formed.

630
00:27:22,673 --> 00:27:24,642
And we also found
some things unexpected

631
00:27:24,642 --> 00:27:25,943
about the composition.

632
00:27:25,943 --> 00:27:27,979
Okay, that's my
most boring slide.

633
00:27:27,979 --> 00:27:32,316
So here is, for scale,
the size of the comet.

634
00:27:32,316 --> 00:27:33,851
Okay, so this is New York City,

635
00:27:33,851 --> 00:27:36,721
with the East river and the
Hudson river on either side.

636
00:27:36,721 --> 00:27:41,192
And this is, it's about as
wide, it's longest length,

637
00:27:41,192 --> 00:27:43,494
is about four point
some kilometers.

638

00:27:43,494 --> 00:27:44,995
It's about 2 1/2 miles.

639
00:27:44,995 --> 00:27:49,100
So it just fit in the, kind
of in the width of Manhattan.

640
00:27:50,234 --> 00:27:52,637
Okay, so it's not very big.

641
00:27:52,637 --> 00:27:55,873
It's a fairly small comet,
Halley's about 10 miles

642
00:27:55,873 --> 00:27:57,441
along its longest side.

643
00:27:57,441 --> 00:27:59,310
But the thing that you
see about this comet

644
00:27:59,310 --> 00:28:02,246
that is the most amazing
and you can see this

645
00:28:02,246 --> 00:28:06,017
here in the model, it
has two separate parts.

646
00:28:07,118 --> 00:28:08,953
And these, we're pretty
certain, you know,

647
00:28:08,953 --> 00:28:10,688
in science you're
never totally certain,

648
00:28:10,688 --> 00:28:13,124
they're separate planetesimals.

649
00:28:13,124 --> 00:28:15,993
They are separate
building-blocks of this body.

650
00:28:15,993 --> 00:28:18,096
Now how do we know that?

651
00:28:18,096 --> 00:28:21,032
Well, we've looked at
layering in the comet

652
00:28:21,032 --> 00:28:23,167
and the layering
seems to be different.

653
00:28:23,167 --> 00:28:25,270
We've also looked
at the density.

654
00:28:25,270 --> 00:28:28,106
As Art was saying,
it's mainly nothing.

655
00:28:28,106 --> 00:28:29,106
I mean, the density.

656
00:28:29,106 --> 00:28:31,609
So water has a density of one.

657
00:28:31,609 --> 00:28:34,078
The density is
about half of that.

658
00:28:34,078 --> 00:28:36,447
So there's a lot of
empty spaces in there

659
00:28:36,447 --> 00:28:38,649
and we think that

if it were processed

660
00:28:38,649 --> 00:28:42,286
and melted and heated
during planet-formation,

661
00:28:42,286 --> 00:28:43,387
it would be more solid.

662
00:28:43,387 --> 00:28:45,089
So it's kind of a fluffy thing.

663
00:28:45,089 --> 00:28:47,725
It just looks like
these two pieces,

664
00:28:47,725 --> 00:28:49,894
like the kids out on the stage,

665
00:28:49,894 --> 00:28:51,495
they kind of were
wandering around

666
00:28:51,495 --> 00:28:54,132
in the early solar system
and just kinda stuck

667
00:28:54,132 --> 00:28:55,399
onto each other.

668
00:28:55,399 --> 00:28:57,234
And some of these
things got bigger.

669
00:28:57,234 --> 00:28:58,469
You know, things stuck together

670
00:28:58,469 --> 00:29:00,104
and became the planets

and some of them didn't.

671
00:29:00,104 --> 00:29:02,039
They were just left over.

672
00:29:02,039 --> 00:29:03,875
And one of the things
you see is there's a lot

673
00:29:03,875 --> 00:29:05,676
of stuff coming out.

674
00:29:05,676 --> 00:29:08,078
We'll talk about these
holes here, later.

675
00:29:08,078 --> 00:29:10,147
These are actually the
centers of activity

676
00:29:10,147 --> 00:29:14,051
and it seems that all
comets have these.

677
00:29:14,051 --> 00:29:18,223
Okay, so we did see a lot of
water coming out of the comet.

678
00:29:19,390 --> 00:29:21,392
We didn't actually
see ice itself

679
00:29:21,392 --> 00:29:23,461
until later in the mission.

680
00:29:23,461 --> 00:29:26,798
So, altogether, during
its active period,

681

00:29:26,798 --> 00:29:29,500
the comet produced
enough water to fill

682
00:29:29,500 --> 00:29:32,503
an Olympic swimming pool
about every 100 days.

683
00:29:32,503 --> 00:29:34,339
Okay, it was mainly in
the form of these jets,

684
00:29:34,339 --> 00:29:37,609
that are hydrogen,
the hydroxyl radical

685
00:29:38,809 --> 00:29:40,745
that come from water
that's dissociated.

686
00:29:40,745 --> 00:29:44,615
But here's an actual
bright spot of fresh ice

687
00:29:44,615 --> 00:29:47,184
which we believe is from a cliff

688
00:29:47,184 --> 00:29:50,287
and the rock, a rock just kind
of got split and opened up.

689
00:29:50,287 --> 00:29:52,556
So there's a crust of dark dust

690
00:29:52,556 --> 00:29:54,324
on the outside of this comet,

691
00:29:54,324 --> 00:29:56,460
but inside, there is water-ice

692
00:29:56,460 --> 00:30:00,165
and other volatiles like
ammonia and carbon dioxide

693
00:30:00,165 --> 00:30:01,599
and monoxide.

694
00:30:01,599 --> 00:30:05,035
But look at some of
these odd little boulders

695
00:30:05,035 --> 00:30:06,236
here in the dust.

696
00:30:06,236 --> 00:30:09,073
You know, where
does that come from?

697
00:30:10,274 --> 00:30:12,176
Okay, well, some of it
comes from these jets.

698
00:30:12,176 --> 00:30:14,812
This is a jet from
August of last year.

699
00:30:14,812 --> 00:30:18,115
And most of the jets we found
come out from the neck, okay?

700
00:30:18,115 --> 00:30:20,485
That is actually not a rock,
that's just a little crevice

701
00:30:20,485 --> 00:30:23,120
that's sticking out, okay?

702
00:30:23,120 --> 00:30:25,489
But a lot of those

boulders, we believe,

703
00:30:25,489 --> 00:30:27,958
that you see on those images,

704
00:30:27,958 --> 00:30:29,861
have actually come
out of the vents.

705
00:30:29,861 --> 00:30:32,263
They're little
tiny planetesimals

706
00:30:32,263 --> 00:30:34,966
that kind of explode out
and collect on the surface

707
00:30:34,966 --> 00:30:36,901
as well as the dust.

708
00:30:36,901 --> 00:30:38,302
Okay, one of the, I
wanna talk a little bit

709
00:30:38,302 --> 00:30:41,238
about the chemistry
on the comet.

710
00:30:41,238 --> 00:30:43,474
You know, the interesting
things about comets

711
00:30:43,474 --> 00:30:46,577
is they are kind of
windows into the past.

712
00:30:46,577 --> 00:30:48,112
You know, what was
the solar system like

713
00:30:48,112 --> 00:30:51,015
4.6 billion years ago when
the planets were formed?

714
00:30:51,015 --> 00:30:53,384
They kind of give
the pristine view

715
00:30:53,384 --> 00:30:57,956
of the temperature conditions,
the pressure conditions.

716
00:30:57,956 --> 00:30:59,757
Well, this was
pretty unexpected.

717
00:30:59,757 --> 00:31:02,527
What are the two major gases
in the Earth's atmosphere?

718
00:31:02,527 --> 00:31:04,361
Nitrogen and oxygen.

719
00:31:04,361 --> 00:31:06,263
Okay, molecular
nitrogen and oxygen.

720
00:31:06,263 --> 00:31:09,634
Well, guess what, we found
both of them on the comet.

721
00:31:09,634 --> 00:31:11,402
Both of these, we
didn't expect this.

722
00:31:11,402 --> 00:31:15,406
And these gases are ice and
they seem to be embedded

723

00:31:15,406 --> 00:31:16,607
in the comet.

724
00:31:16,607 --> 00:31:18,843
They didn't come in
later, they were formed

725
00:31:18,843 --> 00:31:22,646
in the early solar system,
telling us that comets formed

726
00:31:22,646 --> 00:31:26,984
in an extremely low
temperature environment,

727
00:31:26,984 --> 00:31:29,019
like 30 or less kelvins.

728
00:31:29,019 --> 00:31:31,689
Very, very, you know,
400 degrees below zero.

729
00:31:31,689 --> 00:31:33,057
Colder than you can imagine.

730
00:31:33,057 --> 00:31:35,493
So this is a NASA
artist's conception

731
00:31:35,493 --> 00:31:38,495
of what the early solar
system looked like.

732
00:31:38,495 --> 00:31:39,764
So, we have planet

733
00:31:39,764 --> 00:31:41,733
this is actually a
random solar system.

734
00:31:41,733 --> 00:31:42,966
It could be our own.

735
00:31:42,966 --> 00:31:44,535
Jupiter-like planet,
another planet.

736
00:31:44,535 --> 00:31:47,271
There're comets and
asteroids falling

737
00:31:47,271 --> 00:31:50,074
into the planets
causing craters to form.

738
00:31:50,074 --> 00:31:52,376
There're comets coming
from the outer solar system

739
00:31:52,376 --> 00:31:55,445
bringing in these
organics, bringing in these

740
00:31:55,445 --> 00:31:59,516
building-blocks of life,
bringing in molecules

741
00:31:59,516 --> 00:32:01,419
into the inner solar
system where it's too hot

742
00:32:01,419 --> 00:32:03,254
for these things to form.

743
00:32:03,254 --> 00:32:05,188
Most of this was
discovered by an instrument

744
00:32:05,188 --> 00:32:07,324

called Rosina on the spacecraft.

745
00:32:07,324 --> 00:32:08,959
There's a little
spacecraft there.

746
00:32:08,959 --> 00:32:12,062
Now you might have the question:

747
00:32:12,062 --> 00:32:14,531
well, did the Earth's
nitrogen and oxygen

748
00:32:14,531 --> 00:32:16,233
come from comets?

749
00:32:16,233 --> 00:32:18,302
The answer to that, in
the atmosphere, I mean:

750
00:32:18,302 --> 00:32:21,839
no, oxygen, we know,
came from life.

751
00:32:21,839 --> 00:32:25,743
It was produced by bacteria
and other forms of life.

752
00:32:25,743 --> 00:32:28,579
But nitrogen actually came
mainly from volcanoes.

753
00:32:28,579 --> 00:32:31,516
We think some of the
water-ice, or some of the water

754
00:32:31,516 --> 00:32:35,119
on the Earth may have come
from comets, not all of it,

755
00:32:35,119 --> 00:32:36,354
but some of it probably did,

756
00:32:36,354 --> 00:32:38,956
was brought from the
outer solar system

757
00:32:38,956 --> 00:32:40,924
into the inner solar
system by comets.

758
00:32:40,924 --> 00:32:43,327
That's a question
that's still open.

759
00:32:43,327 --> 00:32:45,429
Okay, let's move on here.

760
00:32:45,429 --> 00:32:47,465
Let's look at, look
closely at some

761
00:32:47,465 --> 00:32:51,636
of these primordial
building-blocks of
the solar system.

762
00:32:51,636 --> 00:32:54,005
So if you look in this
pit and most of these pits

763
00:32:54,005 --> 00:32:57,475
are areas of previous
activity, and if you look,

764
00:32:57,475 --> 00:32:59,743
so we're looking down into
the center of the comet.

765

00:32:59,743 --> 00:33:02,346
Look at all these little,
this is about 40 meters, here,

766
00:33:02,346 --> 00:33:05,215
so each of these little,
they're like boulders,

767
00:33:05,215 --> 00:33:07,585
compacted boulders
are about a meter.

768
00:33:07,585 --> 00:33:10,087
We call these dinosaur eggs.

769
00:33:10,087 --> 00:33:12,890
These look like the
ultimate building-blocks

770
00:33:12,890 --> 00:33:14,224
of the solar system.

771
00:33:14,224 --> 00:33:16,860
And they seem to form in layers.

772
00:33:16,860 --> 00:33:20,865
And when the comet is active,
some of these get blown out,

773
00:33:20,865 --> 00:33:22,766
although some of the bigger
ones come from cliffs

774
00:33:22,766 --> 00:33:24,301
and just get broken off.

775
00:33:24,301 --> 00:33:27,471
Because the comet, when it's
out far from, you know, out,

776
00:33:27,471 --> 00:33:30,975
it's out now about 3.5
astronomical units,

777
00:33:30,975 --> 00:33:33,010
so it's getting
colder and colder.

778
00:33:33,010 --> 00:33:35,679
But when it comes in, to
the inner solar system,

779
00:33:35,679 --> 00:33:38,082
it heats up and there's a
lot of thermal processing.

780
00:33:38,082 --> 00:33:42,352
So a lot of these cliffs,
kind of get fractured,

781
00:33:42,352 --> 00:33:45,889
jets come out of these holes,
we have dust from the comet

782
00:33:45,889 --> 00:33:47,792
that falls back onto the surface

783
00:33:47,792 --> 00:33:50,227
and then some boulders get
kicked up and fall back on.

784
00:33:50,227 --> 00:33:52,530
It's quite an awesome sight.

785
00:33:53,931 --> 00:33:56,300
Okay, we also discovered a
lot of layering on the comet.

786
00:33:56,300 --> 00:33:58,536

This was one of the
most significant facts.

787
00:33:58,536 --> 00:34:01,606
And we're not sure how much
of that was from the comet

788
00:34:01,606 --> 00:34:03,140
you know, forming
like an onion skin.

789
00:34:03,140 --> 00:34:04,442
You know, one skin
after the other,

790
00:34:04,442 --> 00:34:06,777
and how much of it
is due to some kind

791
00:34:06,777 --> 00:34:08,145
of cracking or processing.

792
00:34:08,145 --> 00:34:10,013
Probably, it's both of it.

793
00:34:10,013 --> 00:34:12,016
Here are some of these boulders.

794
00:34:12,016 --> 00:34:12,950
We see some of the dust.

795
00:34:12,950 --> 00:34:14,852
This is the neck, okay?

796
00:34:14,852 --> 00:34:18,089
So you can see it is
clearly two planetesimals

797
00:34:18,089 --> 00:34:18,922

that came together.

798
00:34:18,922 --> 00:34:20,357
They didn't smash.

799
00:34:20,357 --> 00:34:22,693
They came together probably
at a fairly low speed.

800
00:34:22,693 --> 00:34:25,429
If they came together really
fast, they would, you know,

801
00:34:25,429 --> 00:34:28,799
break apart or melt or
process in some way.

802
00:34:28,799 --> 00:34:32,703
So these are two planetesimals,
two small bodies.

803
00:34:32,703 --> 00:34:34,272
Okay, here's some more layers.

804
00:34:34,272 --> 00:34:36,774
This image was taken
March, March 16th.

805
00:34:36,774 --> 00:34:39,443
The boulders, here
are, you know,

806
00:34:39,443 --> 00:34:42,513
possibly areas, we think
that some of the fresh ice

807
00:34:42,513 --> 00:34:44,448
is exposed at these cliffs.

808

00:34:44,448 --> 00:34:48,186
There's dust here that
escapes from the comet

809
00:34:49,387 --> 00:34:51,222
then comes back on and
some of it looks like

810
00:34:51,222 --> 00:34:53,524
that it's even
deposited as some,

811
00:34:53,524 --> 00:34:55,793
almost like a
wind-blown, like a dune

812
00:34:55,793 --> 00:34:57,295
or something like that.

813
00:34:57,295 --> 00:35:00,297
We do see that, that type
of processing on the comet.

814
00:35:00,297 --> 00:35:04,134
Lot of boulders, areas
of previous activity.

815
00:35:04,134 --> 00:35:05,469
So, it's quite an awesome sight.

816
00:35:05,469 --> 00:35:09,473
We haven't seen anything
like this before, ever.

817
00:35:09,473 --> 00:35:13,811
And there's this phenomenon
that geologists called ponding.

818
00:35:13,811 --> 00:35:17,848
And where the dust is

thrown up in the jet,

819
00:35:17,848 --> 00:35:19,350
comes back down on the surface

820
00:35:19,350 --> 00:35:22,119
and then gravity kind of
pulls it down into a pond.

821
00:35:22,119 --> 00:35:25,722
And you also see layers
and thermal processing,

822
00:35:25,722 --> 00:35:28,392
a cliff, some of these boulders.

823
00:35:30,161 --> 00:35:31,428
Some more of it.

824
00:35:31,428 --> 00:35:34,397
In fact this is kind
of the ideal example

825
00:35:34,397 --> 00:35:35,766
of a surface that was active.

826
00:35:35,766 --> 00:35:37,802
This is, you know,
these are little holes

827
00:35:37,802 --> 00:35:41,138
where previous out-gassings,
these jets occurred.

828
00:35:41,138 --> 00:35:43,907
And you see the
dust has come back.

829
00:35:43,907 --> 00:35:45,843

It has gone out, fallen back on.

830
00:35:45,843 --> 00:35:49,647
They're boulders, some of them,
you know are from the center

831
00:35:49,647 --> 00:35:52,416
of the comet, or from at
least the mantle of the comet.

832
00:35:52,416 --> 00:35:55,686
Some of them probably just
broke off from this cliff.

833
00:35:55,686 --> 00:35:57,522
You can see some here.

834
00:36:01,558 --> 00:36:04,561
Okay, so I wanted to
get to one more idea,

835
00:36:04,561 --> 00:36:06,030
at least one more idea.

836
00:36:06,030 --> 00:36:10,201
And that is that we found
organic chemistry on the comet.

837
00:36:11,602 --> 00:36:15,071
What we mean is there are
molecules that consist

838
00:36:15,071 --> 00:36:16,907
of the building-blocks of life.

839
00:36:16,907 --> 00:36:20,111
Carbon, hydrogen,
oxygen, nitrogen.

840

00:36:20,111 --> 00:36:24,182
These are things that life
needs to be sustained.

841
00:36:25,616 --> 00:36:28,385
So, some of these, acetone
and formaldehyde, we found,

842
00:36:28,385 --> 00:36:30,254
but I think this
was a real clincher:

843
00:36:30,254 --> 00:36:33,890
Rosina discovered glycine,
which is an amino acid.

844
00:36:33,890 --> 00:36:35,993
As you probably know,
this is one of the,

845
00:36:35,993 --> 00:36:40,030
I think it's 22 molecules,
fairly complex molecules

846
00:36:40,030 --> 00:36:41,532
that make up proteins.

847
00:36:41,532 --> 00:36:44,134
Now Stardust, which
was, you know, a mission

848
00:36:44,134 --> 00:36:47,638
that went to Wild 2
and captured a sample,

849
00:36:49,039 --> 00:36:51,842
did actually also
discover glycine,

850
00:36:51,842 --> 00:36:54,645

but we weren't 100% sure it
was from the comet, itself.

851
00:36:54,645 --> 00:36:57,915
It captured a little sample
from the tail of the comet,

852
00:36:57,915 --> 00:37:00,751
but we weren't sure that maybe
it was from contamination.

853
00:37:00,751 --> 00:37:02,519
But this is actually
on the comet.

854
00:37:02,519 --> 00:37:05,456
Here is an amino
acid on the comet.

855
00:37:05,456 --> 00:37:08,626
We also see amino
acids in meteorites,

856
00:37:10,060 --> 00:37:11,294
which come to the Earth.

857
00:37:11,294 --> 00:37:12,929
Some are from comets,
some are from asteroids.

858
00:37:12,929 --> 00:37:14,998
We see it in the
interstellar medium.

859
00:37:14,998 --> 00:37:16,867
So it is common in outer space,

860
00:37:16,867 --> 00:37:18,502
but how do they
get to the Earth?

861
00:37:18,502 --> 00:37:20,037
Comets are the answer.

862
00:37:20,037 --> 00:37:23,106
Comets, we think delivered
some of these amino acids,

863
00:37:23,106 --> 00:37:24,374
these simple building-blocks

864
00:37:24,374 --> 00:37:25,843
that later formed
life on the Earth.

865
00:37:25,843 --> 00:37:29,579
We're not exact sure how,
but we believe it was too hot

866
00:37:29,579 --> 00:37:31,281
on the Earth, the early Earth,

867
00:37:31,281 --> 00:37:34,318
for these complex
molecules to form.

868
00:37:34,318 --> 00:37:37,788
Now you can see also here,
there're some of these holes

869
00:37:37,788 --> 00:37:40,124
from previous jets and dust

870
00:37:40,124 --> 00:37:43,594
that kind of fell
back onto the comet.

871
00:37:43,594 --> 00:37:47,231
Okay, I wanna show you some

of the very late, whoops.

872
00:37:47,231 --> 00:37:48,165
Sorry.

873
00:37:48,165 --> 00:37:49,700
Some of the latest pictures.

874
00:37:49,700 --> 00:37:51,802
In fact, this was one just
from less than a week ago.

875
00:37:51,802 --> 00:37:54,038
And it's kind of like
an iconic picture,

876
00:37:54,038 --> 00:37:56,006
'cause it shows
the comet kind of

877
00:37:56,006 --> 00:38:00,177
in its ebbing active stage,
but it shows all the features

878
00:38:02,045 --> 00:38:04,915
that are key to its activity.

879
00:38:04,915 --> 00:38:09,686
These holes, that are not
craters, they're actually areas

880
00:38:09,686 --> 00:38:12,223
where previous
out-gassing or volatiles,

881
00:38:12,223 --> 00:38:13,757
mainly water-ice occurred.

882
00:38:13,757 --> 00:38:14,992

They're active for a while

883
00:38:14,992 --> 00:38:16,993
and then they kind
of become quiescent.

884
00:38:16,993 --> 00:38:18,829
But you also see these cliffs.

885
00:38:18,829 --> 00:38:22,132
You can see that many
of them collapsed.

886
00:38:22,132 --> 00:38:26,570
The stresses of thermal
heating and processing

887
00:38:26,570 --> 00:38:27,671
caused weakness
and they collapsed.

888
00:38:27,671 --> 00:38:29,640
And here you see a little crack

889
00:38:29,640 --> 00:38:31,741
that's almost
causing this cliff,

890
00:38:31,741 --> 00:38:33,210
it's about ready to fall over.

891
00:38:33,210 --> 00:38:35,512
And you can see some of
the material, the boulders,

892
00:38:35,512 --> 00:38:38,582
the dinosaur eggs are
eroding from that cliff.

893

00:38:38,582 --> 00:38:40,317
And here's a cliff we
can't quite see into,

894
00:38:40,317 --> 00:38:43,153
but if you look on the
edge, there's layering,

895
00:38:43,153 --> 00:38:45,622
a few dinosaur eggs,
more layering there,

896
00:38:45,622 --> 00:38:47,725
dust that came back on.

897
00:38:47,725 --> 00:38:51,829
It's really a very active
body, quite interesting.

898
00:38:54,264 --> 00:38:56,000
Okay, before we leave, I do

899
00:38:56,000 --> 00:38:57,801
before we get onto the
landing, Art is gonna talk

900
00:38:57,801 --> 00:38:59,469
about the landing
in a couple minutes.

901
00:38:59,469 --> 00:39:01,105
But there's just one
thing I wanna mention.

902
00:39:01,105 --> 00:39:04,040
I just wanna do a little
tribute to Claudia Alexander,

903
00:39:04,040 --> 00:39:08,011
who was the project scientist

for, was it 20 years?

904
00:39:08,011 --> 00:39:09,580
I mean, she was
on before launch.

905
00:39:09,580 --> 00:39:12,349
It was launched in 2005,
and she passed away,

906
00:39:12,349 --> 00:39:14,885
way before her time, in 2015.

907
00:39:14,885 --> 00:39:17,488
And I just wanted to, you
know, offer a tribute,

908
00:39:17,488 --> 00:39:21,659
and we were able to name a
part of the comet after her.

909
00:39:23,593 --> 00:39:25,195
This is Claudia Alexander Gate.

910
00:39:25,195 --> 00:39:28,399
They're these odd features
that we saw on the comet,

911
00:39:28,399 --> 00:39:30,100
that we called them gates.

912
00:39:30,100 --> 00:39:31,735
Looked kind of like,
that's what they are,

913
00:39:31,735 --> 00:39:33,137
they look like gates.

914
00:39:33,137 --> 00:39:37,040

So this is Claudia Alexander
Gate, in her memory.

915
00:39:37,040 --> 00:39:40,810
So with that, I'd like
to hand it back to Art,

916
00:39:40,810 --> 00:39:43,881
whose gonna talk about
the actual landing.

917
00:39:43,881 --> 00:39:44,715
Thank you.

918
00:39:44,715 --> 00:39:46,984
(applause)

919
00:39:52,623 --> 00:39:55,960
- Okay, once again, do we
have any body who is under 15?

920
00:39:55,960 --> 00:39:57,294
Please stand up.

921
00:39:58,461 --> 00:40:01,398
Okay, do we have
anybody who is under 30?

922
00:40:01,398 --> 00:40:02,733
Please stand up.

923
00:40:05,903 --> 00:40:08,639
Okay, do we have
anybody under 45,

924
00:40:08,639 --> 00:40:12,209
or somebody who'd like to
feel that he's under 45?

925

00:40:12,209 --> 00:40:13,544
Please stand up.

926
00:40:16,146 --> 00:40:17,481
Okay, now sit down.

927
00:40:17,481 --> 00:40:18,482
(laughter)

928
00:40:18,482 --> 00:40:19,683
I don't have a job for you,

929
00:40:19,683 --> 00:40:21,452
I just wanted to give
you some exercise.

930
00:40:21,452 --> 00:40:22,753
(laughter)

931
00:40:22,753 --> 00:40:23,587
Okay.

932
00:40:24,554 --> 00:40:26,623
Americans don't exercise enough.

933
00:40:26,623 --> 00:40:30,795
Okay, and that would conclude
the entertainment portion.

934
00:40:31,995 --> 00:40:35,599
So, Bonnie was talking
about dinosaur eggs.

935
00:40:36,967 --> 00:40:38,401
My son is here, Marcus.

936
00:40:38,401 --> 00:40:40,537
Marcus, stand up.

937
00:40:40,537 --> 00:40:41,705
Marcus is 14 now.

938
00:40:41,705 --> 00:40:43,974
(applause)

939
00:40:43,974 --> 00:40:47,744
So, one day I came
home and I told Marcus

940
00:40:47,744 --> 00:40:50,513
about these dinosaur
eggs and I said,

941
00:40:50,513 --> 00:40:53,884
"Oh, we found dinosaur
eggs on the comet."

942
00:40:53,884 --> 00:40:55,052
And that was a few years ago

943
00:40:55,052 --> 00:40:58,589
and Marcus very astutely
observed, he said,

944
00:40:59,723 --> 00:41:02,726
"Dad, if comets
destroyed dinosaurs,

945
00:41:02,726 --> 00:41:05,229
"how can you have dinosaur
eggs on the comet?"

946
00:41:05,229 --> 00:41:07,465
(laughter)

947
00:41:08,631 --> 00:41:12,569
An excellent point,
professor Chmielewski.

948
00:41:12,569 --> 00:41:15,806
So, we're coming to
the second landing,

949
00:41:17,307 --> 00:41:19,710
completely, completely, we're

950
00:41:21,545 --> 00:41:24,047
This is not a landing
that was by any means,

951
00:41:24,047 --> 00:41:26,983
part of the mission
or was planned for.

952
00:41:26,983 --> 00:41:29,186
And, but before we get to it,

953
00:41:29,186 --> 00:41:32,356
I just want you to
take a slight pause

954
00:41:33,757 --> 00:41:37,627
and think about these pictures
that Bonnie showed you.

955
00:41:37,627 --> 00:41:42,365
Because, you know, when
you work on a space program

956
00:41:42,365 --> 00:41:45,636
and you first, for example,
I work on a mission now.

957
00:41:45,636 --> 00:41:49,206
I started working on a
mission, Rosetta is coming down

958

00:41:49,206 --> 00:41:53,810
to its end and I started
working on a new mission.

959
00:41:53,810 --> 00:41:56,080
The launch will be in 2024.

960
00:41:58,349 --> 00:42:02,819
Maybe it will be delayed,
maybe it will be 2030.

961
00:42:02,819 --> 00:42:06,189
But if it is in
2024, we will get

962
00:42:06,189 --> 00:42:08,425
to its destination in 2034.

963
00:42:09,827 --> 00:42:13,463
And we're gonna orbit
this body for three years,

964
00:42:13,463 --> 00:42:17,534
getting data and this
presentation like
we're giving you,

965
00:42:17,534 --> 00:42:21,105
this right now, will
be in 2035, '36, okay?

966
00:42:23,173 --> 00:42:26,576
So this is the kind of planning
and effort goes into it.

967
00:42:26,576 --> 00:42:29,479
And then, you know, you
launch the spacecraft,

968
00:42:29,479 --> 00:42:31,882

the spacecraft goes
there for years.

969
00:42:31,882 --> 00:42:35,185
And one resistor,
burns out, you know.

970
00:42:35,185 --> 00:42:37,921
How many times, for no reason,
your refrigerator failed?

971
00:42:37,921 --> 00:42:39,456
You know, You open an umbrella

972
00:42:39,456 --> 00:42:42,025
and it goes (makes
grinding noise).

973
00:42:42,025 --> 00:42:43,727
And it's like the
simplest mechanism.

974
00:42:43,727 --> 00:42:45,862
One thing breaks, you know?

975
00:42:45,862 --> 00:42:49,566
This spacecraft was
flying for 10 years

976
00:42:49,566 --> 00:42:53,337
and we even had to put it
to sleep for 2 1/2 years,

977
00:42:53,337 --> 00:42:55,839
because we're so far
away from the sun

978
00:42:55,839 --> 00:42:59,143
that the solar arrays
were just not producing

979
00:42:59,143 --> 00:43:02,813
enough electricity
to run the computers

980
00:43:02,813 --> 00:43:04,881
or to run any
science instruments.

981
00:43:04,881 --> 00:43:07,617
So, these solar arrays
are eight kilowatts

982
00:43:07,617 --> 00:43:10,053
when they are in Earth orbit.

983
00:43:10,053 --> 00:43:14,224
But when you are past Jupiter,
they delivered 350 watts.

984
00:43:15,893 --> 00:43:18,261
That's just enough to
run couple of heaters

985
00:43:18,261 --> 00:43:21,731
attached to the computer, so
the computer doesn't freeze.

986
00:43:21,731 --> 00:43:24,000
And the only thing
the computer was doing

987
00:43:24,000 --> 00:43:27,871
is counting down for
2 1/2 years, you know?

988
00:43:27,871 --> 00:43:29,473
Counting down.

989

00:43:29,473 --> 00:43:33,477
Because we were going very
far away from the sun,

990
00:43:33,477 --> 00:43:38,382
very cold and then we were
waiting for the spacecraft,

991
00:43:38,382 --> 00:43:40,917
which was sleeping, to
come closer to the sun

992
00:43:40,917 --> 00:43:44,921
that it will be just enough
power to wake up its systems.

993
00:43:44,921 --> 00:43:47,023
And the wake up was, I was here

994
00:43:47,023 --> 00:43:49,259
in the mission control center.

995
00:43:49,259 --> 00:43:52,395
And the wake-up was
supposed to be at 10 a.m.

996
00:43:52,395 --> 00:43:55,031
And it was 10:01,
it didn't wake up.

997
00:43:55,031 --> 00:43:57,334
10:02, didn't wake up, 10:03.

998
00:43:57,334 --> 00:43:59,570
And usually when something
like this happens,

999
00:43:59,570 --> 00:44:01,538
you know, how late is
gonna be your computer

1000
00:44:01,538 --> 00:44:02,973
in counting down?

1001
00:44:04,074 --> 00:44:06,710
It woke up 16
minutes late, m'kay?

1002
00:44:08,579 --> 00:44:11,214
And there are some good
engineering reasons for this.

1003
00:44:11,214 --> 00:44:12,582
It had to reboot the software

1004
00:44:12,582 --> 00:44:14,151
and it was doing this by itself.

1005
00:44:14,151 --> 00:44:16,453
So it was very impressive
that software engineers

1006
00:44:16,453 --> 00:44:17,921
designed it right.

1007
00:44:17,921 --> 00:44:21,191
But we kinda had a problem
during the 2 1/2 years

1008
00:44:21,191 --> 00:44:22,259
of its sleep.

1009
00:44:24,094 --> 00:44:27,764
But, you know, and then
you get to the comet

1010
00:44:27,764 --> 00:44:31,435
and the comet looks
so bizarre, right?

1011
00:44:31,435 --> 00:44:35,606
And then everything works
and you get these pictures.

1012
00:44:37,407 --> 00:44:41,378
And some of the scientists,
you know, Claudia died,

1013
00:44:41,378 --> 00:44:43,847
without seeing a lot
of these pictures.

1014
00:44:43,847 --> 00:44:47,650
There were people, you know,
we had some deaths on the team,

1015
00:44:47,650 --> 00:44:50,887
professors who designed
the instruments.

1016
00:44:50,887 --> 00:44:52,322
So it's an amazing effort.

1017
00:44:52,322 --> 00:44:56,794
And it's just a testament
to people's hearts,

1018
00:44:56,794 --> 00:45:00,797
people's knowledge,
people's perseverance, okay.

1019
00:45:00,797 --> 00:45:03,266
So, support your space program.

1020
00:45:03,266 --> 00:45:05,201
(laughter)

1021
00:45:05,201 --> 00:45:09,373

(applause)
But it is an incredible thing

1022
00:45:12,776 --> 00:45:14,644
to get these images

1023
00:45:14,644 --> 00:45:18,148
and measurements form a
body that is so far away.

1024
00:45:18,148 --> 00:45:20,416
And, by the way,
Bonnie was telling you

1025
00:45:20,416 --> 00:45:23,520
about possibly a
comet hitting Earth.

1026
00:45:26,156 --> 00:45:29,426
What was it, 65
million years ago?

1027
00:45:29,426 --> 00:45:31,862
You know, there is
a chance that we're

1028
00:45:31,862 --> 00:45:34,698
gonna have a comet
impact in 3044.

1029
00:45:37,067 --> 00:45:38,802
So don't tell me
I didn't warn you.

1030
00:45:38,802 --> 00:45:40,003
(laughing)

1031
00:45:40,003 --> 00:45:40,838
3044.

1032
00:45:42,172 --> 00:45:44,107
And as a matter of fact,
if you wanna understand

1033
00:45:44,107 --> 00:45:47,043
comets better, when you come
and today is a perfect day.

1034
00:45:47,043 --> 00:45:51,448
Today and tomorrow, because
we have Perseid shower, right?

1035
00:45:51,448 --> 00:45:55,419
And what the shower is is
basically tiny little particles

1036
00:45:55,419 --> 00:45:56,886
that came out.

1037
00:45:56,886 --> 00:45:59,890
You know, what we see in
the sky is a tail of a comet

1038
00:45:59,890 --> 00:46:01,391
and it's humongous, okay?

1039
00:46:01,391 --> 00:46:03,560
This thing is tiny,
kilometers, right?

1040
00:46:03,560 --> 00:46:07,897
But the tail is hundreds of
thousands of kilometers, right?

1041
00:46:07,897 --> 00:46:09,132
And that's why you can see it.

1042
00:46:09,132 --> 00:46:11,534
These are little

tiny pieces of dust

1043
00:46:11,534 --> 00:46:14,538
that when they line
up with your eye

1044
00:46:15,705 --> 00:46:18,941
and reflect the
sun into your eye,

1045
00:46:18,941 --> 00:46:20,576
you see it as a little mirror.

1046
00:46:20,576 --> 00:46:24,114
And that's how you see
these amazing tails.

1047
00:46:24,114 --> 00:46:26,616
Well what do you see
today in the sky,

1048
00:46:26,616 --> 00:46:28,485
and as a matter of
fact, if you come out,

1049
00:46:28,485 --> 00:46:30,686
there will be a lot of
lights so you can't see it.

1050
00:46:30,686 --> 00:46:33,223
But around 11 p.m, I think it is

1051
00:46:33,223 --> 00:46:35,324
you know if you look in the
sky, just in this direction

1052
00:46:35,324 --> 00:46:36,826
like you were coming in
out of the auditorium,

1053
00:46:36,826 --> 00:46:39,696
you can see the meteor shower.

1054
00:46:39,696 --> 00:46:42,566
And all it is is these
tiny little particles

1055
00:46:42,566 --> 00:46:44,600
that came out of
the comet, right?

1056
00:46:44,600 --> 00:46:46,536
And Earth is going through it

1057
00:46:46,536 --> 00:46:48,938
and they are reentering
atmosphere and burning up.

1058
00:46:48,938 --> 00:46:49,939
And that's what it is.

1059
00:46:49,939 --> 00:46:51,108
These are, you're gonna see,

1060
00:46:51,108 --> 00:46:53,443
be able to see pieces
of comet today.

1061
00:46:53,443 --> 00:46:56,947
And the reason they burn up
is because they go that fast.

1062
00:46:56,947 --> 00:46:58,748
They go as fast as a comet

1063
00:46:58,748 --> 00:47:02,552
so they reenter like four
times the speeding bullet.

1064
00:47:02,552 --> 00:47:04,855
Right, you'll remember that,
you can impress your friends.

1065
00:47:04,855 --> 00:47:07,190
Oh, ho, pieces of a comet.

1066
00:47:07,190 --> 00:47:10,760
You know, they go four times
as fast as a speeding bullet.

1067
00:47:10,760 --> 00:47:11,994
(laughter)

1068
00:47:11,994 --> 00:47:14,163
Remember that so you can
impress your friends.

1069
00:47:14,163 --> 00:47:17,501
Okay, so, this,
actually today's lecture

1070
00:47:20,570 --> 00:47:22,672
is a preview of
what's gonna happen

1071
00:47:22,672 --> 00:47:25,308
on September the 30th, okay?

1072
00:47:25,308 --> 00:47:28,178
On September the 30th,
what's gonna happen,

1073
00:47:28,178 --> 00:47:30,514
I just wanted to remind
you that what we did

1074
00:47:30,514 --> 00:47:33,483
is we put down

this little lander

1075
00:47:33,483 --> 00:47:36,152
on the surface of
a comet, right?

1076
00:47:36,152 --> 00:47:39,789
And now we're far
away from the sun.

1077
00:47:39,789 --> 00:47:42,392
Again, we would have to
put the spacecraft to sleep

1078
00:47:42,392 --> 00:47:47,264
and we wouldn't know if it's
gonna merged 2 1/2 years later.

1079
00:47:47,264 --> 00:47:48,532
We would have no control.

1080
00:47:48,532 --> 00:47:51,634
So instead of waiting
for 2 1/2 years

1081
00:47:51,634 --> 00:47:55,705
and managers spending
budget, you know,

1082
00:47:55,705 --> 00:47:57,607
we're gonna put it
down on a surface

1083
00:47:57,607 --> 00:48:00,576
and just let it go to
sleep, but on a comet.

1084
00:48:00,576 --> 00:48:03,513
So, this will be certainly,
the end of the mission,

1085
00:48:03,513 --> 00:48:06,650
because we're gonna
be coming down to the

1086
00:48:06,650 --> 00:48:09,352
and maybe we should have
a little demonstration.

1087
00:48:09,352 --> 00:48:12,622
So Nathan, come on
down, come on, come on.

1088
00:48:12,622 --> 00:48:16,293
We need somebody with
big muscles this time.

1089
00:48:17,394 --> 00:48:20,097
And, by the way,
it's worth it to come

1090
00:48:20,097 --> 00:48:24,034
to these lectures sometimes
'cause I met Nathan.

1091
00:48:24,034 --> 00:48:25,268
Where did we meet,
you tell them,

1092
00:48:25,268 --> 00:48:27,036
because, you know, that
I have no credibility.

1093
00:48:27,036 --> 00:48:30,339
- We met at open house and
at the NASA social event.

1094
00:48:30,339 --> 00:48:32,175
- Yeah, yeah, so
we at an open house

1095
00:48:32,175 --> 00:48:35,411
and Nathan was really
interested in the comet.

1096
00:48:35,411 --> 00:48:37,280
So we got into conversation.

1097
00:48:37,280 --> 00:48:40,917
And it turns out now he went
to school of engineering,

1098
00:48:40,917 --> 00:48:45,488
and I want him to come down
and work next summer at JPL.

1099
00:48:45,488 --> 00:48:48,124
Maybe even this
Christmas, right?

1100
00:48:48,124 --> 00:48:49,893
- Yeah
- So, there, yeah.

1101
00:48:49,893 --> 00:48:51,595
- Thank you for that.

1102
00:48:53,697 --> 00:48:56,966
- Because somebody has
to replace me eventually,

1103
00:48:56,966 --> 00:48:58,702
you know, on this job.

1104
00:48:58,702 --> 00:49:01,337
You'll have 'til,
you know, 2044.

1105
00:49:01,337 --> 00:49:02,172

- Yes.

1106
00:49:02,172 --> 00:49:03,006
You'll have to have--

1107
00:49:03,006 --> 00:49:04,174
- I'll be here.

1108
00:49:04,174 --> 00:49:07,277
- Yeah, okay, so,
Nathan, gradually this.

1109
00:49:08,344 --> 00:49:09,979
Don't, you'll have to

1110
00:49:09,979 --> 00:49:11,581
We're gonna show you
how it's gonna land.

1111
00:49:11,581 --> 00:49:14,483
So you're gonna take this and
you're gonna slowly spin it.

1112
00:49:14,483 --> 00:49:17,587
This is more or less how
the comet spins, okay?

1113
00:49:17,587 --> 00:49:21,758
It's about 700 million miles
away from us, right now.

1114
00:49:25,528 --> 00:49:29,098
And this spacecraft,
this is the orbiter,

1115
00:49:29,098 --> 00:49:32,969
not designed for any landing
by any means, you know,

1116

00:49:32,969 --> 00:49:34,470
is orbiting it.

1117
00:49:34,470 --> 00:49:39,009
And let's say, well, let's say
that this is the sun, right?

1118
00:49:39,009 --> 00:49:41,077
So the spacecraft is
orbiting like this

1119
00:49:41,077 --> 00:49:43,980
because it wants to
point its solar arrays

1120
00:49:43,980 --> 00:49:45,382
to the sun, right?

1121
00:49:45,382 --> 00:49:48,318
And it has, and the
tricky thing here

1122
00:49:48,318 --> 00:49:50,987
keep on working, come on,
come on, earn your job.

1123
00:49:50,987 --> 00:49:55,559
Okay, and the antenna has
to be pointed to Earth.

1124
00:49:55,559 --> 00:49:59,196
The solar arrays have to be
pointed to the sun, right?

1125
00:49:59,196 --> 00:50:01,731
And the instruments
at the same time,

1126
00:50:01,731 --> 00:50:02,999
have to be pointed to the comet.

1127
00:50:02,999 --> 00:50:06,169
So you know, it's like
it's a contortionist.

1128
00:50:06,169 --> 00:50:07,704
You know, it's like,
what is this game

1129
00:50:07,704 --> 00:50:09,271
that you put down
your hand and--

1130
00:50:09,271 --> 00:50:10,106
- [Audience Members] Twister.

1131
00:50:10,106 --> 00:50:11,641
- What is it? Twister?

1132
00:50:11,641 --> 00:50:14,610
Yeah, so the spacecraft is a
Twister all the time, right?

1133
00:50:14,610 --> 00:50:17,614
And now, so on the
30th of September,

1134
00:50:17,614 --> 00:50:21,184
we're gonna try to put
this huge spacecraft down.

1135
00:50:21,184 --> 00:50:24,087
You can stop now,
let's stop the gravity.

1136
00:50:24,087 --> 00:50:25,855
And big hand for Nathan.

1137
00:50:25,855 --> 00:50:26,822

(applause)

1138
00:50:26,822 --> 00:50:29,258
Go ahead and sit down, Nathan.

1139
00:50:29,258 --> 00:50:31,694
So now, this thing is spinning.

1140
00:50:31,694 --> 00:50:33,129
And again there was a discussion

1141
00:50:33,129 --> 00:50:36,266
between different scientists,
where you wanna land.

1142
00:50:36,266 --> 00:50:39,069
Some scientists wanted, they
thought it would be really cool

1143
00:50:39,069 --> 00:50:41,671
to land somewhere here
because we would have,

1144
00:50:41,671 --> 00:50:44,807
coming down, we would have a
close-up of the neck region,

1145
00:50:44,807 --> 00:50:48,245
close-up of the head,
of the body, right?

1146
00:50:49,679 --> 00:50:53,283
Or minor lobe or major lobe
or the head of the duck

1147
00:50:54,917 --> 00:50:57,354
and the butt of the
duck, depending, you
know, what do you,

1148
00:50:57,354 --> 00:50:59,622
how do you, what
terminology you want to use.

1149
00:50:59,622 --> 00:51:02,125
But they wanted to land here.

1150
00:51:02,125 --> 00:51:05,495
Some people wanted
to look for Philae.

1151
00:51:05,495 --> 00:51:07,964
You know, for this
tiny little lander.

1152
00:51:07,964 --> 00:51:12,869
And there's scientific reasons
why we wanna know exactly,

1153
00:51:12,869 --> 00:51:15,905
take a image where
the lander is, okay?

1154
00:51:15,905 --> 00:51:18,508
Because if we know
exactly where it was,

1155
00:51:18,508 --> 00:51:21,044
we're doing some
radio-tomography
through the comet,

1156
00:51:21,044 --> 00:51:24,347
we could know exactly
what the radio signal

1157
00:51:24,347 --> 00:51:26,048
was piercing through, right?

1158

00:51:26,048 --> 00:51:28,284
So that would improve our data.

1159
00:51:28,284 --> 00:51:29,485
So there was a reason for this

1160
00:51:29,485 --> 00:51:31,054
and some people were
voting for this.

1161
00:51:31,054 --> 00:51:33,389
But finally, what won?

1162
00:51:33,389 --> 00:51:34,925
What are we gonna see?

1163
00:51:34,925 --> 00:51:36,660
On the way down?

1164
00:51:36,660 --> 00:51:39,028
The dinosaur eggs, right?

1165
00:51:39,028 --> 00:51:42,398
So finally, the
scientists decided

1166
00:51:42,398 --> 00:51:46,570
that we wanna land and fly
very close to these pits,

1167
00:51:48,137 --> 00:51:51,007
these silos and be very close,

1168
00:51:51,007 --> 00:51:55,178
point our camera right
inside of these dinosaur eggs

1169
00:51:58,414 --> 00:52:01,451
because, you know, these

silos go really deep.

1170
00:52:01,451 --> 00:52:03,052
I mean this is just
really phenomenal

1171
00:52:03,052 --> 00:52:04,520
from science
point-of-view, right?

1172
00:52:04,520 --> 00:52:06,489
You can see inside of the comet

1173
00:52:06,489 --> 00:52:08,023
and see what's in there.

1174
00:52:08,023 --> 00:52:09,492
And this is what we're gonna--

1175
00:52:09,492 --> 00:52:10,427
(small thud)

1176
00:52:10,427 --> 00:52:12,162
(dismayed audience groans)

1177
00:52:12,162 --> 00:52:14,397
(laughter)

1178
00:52:16,199 --> 00:52:17,633
He knows whose fault it is.

1179
00:52:17,633 --> 00:52:21,004
Okay, so we're gonna
look and there are three

1180
00:52:21,004 --> 00:52:23,473
of them lined up
in the area here,

1181
00:52:23,473 --> 00:52:25,842
so this is where
we're gonna land.

1182
00:52:25,842 --> 00:52:28,478
You can't see it from over
there but there is a pit here

1183
00:52:28,478 --> 00:52:29,679
and there's another pit here

1184
00:52:29,679 --> 00:52:31,247
and there are three
pits in a row.

1185
00:52:31,247 --> 00:52:33,350
So, this is where we're gonna go

1186
00:52:33,350 --> 00:52:37,753
and try to actually land
almost into the pit if we can.

1187
00:52:37,753 --> 00:52:39,355
But we can't have this precision

1188
00:52:39,355 --> 00:52:41,358
because we have to shut
down the spacecraft

1189
00:52:41,358 --> 00:52:42,892
when it's that high.

1190
00:52:42,892 --> 00:52:45,862
We have to shut it off,
because if we didn't,

1191
00:52:45,862 --> 00:52:47,663
you know there
would be instability

1192
00:52:47,663 --> 00:52:49,933
and the spacecraft
would shut itself off

1193
00:52:49,933 --> 00:52:52,201
and there would be some
uncontrolled situation.

1194
00:52:52,201 --> 00:52:54,337
So we're shutting it
down an hour earlier

1195
00:52:54,337 --> 00:52:56,139
and where ever it
lands, it lands

1196
00:52:56,139 --> 00:52:58,975
and whatever it shows
us, it shows us, okay?

1197
00:52:58,975 --> 00:53:01,043
But probably, you
know, it's gonna hit

1198
00:53:01,043 --> 00:53:05,281
with the solar array first,
maybe with the antenna.

1199
00:53:05,281 --> 00:53:06,983
It will be spectacular, okay?

1200
00:53:06,983 --> 00:53:08,618
(laughter)

1201
00:53:08,618 --> 00:53:10,120
We engineers, we
love it, you know?

1202

00:53:10,120 --> 00:53:12,655
They never, first time they
let us do this, you know?

1203
00:53:12,655 --> 00:53:15,024
Demolish the spacecraft
at the end, yeah!

1204
00:53:15,024 --> 00:53:17,027
(laughter)

1205
00:53:17,027 --> 00:53:18,127
Yes, scientists.

1206
00:53:18,127 --> 00:53:20,697
(applause)

1207
00:53:20,697 --> 00:53:24,600
And this is what you're gonna
see on September the 30th,

1208
00:53:24,600 --> 00:53:27,237
if you like to come back here

1209
00:53:27,237 --> 00:53:31,408
and watch this spectacular
death of our spacecraft,

1210
00:53:32,442 --> 00:53:33,909
then please come

1211
00:53:33,909 --> 00:53:38,215
and of course, you know,
all the science instruments

1212
00:53:38,215 --> 00:53:41,017
are on one facet, so when
we'll be approaching,

1213

00:53:41,017 --> 00:53:42,852
eventually, we're
gonna crush it.

1214
00:53:42,852 --> 00:53:46,422
Crush the camera because we're
gonna be pointing it down.

1215
00:53:46,422 --> 00:53:49,092
And this will be it for Rosetta.

1216
00:53:50,493 --> 00:53:54,564
So please come back on the
30th of September, eight a.m.

1217
00:53:55,798 --> 00:53:59,435
The actual landing
is at 4:10 a.m,

1218
00:53:59,435 --> 00:54:01,671
but you know, it will take,

1219
00:54:01,671 --> 00:54:05,575
just the signal from the comet
takes 40 minutes to get here,

1220
00:54:05,575 --> 00:54:08,511
pictures have to be processed,
so it will take some time.

1221
00:54:08,511 --> 00:54:13,416
I'll be, and we'll see
what's inside of the comet.

1222
00:54:13,416 --> 00:54:15,885
Thank you very much and
thank you so much for coming.

1223
00:54:15,885 --> 00:54:18,154
(applause)

1224
00:54:24,560 --> 00:54:27,998
And now I'll be glad to
answer easy questions

1225
00:54:27,998 --> 00:54:30,066
and Bonnie will answer
very difficult questions.

1226
00:54:30,066 --> 00:54:31,468
(laughter)

1227
00:54:31,468 --> 00:54:33,236
- Also, please go
up to the microphone

1228
00:54:33,236 --> 00:54:35,138
if you have a question.

1229
00:54:37,206 --> 00:54:39,675
- Well, I don't know if it's
easy or hard, you'll tell me.

1230
00:54:39,675 --> 00:54:41,977
I think a lot of us
visualize the comet

1231
00:54:41,977 --> 00:54:44,581
as kind of a very dark exterior

1232
00:54:45,715 --> 00:54:47,817
from all of the water
vapor going away.

1233
00:54:47,817 --> 00:54:50,186
And then a kind of
powdery interior.

1234
00:54:50,186 --> 00:54:52,622

But we saw layering, but
we didn't seen anything

1235
00:54:52,622 --> 00:54:55,558
that bi-modal or
anything did we?

1236
00:54:55,558 --> 00:54:58,628
Or is it covered up, or
do we think that's right?

1237
00:54:58,628 --> 00:55:00,096
- [Art] Okay.

1238
00:55:00,096 --> 00:55:01,797
- Well, you know we didn't
get a very, you know,

1239
00:55:01,797 --> 00:55:04,534
good view of the
interior with the camera.

1240
00:55:04,534 --> 00:55:06,803
But there are
instruments onboard

1241
00:55:06,803 --> 00:55:10,173
that were able to measure the
average density, for example.

1242
00:55:10,173 --> 00:55:11,607
So it's very fluffy.

1243
00:55:11,607 --> 00:55:15,044
You know, there was a
morrow, a microwave sounder

1244
00:55:15,044 --> 00:55:19,416
that was able to look down
into the upper few centimeters

1245
00:55:19,416 --> 00:55:21,183
of the surface.

1246
00:55:21,183 --> 00:55:23,186
So we did get some
knowledge of what it's like

1247
00:55:23,186 --> 00:55:24,386
in the interior.

1248
00:55:24,386 --> 00:55:25,988
It's not what we
call differentiated.

1249
00:55:25,988 --> 00:55:29,125
It seems to be pretty
fluffy all the way through.

1250
00:55:29,125 --> 00:55:30,760
But you brought up something
that's really interesting

1251
00:55:30,760 --> 00:55:32,728
that I didn't mention
because it's kind of,

1252
00:55:32,728 --> 00:55:34,230
you know, you can't
see everything.

1253
00:55:34,230 --> 00:55:38,601
It's very dark, it reflects
only about four to six percent

1254
00:55:38,601 --> 00:55:40,937
of the light that falls
on it in the visible.

1255

00:55:40,937 --> 00:55:44,007
And that's about as
dark as coal tar.

1256
00:55:45,107 --> 00:55:46,976
It's really very dark.

1257
00:55:46,976 --> 00:55:50,246
- So, lemme just add something.

1258
00:55:50,246 --> 00:55:52,648
This is twice as
dark as asphalt,

1259
00:55:52,648 --> 00:55:54,917
that's why it's very
difficult to see this nuclei.

1260
00:55:54,917 --> 00:55:56,653
And the reason it
is, like Bonnie said,

1261
00:55:56,653 --> 00:56:00,790
is because this dust emanates
from the inside, right?

1262
00:56:00,790 --> 00:56:03,092
It's when we get especially
to the perihelion,

1263
00:56:03,092 --> 00:56:05,561
close to the sun,
everything heats up,

1264
00:56:05,561 --> 00:56:09,299
starts sublimating,
goes up and then dust,

1265
00:56:09,299 --> 00:56:12,235
as we cool off and we

go away from the sun,

1266
00:56:12,235 --> 00:56:14,337
slowly descends on
the surface, right?

1267
00:56:14,337 --> 00:56:18,007
And so the whole thing
is covered with very dark

1268
00:56:18,007 --> 00:56:21,677
carbonaceous silicate
dust, but it's very

1269
00:56:21,677 --> 00:56:24,814
You know, it's fluffy
this, nothing, you know,

1270
00:56:24,814 --> 00:56:27,516
that's why it's very
difficult to reflect light.

1271
00:56:27,516 --> 00:56:30,520
Fluffy black carbon
powder, alright?

1272
00:56:33,789 --> 00:56:35,624
And that's what
makes it so dark.

1273
00:56:35,624 --> 00:56:36,458
- Thank you.

1274
00:56:36,458 --> 00:56:37,593
- [Art] Thank you.

1275
00:56:37,593 --> 00:56:40,529
Oh no, Tommy, no, Tommy, no, no.

1276

00:56:40,529 --> 00:56:41,631
Oh, a question for Bonnie now.

1277
00:56:41,631 --> 00:56:42,898
- [Tommy] A question.

1278
00:56:42,898 --> 00:56:44,033
- This guy has IQ
three times mine.

1279
00:56:44,033 --> 00:56:45,535
- Correct, a
question for Bonnie.

1280
00:56:45,535 --> 00:56:47,570
What's the process
that fills up the silos

1281
00:56:47,570 --> 00:56:49,339
and what sort of time
scales is current?

1282
00:56:49,339 --> 00:56:50,873
- It's out-gassing.

1283
00:56:50,873 --> 00:56:53,843
And you know, we're honesty
not sure of the time scales.

1284
00:56:53,843 --> 00:56:55,378
We saw changes on the comet.

1285
00:56:55,378 --> 00:56:58,148
We did see increases
in the size,

1286
00:56:59,315 --> 00:57:00,950
but most of the
ones that you saw,

1287
00:57:00,950 --> 00:57:02,284
that you see on the comet,

1288
00:57:02,284 --> 00:57:06,489
not only on 67P but also
on Wild 2 for example,

1289
00:57:06,489 --> 00:57:09,825
are from past appearances,
past apparitions.

1290
00:57:09,825 --> 00:57:11,461
But we don't know
whether, you know,

1291
00:57:11,461 --> 00:57:15,998
it's only one appearance,
one passage towards the sun

1292
00:57:15,998 --> 00:57:18,901
that each vent is
caused or it gets,

1293
00:57:18,901 --> 00:57:20,402
it opens up successively.

1294
00:57:20,402 --> 00:57:22,071
We just don't know these things.

1295
00:57:22,071 --> 00:57:24,140
We have seen changes
so they do change,

1296
00:57:24,140 --> 00:57:28,211
but we don't if it's million
years, thousand years,

1297
00:57:28,211 --> 00:57:29,245
we just don't know.

1298
00:57:29,245 --> 00:57:30,446
- Thanks.

1299
00:57:30,446 --> 00:57:32,915
- But what was
fascinating to me,

1300
00:57:32,915 --> 00:57:35,418
about the jets, right, is
that some of these jets

1301
00:57:35,418 --> 00:57:36,653
would activate themselves

1302
00:57:36,653 --> 00:57:39,722
and would last only
20 minutes, right?

1303
00:57:39,722 --> 00:57:44,359
And, because the explanation
that I heard of this

1304
00:57:44,359 --> 00:57:45,928
was that you can imagine there

1305
00:57:45,928 --> 00:57:49,565
are like this gas bubbles
forming underneath

1306
00:57:49,565 --> 00:57:51,834
and so there's this
huge gas bubble here,

1307
00:57:51,834 --> 00:57:53,302
underneath the surface.

1308
00:57:53,302 --> 00:57:56,739
And then if something cracks,

there is a little opening

1309
00:57:56,739 --> 00:57:59,642
and the gas starts
coming out, violently,

1310
00:57:59,642 --> 00:58:03,179
and blows off the top
surface like a sewer cover

1311
00:58:03,179 --> 00:58:04,714
into the space.

1312
00:58:04,714 --> 00:58:07,750
And now you have this jet
and the jet shoots out

1313
00:58:07,750 --> 00:58:11,587
and leaves this silo
underneath and comes out.

1314
00:58:11,587 --> 00:58:14,490
And some of these
jets lasted what?

1315
00:58:14,490 --> 00:58:15,324
- [Bonnie] A couple hours.

1316
00:58:15,324 --> 00:58:16,793
- Yeah.
- Yeah.

1317
00:58:16,793 --> 00:58:18,261
- But there was one 19
minutes, very, very short.

1318
00:58:18,261 --> 00:58:19,862
- I think the biggest
ones were a couple hours.

1319
00:58:19,862 --> 00:58:23,366
- So that's how this
surface is processed.

1320
00:58:25,968 --> 00:58:28,704
- So an impossible
question for Bonnie:

1321
00:58:28,704 --> 00:58:32,641
Tonight's comet,
Swift-Tuttle, whose debris

1322
00:58:32,641 --> 00:58:34,910
we're gonna be entering.

1323
00:58:34,910 --> 00:58:36,678
How well is it characterized?

1324
00:58:36,678 --> 00:58:38,614
Do we know it's all
tiny little particles

1325
00:58:38,614 --> 00:58:42,785
or could there be some minor
lobe waiting to hit us?

1326
00:58:43,686 --> 00:58:44,521
- I see.

1327
00:58:46,922 --> 00:58:47,856
You know, there are a lot of

1328
00:58:47,856 --> 00:58:49,292
I don't know the answer to that.

1329
00:58:49,292 --> 00:58:51,694
There are a lot of amateurs
observing these things

1330
00:58:51,694 --> 00:58:53,763
and I would think
that if there were

1331
00:58:53,763 --> 00:58:56,366
Okay, in order to get through
the Earth's atmosphere,

1332
00:58:56,366 --> 00:58:59,369
to hit the ground,
you have to be

1333
00:58:59,369 --> 00:59:01,637
about maybe half the
size of this room.

1334
00:59:01,637 --> 00:59:04,273
And I think if there
were anything that big,

1335
00:59:04,273 --> 00:59:07,276
some amateur like,
would have observed it

1336
00:59:07,276 --> 00:59:08,744
coming off of the comet.

1337
00:59:08,744 --> 00:59:10,813
So I don't think there's
anything that would harm us,

1338
00:59:10,813 --> 00:59:14,049
that's kinda my first, you
know, off the top of my head

1339
00:59:14,049 --> 00:59:14,983
what I would say.

1340
00:59:14,983 --> 00:59:16,219

But there could be things like,

1341
00:59:16,219 --> 00:59:17,686
I mean most of these
things that we see

1342
00:59:17,686 --> 00:59:19,521
are like fist-sized
or even smaller.

1343
00:59:19,521 --> 00:59:21,590
You know, there could be
baseball-sized things coming off

1344
00:59:21,590 --> 00:59:23,459
and that's what we
see in the atmosphere,

1345
00:59:23,459 --> 00:59:25,027
tonight if you look.

1346
00:59:25,027 --> 00:59:29,565
- And what we see, from
Churyumov-Gerasimenko,
for example,

1347
00:59:29,565 --> 00:59:32,267
is that most of these particles

1348
00:59:32,267 --> 00:59:35,070
that you see entering
tonight are probably

1349
00:59:35,070 --> 00:59:37,640
like the size of a grain
of sand and smaller, right?

1350
00:59:37,640 --> 00:59:38,808
- [Bonnie] Yeah, that's
true, they're a lot smaller.

1351
00:59:38,808 --> 00:59:40,943
- Because to be
removed from the comet

1352
00:59:40,943 --> 00:59:43,112
and not fall back, you
know, they would have

1353
00:59:43,112 --> 00:59:46,248
to have very low gravity so
they separated themselves,

1354
00:59:46,248 --> 00:59:49,885
went far away that they
were not under, you know.

1355
00:59:49,885 --> 00:59:51,721
Gravity is mass of one body

1356
00:59:51,721 --> 00:59:54,823
times the mass of
the other body.

1357
00:59:54,823 --> 00:59:57,226
So there would be small sizes

1358
00:59:58,360 --> 01:00:02,097
and that's why these
reentries which we see,

1359
01:00:02,097 --> 01:00:05,768
like Bonnie says, they're just
tiny particles, sand-sized.

1360
01:00:05,768 --> 01:00:08,971
We saw some boulders fly
off Churyumov-Gerasimenko

1361

01:00:08,971 --> 01:00:11,273
and I tell you that this
is an exciting thing.

1362
01:00:11,273 --> 01:00:12,475
And I'm sorry to
keep you standing,

1363
01:00:12,475 --> 01:00:14,543
but let me just tell
you this 'cause this is

1364
01:00:14,543 --> 01:00:16,378
so unintuitional.

1365
01:00:16,378 --> 01:00:19,648
When you're in space
and we're used to seeing

1366
01:00:19,648 --> 01:00:22,618
Okay, I see Rhodie
here in the first row,

1367
01:00:22,618 --> 01:00:25,287
I see him very well because
there's very little air

1368
01:00:25,287 --> 01:00:26,856
and pollution, right?

1369
01:00:26,856 --> 01:00:29,891
And there is also, I know what
size is a human being, right?

1370
01:00:29,891 --> 01:00:31,627
So I know he's in the first row,

1371
01:00:31,627 --> 01:00:33,930
he is three meters from me.

1372
01:00:33,930 --> 01:00:37,166
And the gentleman in the yellow
shirt, what is your name?

1373
01:00:39,268 --> 01:00:38,000
- Tom.

1374
01:00:39,268 --> 01:00:41,070
And Tom is about
20 meters from me,

1375
01:00:41,070 --> 01:00:45,241
because I don't think he's
a tiny, skinny midget, okay.

1376
01:00:46,441 --> 01:00:48,377
I'm thinking he's the
same size as Rhodie.

1377
01:00:48,377 --> 01:00:51,447
Now, in space, you don't
know if you're looking

1378
01:00:51,447 --> 01:00:55,484
at a grain of sand, right
here, or a huge boulder

1379
01:00:55,484 --> 01:00:57,386
there is a kilometer away.

1380
01:00:57,386 --> 01:00:59,689
And as a matter
of fact, you know,

1381
01:00:59,689 --> 01:01:01,757
scientists would always
try to figure out

1382
01:01:01,757 --> 01:01:03,058

what are we looking at.

1383
01:01:03,058 --> 01:01:04,960
Is it a huge boulder
or is it a tiny grain

1384
01:01:04,960 --> 01:01:06,428
in front of the camera?

1385
01:01:06,428 --> 01:01:08,730
And now you have to see
with what velocity it moves,

1386
01:01:08,730 --> 01:01:11,600
how quickly it changes
its size, you know.

1387
01:01:11,600 --> 01:01:13,536
And on that very basis,
they will finally say,

1388
01:01:13,536 --> 01:01:15,037
Oh, this is a boulder.

1389
01:01:15,037 --> 01:01:16,805
And we saw some
boulders fly off,

1390
01:01:16,805 --> 01:01:18,440
they're about two, three meters.

1391
01:01:18,440 --> 01:01:20,943
So, to answer gentleman's
question, you know,

1392
01:01:20,943 --> 01:01:25,080
if Swift-Tuttle is like
Churyumov-Gerasimenko,

1393

01:01:25,080 --> 01:01:27,116
then, you know, we're
not gonna see very many

1394
01:01:27,116 --> 01:01:30,520
of these boulders,
mostly grains of sand.

1395
01:01:32,487 --> 01:01:36,792
- Okay, my question
is about the processes

1396
01:01:36,792 --> 01:01:40,730
that you had in the early
formation of the solar system

1397
01:01:40,730 --> 01:01:42,899
versus what we have today.

1398
01:01:44,600 --> 01:01:47,903
I can see how bodies
circling around,

1399
01:01:47,903 --> 01:01:49,938
they're colliding, they
could sometimes stick

1400
01:01:49,938 --> 01:01:51,807
and form bigger ones and
other times they could

1401
01:01:51,807 --> 01:01:54,243
just break them apart
and make smaller ones.

1402
01:01:54,243 --> 01:01:57,914
And so, is the asteroid
built now in a state

1403
01:01:59,548 --> 01:02:03,852

where it's breaking apart more
than it's putting together?

1404
01:02:03,852 --> 01:02:07,356
And if so, what are
some of the conditions

1405
01:02:09,191 --> 01:02:12,494
that determine whether
you're able to build up

1406
01:02:12,494 --> 01:02:16,332
bigger things or break
up into smaller things?

1407
01:02:17,867 --> 01:02:20,502
- Well, I think, you know, a
lot of this is hand waving.

1408
01:02:20,502 --> 01:02:22,638
You know, the early part
of the solar system,

1409
01:02:22,638 --> 01:02:25,274
but at some point, the
bigger stuff is gonna

1410
01:02:25,274 --> 01:02:27,843
just act as a gravity
well, you know?

1411
01:02:27,843 --> 01:02:29,478
It's gonna like
hog all the stuff.

1412
01:02:29,478 --> 01:02:30,979
As soon as something
gets a little big bigger,

1413
01:02:30,979 --> 01:02:32,247

it's gonna have more gravity

1414
01:02:32,247 --> 01:02:33,482
and it's gonna have more pieces.

1415
01:02:33,482 --> 01:02:35,851
But yes, you're right,
often they collide.

1416
01:02:35,851 --> 01:02:39,321
Right now, the comet 67P is more

1417
01:02:39,321 --> 01:02:40,689
in a state of erosion.

1418
01:02:40,689 --> 01:02:42,557
I mean, it's not
accreting any particles,

1419
01:02:42,557 --> 01:02:44,893
it's blowing them off
through the process

1420
01:02:44,893 --> 01:02:48,264
of the venting from
the jets, the attrition

1421
01:02:48,264 --> 01:02:52,634
that takes place as it enters
the inner solar system.

1422
01:02:52,634 --> 01:02:55,437
So yeah, it's losing mass, now.

1423
01:02:55,437 --> 01:02:57,406
- [Tom] Okay, thank you.

1424
01:02:57,406 --> 01:02:59,008
- And this one,

what is interesting

1425
01:02:59,008 --> 01:03:02,878
about Churyumov-Gerasimenko,
when we noticed the shape,

1426
01:03:02,878 --> 01:03:05,014
I was teasing scientists,
I was telling them,

1427
01:03:05,014 --> 01:03:07,749
"Well, when it comes to
perihelion, close to the sun,

1428
01:03:07,749 --> 01:03:09,285
it's gonna split."

1429
01:03:09,285 --> 01:03:11,687
Because we started actually
seeing a little crack here,

1430
01:03:11,687 --> 01:03:13,055
right at the neck.

1431
01:03:13,055 --> 01:03:16,024
And I said, "Eh, it
probably will split."

1432
01:03:16,024 --> 01:03:18,527
And now you're gonna have
Churyumov and Gerasimenko.

1433
01:03:18,527 --> 01:03:20,763
(laughter)

1434
01:03:22,732 --> 01:03:23,566
Yes.

1435
01:03:24,834 --> 01:03:25,768

You can lower your microphone.
- When will this--

1436
01:03:25,768 --> 01:03:27,703
- You can pull it down.

1437
01:03:31,907 --> 01:03:35,477
- When will this comet
come around again,

1438
01:03:35,477 --> 01:03:38,247
if it, will it be
seen over here?

1439
01:03:39,982 --> 01:03:41,551
And if it is, when?

1440
01:03:44,153 --> 01:03:48,390
- Okay, so the comet has
a period of 6 1/2 years.

1441
01:03:48,390 --> 01:03:51,092
So it means every 6
1/2, it comes back,

1442
01:03:51,092 --> 01:03:52,895
but it comes back to the sun.

1443
01:03:52,895 --> 01:03:56,364
That doesn't mean that
Earth is very close to it.

1444
01:03:56,364 --> 01:03:58,000
Like for example at the landing,

1445
01:03:58,000 --> 01:04:02,604
the comet will be 3.8
astronomical units from the sun,

1446

01:04:02,604 --> 01:04:05,474
meaning distances
between Earth and sun,

1447
01:04:05,474 --> 01:04:09,645
but it will be 4.8 to Earth,
so Earth will be further away.

1448
01:04:10,846 --> 01:04:12,581
So, to answer your question,

1449
01:04:12,581 --> 01:04:15,017
it comes back every 6 1/2 years.

1450
01:04:15,017 --> 01:04:19,654
There are comets that, the
comet that you'll see today,

1451
01:04:19,654 --> 01:04:24,025
the tail, that one comes
back every 133 years.

1452
01:04:24,025 --> 01:04:26,728
So, please, you know, tell me,

1453
01:04:26,728 --> 01:04:28,263
'cause it will be very difficult

1454
01:04:28,263 --> 01:04:32,701
for me to read at that time,
when this comet comes back,

1455
01:04:32,701 --> 01:04:35,437
tell if it was really
a spectacular shower.

1456
01:04:35,437 --> 01:04:38,740
That will be in, what,
about a hundred years or so.

1457
01:04:38,740 --> 01:04:42,411
But this one is 6 1/2 years.

1458
01:04:42,411 --> 01:04:43,579
Good question.

1459
01:04:45,681 --> 01:04:46,782
Yes.

1460
01:04:46,782 --> 01:04:48,017
- Hello.

1461
01:04:48,017 --> 01:04:51,587
So I have a question
about the landing.

1462
01:04:51,587 --> 01:04:55,290
You guys say that you
guys get a sort of signal,

1463
01:04:55,290 --> 01:04:57,293
when it hits the comet.

1464
01:04:57,293 --> 01:04:58,794
- [Art] Right.

1465
01:04:58,794 --> 01:05:01,764
- And, you guys got pictures,
about what the comet looks,

1466
01:05:01,764 --> 01:05:02,931
you know where it lands,
you guys don't know

1467
01:05:02,931 --> 01:05:03,966
where it's gonna land.

1468
01:05:03,966 --> 01:05:05,500

- [Art] Right.

1469
01:05:05,500 --> 01:05:08,471
- So, how do you guys know
if it's gonna land safely

1470
01:05:08,471 --> 01:05:11,706
and what if it
ends up destroying

1471
01:05:11,706 --> 01:05:14,509
and would you guys be
guaranteed pictures

1472
01:05:14,509 --> 01:05:16,879
or if it destroys, you guys
don't get anything back?

1473
01:05:16,879 --> 01:05:18,948
- Yeah, yeah, yeah, yeah.

1474
01:05:20,349 --> 01:05:23,920
So, you know, we're
gonna be getting images

1475
01:05:25,120 --> 01:05:27,690
as we approach the comet, right?

1476
01:05:27,690 --> 01:05:31,226
So, it's actually,
let's clarify one thing,

1477
01:05:31,226 --> 01:05:33,763
'cause people are
used to: Mars landing.

1478
01:05:33,763 --> 01:05:35,430
And seven minutes, what is
it seven minutes of terror.

1479
01:05:35,430 --> 01:05:36,599
- [Bonnie] Minutes of terror.

1480
01:05:36,599 --> 01:05:38,100
- Right, seven minutes?
- Right.

1481
01:05:38,100 --> 01:05:40,703
- Well, we have like seven
hours of patience, okay?

1482
01:05:40,703 --> 01:05:41,737
(laughter)

1483
01:05:41,737 --> 01:05:42,671
- [Bonnie] I like that.

1484
01:05:42,671 --> 01:05:45,374
- So, it really goes, it goes

1485
01:05:45,374 --> 01:05:48,310
about 50 centimeters
per second, so it like,

1486
01:05:48,310 --> 01:05:50,579
you know, it goes like this.

1487
01:05:52,247 --> 01:05:55,050
So, it's very slowly
and it's taking images

1488
01:05:55,050 --> 01:05:56,851
as it approaches this, you know?

1489
01:05:56,851 --> 01:05:59,388
So, the interesting thing is,

1490
01:05:59,388 --> 01:06:01,523

you really have to
figure this out,

1491
01:06:01,523 --> 01:06:03,459
the gravity, the
math, the rotation,

1492
01:06:03,459 --> 01:06:07,096
the geometry, because it's
coming with certain speed here,

1493
01:06:07,096 --> 01:06:10,232
and then this thing is
spinning, so you aim,

1494
01:06:10,232 --> 01:06:14,836
you know, you aim at, you
wanna land here, right?

1495
01:06:14,836 --> 01:06:17,739
But you're actually, maybe,
here and you're waiting

1496
01:06:17,739 --> 01:06:19,708
for the comet to rotate.

1497
01:06:19,708 --> 01:06:22,477
So, but it will be
images as it descends.

1498
01:06:22,477 --> 01:06:24,880
We don't know if it's
gonna even make it

1499
01:06:24,880 --> 01:06:26,915
that close to the surface.

1500
01:06:26,915 --> 01:06:29,017
Because as Bonnie
said, you know,

1501
01:06:29,017 --> 01:06:30,285
these are actually two comets,

1502
01:06:30,285 --> 01:06:32,421
they have slightly
different density.

1503
01:06:32,421 --> 01:06:34,456
So, there's gravity
well, here, okay?

1504
01:06:34,456 --> 01:06:35,991
And we don't understand
it very well.

1505
01:06:35,991 --> 01:06:39,828
So, as this thing will be
flying, maybe it will dip

1506
01:06:39,828 --> 01:06:41,664
and then hit the head.

1507
01:06:43,432 --> 01:06:47,435
You know, it's very difficult
to say what will be happening.

1508
01:06:47,435 --> 01:06:50,572
But it's not sudden
descent, it's a slow,

1509
01:06:50,572 --> 01:06:53,175
very slow, ballistic descent.

1510
01:06:53,175 --> 01:06:54,009
- Thank you.

1511
01:06:54,009 --> 01:06:55,511
- [Art] Thank you.

1512
01:06:58,180 --> 01:07:00,216
- Okay, in view of
the far distance

1513
01:07:00,216 --> 01:07:03,252
and weak solar radiation,
and the orientation problems

1514
01:07:03,252 --> 01:07:06,188
that you had, in this
mission or other missions,

1515
01:07:06,188 --> 01:07:09,624
would it be worth
concern to use solar,

1516
01:07:09,624 --> 01:07:13,362
I mean thermo-electric
thermal generators,

1517
01:07:13,362 --> 01:07:14,797
electric generators?

1518
01:07:14,797 --> 01:07:15,597
- [Bonnie] A solar electric
propelled propulsion?

1519
01:07:15,597 --> 01:07:17,132
- Right, right, right.

1520
01:07:17,132 --> 01:07:18,934
General purpose heat source
radioisotopic thermoelectric

1521
01:07:18,934 --> 01:07:20,269
generators, as
you wanted to say.

1522

01:07:20,269 --> 01:07:21,336
- [Questioner]
Thermoelectric generators.

1523
01:07:21,336 --> 01:07:22,872
- Yeah yeah yeah.
- Yes.

1524
01:07:22,872 --> 01:07:23,706
- Yeah, RTGs, yeah.

1525
01:07:23,706 --> 01:07:25,173
- [Bonnie] RTGs

1526
01:07:25,173 --> 01:07:28,711
- Yeah, we would, you know,
we had RTGs on Cassini.

1527
01:07:29,745 --> 01:07:31,846
We had RTGs on Galileo.

1528
01:07:31,846 --> 01:07:36,084
We would love to have
RTGs, but you know,

1529
01:07:36,084 --> 01:07:38,153
it's very difficult to
get RTGs these days.

1530
01:07:38,153 --> 01:07:40,689
Like, for example, the
mission that I'm working on,

1531
01:07:40,689 --> 01:07:43,859
to Saturn, will have solar
arrays, which is a little crazy,

1532
01:07:43,859 --> 01:07:47,129
but you know, because
some folks feel

1533
01:07:47,129 --> 01:07:48,030
that RTGs--

1534
01:07:51,566 --> 01:07:52,801
- [Questioner] Radioactive.

1535
01:07:52,801 --> 01:07:56,472
- Contain the most toxic
substance on Earth,

1536
01:07:58,473 --> 01:08:00,308
called Plutonium.

1537
01:08:00,308 --> 01:08:04,446
Named after the god
of underground Pluto.

1538
01:08:04,446 --> 01:08:06,681
- [Questioner] Oh, Pluto.

1539
01:08:06,681 --> 01:08:10,652
- And, because of that,
you know, we have some

1540
01:08:10,652 --> 01:08:14,056
very difficult to put
'em on a spacecraft

1541
01:08:14,056 --> 01:08:16,491
without protests and
lawsuits for many years

1542
01:08:16,491 --> 01:08:17,893
and things like that.

1543
01:08:17,893 --> 01:08:18,694
- It's also a European mission,
it's a European mission.

1544
01:08:18,694 --> 01:08:20,128
- [Questioner] Politics.

1545
01:08:20,128 --> 01:08:21,597
- So, they have even
worse problems over there.

1546
01:08:21,597 --> 01:08:23,666
- [Questioner] Thank you.

1547
01:08:26,902 --> 01:08:31,006
- Hi, at one point, you
showed an image that was,

1548
01:08:33,042 --> 01:08:36,311
it showed a dent on
the, on the comet

1549
01:08:36,311 --> 01:08:40,082
and you specified that
it was an old hole

1550
01:08:40,082 --> 01:08:43,085
from one of the jets and
that it shouldn't be confused

1551
01:08:43,085 --> 01:08:45,187
for, what was it, crater.

1552
01:08:46,522 --> 01:08:47,756
- [Bonnie] Crater,
yeah, impact crater.

1553
01:08:47,756 --> 01:08:50,392
- So I wanna know how
you knew the difference

1554
01:08:50,392 --> 01:08:53,194

between a crater and
a hole from a jet.

1555
01:08:53,194 --> 01:08:56,865
- Okay, when scientists
first saw these holes

1556
01:08:56,865 --> 01:08:59,768
on Wild 2, and on other comets,

1557
01:08:59,768 --> 01:09:02,203
the first impression was
that they might be craters

1558
01:09:02,203 --> 01:09:05,808
but then, geologists
actually count craters

1559
01:09:06,975 --> 01:09:10,012
and measure the
diameters of them.

1560
01:09:10,012 --> 01:09:13,248
And from that data,
it wasn't typical

1561
01:09:13,248 --> 01:09:16,017
of what impact craters,
that is, craters formed

1562
01:09:16,017 --> 01:09:18,453
when another object comes
in, hits the object.

1563
01:09:18,453 --> 01:09:21,756
And just the shape of
it wasn't right, either.

1564
01:09:21,756 --> 01:09:23,726
It wasn't really the, you know,

1565
01:09:23,726 --> 01:09:25,327
the kind of bowl-shaped
thing that you see

1566
01:09:25,327 --> 01:09:27,796
on impact craters
like on the moon.

1567
01:09:27,796 --> 01:09:31,166
So, it was, you know, pretty
soon after these holes

1568
01:09:31,166 --> 01:09:35,070
were discovered, theorized
that they were locations

1569
01:09:35,070 --> 01:09:39,241
where gases that were vents
of sublimating gases came out.

1570
01:09:41,142 --> 01:09:42,210
- [Art] An excellent question,
thank you for asking.

1571
01:09:42,210 --> 01:09:43,145
- Thank you

1572
01:09:44,446 --> 01:09:45,281
- Yes.

1573
01:09:47,616 --> 01:09:51,787
- When the Rosetta lander lands,
will it be still functional

1574
01:09:54,156 --> 01:09:56,892
or will it be,
like, obliterated?

1575

01:09:59,295 --> 01:10:00,596
- It will die.

1576
01:10:00,596 --> 01:10:02,898
(laughter)

1577
01:10:02,898 --> 01:10:04,799
(Art sniffles)

1578
01:10:04,799 --> 01:10:07,903
Now, with the, what,
it, it will die.

1579
01:10:09,404 --> 01:10:11,974
- [Questioner] Alright then.

1580
01:10:11,974 --> 01:10:15,044
- Okay, so, you
know, you can imagine

1581
01:10:17,446 --> 01:10:20,649
this spacecraft with
huge solar arrays,

1582
01:10:20,649 --> 01:10:25,053
very difficult to control, so
when it does hit the surface,

1583
01:10:25,053 --> 01:10:27,422
it will tumble, it will
roll, it will bounce,

1584
01:10:27,422 --> 01:10:30,092
it will come down again,
but we will not see it,

1585
01:10:30,092 --> 01:10:31,927
because probably the
instruments will be damaged.

1586
01:10:31,927 --> 01:10:35,931
So, but it certainly will
not survive the crash.

1587
01:10:38,767 --> 01:10:39,934
Yes?

1588
01:10:39,934 --> 01:10:42,337
- Hi, couple of
interrelated questions.

1589
01:10:42,337 --> 01:10:44,406
How close does it get to the sun

1590
01:10:44,406 --> 01:10:46,675
and what, what, did you
measure the temperature

1591
01:10:46,675 --> 01:10:49,178
of the surface and why
don't we see evidence

1592
01:10:49,178 --> 01:10:51,613
of some kind of melting
on the surface if there

1593
01:10:51,613 --> 01:10:55,617
are jets forming
underneath the surface?

1594
01:10:55,617 --> 01:10:56,452
- Yeah.

1595
01:10:57,719 --> 01:10:58,953
- We did measure
the temperature,

1596
01:10:58,953 --> 01:11:01,656
there were instruments

on board to do that.

1597
01:11:01,656 --> 01:11:05,694
And it doesn't have the
atmosphere to sustain,

1598
01:11:05,694 --> 01:11:08,263
you know, liquid water,
it just sublimates

1599
01:11:08,263 --> 01:11:10,332
into, you know, outer space.

1600
01:11:10,332 --> 01:11:12,968
But we do see quite a bit
of thermal processing,

1601
01:11:12,968 --> 01:11:17,338
a lot of the cracking, there's
kneeling, there's a crust

1602
01:11:17,338 --> 01:11:21,910
on the top, so we do see a lot
of thermal processing of it.

1603
01:11:21,910 --> 01:11:24,513
- So to answer your question
about the temperatures.

1604
01:11:24,513 --> 01:11:28,850
So, when we first
caught up with the comet

1605
01:11:28,850 --> 01:11:30,552
and we first landed, right?

1606
01:11:30,552 --> 01:11:32,454
The temperature was,
cause it changes depending

1607
01:11:32,454 --> 01:11:36,091
on how far you are
from the sun, so.

1608
01:11:36,091 --> 01:11:37,860
And this is what's
fascinating to me.

1609
01:11:37,860 --> 01:11:42,031
So, it was about 120 kelvin,
minus 150 Celsius, right?

1610
01:11:44,132 --> 01:11:45,500
Very cold.

1611
01:11:45,500 --> 01:11:47,369
When you got very
close to the sun,

1612
01:11:47,369 --> 01:11:50,572
and it was only one
AU, some, the areas

1613
01:11:52,040 --> 01:11:56,712
that were in the sunshine were
about room temperature, okay?

1614
01:11:56,712 --> 01:11:58,179
So it was very warm.

1615
01:11:58,179 --> 01:12:01,516
But what was fascinating
to me to see on this comet,

1616
01:12:01,516 --> 01:12:05,688
it, you know, like when a
sun sets, on Earth, right?

1617
01:12:07,088 --> 01:12:09,525

Well, what time sun sets now?

1618
01:12:11,226 --> 01:12:12,427
Eight o'clock?

1619
01:12:12,427 --> 01:12:14,696
Eight p.m., something
like this, seven?

1620
01:12:14,696 --> 01:12:19,634
What was the temperature
at 6:30, for example, here?

1621
01:12:19,634 --> 01:12:20,902
Anybody?

1622
01:12:20,902 --> 01:12:21,703
- [Female Audience
Member] Maybe 95.

1623
01:12:21,703 --> 01:12:22,871
- What do you think?

1624
01:12:22,871 --> 01:12:23,772
- [Male Audience Member] 80.

1625
01:12:23,772 --> 01:12:24,606
80?

1626
01:12:24,606 --> 01:12:26,074
- [Questioner] 80s

1627
01:12:26,074 --> 01:12:29,077
- Right, 80s, and after
the sun set, about an hour,

1628
01:12:29,077 --> 01:12:32,648
at nine o'clock, what
was the temperature?

1629
01:12:32,648 --> 01:12:33,848
- 70s, low 70s, high 70s.

1630
01:12:33,848 --> 01:12:35,050
- Yeah, so, you know,
we're used to this

1631
01:12:35,050 --> 01:12:35,984
because we have atmosphere.

1632
01:12:35,984 --> 01:12:38,319
On the comet, what we noticed,

1633
01:12:38,319 --> 01:12:39,954
and that was fascinating to me,

1634
01:12:39,954 --> 01:12:42,891
it's like on, off,
on, off, you know.

1635
01:12:42,891 --> 01:12:46,562
You're in the sun, you
were, you know, 30 C.

1636
01:12:47,996 --> 01:12:51,800
You are in the shade, you
go to minus 100, okay?

1637
01:12:53,201 --> 01:12:55,070
So, it's like, you know,
if you're on a comet

1638
01:12:55,070 --> 01:12:56,771
and, you know, don't
wanna get very cold,

1639
01:12:56,771 --> 01:13:00,875
you would have to be running,

you know, with the sun set,

1640
01:13:00,875 --> 01:13:02,945
so you're always
past the terminator.

1641
01:13:02,945 --> 01:13:07,649
But, that's really, really
something surprising,

1642
01:13:07,649 --> 01:13:11,820
that there's very little
thermal inertia on a comet.

1643
01:13:16,824 --> 01:13:20,061
- How well do you know
what impact the landing

1644
01:13:20,061 --> 01:13:22,397
is gonna have on
the comet in terms

1645
01:13:22,397 --> 01:13:24,566
of when it hits the thing?

1646
01:13:26,969 --> 01:13:28,403
- Very difficult
question, so it's you.

1647
01:13:28,403 --> 01:13:31,072
- Yeah
(laughter)

1648
01:13:31,072 --> 01:13:33,741
- Well, you know,
physics, right?

1649
01:13:33,741 --> 01:13:36,044
Conservation of momentum, right?

1650
01:13:36,044 --> 01:13:39,381
M1 times V1 is equal
M2 times V2, right?

1651
01:13:40,615 --> 01:13:43,719
So the mass of the
comet, M1 is equal

1652
01:13:45,553 --> 01:13:47,890
to 10 to the 13th kilograms.

1653
01:13:50,325 --> 01:13:54,496
The mass of the spacecraft
is 10 to the 3rd, not quite.

1654
01:13:58,633 --> 01:13:59,468
Two, okay?

1655
01:14:00,869 --> 01:14:04,373
The velocity of the comet
is 150,000 kilometers

1656
01:14:06,974 --> 01:14:10,178
times velocity of the
spacecraft is the same,

1657
01:14:10,178 --> 01:14:13,982
so they nullify each other,
so now you have something

1658
01:14:13,982 --> 01:14:17,752
that is 10 to the 13th
and 10 to the 2nd.

1659
01:14:17,752 --> 01:14:20,088
So the effect is negligible.

1660
01:14:21,689 --> 01:14:25,293
Will not knock it

off its trajectory

1661
01:14:25,293 --> 01:14:27,762
and direct it to Earth.

1662
01:14:27,762 --> 01:14:29,598
- [Questioner] Thanks.

1663
01:14:32,200 --> 01:14:36,071
- How did all the gases
get in there in the first,

1664
01:14:36,071 --> 01:14:37,973
well, in the beginning?

1665
01:14:38,874 --> 01:14:40,075
- [Art] Okay.

1666
01:14:40,075 --> 01:14:42,710
- Well, the comets
formed in a cold part

1667
01:14:42,710 --> 01:14:44,512
of the cloud of gas and dust

1668
01:14:44,512 --> 01:14:46,781
from which the
solar system formed.

1669
01:14:46,781 --> 01:14:50,718
So, out there where it
was, it was pretty far out,

1670
01:14:50,718 --> 01:14:53,789
there was just a lot
of stuff that you get,

1671
01:14:53,789 --> 01:14:55,223
you know, when it's cold.

1672
01:14:55,223 --> 01:14:56,858
Like if you go to the
Earth's poles, for example,

1673
01:14:56,858 --> 01:14:59,861
the North or South poles, isn't
there a lot of ice up there?

1674
01:14:59,861 --> 01:15:01,763
Same way in the solar
system, if you go out

1675
01:15:01,763 --> 01:15:05,367
to the areas that were
cold, you see a lot of ice.

1676
01:15:05,367 --> 01:15:08,536
Not just water-ice, but
you see methane, ammonia.

1677
01:15:08,536 --> 01:15:11,172
All those things were frozen
and those things all got frozen

1678
01:15:11,172 --> 01:15:13,541
into the comet because
it was formed out there

1679
01:15:13,541 --> 01:15:15,477
where it's really cold.

1680
01:15:16,878 --> 01:15:18,947
And then when it comes into
the inner solar system,

1681
01:15:18,947 --> 01:15:20,849
it just all sublimates.

1682

01:15:22,817 --> 01:15:25,153
- [Art] We will allow
only 80 more questions.

1683
01:15:25,153 --> 01:15:28,089
(laughing)

1684
01:15:28,089 --> 01:15:31,426
- Each spacecraft, you
design the instruments

1685
01:15:31,426 --> 01:15:34,896
according to the mission and
what you want to accomplish.

1686
01:15:34,896 --> 01:15:37,633
In Voyager or
Cassini or Galileo.

1687
01:15:39,334 --> 01:15:43,571
This one is very peculiar
and very special.

1688
01:15:43,571 --> 01:15:45,541
How are the instruments designed

1689
01:15:45,541 --> 01:15:49,878
for this particular
mission and what did JPL do

1690
01:15:49,878 --> 01:15:52,581
and the European
spacecraft, what

1691
01:15:54,015 --> 01:15:57,853
Give me some idea about
the instruments and stuff.

1692
01:15:59,421 --> 01:16:00,922
- Wanna talk about a

few instruments, Bonnie?

1693
01:16:00,922 --> 01:16:04,192
- Yeah, well, first of all,
when you begin a mission,

1694
01:16:04,192 --> 01:16:05,660
you do it for the science.

1695
01:16:05,660 --> 01:16:07,829
I mean, engineering is really
fun but you're going there

1696
01:16:07,829 --> 01:16:09,264
to answer questions.

1697
01:16:09,264 --> 01:16:12,400
So you first start
out with the questions

1698
01:16:12,400 --> 01:16:14,269
that you wanna answer, okay?

1699
01:16:14,269 --> 01:16:16,905
Well, that's called
the science objectives.

1700
01:16:16,905 --> 01:16:18,840
And then to answer
those questions,

1701
01:16:18,840 --> 01:16:20,441
you have to have
specific instruments,

1702
01:16:20,441 --> 01:16:24,912
so if you want to know the
composition of the comet,

1703

01:16:24,912 --> 01:16:26,714
that was a big question,
you have to have

1704
01:16:26,714 --> 01:16:28,316
what's known as a spectrometer,

1705
01:16:28,316 --> 01:16:30,218
something that will measure

1706
01:16:30,218 --> 01:16:34,589
how the surface reflects
light as a function

1707
01:16:34,589 --> 01:16:35,824
of color or wavelength.

1708
01:16:35,824 --> 01:16:37,558
So we had a
spectrometer on board,

1709
01:16:37,558 --> 01:16:40,562
that was a european instrument.

1710
01:16:40,562 --> 01:16:41,964
And we had of
course, the camera.

1711
01:16:41,964 --> 01:16:45,133
You basically need a
camera, just to understand,

1712
01:16:45,133 --> 01:16:46,635
you know, the
shape of the comet.

1713
01:16:46,635 --> 01:16:51,205
We had a microwave sounder,
that was a JPL instrument.

1714
01:16:51,205 --> 01:16:54,109
We had an ultraviolet
spectrometer,

1715
01:16:56,577 --> 01:16:59,347
to understand the
coma or the gases,

1716
01:16:59,347 --> 01:17:01,382
the ions around the comet.

1717
01:17:01,382 --> 01:17:03,418
That was another big objective.

1718
01:17:03,418 --> 01:17:05,987
And then we also had a
radar instrument, that was,

1719
01:17:05,987 --> 01:17:08,623
it was really a european
team, but JPL used

1720
01:17:08,623 --> 01:17:11,059
the Deep Space Network
a lot for that.

1721
01:17:11,059 --> 01:17:14,796
Where we used radio waves,
to study the interior

1722
01:17:14,796 --> 01:17:16,031
of the comet.

1723
01:17:16,031 --> 01:17:17,932
So, you go from the
science objectives

1724
01:17:17,932 --> 01:17:20,268
to the specific instruments,

1725
01:17:20,268 --> 01:17:22,937
which JPL had a few instruments.

1726
01:17:22,937 --> 01:17:26,842
- 16 instruments on
board of this spacecraft.

1727
01:17:26,842 --> 01:17:30,178
You know, normally, you see
maybe three, four or five.

1728
01:17:30,178 --> 01:17:33,382
This one had 16 on the
orbiter and 10 on the lander.

1729
01:17:33,382 --> 01:17:35,383
26 instruments.

1730
01:17:35,383 --> 01:17:38,152
So, you know, it's
very expensive.

1731
01:17:38,152 --> 01:17:40,522
We call it Flagship missions.

1732
01:17:40,522 --> 01:17:43,057
Europeans called
Cornerstone missions.

1733
01:17:43,057 --> 01:17:44,726
Very expensive,
lot of instruments,

1734
01:17:44,726 --> 01:17:48,262
lot of difficult
operations, you know.

1735
01:17:48,262 --> 01:17:50,298

We call it Battlestar Galactica.

1736
01:17:50,298 --> 01:17:52,434
(laughter)

1737
01:17:52,434 --> 01:17:55,904
- Another question
about the RTGs.

1738
01:17:55,904 --> 01:18:00,709
Besides that we don't have
enough plutonium to actually

1739
01:18:00,709 --> 01:18:05,480
but was the main reason
for going with the solar

1740
01:18:05,480 --> 01:18:06,915
rather than RTGs?

1741
01:18:08,316 --> 01:18:12,153
- Well, you know there
are a lot of reasons to go

1742
01:18:12,153 --> 01:18:14,021
if you can go
solar, you go solar.

1743
01:18:14,021 --> 01:18:17,292
If you think that you can
stabilize the spacecraft,

1744
01:18:17,292 --> 01:18:18,226
you go solar.

1745
01:18:18,226 --> 01:18:20,195
It's cheaper, it's safer.

1746
01:18:21,563 --> 01:18:25,567

You know, I worked
on nuclear generators

1747
01:18:25,567 --> 01:18:28,903
for Ulysses and
Cassini, the RTGs.

1748
01:18:28,903 --> 01:18:31,406
And it didn't effect
me at all, you know?

1749
01:18:31,406 --> 01:18:33,274
The radiation has no effect.

1750
01:18:33,274 --> 01:18:35,043
No, okay, sorry about

1751
01:18:39,580 --> 01:18:40,448
Could you please stop recording?

1752
01:18:40,448 --> 01:18:41,849
- You could really act.

1753
01:18:41,849 --> 01:18:44,452
- But, so you know, the process

1754
01:18:44,452 --> 01:18:48,290
of environmental safety
approval is very long.

1755
01:18:49,690 --> 01:18:52,260
You know, it costs hundreds
of millions of dollars,

1756
01:18:52,260 --> 01:18:56,431
so you do it for cost, you
do it for difficulty reasons,

1757
01:18:57,766 --> 01:19:00,034

installations are difficult
because you have to,

1758
01:19:00,034 --> 01:19:02,470
you know, if you have
radioactive source.

1759
01:19:02,470 --> 01:19:05,773
It's, yeah, you do
it for many reasons.

1760
01:19:05,773 --> 01:19:08,576
If you can go
solar, you go solar.

1761
01:19:08,576 --> 01:19:11,813
Thank you, and last
question, maybe?

1762
01:19:11,813 --> 01:19:13,214
The last question, yes?

1763
01:19:13,214 --> 01:19:14,448
- [Male Stagehand] And
questions from the web.

1764
01:19:14,448 --> 01:19:16,150
- [Art] Oh, okay, yeah,
maybe in the meantime,

1765
01:19:16,150 --> 01:19:18,987
you can ask your
question, please?

1766
01:19:20,121 --> 01:19:23,858
- This project started
like 20 years ago,

1767
01:19:23,858 --> 01:19:27,896
and the planning and the

making parts, then you know.

1768
01:19:27,896 --> 01:19:32,067
Travel, 10 years, so now
we have this information.

1769
01:19:34,268 --> 01:19:36,838
When you planned this
project, do you aim

1770
01:19:36,838 --> 01:19:41,009
this special comet, or you
happen to be land that comet?

1771
01:19:44,846 --> 01:19:46,414
- Yeah, you were asking
if we're planning it

1772
01:19:46,414 --> 01:19:47,949
for this comet?

1773
01:19:47,949 --> 01:19:51,820
- Yeah, how do you choose
this one and end up here?

1774
01:19:55,523 --> 01:19:58,325
- Well, we didn't
choose this one,

1775
01:19:58,325 --> 01:20:02,563
we chose another one,
but the rocket on which

1776
01:20:02,563 --> 01:20:05,466
we were supposed to,
the rocket before us,

1777
01:20:05,466 --> 01:20:08,537
we were going to go on
a second REN rocket,

1778
01:20:08,537 --> 01:20:10,972
blew up on the launch pad
and there were delays.

1779
01:20:10,972 --> 01:20:13,874
So we couldn't go to
the comet Virtanen,

1780
01:20:13,874 --> 01:20:15,977
to which originally
we wanted to go,

1781
01:20:15,977 --> 01:20:18,212
so we picked this
pixel in the sky

1782
01:20:18,212 --> 01:20:20,415
because it was in
the right orbit.

1783
01:20:20,415 --> 01:20:23,118
It wasn't going too close
to the sun to overheat

1784
01:20:23,118 --> 01:20:24,919
and break up when we land.

1785
01:20:24,919 --> 01:20:27,022
It wasn't going
too far, you know.

1786
01:20:27,022 --> 01:20:30,357
the velocity of the comet, to
the size, all of these things

1787
01:20:30,357 --> 01:20:32,827
were considered and it
was, the main thing was

1788
01:20:32,827 --> 01:20:35,396
that it was in the right
place that we could launch

1789
01:20:35,396 --> 01:20:36,831
and catch up with it.

1790
01:20:36,831 --> 01:20:41,102
So it's a lot of flight dynamics
calculations go into it.

1791
01:20:41,102 --> 01:20:44,606
Mainly because this is a
comet we could catch up with,

1792
01:20:44,606 --> 01:20:46,741
but it wasn't our
original choice.

1793
01:20:46,741 --> 01:20:48,376
And it gave us a
beautiful surprise

1794
01:20:48,376 --> 01:20:50,645
because its such
a bizarre object.

1795
01:20:50,645 --> 01:20:54,582
- So when you launched
this spacecraft

1796
01:20:54,582 --> 01:20:56,384
you aimed at this object.

1797
01:20:56,384 --> 01:20:57,318
- [Art] Absolutely, yes.

1798
01:20:57,318 --> 01:20:58,920
- Okay, thank you.

1799
01:20:58,920 --> 01:21:00,321
- We have a couple
questions from the web

1800
01:21:00,321 --> 01:21:03,124
that I'm gonna also
briefly go over.

1801
01:21:03,124 --> 01:21:05,727
Alexander asks, "Can the
weight or density of the comet

1802
01:21:05,727 --> 01:21:08,129
"be compared with any
mineral on Earth?"

1803
01:21:08,129 --> 01:21:10,031
I think pumice is the
only one I can think of

1804
01:21:10,031 --> 01:21:11,465
that would be, you know,

1805
01:21:11,465 --> 01:21:13,768
that basically would
float on water, you know,

1806
01:21:13,768 --> 01:21:15,569
It's hard, not many
things on Earth--

1807
01:21:15,569 --> 01:21:17,539
- But you have to
realize that the,

1808
01:21:17,539 --> 01:21:20,809
so this comet is about
half the density of water,

1809
01:21:20,809 --> 01:21:23,611
but it's actually,
because it's so porous.

1810
01:21:23,611 --> 01:21:27,782
But it's about 80% solids
and 20% gases, okay,

1811
01:21:29,784 --> 01:21:31,686
which are frozen.

1812
01:21:31,686 --> 01:21:36,224
And it's reason so light
is because lot of pores.

1813
01:21:36,224 --> 01:21:39,594
- And then another person
asks, "How do the gases form,

1814
01:21:39,594 --> 01:21:40,862
"inside the comet."

1815
01:21:40,862 --> 01:21:42,430
Well, they're there
in the beginning.

1816
01:21:42,430 --> 01:21:44,999
I mean this was, the comet
formed in a very cold part

1817
01:21:44,999 --> 01:21:48,670
of the, what we call
the protosolar nebula,

1818
01:21:48,670 --> 01:21:51,338
the gas and dust from
which the planets formed,

1819
01:21:51,338 --> 01:21:52,673

so it was very cold out there,

1820
01:21:52,673 --> 01:21:54,608
so they were just included in it

1821
01:21:54,608 --> 01:21:57,545
and there's the space
between the layers.

1822
01:21:57,545 --> 01:21:59,947
There're little, a lot of
little spaces and gases,

1823
01:21:59,947 --> 01:22:01,282
that, you know,
as Art mentioned,

1824
01:22:01,282 --> 01:22:04,085
do get pressurized and blow up.

1825
01:22:04,085 --> 01:22:06,321
That's what forms the jets.

1826
01:22:07,489 --> 01:22:09,991
Art, this is one you
might wanna take.

1827
01:22:09,991 --> 01:22:13,694
- "Did you take deep
space communication delay

1828
01:22:13,694 --> 01:22:17,866
"into account when deciding
where to land the spacecraft?"

1829
01:22:21,569 --> 01:22:22,904
Absolutely, yes.

1830
01:22:24,372 --> 01:22:27,441

So, of course, the delays,
there are different delays

1831
01:22:27,441 --> 01:22:29,244
and I don't wanna get
too technical here,

1832
01:22:29,244 --> 01:22:33,414
but of course there is a
delay in the flight time

1833
01:22:33,414 --> 01:22:36,451
of the signal; the signal
flies through vacuum

1834
01:22:36,451 --> 01:22:39,353
with the speed of light but
because it's so far away,

1835
01:22:39,353 --> 01:22:44,258
you know, light flies with a
speed of 300,000 kilometers

1836
01:22:44,258 --> 01:22:46,928
per second, but we are right now

1837
01:22:48,262 --> 01:22:51,766
about 750 million kilometers
away, so you know,

1838
01:22:53,301 --> 01:22:57,605
we're, so the signal takes
about 39 minutes to get to us.

1839
01:22:57,605 --> 01:23:00,375
So that's one delay
and then of course,

1840
01:23:00,375 --> 01:23:04,212
there are the delays because

the spacecraft is moving.

1841
01:23:04,212 --> 01:23:06,280
There's the relative
motion, right?

1842
01:23:06,280 --> 01:23:10,251
So, there is also for
Doppler tracking, right?

1843
01:23:10,251 --> 01:23:12,020
So there's the relative
motion of the spacecraft

1844
01:23:12,020 --> 01:23:16,257
moving away from Earth
and the antennas on Earth

1845
01:23:16,257 --> 01:23:19,661
are rotating, so there's, you
know, it's a nice exercise

1846
01:23:19,661 --> 01:23:21,262
in vector addition.

1847
01:23:24,732 --> 01:23:26,400
- We have everything.

1848
01:23:26,400 --> 01:23:27,334
I wanna thank
everybody for coming.

1849
01:23:27,334 --> 01:23:28,602
- Thank you so much for coming.

1850
01:23:28,602 --> 01:23:30,204
- Don't forget to
come to the event.

1851

01:23:30,204 --> 01:23:32,573
(applause)

1852
01:23:32,573 --> 01:23:33,408
Thank you.

1853
01:23:34,909 --> 01:23:37,846
- And if you, if
you wanna photo-op

1854
01:23:39,313 --> 01:23:41,883
with Churyumov-Gerasimenko
please come on, on stage,

1855
01:23:41,883 --> 01:23:46,887
and you can take your picture,
your selfie with a comet.

1856
01:23:46,887 --> 01:23:48,089
- [Bonnie] Yeah,
that's a good idea.