
2021
GODDARD SUMMER
FILM FESTIVAL

1
00:00:34,367 --> 00:00:35,435
Come on green light.

2
00:01:15,608 --> 00:01:19,212
We are minutes away
from the launch of NASA's Lucy mission

3
00:01:19,379 --> 00:01:22,215
to the never before explored
Trojan asteroids.

4
00:01:23,683 --> 00:01:26,686
Lucy's long journey to space begins today,

5
00:01:26,753 --> 00:01:29,355
but her story actually started years ago.

6
00:01:29,956 --> 00:01:33,193
It took a team of scientists and engineers
many years to plan

7
00:01:33,193 --> 00:01:35,595
where Lucy would go
and what she would have to do.

8
00:01:36,463 --> 00:01:39,999
Then Lucy's engineers had to build her
out of individual parts

9
00:01:40,366 --> 00:01:43,203
and put her together like a puzzle.

10
00:01:43,203 --> 00:01:47,707
Lucy had to go through tough physical
tests to prove she was mission ready.

11
00:01:48,575 --> 00:01:50,910
How are you holding up, Lucy?

12
00:01:51,945 --> 00:01:54,681
These are the vibration
and acoustic tests to make sure

13
00:01:54,681 --> 00:01:58,485
that Lucy won't lose any screws
during the shaky launch on a rocket.

14
00:01:59,018 --> 00:02:01,121
Lucy wasn't quite ready just yet.

15
00:02:01,754 --> 00:02:03,223
The engineers still had to be sure

16
00:02:03,223 --> 00:02:05,825
that she was prepared
for the harsh environment of space.

17
00:02:06,593 --> 00:02:08,962
They chilled Lucy
to freezing temperatures,

18
00:02:09,362 --> 00:02:13,700
then warmed her up to scalding hot
temperatures in the thermal vacuum test.

19
00:02:13,933 --> 00:02:17,770
Sure, those tests weren't easy,
but they prepared Lucy for the long

20
00:02:17,770 --> 00:02:18,571
adventure ahead.

21
00:02:20,773 --> 00:02:23,376
Ignition and liftoff.

22
00:02:47,567 --> 00:02:52,071
We're glad you can join Lucy on her
adventure to explore the Trojan asteroids.

23
00:02:52,605 --> 00:02:56,409
Now let's get the journey started.

24
00:02:59,979 --> 00:03:08,221
On May 8, 2021, NOAA satellites observed a von Kármán
vortex street over Guadalupe Island.

25
00:03:08,221 --> 00:03:18,364
These cloud formations often occur over the ocean when islands disrupt the flow of the wind.

26
00:03:19,165 --> 00:03:25,805
This disruption creates spiral patterns in the clouds.

27
00:03:26,472 --> 00:03:32,845
The intensity of the wind affects the pattern of swirls that are formed.

28
00:03:36,816 --> 00:03:44,924
NOAA satellites and those from international partners
observe this phenomenon all over the world.

29
00:03:54,300 --> 00:04:02,141
When von Kármán vortices form, satellites capture them in stunning detail.

30
00:04:08,915 --> 00:04:11,618
Special thank you to our partners at JMA (Himawari-8)
and EUMESAT (Meteosat-11) for additional imagery.

31
00:04:18,191 --> 00:04:22,195
Hi, I'm Noah Petro, The project scientist
for the Lunar Reconnaissance Orbiter,

32
00:04:22,595 --> 00:04:24,998
a spacecraft that has been
orbiting the Moon for over a decade,

33
00:04:25,465 --> 00:04:27,533
paving the way for humans
to return to the surface.

34
00:04:28,201 --> 00:04:30,637
As a scientist, I get excited
about the amount of data

35
00:04:30,637 --> 00:04:32,538
that we've been able
to collect on the Moon.

36
00:04:32,538 --> 00:04:33,806
We now know more about its

37
00:04:33,806 --> 00:04:37,343
geological history, its chemistry
and topography than ever before.

38
00:04:37,910 --> 00:04:39,145
But to me, the data also shows

39
00:04:39,145 --> 00:04:42,315
something beyond the science
we've investigated: its beauty.

40
00:04:42,315 --> 00:04:45,551
The visualizations you're about to see
not only hold important

41
00:04:45,551 --> 00:04:48,087
scientific value,
but artistic value as well.

42
00:04:48,688 --> 00:04:51,090
These Moonscapes
have a fascinating story to tell,

43
00:04:51,357 --> 00:04:52,659
and I hope it's one that you enjoy.

44
00:04:57,130 --> 00:05:00,867

The Moon is our nearest
neighbor, our nightlight.

45
00:05:01,534 --> 00:05:03,069
It's also our memory.

46
00:05:03,069 --> 00:05:07,273
Wind, water and molten rock erase
Earth's deep history.

47
00:05:07,707 --> 00:05:10,443
The Moon remembers everything
that has happened in the last four

48
00:05:10,443 --> 00:05:12,845
and a half billion years.

49
00:05:14,881 --> 00:05:18,918
The impact that formed the Orientale
Basin provides a window to understanding

50
00:05:18,918 --> 00:05:23,323
how similar large events on other planets
and moons have shaped their landscapes.

51
00:05:30,897 --> 00:05:34,300
The discovery of water
on the sunlit surface of Clavius Crater

52
00:05:34,600 --> 00:05:38,104
not only unlocks new possibilities
for future lunar exploration,

53
00:05:38,805 --> 00:05:42,175
but also our understanding of where
the ingredients of life could exist

54
00:05:42,542 --> 00:05:44,677
in our vast universe.

55
00:05:59,559 --> 00:06:03,629
The steep trenches and cracked surface
of Komarov Crater on the far side

56
00:06:04,197 --> 00:06:07,834
tell a story of the ancient volcanic
activity from the Moon's interior,

57
00:06:08,668 --> 00:06:12,705
revealing the history of geologic forces
carving the lunar terrain through time.

58
00:06:26,352 --> 00:06:27,787
Traversing the landscape,

59
00:06:27,787 --> 00:06:31,924
we can see a beautiful tapestry
of ridges, valleys and mountains.

60
00:06:32,425 --> 00:06:35,428
Best encapsulated
by the view of Tycho Crater.

61
00:06:37,663 --> 00:06:41,501
The summit of its central peak extends
nearly three miles above the crater floor.

62
00:06:42,034 --> 00:06:45,438
A visual metaphor for the steep
challenges, but exciting rewards

63
00:06:45,671 --> 00:06:49,642
await us on the Moon and beyond.

64
00:06:53,312 --> 00:06:54,680
And on the lunar horizon,

65
00:06:54,680 --> 00:06:57,750
the most consequential view of all.

66
00:06:58,418 --> 00:07:00,920
Home. To study the Moon is to study

67
00:07:00,920 --> 00:07:04,557
ourselves, our past,
our present and our future.

68
00:07:05,224 --> 00:07:08,394
Each new discovery
bringing us from darkness into light.

69
00:07:11,531 --> 00:07:15,468
The gravitational forces between Earth
and Moon make our very existence possible,

70
00:07:16,302 --> 00:07:20,039
creating one of the most special
relationships throughout time and space.

71
00:07:27,513 --> 00:07:30,917
There are a few ways to think
about the edge of the solar system.

72
00:07:31,484 --> 00:07:34,086
One is with the extent of the solar wind.

73
00:07:35,354 --> 00:07:37,890
This is the constant
flow of charged particles

74
00:07:37,890 --> 00:07:42,361
gushing out of the sun at a million miles
per hour and bathing the planets.

75
00:07:42,762 --> 00:07:45,531
The wind forms a giant
protective bubble around

76

00:07:45,531 --> 00:07:48,134
our solar system known as the heliosphere.

77
00:07:48,835 --> 00:07:52,405
This huge region says through the Milky
Way, shielding us

78
00:07:52,405 --> 00:07:55,875
from interstellar radiation
and creating an environment

79
00:07:55,875 --> 00:07:58,377
that helps life on Earth to flourish.

80
00:07:58,978 --> 00:08:00,813
But its borders aren't fixed.

81
00:08:00,813 --> 00:08:04,650
Around 11 billion miles from Earth, far
past the planet's

82
00:08:04,884 --> 00:08:07,353
solar wind pushes
against interstellar space.

83
00:08:07,987 --> 00:08:11,457
Scientists have been monitoring
this boundary over the past decade,

84
00:08:11,824 --> 00:08:14,827
and they're seeing it change
with the Sun's activity

85
00:08:16,996 --> 00:08:18,664
roughly every 11 years.

86
00:08:18,664 --> 00:08:20,833
The Sun's magnetic field ramps up.

87

00:08:21,434 --> 00:08:23,569
This is known as the solar cycle.

88
00:08:23,603 --> 00:08:29,242
And at the peak, the Sun's magnetic poles
flip north, become south and vice versa.

89
00:08:29,976 --> 00:08:34,914
This cycle causes the sun's activity
to sway from calm to turbulent,

90
00:08:34,914 --> 00:08:39,452
with an abundance of flares and eruptions,
which in turn affects the solar wind.

91
00:08:40,219 --> 00:08:43,523
Changes from the Sun
can make the solar wind gust hard.

92
00:08:43,823 --> 00:08:47,126
When it does, the heliosphere
expands like a balloon.

93
00:08:47,760 --> 00:08:51,831
Over the past solar cycle,
scientists mapped what that looked like.

94
00:08:53,366 --> 00:08:54,400
To understand these

95
00:08:54,400 --> 00:08:57,904
maps, you need to know how we observe
the edge of the solar system.

96
00:08:58,437 --> 00:09:02,842
Scientists use NASA's
Interstellar Boundary Explorer, or IBEX.

97
00:09:03,075 --> 00:09:06,546
About the size of a bus tire

and in the orbit around Earth,

98
00:09:06,746 --> 00:09:10,783
IBEX maps the heliosphere with a process
similar to sonar.

99
00:09:11,050 --> 00:09:14,153
But instead of using sound
to detect objects,

100
00:09:14,320 --> 00:09:17,356
it uses the echo of solar wind variations.

101
00:09:17,890 --> 00:09:20,393
For example, starting in 2014,

102
00:09:20,393 --> 00:09:23,996
there was a huge and prolonged increase
in solar wind pressure.

103
00:09:24,497 --> 00:09:27,600
NASA's spacecraft
near Earth detected solar wind

104
00:09:27,600 --> 00:09:30,903
gusting 50 percent harder
than previous years.

105
00:09:31,370 --> 00:09:35,841
After traveling outward for a year, solar,
wind hit the edge of the heliosphere.

106
00:09:36,375 --> 00:09:39,278
First, the termination shock,
and then it entered the heliosheath

107
00:09:39,912 --> 00:09:42,014
that's encased by the heliopause.

108

00:09:42,615 --> 00:09:45,618
Solar wind particle
spent another year or so in this region.

109
00:09:45,985 --> 00:09:49,221
Some collided with interstellar gases
in the heliosheath

110
00:09:49,355 --> 00:09:53,025
and turned into energetic,
neutral atoms or ENA's.

111
00:09:53,025 --> 00:09:55,728
ENA's travel in all directions.

112
00:09:56,162 --> 00:09:58,164
Some even back toward Earth.

113
00:09:58,164 --> 00:10:03,703
And between 2017 and 2019,
a few of the returning ENA's reached IBEX,

114
00:10:04,036 --> 00:10:07,206
an echo of where the boundary
is and what it looks like.

115
00:10:10,242 --> 00:10:11,811
If you cut the heliosphere

116
00:10:11,811 --> 00:10:15,948
and laid it out onto a flat surface,
this is what you would see.

117
00:10:16,282 --> 00:10:18,985
This is the nose, and this is the tail.

118
00:10:19,185 --> 00:10:22,955
The nose shows high
ENA fluxes, which indicate

119
00:10:22,955 --> 00:10:26,325
a strong gust of wind
and the heliosphere ballooning.

120
00:10:26,993 --> 00:10:29,495
From tracking this expansion,
scientists found that

121
00:10:29,495 --> 00:10:32,131
the nose and tail were not symmetrical.

122
00:10:32,865 --> 00:10:37,570
If we compare the maps, ENA's from that
big 2014 solar wind increase

123
00:10:38,004 --> 00:10:42,108
have returned from the nose, but
they haven't returned from the tail yet,

124
00:10:42,742 --> 00:10:46,545
suggesting that the tail is much farther
away from the sun than the nose.

125
00:10:47,046 --> 00:10:50,449
This indicates that the heliosphere
looks more like a comet

126
00:10:50,583 --> 00:10:53,319
rather than a round bubble.

127
00:10:53,319 --> 00:10:57,957
Having a full solar cycle of observations
of the heliosphere opens doors

128
00:10:57,957 --> 00:11:02,328
to understanding the only environment
we so far know can support life.

129
00:11:02,662 --> 00:11:04,730

And there have been a few surprises.

130
00:11:04,730 --> 00:11:08,300
Beyond the heliosphere near the nose,
there was one region

131
00:11:08,300 --> 00:11:12,705
that took two years longer to respond
to the 2014 increase of solar wind.

132
00:11:13,239 --> 00:11:16,742
Scientists think these ENA's bounced
out of the heliopause

133
00:11:16,742 --> 00:11:20,146
and into interstellar space
before heading back toward Earth.

134
00:11:21,013 --> 00:11:24,917
These are signs that we're still learning
about the quirks of our heliosphere.

135
00:11:25,351 --> 00:11:28,754
But one thing's for sure,
these characteristics could tell us

136
00:11:28,754 --> 00:11:33,359
about the key ingredients
for life around a star.

137
00:11:38,998 --> 00:11:42,968
[Music throughout]

138
00:11:42,968 --> 00:11:48,974
In 2003, the Hubble Space Telescope pointed at a dark, empty patch of sky.

139
00:11:49,809 --> 00:11:56,982
It watched this spot for 270 hours, patiently collecting light…

140

00:12:02,988 --> 00:12:08,994
and found the most distant galaxies known.

141
00:12:14,967 --> 00:12:25,277
10,000 galaxies in one tiny patch of sky.

142
00:12:26,078 --> 00:12:31,350
Forever changing our understanding of how truly vast the universe is,

143
00:12:34,320 --> 00:12:39,992
and how many galaxies are out there.

144
00:12:41,727 --> 00:12:49,001
The Nancy Grace Roman Space Telescope could do the same thing…

145
00:12:49,001 --> 00:12:55,841
on a much larger scale.

146
00:12:58,010 --> 00:13:03,082
There is no telling what we might learn.

147
00:14:12,384 --> 00:14:14,386
It's really an amazing little critter,

148
00:14:14,386 --> 00:14:17,790
and it's been around for over
three billion years.

149
00:14:17,790 --> 00:14:22,494
In 2016 Utah Lake
exploded and cyanobacteria blooms.

150
00:14:23,128 --> 00:14:27,533
The problem is that
many cyanobacteria produce toxins.

151
00:14:28,234 --> 00:14:32,004
You may have heard it called blue green
algae, but it's really a kind of bacteria,

152
00:14:32,238 --> 00:14:35,975
taking in sunlight to drive photosynthesis
and giving off oxygen.

153
00:14:36,642 --> 00:14:39,511
It actually requires quite a bit of lab

154
00:14:39,511 --> 00:14:42,381
testing to know whether or not it's
a harmful algal bloom.

155
00:14:43,148 --> 00:14:46,819
And what we're really worried about
is people and pets

156
00:14:47,119 --> 00:14:49,855
ingesting that cyanobacteria.

157
00:14:49,855 --> 00:14:54,226
Dr. Kate Fickas is a harmful algal
bloom scientist at Utah State University.

158
00:14:54,627 --> 00:14:56,028
She hopes the Utah Department

159
00:14:56,028 --> 00:14:59,231
of Environmental Quality tracked
conditions in lakes and reservoirs.

160
00:15:00,065 --> 00:15:02,935
So Utah is the second dry
state of the nation.

161
00:15:02,968 --> 00:15:06,372
Most of our major
lakes are actually manmade reservoirs.

162
00:15:06,372 --> 00:15:08,707

They're heavily used for recreation.

163
00:15:08,707 --> 00:15:11,210
They're heavily used for agriculture,

164
00:15:11,210 --> 00:15:13,879
and they're really important
to the state as a resource.

165
00:15:14,880 --> 00:15:18,517
In 2017, harmful
algal blooms returned to Utah Lake.

166
00:15:18,884 --> 00:15:22,721
This time, officials use satellite data
to identify troubled locations.

167
00:15:23,322 --> 00:15:26,992
But how can instruments up in space
tell us about microscopic organisms

168
00:15:26,992 --> 00:15:28,794
in a lake down on Earth?

169
00:15:28,794 --> 00:15:30,829
By measuring their blue green color.

170
00:15:31,397 --> 00:15:34,400
Landsat collects light invisible
and infrared wavelengths.

171
00:15:34,767 --> 00:15:38,170
Cyanobacteria reflect
more green light than plain water does,

172
00:15:38,404 --> 00:15:40,839
allowing Landsat to identify algal blooms.

173
00:15:41,573 --> 00:15:46,445

From satellite what we see
is basically that primary pigments,

174
00:15:46,445 --> 00:15:51,083
which is chlorophyl a, but the color
by itself could be misleading.

175
00:15:51,383 --> 00:15:57,122
A nice picture is not necessarily
providing a sort of quantitative data.

176
00:15:57,823 --> 00:15:59,925
Algal blooms can look
beautiful from space,

177
00:15:59,925 --> 00:16:03,028
but the numbers behind
the images are the important part.

178
00:16:03,762 --> 00:16:06,265
Each measurements is highly accurate.

179
00:16:06,265 --> 00:16:10,235
And it's very it's very much corresponding
to the number of photons

180
00:16:10,235 --> 00:16:12,137
that are leaving the body of water,

181
00:16:12,137 --> 00:16:16,175
which could be related to the biomass
and the amount of phytoplankton.

182
00:16:16,909 --> 00:16:19,611
Dr Nima Pahlevan
is working with NASA and the U.S.

183
00:16:19,611 --> 00:16:23,549
Geological Survey to make sure
Landsat users have consistent, accurate

184
00:16:23,549 --> 00:16:26,051
and ready to use data
about lakes and rivers.

185
00:16:26,919 --> 00:16:29,121
Water is difficult to study from space

186
00:16:29,121 --> 00:16:32,358
because only a fraction of the sunlight
is reflected back to the satellite.

187
00:16:32,725 --> 00:16:36,295
But engineering improvements on Landsat
8 have leveled up its ability

188
00:16:36,295 --> 00:16:39,665
to measure the small signals
from water bodies.

189
00:16:39,665 --> 00:16:42,668
After Landsat collects
the data, it gets beamed

190
00:16:42,668 --> 00:16:46,305
down to the USGS EROS Center,
where it is archived.

191
00:16:46,538 --> 00:16:51,076
The raw numbers pass through checkpoints
to align the geography correct

192
00:16:51,076 --> 00:16:55,180
for sun strength and then compensate
for the effects of the atmosphere.

193
00:16:55,547 --> 00:17:01,387
So you're essentially removing those
atmospheric scattering, that absorption.

194
00:17:01,920 --> 00:17:04,256
Let's break down what Nima means here.

195
00:17:04,256 --> 00:17:07,659
To measure the amount of cyanobacteria,
you need to know how much light reflected

196
00:17:07,659 --> 00:17:08,727
off the surface.

197
00:17:08,727 --> 00:17:11,764
But some of that light gets
scattered by molecules in the atmosphere

198
00:17:11,897 --> 00:17:15,234
on the way to the satellite,
lessening the signal received.

199
00:17:15,534 --> 00:17:17,236
And sometimes light that never made it to

200
00:17:17,236 --> 00:17:20,806
the surface gets scattered
into the satellite, adding a false signal.

201
00:17:21,173 --> 00:17:24,710
Like removing the haze from a photograph,
atmospheric corrections

202
00:17:24,710 --> 00:17:28,313
leave you with a quantitative measurement
of exactly how much light left

203
00:17:28,313 --> 00:17:30,949
the water, known as aquatic reflectance.

204
00:17:31,316 --> 00:17:37,122
You want to look at the actual
physical measurements to derive

205
00:17:37,289 --> 00:17:41,226
physically meaningful products
from satellite data.

206
00:17:41,460 --> 00:17:45,564
And that's the goal, to transform
the raw materials into finished products.

207
00:17:45,864 --> 00:17:48,567
So that end users
don't have to build it themselves

208
00:17:49,001 --> 00:17:52,271
by aquatic reflectance products, you're

209
00:17:53,605 --> 00:17:55,674
reducing majorly reducing the

210
00:17:55,674 --> 00:17:58,944
burden on satellite users.

211
00:17:59,845 --> 00:18:02,781
Although it is still provisional,
Nima's Aquatic Reflectance

212
00:18:02,781 --> 00:18:05,784
Data product is available
for download from the USGS.

213
00:18:06,552 --> 00:18:09,822
Scientists like Kate Fickas
convert the data product to maps,

214
00:18:09,822 --> 00:18:13,392
showing the amount of chlorophyl
A, helping local officials

215
00:18:13,392 --> 00:18:16,562

pinpoint where to test for toxins
and warn residents.

216
00:18:16,895 --> 00:18:19,631
I use Landsat and other remote
sensing technology

217
00:18:19,631 --> 00:18:23,168
to help local health departments
understand where there's a bloom,

218
00:18:23,435 --> 00:18:26,672
the magnitude of the bloom
and the size of the bloom.

219
00:18:27,306 --> 00:18:30,776
The spatial detail is another benefit
of using Landsat data.

220
00:18:31,443 --> 00:18:35,180
Each pixel is only a 30 meter square
the size of a baseball diamond,

221
00:18:35,714 --> 00:18:38,050
yet it collects data across a broad area.

222
00:18:39,017 --> 00:18:42,421
In other words, there is a lot of data
at a fairly high resolution.

223
00:18:42,421 --> 00:18:44,590
With Landsat we can get into some of the

224
00:18:44,590 --> 00:18:48,327
marinas that are popular fishing
and swimming spots in order to inform

225
00:18:48,327 --> 00:18:52,064
local health departments
about making public health decisions.

226
00:18:52,731 --> 00:18:55,734
For the 2017 outbreak,
that's exactly what happened.

227
00:18:56,268 --> 00:18:59,638
Satellite data gave an early warning
to local officials in Utah.

228
00:18:59,938 --> 00:19:02,641
The extra week of warning
saved hundreds of thousands of

229
00:19:02,641 --> 00:19:04,209
dollars in healthcare costs.

230
00:19:05,944 --> 00:19:08,380
Monitoring algal
blooms from aquatic reflectance

231
00:19:08,380 --> 00:19:11,950
data is just one example of benefits
from Landsat's data products.

232
00:19:12,718 --> 00:19:17,089
Wildfires, snow cover,
vegetation, health temperature

233
00:19:17,422 --> 00:19:20,359
and more are available
for every spot on Earth.

234
00:19:23,996 --> 00:19:26,331
Landsat's highly calibrated data products

235
00:19:26,565 --> 00:19:30,769
free to download and use
are making detailed Earth observation data

236

00:19:30,769 --> 00:19:34,673
more accessible to users
and bringing a greater benefit to society.

237
00:19:40,512 --> 00:19:45,284
There is evidence that a planet
around a distant star lost its atmosphere,

238
00:19:45,284 --> 00:19:48,353
then gained a second one
through volcanic activity,

239
00:19:48,353 --> 00:19:51,723
according to scientists using NASA's
Hubble Space Telescope.

240
00:19:52,191 --> 00:19:56,195
The planet GJ 1132b is hypothesized

241
00:19:56,195 --> 00:19:59,431
to have begun as a gaseous world
with the rocky core.

242
00:19:59,798 --> 00:20:02,601
Starting out at several times
the diameter of Earth,

243
00:20:02,768 --> 00:20:08,507
this so-called sub Neptune quickly lost
its early hydrogen and helium atmosphere

244
00:20:08,707 --> 00:20:12,711
due to the intense radiation
of the young hot star it orbits.

245
00:20:13,045 --> 00:20:17,382
Then the planet was stripped down
to a bare core about the size of Earth.

246
00:20:17,549 --> 00:20:19,718

And that's when things got interesting.

247
00:20:21,019 --> 00:20:21,954
To the surprise of

248
00:20:21,954 --> 00:20:26,091
astronomers, Hubble observed an atmosphere
which, according to their theory,

249
00:20:26,325 --> 00:20:29,228
is a secondary atmosphere
that is present now.

250
00:20:30,162 --> 00:20:33,365
Based on a combination of direct
observational evidence

251
00:20:33,498 --> 00:20:36,768
and inference through computer modeling,
the team reports

252
00:20:36,768 --> 00:20:39,638
that the atmosphere
consists of molecular hydrogen, hydrogen

253
00:20:40,472 --> 00:20:44,676
cyanide and methane,
and also contains an aerosol haze.

254
00:20:45,310 --> 00:20:49,114
Scientists think hydrogen
from the original atmosphere was absorbed

255
00:20:49,114 --> 00:20:52,951
into the planet's molten magma mantle,
then slowly released

256
00:20:52,951 --> 00:20:56,021
through volcanic processes
to form a new atmosphere.

257
00:20:56,655 --> 00:20:58,290
Though this hydrogen continues

258
00:20:58,290 --> 00:21:02,527
to escape into space,
the secondary atmosphere is replenished

259
00:21:02,661 --> 00:21:06,798
by volcanic gases that seep through cracks
in the planet's thin crust.

260
00:21:07,499 --> 00:21:10,569
Scientists are wondering
how many other planets might

261
00:21:10,569 --> 00:21:14,673
have started out as gas giants,
but became smaller and rocky

262
00:21:14,773 --> 00:21:17,476
after their early atmospheres
evaporated away.

263
00:21:17,943 --> 00:21:21,713
Astronomers hope to use the upcoming
James Webb Space Telescope

264
00:21:21,813 --> 00:21:26,218
infrared vision to detect hot
areas of volcanic activity on the planet.

265
00:21:27,619 --> 00:21:32,791
GJ 1132b be might be orbiting
a distant star, 41 light years away,

266
00:21:32,791 --> 00:21:39,097
but thanks to the Hubble Space Telescope,
it just got a little bit closer.

267
00:21:51,410 --> 00:21:53,612
Carbon dioxide is a kind of plant food.

268
00:21:54,813 --> 00:21:57,316
Plants break down carbon dioxide
as they make energy

269
00:21:57,316 --> 00:22:00,485
through photosynthesis,
releasing oxygen in the process.

270
00:22:01,953 --> 00:22:04,623
That's why as humans have increased
the amount of carbon dioxide

271
00:22:04,623 --> 00:22:07,626
in the atmosphere, some places have seen
increased plant growth.

272
00:22:08,660 --> 00:22:11,463
But that won't continue forever.

273
00:22:12,831 --> 00:22:16,568
Carbon dioxide is a greenhouse
gas, responsible for warming our planet.

274
00:22:17,969 --> 00:22:20,038
Right now, the land and the ocean absorb

275
00:22:20,038 --> 00:22:23,008
about 55 percent of the carbon
dioxide released by humans.

276
00:22:23,442 --> 00:22:27,279
The rest stays in the atmosphere,
acting like a blanket around Earth.

277
00:22:27,279 --> 00:22:31,983
As the climate gets warmer,

plants are absorbing less carbon dioxide.

278
00:22:33,218 --> 00:22:36,922
In some places like the Arctic region,
water is becoming scarcer,

279
00:22:36,955 --> 00:22:39,691
acting as a limiting factor
that inhibits plant growth.

280
00:22:40,926 --> 00:22:43,195
In other places like
the tropical latitudes,

281
00:22:43,528 --> 00:22:44,930
low soil nutrients limit

282
00:22:44,930 --> 00:22:47,833
the growth of plants even when there's
plenty of carbon dioxide.

283
00:22:49,634 --> 00:22:51,336
But it's not just external factors

284
00:22:51,336 --> 00:22:53,672
that could affect
how plants absorb carbon dioxide.

285
00:22:55,407 --> 00:22:59,578
As the concentration in the atmosphere
increases, plants seem to use less of it.

286
00:23:00,412 --> 00:23:03,882
From 1982 to 2015,
we've already seen a decrease

287
00:23:03,882 --> 00:23:06,551
in how efficient plants
are at absorbing carbon dioxide.

288
00:23:07,786 --> 00:23:11,123
NASA researchers are using data
from a variety of different satellites

289
00:23:11,123 --> 00:23:14,292
to calculate how efficient plants
are at absorbing carbon dioxide.

290
00:23:15,994 --> 00:23:18,663
They're working to understand
how more carbon emissions will warm

291
00:23:18,663 --> 00:23:23,068
the planet as plants use less of it,
important for understanding

292
00:23:23,068 --> 00:23:24,336
how hot Earth will get.

293
00:23:31,076 --> 00:23:31,777
There's a rhythm

294
00:23:31,777 --> 00:23:34,880
emanating from the Sun
to the edges of the solar system.

295
00:23:35,547 --> 00:23:38,850
Roughly every 11 years,
our star ramps up to a turbulent

296
00:23:38,850 --> 00:23:42,254
state, expelling
violent eruptions after a peak.

297
00:23:42,354 --> 00:23:46,024
It calms down to a quiet phase
before starting all over again.

298
00:23:46,591 --> 00:23:48,960

This is known as the solar cycle.

299
00:23:48,960 --> 00:23:53,098
This ebb and flow of solar activity
affects the entire solar system,

300
00:23:53,665 --> 00:23:56,435
including spacecraft
electronics and astronauts

301
00:23:56,535 --> 00:24:00,605
that can be affected by particle radiation
if they're not sufficiently protected.

302
00:24:01,506 --> 00:24:04,709
Understanding the solar cycle
is one of the oldest problems

303
00:24:04,709 --> 00:24:08,713
in solar physics, and now predicting
it is more critical than ever

304
00:24:08,747 --> 00:24:11,450
as we venture to the Moon,
Mars and beyond.

305
00:24:11,750 --> 00:24:14,085
So here are ways
we've learned about tracking it.

306
00:24:17,856 --> 00:24:20,125
So welcome to the dome.

307
00:24:20,125 --> 00:24:23,929
Today we're gonna observe the Sun
and see if there are some sunspots.

308
00:24:24,796 --> 00:24:26,698
Every morning when the skies are clear

309
00:24:26,698 --> 00:24:30,101
Olivier looks through this telescope
in search of sunspots.

310
00:24:30,368 --> 00:24:34,773
These are dark blotches on the Sun that
are the main source of solar eruptions.

311
00:24:34,906 --> 00:24:37,175
They appear and disappear
on the Sun's surface.

312
00:24:37,843 --> 00:24:39,511
So we're not looking at the Sun.

313
00:24:39,511 --> 00:24:43,615
In fact, we're looking at
the shadow of the instrument.

314
00:24:44,683 --> 00:24:48,186
Then we put the paper
always the same place.

315
00:24:49,154 --> 00:24:52,023
And then we can start drawing.

316
00:24:52,324 --> 00:24:56,962
Olivier and a team of Sun observers
record the pattern of sunspots by pencil.

317
00:24:57,496 --> 00:24:58,463
The first known record

318
00:24:58,463 --> 00:25:01,933
of sunspots date back
to around a thousand years ago in China.

319
00:25:02,267 --> 00:25:05,937
After the invention of the telescope

in the 17th century, routine

320
00:25:05,937 --> 00:25:07,572
observations were made.

321
00:25:07,572 --> 00:25:10,842
Today sunspot drawers
still use the same technique.

322
00:25:11,376 --> 00:25:14,613
While we've created satellites
that can see the Sun in much more detail

323
00:25:14,613 --> 00:25:19,684
in recent decades, drawing by hand keeps
the centuries long record consistent.

324
00:25:20,385 --> 00:25:24,022
The sunspot number record goes back
farther than any other instrument,

325
00:25:24,155 --> 00:25:28,493
allowing scientists to analyze the Sun's
behavior over many, many solar cycles.

326
00:25:28,960 --> 00:25:30,395
.Sunspot numbers are collected

327
00:25:30,395 --> 00:25:33,398
from observatories around the world
and are averaged.

328
00:25:33,765 --> 00:25:37,235
During every 11 year cycle,
the number of sunspots rise

329
00:25:37,235 --> 00:25:40,472
from zero to a peak
and then go back down to zero again.

330
00:25:40,839 --> 00:25:44,776
Scientists use these numbers to determine
when a new solar cycle begins

331
00:25:45,043 --> 00:25:47,078
and how active a cycle is.

332
00:25:47,379 --> 00:25:51,149
Solar maximum, the period of highest
activity, can vary

333
00:25:51,149 --> 00:25:53,785
wildly from cycle to cycle.

334
00:25:53,785 --> 00:25:58,056
The more sunspots there are, the higher
the frequency of solar storms of all

335
00:25:58,056 --> 00:26:03,161
types. Some that create aurora and some
that can affect power grids on Earth.

336
00:26:03,595 --> 00:26:06,698
But sunspot number isn't
the only indicator we see.

337
00:26:06,698 --> 00:26:09,367
These numbers are often combined
with other signs.

338
00:26:10,302 --> 00:26:13,505
At the beginning of each cycle,
sunspots appear on the Sun

339
00:26:13,505 --> 00:26:16,374
in the mid latitudes
for a brief few hours to days.

340
00:26:16,775 --> 00:26:19,945

At solar minimum, there are often days
without any spots at all.

341
00:26:20,245 --> 00:26:23,248
As the Sun becomes
more active, sunspots form

342
00:26:23,248 --> 00:26:27,052
closer to the equator
and can stick around for weeks to months.

343
00:26:27,319 --> 00:26:31,156
These sunspot patterns give clues to
what drives the solar cycle.

344
00:26:31,289 --> 00:26:33,725
The twisting of the Sun's magnetic field.

345
00:26:34,125 --> 00:26:38,263
Like Earth, the Sun has a magnetic field
with a north and south pole,

346
00:26:38,496 --> 00:26:42,934
but unlike Earth, the sun's magnetic field
becomes extremely complex.

347
00:26:43,034 --> 00:26:46,371
This is because the Sun is made
of plasma, a charged gas

348
00:26:46,371 --> 00:26:49,574
that generates electric currents
as the Sun rotates.

349
00:26:49,708 --> 00:26:53,011
Plasma around the equator moves
faster than near the poles,

350
00:26:53,445 --> 00:26:57,682
causing the magnetic fields to become

stretched, elongated and then twisted.

351
00:26:58,083 --> 00:27:01,553
Then kinks in the magnetic fields
burst through the surface

352
00:27:01,553 --> 00:27:04,089
as sunspots larger than the size of Earth.

353
00:27:04,556 --> 00:27:07,325
As the solar cycle unfolds, more sunspots

354
00:27:07,325 --> 00:27:10,328
appear and the magnetic field
becomes more tangled.

355
00:27:10,428 --> 00:27:14,265
At the peak of the solar cycle,
the Sun's magnetic field flips

356
00:27:14,733 --> 00:27:17,636
the North Pole, switches
to the south and vice versa.

357
00:27:18,136 --> 00:27:20,939
The cycle then ramps down, ready
to start a new cycle.

358
00:27:21,139 --> 00:27:24,909
Scientists can eventually see the result
of this flip inside

359
00:27:24,909 --> 00:27:26,578
sunspots using satellites.

360
00:27:29,414 --> 00:27:30,281
This black and white

361
00:27:30,281 --> 00:27:33,618

image of the Sun shows
the magnetic field on the surface.

362
00:27:34,119 --> 00:27:36,254
Most sunspots appear in pairs.

363
00:27:36,454 --> 00:27:39,624
Like a magnet, one side is positive
and the other is negative.

364
00:27:39,924 --> 00:27:43,428
After they form,
they gradually disappear again, leaving

365
00:27:43,428 --> 00:27:47,666
behind remnants of magnetic fields
that move towards the Sun's poles.

366
00:27:47,966 --> 00:27:51,569
Eventually, each pole accumulates enough
magnetic fields,

367
00:27:51,569 --> 00:27:54,806
forcing the Sun's poles
to flip at the peak of the cycle.

368
00:27:55,774 --> 00:28:00,545
Then new sunspot groups appear with
the polarities in the opposite direction.

369
00:28:01,079 --> 00:28:04,549
Scientists look for a consistent string
of these new sunspots

370
00:28:04,549 --> 00:28:06,785
in order to declare the next solar cycle.

371
00:28:07,385 --> 00:28:10,488
But the transition between cycles
is slow and messy.

372
00:28:10,889 --> 00:28:14,225
Cycles often overlap,
creating fractals of old

373
00:28:14,225 --> 00:28:16,828
and new sunspots on the Sun
at the same time.

374
00:28:17,295 --> 00:28:20,165
Scientists can only determine
we're in the new cycle

375
00:28:20,165 --> 00:28:23,068
when the number of new sunspots
overtake old ones,

376
00:28:23,334 --> 00:28:26,871
which can be six months to year
after the new cycle has begun.

377
00:28:27,372 --> 00:28:30,842
While these spots give us a visible
tracker, in recent years,

378
00:28:30,842 --> 00:28:34,412
scientists have discovered another signal
that's hard to see from Earth.

379
00:28:35,447 --> 00:28:39,551
The strength of the Sun's poles
during solar minimum can help predict

380
00:28:39,551 --> 00:28:45,090
how active the next cycle will be after
the poles have reversed at the peak.

381
00:28:45,223 --> 00:28:48,093
Scientists keep a close eye on it
for the next few years.

382
00:28:48,626 --> 00:28:52,564
If the magnetic fields accumulated
at the poles become strong during this

383
00:28:52,564 --> 00:28:56,334
time, it's likely the next solar cycle
will be an active one.

384
00:28:56,568 --> 00:29:00,138
If the build up is weak,
the next solar cycle won't be as active.

385
00:29:01,573 --> 00:29:06,311
While we use these indicators to track
the Sun, predictions are still hard.

386
00:29:07,078 --> 00:29:09,347
After all, we've only had detailed

387
00:29:09,347 --> 00:29:12,584
satellite observations
of the last four solar cycles.

388
00:29:12,751 --> 00:29:16,488
And scientists are still learning
about what causes the Sun's cycle.

389
00:29:16,788 --> 00:29:20,692
So until we piece together
those missing pieces, the Sun,

390
00:29:20,692 --> 00:29:25,163
even with its 11 year
clock, will continue to surprise us.

391
00:29:33,872 --> 00:29:35,507
Five years ago, a

392

00:29:35,507 --> 00:29:40,111
NASA-funded science team
ventured onto an ever-changing region

393
00:29:40,111 --> 00:29:43,815
of the Greenland ice sheet
in the peak of summer melt season,

394
00:29:44,349 --> 00:29:47,619
when the ice was literally melting out
from under their feet.

395
00:29:50,355 --> 00:29:51,389
What they learned

396
00:29:51,389 --> 00:29:54,692
is changing the way
we think about the movement of ice sheets

397
00:29:55,126 --> 00:29:59,631
and possibly changing our computer models
that predict how fast ice

398
00:29:59,631 --> 00:30:04,169
will melt, a question which matters
to every coastline on the planet.

399
00:30:06,004 --> 00:30:08,206
The number one reason we are here

400
00:30:08,840 --> 00:30:11,843
is all about global sea level rise.

401
00:30:12,677 --> 00:30:17,148
Greenland is the single largest melting
chunk of ice in the world.

402
00:30:17,715 --> 00:30:19,918
What really matters to the world
is how much of that water

403
00:30:19,918 --> 00:30:22,086
melted in the ice sheet,
gets out to the ocean.

404
00:30:23,154 --> 00:30:27,358
In order to collect this data,
the team had to first transport

405
00:30:27,358 --> 00:30:32,463
scientific equipment and survival
gear to Greenland and then travel via

406
00:30:32,463 --> 00:30:38,303
helicopter to set up camp in the ablation
zone, a region of melting ice.

407
00:30:39,237 --> 00:30:41,573
Camping out here
logistically is very difficult.

408
00:30:41,806 --> 00:30:45,109
We're camping the ablation
zone. It's very wet, as you can see.

409
00:30:45,109 --> 00:30:48,780
The ablation zone is where it is
melting over the summer.

410
00:30:48,980 --> 00:30:50,448
Even talking to the logistics

411
00:30:50,448 --> 00:30:52,383
coordinators, they're
very interested in our camp

412
00:30:52,383 --> 00:30:56,187
because they're trying to learn things about how do you camp in the ablation zone.

413

00:30:57,222 --> 00:30:59,457
One lesson is to be quick and nimble.

414
00:30:59,824 --> 00:31:02,627
The team had to evacuate
from the first spot they scouted

415
00:31:03,127 --> 00:31:06,164
because the surface started
melting right under their camp.

416
00:31:07,165 --> 00:31:11,202
So what big science questions are
at the heart of this bold undertaking?

417
00:31:12,170 --> 00:31:17,375
In 2015, when we started this study,
there was surprisingly little attention

418
00:31:17,375 --> 00:31:20,912
paid to this hydrology
of streams and rivers

419
00:31:21,246 --> 00:31:24,782
on the ice sheet,
especially inland, away from the ice edge.

420
00:31:25,316 --> 00:31:29,888
And we felt that
this was a critical scientific gap.

421
00:31:30,321 --> 00:31:34,893
Just from looking at satellite images
of the ice sheet, it was very apparent

422
00:31:34,893 --> 00:31:38,663
that very large volumes of meltwater
were moving through these systems.

423
00:31:39,063 --> 00:31:44,168

And one of the things we learned
is that the total volume of water

424
00:31:44,235 --> 00:31:46,337
passing through these river systems

425
00:31:46,337 --> 00:31:50,475
far exceeds the volume of water
contained by lakes.

426
00:31:51,042 --> 00:31:54,345
Much like the terrestrial land
surface, lakes catch your eye because

427
00:31:54,345 --> 00:31:57,315
they're so big, but the real action,
the real fluxes be the rivers.

428
00:31:59,384 --> 00:32:01,920
All of these rivers

429
00:32:01,920 --> 00:32:07,525
terminate in a stunning and dangerous
feature called a moulin,

430
00:32:07,525 --> 00:32:12,096
which is a essentially a sinkhole
in the glacier surface

431
00:32:12,497 --> 00:32:16,834
that develops when these large rivers

432
00:32:17,769 --> 00:32:20,371
melt down into the ice to a point

433
00:32:20,371 --> 00:32:23,274
where they encounter a crack of some type.

434
00:32:23,675 --> 00:32:27,979

At that point, the river is captured
and it ceases to flow over

435
00:32:27,979 --> 00:32:33,151
the surface of the ice sheet and instead
plummets down into the interior.

436
00:32:33,551 --> 00:32:39,524
And this year, we mapped 538 of these
very large blue rivers

437
00:32:39,791 --> 00:32:43,895
and showed that every single one of them
terminates in one of these moulins.

438
00:32:44,595 --> 00:32:50,101
So water that's melted on top of the ice
sheet is quickly and effectively gathered

439
00:32:50,401 --> 00:32:55,106
and transferred through these branching
stream and river network systems.

440
00:32:55,406 --> 00:32:59,077
They are swept off
the surface of the sheet

441
00:32:59,110 --> 00:33:03,181
within a matter of a few hours
or even less, and ultimately

442
00:33:03,181 --> 00:33:06,184
emerge 80 kilometers
from here at the ice edge.

443
00:39:10,715 --> 00:39:12,516
Aww that's a beautiful shot.

444
00:39:21,525 --> 00:39:22,793
What makes data visualization

445
00:39:22,793 --> 00:39:24,729
a bit different from other
types of animation

446
00:39:24,729 --> 00:39:26,564
is that some component of the visual,

447
00:39:26,564 --> 00:39:29,767
some aspect of the visual, is directly
based on some type of science data.

448
00:39:30,067 --> 00:39:32,203
So in the case of the tour
of asteroid Bennu,

449
00:39:32,203 --> 00:39:35,973
the OSIRIS-REx trajectory
is actually based on mission data.

450
00:39:36,073 --> 00:39:38,342
The model itself, the asteroid model,

451
00:39:38,542 --> 00:39:42,179
that is real lidar data that was collected
from the OSIRIS-REx spacecraft.

452
00:39:42,179 --> 00:39:44,749
The imagery that you're seeing wrapped
in the surface of Bennu,

453
00:39:44,782 --> 00:39:47,651
that is actual satellite imagery
taken by the spacecraft.

454
00:39:47,885 --> 00:39:48,853
And so that's kind of the difference

455
00:39:48,853 --> 00:39:51,655

between visualization and animation,
is we're showing the real data.

456
00:39:51,655 --> 00:39:52,857
This is the real asteroid.

457
00:39:52,857 --> 00:39:55,459
So if we zoom all the way in on a boulder,
that's the real boulder.

458
00:39:55,459 --> 00:39:57,995
That's that's what it looked like
from the perspective of the spacecraft.

459
00:39:58,396 --> 00:40:02,266
I'm Kel Elkins, and I was the lead data
visualizer on the tour of asteroid Bennu.

460
00:40:02,666 --> 00:40:03,567
I'm Dan Gallagher.

461
00:40:03,567 --> 00:40:06,370
I was the producer and writer
on the tour of Asteroid Bennu.

462
00:40:06,904 --> 00:40:11,208
Tour of asteroid Bennu was inspired
by an earlier video that was also made by

463
00:40:11,208 --> 00:40:15,746
NASA's Scientific Visualization Studio,
and that video is called Tour of the Moon.

464
00:40:15,946 --> 00:40:20,551
The Visualizer, Ernie Wright, used
elevation data and high resolution

465
00:40:20,551 --> 00:40:24,155
imagery from a NASA's spacecraft
called the Lunar Reconnaissance Orbiter.

466
00:40:24,455 --> 00:40:27,958
And he was able to fly the camera
very close to the lunar surface

467
00:40:27,958 --> 00:40:31,629
and show the actual textures,
shadows, highlights,

468
00:40:31,862 --> 00:40:33,063
just the way that they would appear

469
00:40:33,063 --> 00:40:35,299
if you were hovering
close to the surface of the Moon.

470
00:40:35,533 --> 00:40:38,869
So we kind of borrowed some of those
techniques for the tour of asteroid Bennu.

471
00:40:38,903 --> 00:40:42,807
Really using lighting as a way to help
viewers understand the shape of Bennu,

472
00:40:42,807 --> 00:40:46,110
in the shape of these different
geological features we were zooming in

473
00:40:46,110 --> 00:40:49,213
on, which would just really help
the visualization come to life.

474
00:40:51,015 --> 00:40:54,185
So a good example of how we use
lidar comes about halfway

475
00:40:54,185 --> 00:40:57,755
through the video when we take viewers
to a boulder called the Gargoyle.

476
00:40:58,189 --> 00:41:01,592
Now, the Gargoyle has a very complex,
amorphous shape,

477
00:41:01,859 --> 00:41:05,830
and it looks really different
when you see it from different angles

478
00:41:05,830 --> 00:41:07,565
in two dimensional photographs.

479
00:41:07,565 --> 00:41:11,769
But when we finally got a good 3-D
model of the gargoyle, Kel was able

480
00:41:11,769 --> 00:41:16,507
to put a virtual camera down
near the surface of Bennu and rotate it

481
00:41:16,507 --> 00:41:20,077
around the boulder in a way that we never
could with two dimensional imagery.

482
00:41:20,578 --> 00:41:23,681
So something really cool about working
on this particular visualization--and

483
00:41:23,681 --> 00:41:27,117
actually all the visualizations we made
for the OSIRIS-REx mission--was

484
00:41:27,151 --> 00:41:30,754
as the spacecraft got closer and closer
to the asteroid on its way there,

485
00:41:30,754 --> 00:41:32,790
and as it spent more time
studying the asteroid,

486

00:41:32,823 --> 00:41:34,425
the models got better and better.

487
00:41:34,425 --> 00:41:36,560
The data that was collected
was getting better and better.

488
00:41:36,794 --> 00:41:40,331
So some of our early visualization tests,
we had this relatively low poly

489
00:41:40,331 --> 00:41:43,100
model of the asteroid and we could only
push in so far with the camera.

490
00:41:43,100 --> 00:41:46,003
You can't push in too far
and you just see an individual polygons.

491
00:41:46,003 --> 00:41:49,507
But as we got further and further along,
we ended up with five centimeter

492
00:41:49,507 --> 00:41:52,776
resolution tiles and you could push
all the way into individual boulders.

493
00:41:52,943 --> 00:41:54,778
And that's just the nature
of how these science missions work.

494
00:41:54,778 --> 00:41:56,113
The more time you spend with something

495
00:41:56,113 --> 00:41:58,415
more data collect,
the better the models get.

496
00:41:58,983 --> 00:42:02,186
Missions like OSIRIS-REx

take us to places that we haven't

497
00:42:02,186 --> 00:42:05,923
been before, literally new worlds
that we've never experienced.

498
00:42:06,357 --> 00:42:12,029
But they show us those places in ways
that can't always be easily seen.

499
00:42:12,296 --> 00:42:17,001
Tour of asteroid Bennu gives us a way
not only to show the public

500
00:42:17,001 --> 00:42:21,038
what these places are like,
but it almost gives us remote presence.

501
00:42:21,272 --> 00:42:24,642
It allows viewers
and even scientists on the mission

502
00:42:24,875 --> 00:42:28,445
to see these objects
up close through technology.

503
00:42:39,990 --> 00:42:41,225
So you're looking to find

504
00:42:41,225 --> 00:42:44,528
and watch some black holes,
and there are quite a few of them.

505
00:42:44,728 --> 00:42:46,530
So you're in for a treat.

506
00:42:46,530 --> 00:42:48,632
But before you get to all the fancy ones,

507

00:42:48,632 --> 00:42:50,768
let's first take a look
at some of the simplest ones.

508
00:42:51,302 --> 00:42:54,305
After all, looking at the fancy ones
first, it would be like trying to spot

509
00:42:54,305 --> 00:42:57,541
a Zordogian Grandlebuss before
you even know basic Grandlebuss anatomy.

510
00:42:57,575 --> 00:42:59,410
And that would just be silly.

511
00:42:59,410 --> 00:43:04,048
Anyway, your basic solitary black hole is
well, basic, relatively speaking.

512
00:43:04,949 --> 00:43:06,483
It has a lot of mass.

513
00:43:06,483 --> 00:43:10,254
A bit of spin, a boundary inside of which
everything, including light,

514
00:43:10,321 --> 00:43:11,755
can only form inward.

515
00:43:11,755 --> 00:43:15,926
And beyond that, well,
we actually have no idea, however,

516
00:43:16,026 --> 00:43:19,296
because solitary black holes
are so simple, they're quite hard to spot.

517
00:43:19,930 --> 00:43:23,167
But if you have a keen eye,
you might be able to catch a glimpse of it

518
00:43:23,200 --> 00:43:24,868
by looking at their surroundings.

519
00:43:24,868 --> 00:43:28,639
For example, black holes bend the light
traveling past them, and you can see this

520
00:43:28,639 --> 00:43:31,342
effect, called lensing,
around the edge of the black hole.

521
00:43:31,976 --> 00:43:35,346
There you are! Also
because black holes tend to mess

522
00:43:35,346 --> 00:43:38,515
with their environments, you can sometimes
find one by using other clues,

523
00:43:38,716 --> 00:43:41,352
such as a bunch of stuff orbiting
what appears to be nothing.

524
00:43:41,919 --> 00:43:45,789
Anyway, now that you know a bit more,
grab your telescopes and enjoy.

525
00:43:53,964 --> 00:43:56,667
An unusual eruption
on the Sun may offer clues

526
00:43:56,667 --> 00:43:59,603
to understanding our star's
mysterious explosions.

527
00:44:01,372 --> 00:44:03,440
Solar eruptions are massive releases

528

00:44:03,440 --> 00:44:05,476
of material off the surface of the Sun.

529
00:44:09,346 --> 00:44:14,084
This material can travel
across the solar system to Earth and Mars.

530
00:44:18,756 --> 00:44:21,725
The radiation and the material from
the Sun can interact

531
00:44:21,725 --> 00:44:26,397
with the planet's magnetic fields,
affecting astronauts and technology.

532
00:44:28,799 --> 00:44:31,635
Eruptions on the sun
usually come in one of three forms:

533
00:44:33,637 --> 00:44:37,574
coronal mass ejections, jets
and partial eruptions.

534
00:44:40,277 --> 00:44:41,612
The new research studying

535
00:44:41,612 --> 00:44:44,848
an event named the Rosetta
Stone of Solar Eruptions.

536
00:44:45,849 --> 00:44:48,419
Just as the Rosetta Stone
was the key to understanding

537
00:44:48,419 --> 00:44:52,156
Egyptian hieroglyphics, studying
this eruption could be the key

538
00:44:52,156 --> 00:44:54,825
to understanding all types

of solar eruptions.

539
00:44:56,827 --> 00:44:57,895
In the Rosetta Stone

540
00:44:57,895 --> 00:45:01,365
eruption, all three types of eruptions
happened in the same event.

541
00:45:02,900 --> 00:45:05,669
They usually occur separately.

542
00:45:07,004 --> 00:45:08,505
The main eruption was too big

543
00:45:08,505 --> 00:45:11,842
to be a jet, but too narrow
to be a coronal mass ejection.

544
00:45:12,676 --> 00:45:15,746
A second cooler layer of material
on the surface of the Sun

545
00:45:15,746 --> 00:45:18,382
also started to erupt
about a half an hour later,

546
00:45:19,883 --> 00:45:22,853
but it fell back down
as a partial solar eruption.

547
00:45:25,622 --> 00:45:28,859
This Rosetta Stone of solar eruptions
will also give clues

548
00:45:28,859 --> 00:45:31,695
to help scientists
predict large eruptions in the future.

549

00:45:34,565 --> 00:45:37,468
The better our predictions are,
the more time we have to prepare

550
00:45:37,468 --> 00:45:40,971
for material from the Sun
to interact with Earth's magnetic field.

551
00:45:45,309 --> 00:45:47,578
Predicting large
solar eruptions can help better

552
00:45:47,578 --> 00:45:51,648
protect our astronauts and technology,
near Earth and beyond.

553
00:46:02,159 --> 00:46:10,167
Morning. This is the 22nd of March 2021.

554
00:46:10,167 --> 00:46:14,671
4:15 in the morning.

555
00:46:15,339 --> 00:46:20,043
We are here this early to load
the SPEXone instrument into the truck.

556
00:46:42,933 --> 00:46:47,538
SPEXone will measure the intensity
and degree of polarization of light

557
00:46:47,971 --> 00:46:51,542
that is reflected by small particles
in the atmosphere.

558
00:46:52,209 --> 00:46:54,211
These particles are called aerosols.

559
00:46:55,412 --> 00:46:58,048
So overall aerosols

560
00:46:58,048 --> 00:47:03,954
counterbalance the warming by greenhouse
gases, but we don't know by what amount.

561
00:47:04,421 --> 00:47:10,127
And because this is so known, it's
hard to predict future climate change.

562
00:47:10,561 --> 00:47:14,665
And with SPEXone,
we want to accurately measure

563
00:47:14,965 --> 00:47:17,534
the effect of aerosols on
clouds and climate.

564
00:47:34,785 --> 00:47:35,752
One challenge in

565
00:47:35,752 --> 00:47:38,722
building and designing SPEXone
was the design of the optical system.

566
00:47:38,822 --> 00:47:40,858
Since SPEXone is a
multi-viewing instrument,

567
00:47:41,358 --> 00:47:44,828
we need to be able to capture the light
from five different directions

568
00:47:44,828 --> 00:47:48,198
into a single compact instrument.

569
00:49:12,115 --> 00:49:16,353
The Blue Marble that was our first

570
00:49:16,653 --> 00:49:20,824
view of ourselves,

we really are the blue planet.

571
00:49:21,191 --> 00:49:23,093
We're hanging out here
in the middle of nowhere.

572
00:49:28,365 --> 00:49:33,270
In fact, Apollo imagery
was part of the justification

573
00:49:33,270 --> 00:49:38,008
for putting together
a satellite that would look at the Earth.

574
00:49:38,008 --> 00:49:40,711
That satellite was the first Landsat.

575
00:49:40,711 --> 00:49:45,315
The Landsat mission now holds the title
for the longest continuous space

576
00:49:45,315 --> 00:49:47,751
based record of Earth's land in existence.

577
00:49:50,721 --> 00:49:55,258
At least one Landsat satellite
has been orbiting the Earth since 1972.

578
00:49:55,726 --> 00:49:58,795
That's nearly 50 years
of steadfast observation.

579
00:49:59,363 --> 00:50:02,466
The program was born in the midst
of several historical flashpoints

580
00:50:02,666 --> 00:50:05,268
during a time when the world
was changing quickly.

581
00:50:06,870 --> 00:50:08,705
Well, it really was a perfect storm.

582
00:50:08,705 --> 00:50:14,244
We had a lot of technology coming out
of World War II with air flown sensors.

583
00:50:14,711 --> 00:50:19,616
We also had an awareness
of the environment between Rachel Carson.

584
00:50:19,916 --> 00:50:23,153
Even Stewart Udall wrote
a book called The Quiet Crisis.

585
00:50:23,453 --> 00:50:28,625
Those two things together, the space race,
all of those came together.

586
00:50:29,359 --> 00:50:32,329
But the Landsat story doesn't
actually start with NASA.

587
00:50:32,629 --> 00:50:35,365
It starts with the United States
Geological Survey.

588
00:50:35,932 --> 00:50:39,503
There were a couple
of really interesting players.

589
00:50:40,137 --> 00:50:45,475
The primary one is William Pecora,
and he was director of the U.S.

590
00:50:45,642 --> 00:50:47,444
Geological Survey.

591
00:50:47,444 --> 00:50:49,446

His boss was Stuart Udall.

592
00:50:49,446 --> 00:50:52,883
He tried floating it around
and it didn't quite make it.

593
00:50:54,017 --> 00:50:59,723
Department of Defense, the CIA, NASA
which was just beginning at that point.

594
00:50:59,756 --> 00:51:02,592
They all said, you know,
this isn't the right time.

595
00:51:03,193 --> 00:51:06,329
So in 1966, Pecora and Udall

596
00:51:06,329 --> 00:51:10,634
announced that, OK, fine,
Department of Interior will launch.

597
00:51:11,134 --> 00:51:14,204
And so that caused a big kerfuffle.

598
00:51:14,805 --> 00:51:16,106
And the bottom line was

599
00:51:16,106 --> 00:51:19,676
that NASA was forced to step up and say,
yeah, OK, we'll do it.

600
00:51:19,976 --> 00:51:21,678
But let's pause for a second.

601
00:51:21,678 --> 00:51:24,748
Obviously, there was a big push
to make an Earth observing satellite.

602
00:51:25,082 --> 00:51:27,818

But what exactly did it need to do?

603
00:51:27,818 --> 00:51:29,986
Landsat's entire job is to collect light,

604
00:51:30,187 --> 00:51:33,256
visible light like this,
and non visible light like this.

605
00:51:33,723 --> 00:51:37,661
After Landsat captures the light it sees,
it can make two kinds of pictures:

606
00:51:37,928 --> 00:51:40,530
true color images and false color images.

607
00:51:41,264 --> 00:51:44,000
Did you know your eyes can only detect
red, green and blue?

608
00:51:44,201 --> 00:51:46,036
It sounds crazy, but it's true.

609
00:51:46,036 --> 00:51:49,306
In fact, if you took a magnifying glass
to the screen you're probably looking at

610
00:51:49,306 --> 00:51:52,342
right now, you'd see a jumble of red,
green and blue dots.

611
00:51:52,576 --> 00:51:54,744
Mix Those colors together
with different intensities

612
00:51:55,011 --> 00:51:57,547
and your brain, interprets
all the colors of the rainbow.

613

00:51:57,981 --> 00:52:01,485
True color images are made
by combining red, blue and green light.

614
00:52:01,952 --> 00:52:03,487
But what's even more amazing,

615
00:52:03,487 --> 00:52:07,023
Landsat also captures
infrared light beyond what we can see.

616
00:52:07,224 --> 00:52:08,625
And that light can reveal

617
00:52:08,625 --> 00:52:11,695
some incredible things
when you look at a false color image.

618
00:52:11,695 --> 00:52:15,132
Like the difference between types
of plants, how healthy those plants are,

619
00:52:15,365 --> 00:52:19,336
healthy coral reefs, and even dead coral
reefs, fire tracking, ocean pollution.

620
00:52:19,603 --> 00:52:22,405
The possibilities are nearly endless.

621
00:52:22,405 --> 00:52:25,675
In fact, I bet you've probably seen
Landsat's influence on pop culture

622
00:52:25,675 --> 00:52:27,310
without even knowing it.

623
00:52:27,310 --> 00:52:30,480
From Google Earth
and works of art to television and movies.

624
00:52:31,014 --> 00:52:32,315
And I should know.

625
00:52:32,315 --> 00:52:36,319
Before my untimely smushing by an 85
foot tall great ape deep into the film,

626
00:52:36,319 --> 00:52:40,557
I, your narrator, played Landsat
Steve in Kong: Skull Island.

627
00:52:41,124 --> 00:52:43,593
But I digress. Now back to our story.

628
00:52:44,361 --> 00:52:47,731
NASA and USGS get to work
largely under the direction of lead

629
00:52:47,731 --> 00:52:51,601
engineer Virginia Norwood, who was often
called the Mother of Landsat.

630
00:52:52,969 --> 00:52:55,872
Norwood and her team had to design
an experimental instrument,

631
00:52:55,906 --> 00:52:59,776
the Multispectral Scanner,
that had never been flown in space before.

632
00:53:00,177 --> 00:53:05,815
We took a--NASA took a real gamble
to propose a scanner for this.

633
00:53:06,116 --> 00:53:08,585
That was quite a bit of skepticism.

634
00:53:08,585 --> 00:53:11,354
To assuage the skeptics

and test the scanner's capabilities,

635
00:53:11,388 --> 00:53:14,824
the team loaded up the test model
on a truck and headed to Yosemite.

636
00:53:15,225 --> 00:53:18,929
And this was because nobody believes
that scanner would work.

637
00:53:18,962 --> 00:53:22,332
I think you better,
you better give us some assurance.

638
00:53:23,166 --> 00:53:26,870
But the true test came

639
00:53:26,870 --> 00:53:30,674
when Landsat one
launched on July 23, 1972.

640
00:53:31,208 --> 00:53:32,409
Sadly, William T.

641
00:53:32,409 --> 00:53:35,545
Pecora, one of the project's
original champions, died

642
00:53:35,545 --> 00:53:38,481
just three days before
Landsat took its place in orbit.

643
00:53:39,049 --> 00:53:41,585
But with this launch,
the United States, and soon

644
00:53:41,585 --> 00:53:45,155
the world, would step into a new paradigm
of Earth observation.

645
00:53:45,822 --> 00:53:48,825
Never before seen snapshots of land
resources and the environment

646
00:53:48,992 --> 00:53:52,762
would be key for critical decision
making decades into the future.

647
00:54:01,338 --> 00:54:03,473
As we started to
approach Bennu from a distance

648
00:54:03,473 --> 00:54:05,609
and it started to fill up
the camera field of view,

649
00:54:05,642 --> 00:54:09,112
it looked exactly like we thought
it would with a few boulders sticking out.

650
00:54:09,145 --> 00:54:13,049
But as we got closer,
we expected to see a very sandy surface

651
00:54:13,049 --> 00:54:15,085
with maybe a few boulders here and there.

652
00:54:15,085 --> 00:54:17,587
And what we saw is very little sand.

653
00:54:17,754 --> 00:54:20,757
And we saw these mountains,
we saw boulders, we saw rocks,

654
00:54:20,924 --> 00:54:24,928
and we saw very few areas
that had this sandy surface

655
00:54:24,928 --> 00:54:27,430

that we were expecting
and what we had designed to.

656
00:54:33,403 --> 00:54:35,772
We have never done this before.

657
00:54:35,772 --> 00:54:39,142
We're actually going to collect a sample
and bring it back down to Earth

658
00:54:39,142 --> 00:54:41,144
for further examination by scientists.

659
00:54:42,212 --> 00:54:45,415
In order to achieve that objective,
the OSIRIS-REx spacecraft

660
00:54:45,415 --> 00:54:46,716
has been navigating around

661
00:54:46,716 --> 00:54:50,153
Bennu for about the last two years,
studying it in great detail

662
00:54:50,520 --> 00:54:54,924
and also overcoming a number of challenges
that Bennu has presented.

663
00:54:55,158 --> 00:54:59,462
We were looking for locations on Bennu
that were 50 meters in diameter,

664
00:54:59,696 --> 00:55:02,866
relatively flat and covered
with fine grained material

665
00:55:02,866 --> 00:55:07,070
and by fine-grained material, I mean stuff
that's the size of a dime or smaller.

666
00:55:07,137 --> 00:55:10,206
We realized that there were no sites on
Bennu that even came close

667
00:55:10,206 --> 00:55:11,508
to meeting this criteria.

668
00:55:11,508 --> 00:55:14,511
Everywhere we looked was too small
and covered with boulders.

669
00:55:14,611 --> 00:55:17,514
So we actually had to fly a number
of additional close passes

670
00:55:17,514 --> 00:55:21,484
over the asteroid and rethink our entire
plan for grabbing the sample.

671
00:55:23,653 --> 00:55:25,989
After the additional
observations of Bennu,

672
00:55:25,989 --> 00:55:29,426
we had to downselect to four sites
and then go back and survey

673
00:55:29,426 --> 00:55:33,163
those sites even further
to select the final primary sample site.

674
00:55:33,496 --> 00:55:37,167
My first impression of Nightingale
is that's the last place I wanted to go.

675
00:55:37,634 --> 00:55:40,837
But as we started looking at other sites,
we saw that one.

676

00:55:40,837 --> 00:55:45,175
This is probably one of the most sampled
both sites and two,

677
00:55:45,175 --> 00:55:49,379
we were over performing in our navigation
capability and our ability to contact.

678
00:55:50,313 --> 00:55:52,782
Natural feature tracking works
a lot like the human mind

679
00:55:52,782 --> 00:55:55,785
in that we pick up landmarks
along the way as we descend.

680
00:55:55,819 --> 00:55:57,821
We look at features on the ground.

681
00:55:57,821 --> 00:56:00,290
We program the computer
to recognize certain features.

682
00:56:00,323 --> 00:56:02,959
It takes a picture,
says this feature is not

683
00:56:02,959 --> 00:56:03,960
where I expected it to be,

684
00:56:03,960 --> 00:56:07,997
it's a little bit off to the side, updates
its position based on where it's pointed

685
00:56:07,997 --> 00:56:10,266
and where that feature shows
up in the camera position.

686
00:56:12,202 --> 00:56:15,438
The TAG event is our touch and go event,

687
00:56:15,505 --> 00:56:19,609
which is where we'll actually be
retrieving the sample from Asteroid Benu.

688
00:56:19,642 --> 00:56:23,213
We start with a series of maneuvers,
one of them being the checkpoint burn,

689
00:56:23,213 --> 00:56:26,683
which is where we'll actually check
our position velocity in relation

690
00:56:26,950 --> 00:56:28,485
to the sample sites.

691
00:56:28,485 --> 00:56:29,819
And then the matchpoint burn.

692
00:56:29,819 --> 00:56:31,454
about 10 minutes later,

693
00:56:31,454 --> 00:56:34,457
we'll zero out our horizontal velocity
relative to the surface.

694
00:56:34,624 --> 00:56:36,359
And then about 10 minutes after that,

695
00:56:36,359 --> 00:56:40,230
we make contact with the TAGSAM team,
fire the gas bottle, and then back away.

696
00:56:40,463 --> 00:56:43,600
And we hope to get
at least 60 grams of sample.

697
00:56:43,600 --> 00:56:47,103
And then we'll be able to store that

and bring it back down to Earth.

698
00:56:47,170 --> 00:56:48,705
But there are several
things that could go wrong,

699
00:56:48,705 --> 00:56:49,706
and we also have to be

700
00:56:49,706 --> 00:56:53,243
prepared that we won't be successful
on our first try at Nightingale.

701
00:56:53,743 --> 00:56:57,614
We don't only get one shot at TAG,
we actually have three nitrogen

702
00:56:57,614 --> 00:57:00,884
bottles onboard the spacecraft
so we can potentially do three

703
00:57:00,917 --> 00:57:02,452
TAG attempts if needed.

704
00:57:02,452 --> 00:57:06,689
We go through several what-if scenarios,
and this is how we actually prepare

705
00:57:06,689 --> 00:57:08,591
for a lot of our contingencies.

706
00:57:08,591 --> 00:57:11,928
So we've had to look all around
the surface and identify the rocks

707
00:57:11,928 --> 00:57:15,698
and boulders that if the spacecraft were
to tip over up to twenty five degrees,

708

00:57:16,099 --> 00:57:18,101
it could come into contact and be damaged.

709
00:57:18,134 --> 00:57:21,504
We had to develop a hazard map,
which we programed into the computer

710
00:57:21,504 --> 00:57:25,041
and says, if you're getting too close to
those hazards, we'll do a wave off.

711
00:57:25,341 --> 00:57:28,645
We'll back away from the asteroid,
we'll come back and do this another day.

712
00:57:28,812 --> 00:57:30,447
Everything might work perfectly.

713
00:57:30,447 --> 00:57:35,185
We come down, we touch the surface just
where we want to, we fire the gas bottle.

714
00:57:35,452 --> 00:57:39,622
But the area we contact
is covered in large rocks.

715
00:57:40,123 --> 00:57:43,293
Those rocks would prevent
any fine grained material

716
00:57:43,293 --> 00:57:46,763
from being stirred up
and captured in the TAGSAM head.

717
00:57:46,763 --> 00:57:50,166
Another similar scenario
is that the TAGSAM were to touch

718
00:57:50,166 --> 00:57:52,235
on the edge of a boulder

and become tipped up?

719
00:57:52,702 --> 00:57:56,105
In that case, when the gas bottle fires,
much of that gas escapes out

720
00:57:56,105 --> 00:57:59,275
the side, not turning up the material
that we want to capture.

721
00:57:59,476 --> 00:58:03,046
The day of TAG is going to be really
exciting, but the excitement for our team

722
00:58:03,046 --> 00:58:04,113
doesn't end there.

723
00:58:04,113 --> 00:58:07,517
We have to verify
that we have a proper sample.

724
00:58:07,884 --> 00:58:10,119
First, we're going
to image the TAGSAM head

725
00:58:10,119 --> 00:58:11,821
by sticking it in
front of one of the cameras.

726
00:58:11,821 --> 00:58:14,557
Then we're going to do a maneuver
called the sample mass measurement,

727
00:58:14,557 --> 00:58:18,695
in which we stick out the arm and spin
the spacecraft in order for us to decide

728
00:58:18,695 --> 00:58:22,432
if we've collected enough mass to be able
to stow the sample and return home

729
00:58:22,732 --> 00:58:24,000
or if we have to try again.

730
00:58:24,000 --> 00:58:26,202
This is the culmination of a lot of work.

731
00:58:26,202 --> 00:58:28,505
It's probably one of the most exciting
missions that I've worked on.

732
00:58:28,505 --> 00:58:32,509
It is really exciting to know that
we're finally going to be able to touch