



1
00:00:01,100 --> 00:00:07,100
[music playing]

2
00:00:16,866 --> 00:00:21,100
- Welcome to the 2016
NASA Ames Summer Series.

3
00:00:22,466 --> 00:00:25,566
Biology is the magnification
of the physical laws

4
00:00:25,566 --> 00:00:29,300
and structures
that it is made of.

5
00:00:29,300 --> 00:00:32,000
Planets, until recently,

6
00:00:32,000 --> 00:00:34,500
have been thought
to be unique.

7
00:00:34,500 --> 00:00:37,266
But the Kepler mission
has demonstrated

8
00:00:37,266 --> 00:00:38,800
that they are ubiquitous,

9
00:00:38,800 --> 00:00:40,800
part of the physical universe,

10
00:00:40,800 --> 00:00:44,933
and just a reflection
of the physical universe.

11
00:00:46,800 --> 00:00:50,166
K2 has taken
the Kepler satellite

12

00:00:50,166 --> 00:00:51,900
that's lost its ability

13

00:00:51,900 --> 00:00:57,500
to maintain its long-duration
pointing stability

14

00:00:57,500 --> 00:00:59,000
and created a new mission

15

00:00:59,000 --> 00:01:02,933
that observes the fields
along the ecliptical plane.

16

00:01:02,933 --> 00:01:06,266
What discoveries await?

17

00:01:06,266 --> 00:01:08,633
Today's presentation, entitled

18

00:01:08,633 --> 00:01:11,933
"Microlensing
and the K2 Experiment,"

19

00:01:11,933 --> 00:01:14,900
will be given
by Dr. Thomas Barclay.

20

00:01:14,900 --> 00:01:16,466
Dr. Barclay is the director

21

00:01:16,466 --> 00:01:21,066
of the Kepler K2
Guest Observer Office,

22

00:01:21,066 --> 00:01:24,600
where he is in part,
as part of the duties,

23

00:01:24,600 --> 00:01:26,366
responsible for performing

24

00:01:26,366 --> 00:01:30,866
Kepler- and K2-driven
investigations.

25

00:01:30,866 --> 00:01:33,600
He received a Bachelor's
of Science in physics

26

00:01:33,600 --> 00:01:36,200
from the University of Leeds,

27

00:01:36,200 --> 00:01:38,466
followed by
a Master's of Science

28

00:01:38,466 --> 00:01:40,066
in astronomy and radio astronomy

29

00:01:40,066 --> 00:01:42,900
from the University
of Manchester.

30

00:01:42,900 --> 00:01:46,866
He then went on to receive
a PhD in astrophysics

31

00:01:46,866 --> 00:01:50,900
from the University
College London.

32

00:01:52,666 --> 00:01:57,633
Several notable discoveries
that Dr. Barclay led

33

00:01:57,633 --> 00:02:02,366

include the detection
of the smallest known exoplanet

34

00:02:02,366 --> 00:02:04,900

and characterization
of the first

35

00:02:04,900 --> 00:02:07,800

super-Earth-sized planet

36

00:02:07,800 --> 00:02:13,033

orbiting close
to its star's habitable zone.

37

00:02:13,033 --> 00:02:16,433

Please join me
in welcoming Dr. Barclay.

38

00:02:16,433 --> 00:02:19,433

[applause]

39

00:02:23,100 --> 00:02:24,666

- Good morning, everyone,
and thanks for coming.

40

00:02:24,666 --> 00:02:26,600

And hopefully you're all
well-rested

41

00:02:26,600 --> 00:02:28,166

from the three-day weekend,

42

00:02:28,166 --> 00:02:30,933

so you'll be awake
for the entire presentation,

43

00:02:30,933 --> 00:02:33,166

which is gonna be
a really great thing.

44

00:02:33,166 --> 00:02:35,800

I'm going to talk about K2,
the K2 mission.

45

00:02:35,800 --> 00:02:37,466

But I'm gonna start
actually by talking

46

00:02:37,466 --> 00:02:38,800

about the Kepler mission.

47

00:02:38,800 --> 00:02:41,066

We use the Kepler spacecraft
for K2,

48

00:02:41,066 --> 00:02:43,300

and the Kepler mission,
I think,

49

00:02:43,300 --> 00:02:44,966

was one of the most
important missions

50

00:02:44,966 --> 00:02:47,233

we as an agency have ever done.

51

00:02:47,233 --> 00:02:50,400

It's--can truly say
that it's redefined

52

00:02:50,400 --> 00:02:53,600

where we see ourselves
in the universe.

53

00:02:53,600 --> 00:02:54,700

What is our place?

54

00:02:54,700 --> 00:02:55,700

Where do we come from?

55

00:02:55,700 --> 00:02:56,700

Where are we going?

56

00:02:56,700 --> 00:02:59,100

It's telling us about ourselves,

57

00:02:59,100 --> 00:03:00,466

and I think that's really,

58

00:03:00,466 --> 00:03:03,166

really wonderful and fantastic

59

00:03:03,166 --> 00:03:06,133

and changes our paradigm.

60

00:03:06,133 --> 00:03:07,766

So the Kepler mission's goal

61

00:03:07,766 --> 00:03:12,000

was to determine the fraction
of habitable zone planets

62

00:03:12,000 --> 00:03:14,433

that are Earth-sized
in our galaxy.

63

00:03:14,433 --> 00:03:16,466

And I think the mission
has really done this,

64

00:03:16,466 --> 00:03:18,500

and it's told us that
there are planets everywhere,

65

00:03:18,500 --> 00:03:20,100

and that once again,

66

00:03:20,100 --> 00:03:22,600

we learn that we are not
especially unique

67

00:03:22,600 --> 00:03:24,233

or special out there,

68

00:03:24,233 --> 00:03:26,833

at least in terms
of where we live.

69

00:03:26,833 --> 00:03:31,366

So just a brief mention
of how we find planets.

70

00:03:31,366 --> 00:03:33,166

What we do is,
we look at stars.

71

00:03:33,166 --> 00:03:36,733

Planets pass across
the face of a star--

72

00:03:36,733 --> 00:03:38,000

is it still going?

Yes.

73

00:03:38,000 --> 00:03:39,700

I'll show it like this.

This is even better.

74

00:03:39,700 --> 00:03:41,800

Planets pass across
the face of a star,

75

00:03:41,800 --> 00:03:43,000

and when they pass across,

76

00:03:43,000 --> 00:03:45,466

they block a little bit

of the star's light.

77

00:03:45,466 --> 00:03:47,033

And that dimming, we detect.

78

00:03:47,033 --> 00:03:48,466

We call it a transit.

79

00:03:48,466 --> 00:03:50,033

We named this transit
after things

80

00:03:50,033 --> 00:03:51,566

that happen
in our own solar system.

81

00:03:51,566 --> 00:03:53,233

This is our own
solar system.

82

00:03:53,233 --> 00:03:55,033

This is the Sun,
and this is Venus

83

00:03:55,033 --> 00:03:56,400

passing in front of it.

84

00:03:58,166 --> 00:04:01,333

Fortunately, I got to see
two transits of Venus.

85

00:04:01,333 --> 00:04:03,200

If you didn't see one,
you're gonna hope

86

00:04:03,200 --> 00:04:05,133

that you live well, eat well,

87

00:04:05,133 --> 00:04:07,233

and live for another 100
or 200 years,

88

00:04:07,233 --> 00:04:10,333

because they don't
occur very often,

89

00:04:10,333 --> 00:04:12,600

certainly not again
in my lifetime.

90

00:04:12,600 --> 00:04:14,133

But this is
the transit of Venus.

91

00:04:14,133 --> 00:04:16,166

You can see some really
wonderful things like this.

92

00:04:16,166 --> 00:04:17,566

Do you can see this jittering

93

00:04:17,566 --> 00:04:20,566

on the surface of the star,
of the Sun here?

94

00:04:20,566 --> 00:04:23,733

This isn't just the projector
putting noise in there.

95

00:04:23,733 --> 00:04:26,033

This is actually what's going on
on the surface of our star.

96

00:04:26,033 --> 00:04:27,200

This is granulation.

97

00:04:27,200 --> 00:04:29,533

This is motion--
convective motion coming out.

98

00:04:29,533 --> 00:04:32,333

One of the amazing things
about our spacecraft

99

00:04:32,333 --> 00:04:35,033

and what it does
and how sensitive it is,

100

00:04:35,033 --> 00:04:37,300

is that this granulation noise

101

00:04:37,300 --> 00:04:39,533

and surface noise
and convective features

102

00:04:39,533 --> 00:04:41,133

is actually what
limits our ability

103

00:04:41,133 --> 00:04:44,266

to find planets
among many of our stars.

104

00:04:44,266 --> 00:04:46,666

It's the stars themselves
are too noisy

105

00:04:46,666 --> 00:04:49,266

and they limit
our detecting ability.

106

00:04:49,266 --> 00:04:50,666

I think that's really wonderful.

107

00:04:50,666 --> 00:04:53,233

But you see some nice things
there about finding planets.

108

00:04:53,233 --> 00:04:55,700

You see the limb
of the star's darker

109

00:04:55,700 --> 00:04:56,900

than the center of the star.

110

00:04:56,900 --> 00:04:58,400

This is what we
call limb darkening.

111

00:04:58,400 --> 00:05:01,400

We see this in our Kepler data.

112

00:05:01,400 --> 00:05:03,766

You even see a little bit
of the atmosphere of Venus,

113

00:05:03,766 --> 00:05:06,000

and I think the next 20
or 30 years

114

00:05:06,000 --> 00:05:09,133

of our agency's exoplanet
hunting and search

115

00:05:09,133 --> 00:05:10,800

will be to try and model

116

00:05:10,800 --> 00:05:12,900

the atmospheres
of other planets,

117

00:05:12,900 --> 00:05:16,333

not just ones
in our own solar system.

118

00:05:16,333 --> 00:05:18,633

So why is it so difficult?

119

00:05:18,633 --> 00:05:21,633

Why didn't we find lots
and lots of planets

120

00:05:21,633 --> 00:05:25,200

until we had a mission
in space to detect them?

121

00:05:25,200 --> 00:05:27,733

Well, this is what
Jupiter would look like

122

00:05:27,733 --> 00:05:30,066

transiting the Sun.

123

00:05:30,066 --> 00:05:31,300

You see it's pretty big.

124

00:05:31,300 --> 00:05:34,766

It's about 1/10
the radius of the star.

125

00:05:34,766 --> 00:05:37,733

Therefore blocks out
about 1% of the area.

126

00:05:37,733 --> 00:05:38,933

It's fairly easy to detect.

127

00:05:38,933 --> 00:05:42,000

We call it a 1% transit,
a 1% dip.

128

00:05:42,000 --> 00:05:43,733

We see these from the ground.

129

00:05:43,733 --> 00:05:46,166

These were amongst
the first planets found.

130

00:05:46,166 --> 00:05:48,833

Now let's look what
Earth would look like.

131

00:05:48,833 --> 00:05:50,600

Do you see this
tiny dot up here?

132

00:05:50,600 --> 00:05:51,800

Here it is.

133

00:05:51,800 --> 00:05:54,100

That's what Earth
would look like.

134

00:05:54,100 --> 00:05:56,933

The amount of light
blocked by Earth

135

00:05:56,933 --> 00:05:59,166

is about a hundred
parts a million.

136

00:05:59,166 --> 00:06:02,100

Now, to put that another way,
just imagine, you know,

137

00:06:02,100 --> 00:06:04,100

there's a million photons
coming from this star.

138

00:06:04,100 --> 00:06:06,833

Just a hundred are blocked
by this planet.

139

00:06:06,833 --> 00:06:08,233

And yet we can
detect these things.

140

00:06:08,233 --> 00:06:10,966

In fact, we can detect many
of these things.

141

00:06:10,966 --> 00:06:13,566

But we needed to build
a special instrument.

142

00:06:13,566 --> 00:06:16,466

And so I have a little
short movie here,

143

00:06:16,466 --> 00:06:18,600

showing some of the heroes
of this story.

144

00:06:18,600 --> 00:06:21,200

You know, we scientists get
to talk a lot about the results,

145

00:06:21,200 --> 00:06:22,700

but it's the engineers

146

00:06:22,700 --> 00:06:25,266

and the ingenuity
that time and again

147

00:06:25,266 --> 00:06:28,766

has enabled us to both
build a wonderful instrument,

148

00:06:28,766 --> 00:06:32,166

and then keep the mission going
and keep it operating.

149

00:06:32,166 --> 00:06:33,666

Throughout this talk,

150

00:06:33,666 --> 00:06:35,533

I think everything we've done

151

00:06:35,533 --> 00:06:38,100
is dependent on the ingenuity

152

00:06:38,100 --> 00:06:39,500
and the resourcefulness

153

00:06:39,500 --> 00:06:43,500
and the childlike excitement
of brilliant engineers.

154

00:06:43,500 --> 00:06:45,966
So I'm just gonna go back
to the start, and I'll just

155

00:06:45,966 --> 00:06:47,966
show you some of the components
of the spacecraft.

156

00:06:47,966 --> 00:06:50,500
This is our mirror.
It's a 1.4-meter mirror.

157

00:06:50,500 --> 00:06:52,100
It goes at the bottom
of the spacecraft.

158

00:06:52,100 --> 00:06:53,866
This is our camera up there.

159

00:06:53,866 --> 00:06:56,666
So you'll see some images
that look like this camera.

160

00:06:56,666 --> 00:06:58,666
They have the same shape.

161

00:06:58,666 --> 00:07:01,133

This is actually a movie,
but I'm moving very slowly,

162
00:07:01,133 --> 00:07:03,433
but that's the solar panel.

163
00:07:03,433 --> 00:07:06,300
And later on, the solar panel
is gonna become very important

164
00:07:06,300 --> 00:07:07,866
for what I'm gonna tell you.

165
00:07:07,866 --> 00:07:09,266
This is just the thing arriving

166
00:07:09,266 --> 00:07:12,200
at the Kennedy Space Center
for launch

167
00:07:12,200 --> 00:07:14,100
while they unpack it.

168
00:07:17,533 --> 00:07:19,600
And here they are just
putting everything together.

169
00:07:19,600 --> 00:07:21,466
And again, you see
this spacecraft.

170
00:07:21,466 --> 00:07:24,133
You see the solar panel here,

171
00:07:24,133 --> 00:07:26,433
which became very important.

172
00:07:26,433 --> 00:07:31,266
So the mission launched

in 2009 in March

173

00:07:31,266 --> 00:07:33,433
and since then
has been operating,

174

00:07:33,433 --> 00:07:34,900
firstly as the Kepler mission

175

00:07:34,900 --> 00:07:36,700
and now as the K2 mission.

176

00:07:38,033 --> 00:07:41,733
It was aboard a Delta II
for those of you interested.

177

00:07:41,733 --> 00:07:44,000
One important thing to know
about the spacecraft--

178

00:07:44,000 --> 00:07:45,500
and for the microlensing
component,

179

00:07:45,500 --> 00:07:47,366
this is absolutely essential--

180

00:07:47,366 --> 00:07:49,933
is that Kepler
doesn't orbit the Earth.

181

00:07:49,933 --> 00:07:52,500
Kepler orbits the Sun
and trails the Earth

182

00:07:52,500 --> 00:07:54,900
in what we call
an Earth-trailing orbit.

183

00:07:54,900 --> 00:07:56,300
Actually, as time goes on,

184
00:07:56,300 --> 00:07:59,600
Kepler gets further
and further away from Earth,

185
00:07:59,600 --> 00:08:02,400
and communication
bandwidth decreases

186
00:08:02,400 --> 00:08:06,000
as a function of time.

187
00:08:06,000 --> 00:08:08,133
Eventually it will drift
and drift and drift

188
00:08:08,133 --> 00:08:13,066
until it goes behind the Sun.

189
00:08:13,066 --> 00:08:14,833
This is where the main
Kepler mission,

190
00:08:14,833 --> 00:08:16,933
which lasted until 2013--

191
00:08:16,933 --> 00:08:19,900
we looked at a single patch
of sky the entire time.

192
00:08:19,900 --> 00:08:22,500
A region in the sky
in the constellations

193
00:08:22,500 --> 00:08:25,633
of Lyra and...

194

00:08:27,066 --> 00:08:30,133
Cygnus, that's the consolation
that was escaping me.

195
00:08:30,133 --> 00:08:32,500
And you see here, this is
the picture of the camera,

196
00:08:32,500 --> 00:08:35,833
that camera that I was
showing you earlier onboard.

197
00:08:35,833 --> 00:08:38,933
It's about a hundred
megapixels or so.

198
00:08:38,933 --> 00:08:43,066
It has 84 CCDs arranged
in this pattern.

199
00:08:43,066 --> 00:08:44,566
And so when you see
big images of ours,

200
00:08:44,566 --> 00:08:45,866
the reason they look
like they do

201
00:08:45,866 --> 00:08:47,666
is because that's what
our camera looks like.

202
00:08:47,666 --> 00:08:48,800
And the bottom left here

203
00:08:48,800 --> 00:08:53,166
is actually an image
of some of our data.

204
00:08:53,166 --> 00:08:56,433

People don't often show
real Kepler data.

205

00:08:56,433 --> 00:08:57,600

They show lots of the results.

206

00:08:57,600 --> 00:08:59,433

They show lots
of artistic images,

207

00:08:59,433 --> 00:09:01,300

but they don't often
show the data.

208

00:09:01,300 --> 00:09:02,866

And there's a very
good reason for that.

209

00:09:02,866 --> 00:09:05,000

Our data doesn't look
like Hubble data.

210

00:09:05,000 --> 00:09:07,466

Hubble data--essentially,
you need to take it,

211

00:09:07,466 --> 00:09:09,100

you put it up as an image,

212

00:09:09,100 --> 00:09:10,466

and it looks beautiful.

213

00:09:10,466 --> 00:09:12,666

And then people work to make it
look even more beautiful,

214

00:09:12,666 --> 00:09:15,000

but the beauty is intrinsic
to the image.

215
00:09:15,000 --> 00:09:17,200
The beauty isn't intrinsic
to our images.

216
00:09:17,200 --> 00:09:20,466
Our images look
like fuzzy blobs.

217
00:09:20,466 --> 00:09:22,900
They're somewhat large blobs.

218
00:09:22,900 --> 00:09:24,166
These are the stars,

219
00:09:24,166 --> 00:09:26,266
and this is where
the magic happens.

220
00:09:26,266 --> 00:09:28,133
But, simply, all we do is,

221
00:09:28,133 --> 00:09:30,800
we take essentially
a photograph

222
00:09:30,800 --> 00:09:33,233
every 30 minutes continuously.

223
00:09:33,233 --> 00:09:37,400
We did that for four years
of the same different regions

224
00:09:37,400 --> 00:09:39,966
of these--where the stars are,
these fuzzy blobs.

225
00:09:39,966 --> 00:09:42,866
So you have a nice
time series of images

226

00:09:42,866 --> 00:09:45,333
just like this one.

227

00:09:45,333 --> 00:09:47,200
But what can they tell us?

228

00:09:47,200 --> 00:09:49,633
This is actually
how we find planets.

229

00:09:49,633 --> 00:09:53,066
And there's so much information
in this time series.

230

00:09:53,066 --> 00:09:54,366
I showed a little bit
of the movie

231

00:09:54,366 --> 00:09:56,000
of what a transit
would look like.

232

00:09:56,000 --> 00:09:58,866
But remember, stars here
are just blobs.

233

00:09:58,866 --> 00:10:01,966
We see them--actually, they're
what we call point sources.

234

00:10:01,966 --> 00:10:03,566
And we don't
resolve the stars.

235

00:10:03,566 --> 00:10:07,300
We can't tell the brightness
across the surface of a star

236

00:10:07,300 --> 00:10:08,400
just from the image.

237
00:10:08,400 --> 00:10:09,833
They're just
a single point of light

238
00:10:09,833 --> 00:10:11,566
that then gets dispersed a bit.

239
00:10:11,566 --> 00:10:13,466
So you can't physically
see a planet

240
00:10:13,466 --> 00:10:15,066
passing through
the middle of this.

241
00:10:15,066 --> 00:10:16,433
You just see
the integrated light

242
00:10:16,433 --> 00:10:18,866
of the point source decreasing.

243
00:10:18,866 --> 00:10:20,400
And that's what
you're seeing here.

244
00:10:20,400 --> 00:10:23,033
This is actually some real data.
It's actually some early data.

245
00:10:23,033 --> 00:10:26,700
But I think it shows nicely
of what a planet looks like.

246
00:10:26,700 --> 00:10:28,900
You see this random scatter,

247

00:10:28,900 --> 00:10:31,833

this kind of small level scatter
across the data.

248

00:10:31,833 --> 00:10:34,233

That's the noise
from the surface of a star

249

00:10:34,233 --> 00:10:37,000

in addition to some of the noise
from our instrument.

250

00:10:37,000 --> 00:10:40,900

You see regular dips
on top of this noise,

251

00:10:40,900 --> 00:10:42,566

or dips down.

252

00:10:42,566 --> 00:10:46,300

The size of these dips tells us
that there's a planet there.

253

00:10:46,300 --> 00:10:49,600

There's a planet crossing
across the surface of the star.

254

00:10:49,600 --> 00:10:53,166

The depth of the dips
tells us about the ratio

255

00:10:53,166 --> 00:10:55,466

of the size of the star
to the size of the planet.

256

00:10:55,466 --> 00:10:57,066

It's actually
the ratio of the area.

257

00:10:57,066 --> 00:10:59,500

It tells us how much--
what percentage of the area

258

00:10:59,500 --> 00:11:01,566

of the star are we blocking.

259

00:11:02,966 --> 00:11:06,766

So if we block--
if we know how big the star is,

260

00:11:06,766 --> 00:11:08,200

and we know
what percentage of light

261

00:11:08,200 --> 00:11:10,400

the star is being blocked,

262

00:11:10,400 --> 00:11:11,700

we know how big the planet is.

263

00:11:11,700 --> 00:11:13,433

It's just simple as that.

264

00:11:13,433 --> 00:11:17,566

The other thing we can tell is
by how frequent the dips are,

265

00:11:17,566 --> 00:11:20,000

we can tell how fast the star--

266

00:11:20,000 --> 00:11:22,533

the planet goes around the star,
its orbital period.

267

00:11:22,533 --> 00:11:27,466

Earth would have one transit
every 365 days.

268

00:11:27,466 --> 00:11:29,300
That's all it is.

269
00:11:29,300 --> 00:11:33,233
By knowing how fast the planet
goes around the star,

270
00:11:33,233 --> 00:11:34,800
and knowing how big the star is,

271
00:11:34,800 --> 00:11:37,566
we know how far the planet
is away from star,

272
00:11:37,566 --> 00:11:39,333
we can start to understand
how much energy

273
00:11:39,333 --> 00:11:40,866
the planet's receiving
from its star,

274
00:11:40,866 --> 00:11:42,900
and then our imaginations
go wild

275
00:11:42,900 --> 00:11:45,100
thinking about
what kind of biology

276
00:11:45,100 --> 00:11:46,966
could be on this star.

277
00:11:46,966 --> 00:11:49,000
There are actually
lots of experts

278
00:11:49,000 --> 00:11:50,900
who know a lot more than we do

279

00:11:50,900 --> 00:11:53,933

and really turning this
from being what in my mind

280

00:11:53,933 --> 00:11:56,033

is amazing science fiction,
into science fact.

281

00:11:56,033 --> 00:11:58,333

And wonderful, in-depth, real,

282

00:11:58,333 --> 00:12:02,033

new understanding
about where we come from.

283

00:12:02,033 --> 00:12:03,333

So this is what I was saying.

284

00:12:03,333 --> 00:12:04,900

Turning pixels
into planets.

285

00:12:04,900 --> 00:12:06,233

We start off
with this fuzzy blob.

286

00:12:06,233 --> 00:12:08,166

This is one star here.

287

00:12:08,166 --> 00:12:10,100

We measure it continuously
for several years,

288

00:12:10,100 --> 00:12:13,000

and we get up the thing
in the center.

289

00:12:13,000 --> 00:12:14,733

This is showing that dip here.

290

00:12:14,733 --> 00:12:16,966

This is the transit.

291

00:12:16,966 --> 00:12:20,100

This transit's just less than--

292

00:12:20,100 --> 00:12:23,300

it's, like, one part in--

was it--

293

00:12:23,300 --> 00:12:24,833

one part in ten

to the four or so.

294

00:12:24,833 --> 00:12:26,933

Or ten to the four.

295

00:12:26,933 --> 00:12:29,566

That was the first rocky planet
we ever found.

296

00:12:29,566 --> 00:12:34,166

This planet was about 50%
larger than the Earth.

297

00:12:34,166 --> 00:12:36,333

It's the first
terrestrial planet we knew of

298

00:12:36,333 --> 00:12:39,633

outside of our own
solar system.

299

00:12:39,633 --> 00:12:41,833

And then there's the artistic
image in the bottom right.

300

00:12:41,833 --> 00:12:44,300

Because we like
artistic images.

301
00:12:46,533 --> 00:12:49,833
So this really tells a story

302
00:12:49,833 --> 00:12:52,433
of what the Kepler mission did

303
00:12:52,433 --> 00:12:56,700
and why I think when I use
a lot of superlatives

304
00:12:56,700 --> 00:12:58,766
to describe the impact
of this mission,

305
00:12:58,766 --> 00:13:01,033
I don't think
I'm overstating things.

306
00:13:01,033 --> 00:13:03,633
This is our understanding
in 2009

307
00:13:03,633 --> 00:13:07,100
of what the planets outside
our own solar system did.

308
00:13:07,100 --> 00:13:09,733
So the first planet
was found in 1995

309
00:13:09,733 --> 00:13:11,066
that was 51 Peg.

310
00:13:11,066 --> 00:13:14,133
First planet outside
our own solar system.

311
00:13:14,133 --> 00:13:15,400
And then, since then,

312
00:13:15,400 --> 00:13:17,533
there've been a--

313
00:13:17,533 --> 00:13:18,933
there was
a number of discoveries,

314
00:13:18,933 --> 00:13:21,033
most of them
very large planets.

315
00:13:21,033 --> 00:13:22,766
Most of them
things Jupiter-size.

316
00:13:22,766 --> 00:13:24,533
So this is a graph here.

317
00:13:24,533 --> 00:13:28,666
The Y axis,
the vertical axis shows

318
00:13:28,666 --> 00:13:31,900
the size of a planet
and the relative to Earth,

319
00:13:31,900 --> 00:13:33,733
where Earth is at 1.
Jupiter's at 11.

320
00:13:33,733 --> 00:13:35,100
Neptune's about 4.

321
00:13:35,100 --> 00:13:37,066
And the orbital period
of the planet,

322

00:13:37,066 --> 00:13:38,500
so the planet's year.

323

00:13:38,500 --> 00:13:40,400
You can see there's lots
of giant planets.

324

00:13:40,400 --> 00:13:42,533
There were some hot
giant planets in pink.

325

00:13:42,533 --> 00:13:44,233
These are ones found
by the transit method,

326

00:13:44,233 --> 00:13:46,200
the method that we used
with Kepler.

327

00:13:46,200 --> 00:13:48,766
And there are a few
smaller ones found,

328

00:13:48,766 --> 00:13:50,566
but nothing really that was

329

00:13:50,566 --> 00:13:53,833
definitely Earth--
looking like Earth.

330

00:13:53,833 --> 00:13:57,700
There was really a dearth
of planets around Neptune-size.

331

00:13:57,700 --> 00:14:01,166
So before we launched Kepler,

332

00:14:01,166 --> 00:14:03,933

we didn't know if Earths
were rare or common.

333

00:14:03,933 --> 00:14:05,966

We didn't know if Neptunes
were rare or common.

334

00:14:05,966 --> 00:14:07,866

Are most planets
Jupiter-size?

335

00:14:07,866 --> 00:14:10,166

You know, the most things
we found were Jupiter-size,

336

00:14:10,166 --> 00:14:12,900

but that's 'cause
that's all we could find.

337

00:14:12,900 --> 00:14:15,700

And this is what happened
over the next four years.

338

00:14:15,700 --> 00:14:19,466

Bam. There's about 4,600
planet candidates in here,

339

00:14:19,466 --> 00:14:22,166

of which so far
we know 2,300 of those

340

00:14:22,166 --> 00:14:24,833

are real confirmed exoplanets.

341

00:14:26,766 --> 00:14:28,066

So this has gone from knowing

342

00:14:28,066 --> 00:14:30,933

of tens of planets Jupiter-size

343

00:14:30,933 --> 00:14:34,233

to knowing that there are
thousands of planets out there.

344

00:14:34,233 --> 00:14:36,600

And most of them, interestingly,
aren't like the Earth.

345

00:14:36,600 --> 00:14:38,066

They're not like Neptune either.

346

00:14:38,066 --> 00:14:40,566

They're in this middle range
between Earth and Neptune,

347

00:14:40,566 --> 00:14:42,666

what we call super-Earths.

348

00:14:42,666 --> 00:14:44,633

Super-Earths are wonderful
and fantastic,

349

00:14:44,633 --> 00:14:46,933

because we don't have any
of them of our own solar system,

350

00:14:46,933 --> 00:14:49,633

so we really don't understand
very much about them.

351

00:14:49,633 --> 00:14:51,400

You know, if we find
something Earth-sized,

352

00:14:51,400 --> 00:14:52,700

we can make a good guess

353

00:14:52,700 --> 00:14:54,966

that it's maybe like Venus

or maybe like Earth.

354

00:14:54,966 --> 00:14:57,500

We find something Jupiter-size,
well, maybe it's like Jupiter.

355

00:14:57,500 --> 00:14:59,766

If we find something
super-Earth-sized,

356

00:14:59,766 --> 00:15:01,700

we really don't know.

357

00:15:03,633 --> 00:15:04,766

So it's an exciting time

358

00:15:04,766 --> 00:15:06,900

trying to learn
what these are made of

359

00:15:06,900 --> 00:15:09,300

and why are they so common.

360

00:15:09,300 --> 00:15:12,066

But you can see,
there's no planets out here.

361

00:15:12,066 --> 00:15:13,766

So this is 2013.

362

00:15:13,766 --> 00:15:15,466

And since then,
when the mission stopped--

363

00:15:15,466 --> 00:15:17,466

and since then, we've been
working extremely hard

364

00:15:17,466 --> 00:15:19,133

to develop our algorithms
and software

365

00:15:19,133 --> 00:15:21,300

to improve our detection methods

366

00:15:21,300 --> 00:15:24,233

and methodologies

and signal-to-noise

367

00:15:24,233 --> 00:15:25,233

so we can find these.

368

00:15:25,233 --> 00:15:26,300

We can dig in the noise

369

00:15:26,300 --> 00:15:29,300

and find these new planets

out here,

370

00:15:29,300 --> 00:15:32,266

which is where we're really

hoping to find exoplanets.

371

00:15:32,266 --> 00:15:35,833

Because at least as far

as we can understand,

372

00:15:35,833 --> 00:15:39,500

planets like ours

have liquid water,

373

00:15:39,500 --> 00:15:41,600

and they are the size of ours.

374

00:15:41,600 --> 00:15:43,466

So we're trying to find things

in that regime,

375

00:15:43,466 --> 00:15:46,266

that are temperate enough
to have liquid water, perhaps.

376

00:15:46,266 --> 00:15:49,100

And so this is the latest,
as of--

377

00:15:49,100 --> 00:15:51,700

the latest planet candidate
to come out in 2015.

378

00:15:51,700 --> 00:15:53,900

There are very little updates
since then,

379

00:15:53,900 --> 00:15:56,733

but there'll be
another update this year.

380

00:15:56,733 --> 00:15:59,466

And you can see that finally
we're starting to find

381

00:15:59,466 --> 00:16:04,500

small numbers of planets
out at this Earth region.

382

00:16:04,500 --> 00:16:07,166

That means we're sensitive
to Earth-sized things,

383

00:16:07,166 --> 00:16:08,900

and we're finding
Earth-sized things

384

00:16:08,900 --> 00:16:10,900

at orbital periods of one year.

385

00:16:10,900 --> 00:16:14,900

This is places
like where we live, perhaps.

386
00:16:14,900 --> 00:16:17,100
And the next mission is going
to try and understand them.

387
00:16:17,100 --> 00:16:18,900
Do they have atmospheres?
What are they like?

388
00:16:18,900 --> 00:16:20,666
Do they have water?
This is the future.

389
00:16:20,666 --> 00:16:22,533
This is--for the interns
in the room,

390
00:16:22,533 --> 00:16:24,500
this is your generation

391
00:16:24,500 --> 00:16:27,900
is to help us learn
and help us understand,

392
00:16:27,900 --> 00:16:29,833
or even just to exist
at the time

393
00:16:29,833 --> 00:16:33,033
when we're finding atmospheres
on other planets.

394
00:16:34,866 --> 00:16:38,366
Okay, so as I mentioned,
before the Kepler launch,

395
00:16:38,366 --> 00:16:41,100
we knew of just

Jupiter-sized things.

396

00:16:41,100 --> 00:16:42,533

So are they common?

The answer is no.

397

00:16:42,533 --> 00:16:44,133

Jupiters are extremely rare.

398

00:16:44,133 --> 00:16:45,233

If you look at what we find,

399

00:16:45,233 --> 00:16:48,900

we find very few

Jupiter-sized planets.

400

00:16:48,900 --> 00:16:51,133

Other detection methods

are finding the same thing.

401

00:16:51,133 --> 00:16:52,966

Jupiter isn't a common thing.

402

00:16:52,966 --> 00:16:56,600

In fact, if you found

another Earth-sized planet

403

00:16:56,600 --> 00:16:57,966

in the habitable zone,

404

00:16:57,966 --> 00:17:02,866

it probably doesn't have

a Jupiter companion.

405

00:17:02,866 --> 00:17:04,466

The most common things

we're finding are

406

00:17:04,466 --> 00:17:06,700

sort of Neptunes, super-Earths,
and Neptunes,

407

00:17:06,700 --> 00:17:09,833

and then a good number
of Earth-sized things.

408

00:17:09,833 --> 00:17:12,633

When you correct
for our detection sensitivity,

409

00:17:12,633 --> 00:17:15,600

you find that probably the most
common planets out there

410

00:17:15,600 --> 00:17:17,700

are things
that are Earth-sized.

411

00:17:20,766 --> 00:17:24,133

I just wanted to touch upon some
of the individual discoveries,

412

00:17:24,133 --> 00:17:27,766

a lot of them led by people
who work within NASA Ames

413

00:17:27,766 --> 00:17:29,666

along with some wonderful
external scientists

414

00:17:29,666 --> 00:17:32,366

who've been involved
with our team.

415

00:17:32,366 --> 00:17:36,000

This includes things that are
the first Earth-sized planets,

416

00:17:36,000 --> 00:17:38,833

the first--
Kepler-22b,

417
00:17:38,833 --> 00:17:42,033
the first planet
inside its habitable zone.

418
00:17:42,033 --> 00:17:43,400
And then as we move along,

419
00:17:43,400 --> 00:17:45,666
the first Earth-sized planet
inside its habitable zone.

420
00:17:45,666 --> 00:17:46,833
This is Kepler-186f.

421
00:17:46,833 --> 00:17:49,300
And the first sort of
super-Earth-sized thing

422
00:17:49,300 --> 00:17:51,900
orbiting within
the habitable zone.

423
00:17:51,900 --> 00:17:53,733
None of these are
quite earthlike yet,

424
00:17:53,733 --> 00:17:57,366
so these are just
the most exciting planets

425
00:17:57,366 --> 00:17:58,833
we've discovered so far.

426
00:17:58,833 --> 00:18:02,133
I think we're moving towards,
every step we make,

427

00:18:02,133 --> 00:18:03,933

things that remind us of Earth.

428

00:18:06,633 --> 00:18:09,100

And if you think if we've found
these thousands of planets,

429

00:18:09,100 --> 00:18:11,033

we must be looking
at a lot of the sky.

430

00:18:11,033 --> 00:18:13,666

Actually, no.

We look at one tiny area.

431

00:18:13,666 --> 00:18:16,966

This region just shows you
the tiny span

432

00:18:16,966 --> 00:18:18,700

where we're finding planets
with Kepler.

433

00:18:18,700 --> 00:18:20,200

In fact, it's even
smaller than this,

434

00:18:20,200 --> 00:18:21,433

because we can only find planets

435

00:18:21,433 --> 00:18:23,300

that cross in front
of their star.

436

00:18:23,300 --> 00:18:25,166

But of course,
the vast majority of planets

437

00:18:25,166 --> 00:18:26,833

don't cross in front
of their star.

438

00:18:26,833 --> 00:18:30,133

Their ecliptic plane
isn't angled towards us;

439

00:18:30,133 --> 00:18:31,500

therefore, we don't find them.

440

00:18:31,500 --> 00:18:33,166

We only detect a few percent

441

00:18:33,166 --> 00:18:36,333

or less than a percent
of planets around their stars.

442

00:18:36,333 --> 00:18:37,600

So while we've found thousands,

443

00:18:37,600 --> 00:18:39,566

the galaxy is huge,
and we detect very few.

444

00:18:39,566 --> 00:18:42,466

So there really are truly
planets everywhere.

445

00:18:43,766 --> 00:18:47,233

So Kepler's--unfortunately,
the Kepler mission

446

00:18:47,233 --> 00:18:50,666

came to an end
after four years in 2013.

447

00:18:50,666 --> 00:18:54,866

In 2012, we had a good inkling
that the--

448

00:18:54,866 --> 00:18:57,733

that our time operating
the Kepler mission

449

00:18:57,733 --> 00:18:59,633

was going to come to an end.

450

00:18:59,633 --> 00:19:02,000

We lost a reaction wheel.

451

00:19:02,000 --> 00:19:03,533

So on the spacecraft
we launched,

452

00:19:03,533 --> 00:19:04,733

we have four reaction wheels.

453

00:19:04,733 --> 00:19:06,633

You can actually see them here.

454

00:19:06,633 --> 00:19:08,566

These are the wheels.

455

00:19:08,566 --> 00:19:12,566

These things--I'm not
actually pointing to the wheel.

456

00:19:12,566 --> 00:19:14,666

Those are wheels.

457

00:19:14,666 --> 00:19:18,000

These actually--this is
how we point the spacecraft.

458

00:19:18,000 --> 00:19:19,033

You have wheels.

459

00:19:19,033 --> 00:19:20,733

You have them orthogonal
to each other,

460
00:19:20,733 --> 00:19:22,100
and you spin them.

461
00:19:22,100 --> 00:19:23,700
And by spinning
in the right way,

462
00:19:23,700 --> 00:19:24,833
you can turn the spacecraft,

463
00:19:24,833 --> 00:19:26,533
or you can hold it
pointing steady.

464
00:19:26,533 --> 00:19:29,766
The solar wind is
constantly blowing towards us,

465
00:19:29,766 --> 00:19:31,600
and it's trying
to turn the spacecraft.

466
00:19:31,600 --> 00:19:33,833
And so we need to counteract
that by spinning wheels.

467
00:19:33,833 --> 00:19:34,833
It's very simple.

468
00:19:34,833 --> 00:19:36,166
It's nicely--

469
00:19:36,166 --> 00:19:38,600
just using angular momentum
to keep us pointing.

470

00:19:38,600 --> 00:19:41,466

Unfortunately,
losing one is okay,

471

00:19:41,466 --> 00:19:44,633

because you still have
three axes and three dimensions,

472

00:19:44,633 --> 00:19:46,433

and you still have three wheels.

473

00:19:46,433 --> 00:19:48,300

Losing two is not good.

474

00:19:48,300 --> 00:19:51,400

And in 2013, we lost
the second of these.

475

00:19:51,400 --> 00:19:54,033

So that meant
that we have two axes

476

00:19:54,033 --> 00:19:55,900

and three spatial dimensions.

477

00:19:55,900 --> 00:19:59,500

And many people thought that
that was the mission over.

478

00:19:59,500 --> 00:20:02,766

But here are some
nice headlines I found.

479

00:20:02,766 --> 00:20:07,333

Kepler planet hunting suffers
major failure, says NASA.

480

00:20:07,333 --> 00:20:09,000

That was it.
Perhaps that was it.

481

00:20:09,000 --> 00:20:11,500

Perhaps that was
the end of the mission.

482

00:20:11,500 --> 00:20:14,700

Rest in peace, Kepler.

483

00:20:14,700 --> 00:20:17,366

NASA gives up hope of fixing it.

484

00:20:17,366 --> 00:20:19,500

One thing you should learn
about engineers is,

485

00:20:19,500 --> 00:20:21,600

I think they never give up

486

00:20:21,600 --> 00:20:23,533

even if they're told
they have to give up.

487

00:20:23,533 --> 00:20:25,700

They're gonna keep
digging away,

488

00:20:25,700 --> 00:20:29,100

and I think talking
to some of the engineers,

489

00:20:29,100 --> 00:20:32,033

Ball Aerospace and here at Ames
who were involved in this--

490

00:20:32,033 --> 00:20:35,933

the time when Kepler broke
and things looked pretty dire,

491

00:20:35,933 --> 00:20:37,600

I think they had the most fun

492

00:20:37,600 --> 00:20:39,433
they've ever had
in their entire lives.

493

00:20:39,433 --> 00:20:42,966
NASA missions are fairly
restricted, you know?

494

00:20:42,966 --> 00:20:46,266
You don't want to go--
draw outside the lines,

495

00:20:46,266 --> 00:20:49,000
because your spacecraft
is operating well,

496

00:20:49,000 --> 00:20:50,533
and you don't want
to break anything.

497

00:20:50,533 --> 00:20:53,033
And it's very easy
to break things in space.

498

00:20:53,033 --> 00:20:55,366
But suddenly you had
something that was broken,

499

00:20:55,366 --> 00:20:57,766
and you couldn't
make it more broken.

500

00:20:57,766 --> 00:20:59,100
It didn't work.

501

00:20:59,100 --> 00:21:01,366
So you are allowed
to do anything--

502

00:21:01,366 --> 00:21:04,733
within reason--anything you like
to try and fix it.

503

00:21:04,733 --> 00:21:07,766
All wacky ideas
were entertained

504

00:21:07,766 --> 00:21:10,100
about what we could do
with the spacecraft.

505

00:21:10,100 --> 00:21:12,600
And you got to play
doing all these things

506

00:21:12,600 --> 00:21:14,900
that at graduate school
and at undergraduate,

507

00:21:14,900 --> 00:21:20,033
you learned about operating.

508

00:21:22,066 --> 00:21:25,300
So this was the next report
that came out.

509

00:21:25,300 --> 00:21:26,900
"All is not lost."

510

00:21:26,900 --> 00:21:30,333
Suddenly someone had an idea
of how we can keep going,

511

00:21:30,333 --> 00:21:31,633
and hobbled spacecraft

512

00:21:31,633 --> 00:21:33,466

"now on the hunt
for a new mission."

513

00:21:33,466 --> 00:21:35,666

So this was great.

What was this new mission?

514

00:21:35,666 --> 00:21:38,000

This new mission

was the K2 mission.

515

00:21:41,133 --> 00:21:43,366

Many people say,

why is it called K2?

516

00:21:43,366 --> 00:21:44,733

Why is it not Kepler2?

517

00:21:44,733 --> 00:21:46,600

Well, I'm gonna answer that.

518

00:21:46,600 --> 00:21:47,733

Because, well, it's named

519

00:21:47,733 --> 00:21:50,033

after the mountain K2,

not Kepler.

520

00:21:50,033 --> 00:21:52,666

While Everest may be

the highest mountain,

521

00:21:52,666 --> 00:21:55,800

a higher proportion of people

died climbing K2,

522

00:21:55,800 --> 00:21:58,233

so I thought this was

an appropriate metaphor

523
00:21:58,233 --> 00:21:59,733
for our mission,

524
00:21:59,733 --> 00:22:04,633
an extremely challenging thing
to do

525
00:22:04,633 --> 00:22:07,133
and to try and keep operating.

526
00:22:07,133 --> 00:22:10,333
So how does this
new Kepler mission work?

527
00:22:10,333 --> 00:22:14,000
So you have three axes.

528
00:22:14,000 --> 00:22:15,833
I brought a model.
I have a prop.

529
00:22:15,833 --> 00:22:17,866
So you have three axes.

530
00:22:17,866 --> 00:22:19,333
And if you think
you point it like this

531
00:22:19,333 --> 00:22:21,066
and your solar pressure
goes like this,

532
00:22:21,066 --> 00:22:23,600
you're going to roll like this
and tumble.

533
00:22:23,600 --> 00:22:25,433
And you might be able
to hold two dimensions,

534

00:22:25,433 --> 00:22:26,900

but you're still gonna
start to roll,

535

00:22:26,900 --> 00:22:28,700

and you're gonna
start to tumble.

536

00:22:28,700 --> 00:22:30,900

So what we need--
what the engineers realized is,

537

00:22:30,900 --> 00:22:34,666

we need to find a way
to balance the spacecraft.

538

00:22:34,666 --> 00:22:38,066

To hold the spacecraft
in fine-pointing while--

539

00:22:38,066 --> 00:22:39,266

with the two reaction wheels

540

00:22:39,266 --> 00:22:41,166

and then balance
against the solar pressure.

541

00:22:41,166 --> 00:22:42,500

And then once you come up
with that idea,

542

00:22:42,500 --> 00:22:43,933

the answer's fairly simple.

543

00:22:43,933 --> 00:22:45,866

The solar pressure
comes at you like this,

544

00:22:45,866 --> 00:22:47,433

so you need to point
like this at the Sun.

545

00:22:47,433 --> 00:22:50,666

You can hold the pitch
and yaw steady.

546

00:22:50,666 --> 00:22:52,266

You guys are the Sun
in this image.

547

00:22:52,266 --> 00:22:54,200

Pitch and yaw steady.

548

00:22:54,200 --> 00:22:56,000

That's this way.

549

00:22:56,000 --> 00:22:59,766

And then all that's uncontrolled
is this roll vector.

550

00:22:59,766 --> 00:23:02,800

So if you point
your solar panels,

551

00:23:02,800 --> 00:23:04,433

the thing I told you
would be important,

552

00:23:04,433 --> 00:23:07,200

at the Sun so that
they're finely balanced,

553

00:23:07,200 --> 00:23:09,100

so that the spacecraft
looks symmetrical

554

00:23:09,100 --> 00:23:10,766

and normal to the Sun,

555

00:23:10,766 --> 00:23:13,600

you minimize roll, and you can
balance your spacecraft.

556

00:23:13,600 --> 00:23:16,100

You can point precisely
right over here,

557

00:23:16,100 --> 00:23:19,200

and you can operate
your mission again.

558

00:23:19,200 --> 00:23:22,233

So this ridge is what
we call the balance point.

559

00:23:23,566 --> 00:23:25,966

And this is just another image
showing you this way,

560

00:23:25,966 --> 00:23:27,766

down the boresight
of the spacecraft.

561

00:23:27,766 --> 00:23:29,500

And you can see
what we need to do is,

562

00:23:29,500 --> 00:23:31,133

we need to find--
find a way

563

00:23:31,133 --> 00:23:33,966

so that the Sun coming from here
is just balanced,

564

00:23:33,966 --> 00:23:37,133

and so we spent several months
commissioning the spacecraft,

565

00:23:37,133 --> 00:23:40,066

essentially learning
what the spacecraft looked like

566

00:23:40,066 --> 00:23:41,466

in the normal to the Sun.

567

00:23:41,466 --> 00:23:44,000

So our commissioning involved us
pointing at the--

568

00:23:44,000 --> 00:23:47,100

pointing at the field of the sky
and seeing how much we roll

569

00:23:47,100 --> 00:23:48,433

and then changing
the angle of it

570

00:23:48,433 --> 00:23:50,433

and seeing how much we roll
until we learned

571

00:23:50,433 --> 00:23:52,600

where the balance
of the spacecraft was.

572

00:23:52,600 --> 00:23:55,000

And amazingly,
we were able to do this.

573

00:23:55,000 --> 00:23:58,500

We were able to learn the shape
of the spacecraft in space

574

00:23:58,500 --> 00:24:00,566

and point the spacecraft
precisely

575

00:24:00,566 --> 00:24:02,800

using wheels
and by balancing it.

576

00:24:02,800 --> 00:24:06,900

Now, it's not a finely
precise balance.

577

00:24:06,900 --> 00:24:08,433

It's an unstable equilibrium.

578

00:24:08,433 --> 00:24:10,600

Eventually, you're gonna roll
one way or the other.

579

00:24:10,600 --> 00:24:12,833

So the way we control for that

580

00:24:12,833 --> 00:24:15,400

is that if we point it,
we start to roll.

581

00:24:15,400 --> 00:24:17,233

If we roll too far,
we fire a thruster,

582

00:24:17,233 --> 00:24:18,600

which puts us back.

583

00:24:18,600 --> 00:24:21,700

And the thrusters--
the thrusters are on here.

584

00:24:21,700 --> 00:24:23,400

It puts us back
to where we were.

585

00:24:23,400 --> 00:24:25,400

And so you have this

continual motion of pointing,

586

00:24:25,400 --> 00:24:27,366

roll, reset, roll, reset.

587

00:24:27,366 --> 00:24:29,900

And we do that about
every 6-12 hours.

588

00:24:31,666 --> 00:24:33,400

So this is the nice headline.

589

00:24:33,400 --> 00:24:34,833

I thought this was
well-described,

590

00:24:34,833 --> 00:24:36,333

exactly what we're doing there.

591

00:24:36,333 --> 00:24:40,166

That description: Kepler
"resurrects planet-hunting"--

592

00:24:40,166 --> 00:24:42,100

"NASA resurrects
planet-hunting Kepler

593

00:24:42,100 --> 00:24:46,500

with broken parts
with magical sun."

594

00:24:46,500 --> 00:24:48,733

So I think that's--
I thought that was very nice.

595

00:24:50,900 --> 00:24:53,866

So yeah.
Magical sun.

596

00:24:53,866 --> 00:24:57,533

Because of what we're doing,
it actually limits us

597

00:24:57,533 --> 00:24:59,666

but also created our mission

598

00:24:59,666 --> 00:25:01,333

and created what we're doing.

599

00:25:01,333 --> 00:25:03,633

Our limitations, though, are
that we could only look for--

600

00:25:03,633 --> 00:25:06,300

part of the sky
for about 80 days.

601

00:25:06,300 --> 00:25:08,633

The reason being,
if you think of the--

602

00:25:08,633 --> 00:25:09,866

again, you're the Sun,

603

00:25:09,866 --> 00:25:12,900

and you're going around
the Sun like--

604

00:25:12,900 --> 00:25:16,066

around the Sun like this
looking backwards,

605

00:25:16,066 --> 00:25:18,866

you can look
at somewhere over here,

606

00:25:18,866 --> 00:25:21,533

and your limit is,
you can't go too far around,

607

00:25:21,533 --> 00:25:23,566

or you're gonna start
getting light down the barrel

608

00:25:23,566 --> 00:25:25,166

of the spacecraft,
which is terrible.

609

00:25:25,166 --> 00:25:26,633

You don't want
sunlight down there.

610

00:25:26,633 --> 00:25:28,433

And then--that's around here.

611

00:25:28,433 --> 00:25:30,000

You don't--
and in the other side,

612

00:25:30,000 --> 00:25:32,866

you can't get too far around
this way as you orbit the Sun,

613

00:25:32,866 --> 00:25:34,500

because you don't want--
you want to get

614

00:25:34,500 --> 00:25:36,200

the solar panel
to keep having light.

615

00:25:36,200 --> 00:25:38,700

So that limits us
to observations of--

616

00:25:38,700 --> 00:25:39,833

in one way, about 30 degrees,

617

00:25:39,833 --> 00:25:41,066
and the other way,
about 50 degrees,

618
00:25:41,066 --> 00:25:42,366
so about 80 degrees.

619
00:25:42,366 --> 00:25:46,266
Because our orbital period
is roughly 360 degrees,

620
00:25:46,266 --> 00:25:47,700
that's about 1 degree a day.

621
00:25:47,700 --> 00:25:50,166
So that gives us
an 80-day campaign.

622
00:25:50,166 --> 00:25:51,766
So this is what this is showing.

623
00:25:51,766 --> 00:25:53,500
This is us going around
the Sun this way.

624
00:25:53,500 --> 00:25:54,933
We point at a field over here.

625
00:25:54,933 --> 00:25:56,800
We move around.
We keep pointing.

626
00:25:56,800 --> 00:25:58,900
And then we point
to one 90 degrees away.

627
00:25:58,900 --> 00:26:00,700
And this is
in 80 days of motion.

628
00:26:00,700 --> 00:26:02,300
We point backwards,

629
00:26:02,300 --> 00:26:06,333
so we don't get bugs
on the mirror when we move.

630
00:26:06,333 --> 00:26:08,566
It's actually so we don't
get Earth in the field of view.

631
00:26:08,566 --> 00:26:11,366
If you point forwards,
you would get Earth

632
00:26:11,366 --> 00:26:12,966
in the field of view
very naturally.

633
00:26:12,966 --> 00:26:15,133
Earth would have to pass
through the field of view.

634
00:26:15,133 --> 00:26:16,733
Earth's extremely bright,

635
00:26:16,733 --> 00:26:18,300
and when we were
commissioning this,

636
00:26:18,300 --> 00:26:20,433
and we weren't sure
what would happen if something

637
00:26:20,433 --> 00:26:22,700
that bright fell
into our focal plane,

638
00:26:22,700 --> 00:26:23,933

and so we decided, well,

639

00:26:23,933 --> 00:26:25,866

given the balance
between pulling forwards

640

00:26:25,866 --> 00:26:27,400

and backwards, it's fairly even.

641

00:26:27,400 --> 00:26:28,700

Let's point backwards.

642

00:26:28,700 --> 00:26:30,466

We've since learned
that it's actually fine

643

00:26:30,466 --> 00:26:32,600

if Earth gets
into our field of view.

644

00:26:32,600 --> 00:26:35,933

It doesn't cause any long-term
damage or anything.

645

00:26:35,933 --> 00:26:39,233

But that was just the way
we built the mission.

646

00:26:39,233 --> 00:26:43,333

So what happens then is,
you get a lot of fields observed

647

00:26:43,333 --> 00:26:45,000

along this ecliptic plane,

648

00:26:45,000 --> 00:26:48,833

the plane that our spacecraft--

649

00:26:48,833 --> 00:26:50,766

our spacecraft looks out on,

650

00:26:50,766 --> 00:26:52,766

the plane that the Earth
and Sun are in.

651

00:26:52,766 --> 00:26:54,066

And so this is nice.

652

00:26:54,066 --> 00:26:56,233

You all know the constellations
in the ecliptic plane,

653

00:26:56,233 --> 00:26:57,433

or probably most of you,

654

00:26:57,433 --> 00:27:01,600

because they're
the zodiacal constellations.

655

00:27:01,600 --> 00:27:03,433

So the first two years
of our mission

656

00:27:03,433 --> 00:27:07,433

is shown in brown.

657

00:27:07,433 --> 00:27:09,833

It's probably brown--
brown here.

658

00:27:09,833 --> 00:27:13,033

And the next two years
are shown in green.

659

00:27:13,033 --> 00:27:15,233

So these next two years
have just been funded,

660

00:27:15,233 --> 00:27:19,833
so we know we're gonna go
be at least a four-year mission.

661
00:27:19,833 --> 00:27:22,533
I'm gonna talk
a little bit soon

662
00:27:22,533 --> 00:27:24,866
about the yellow arrow here.

663
00:27:24,866 --> 00:27:25,900
This is Campaign 9.

664
00:27:25,900 --> 00:27:27,433
This is our
microlensing campaign.

665
00:27:27,433 --> 00:27:29,600
We did a dedicated campaign
to microlensing,

666
00:27:29,600 --> 00:27:32,133
and you're gonna hear
some of that later.

667
00:27:32,133 --> 00:27:33,400
I might give you a talk,
or someone else

668
00:27:33,400 --> 00:27:34,433
will give you
a talk in two years,

669
00:27:34,433 --> 00:27:36,600
telling you about
the next arrow,

670
00:27:36,600 --> 00:27:38,033
the supernova focus campaign,

671

00:27:38,033 --> 00:27:42,133
a single experiment dedicating
to understanding supernova

672

00:27:42,133 --> 00:27:44,466
and the early rise
of when a supernova happens,

673

00:27:44,466 --> 00:27:47,233
but that's gonna happen
sometime next year.

674

00:27:49,366 --> 00:27:53,700
K2 isn't just Kepler, but worse.

675

00:27:53,700 --> 00:27:56,333
That's the important thing.

676

00:27:56,333 --> 00:27:57,666
It's a very different mission,

677

00:27:57,666 --> 00:28:00,233
and we knew we couldn't survive
being Kepler, but worse.

678

00:28:00,233 --> 00:28:03,666
Kepler changed everything,

679

00:28:03,666 --> 00:28:05,133
but Kepler took all this data,

680

00:28:05,133 --> 00:28:08,433
and we're using it
to understand around us,

681

00:28:08,433 --> 00:28:10,933
but I think Kepler's done.

682

00:28:10,933 --> 00:28:13,900

I mean, we got the data
we needed

683

00:28:13,900 --> 00:28:15,900

to learn a lot
about our universe.

684

00:28:15,900 --> 00:28:17,466

We don't want to collect
that data again

685

00:28:17,466 --> 00:28:18,566

and learn the same things.

686

00:28:18,566 --> 00:28:20,800

We want to do something new.

687

00:28:20,800 --> 00:28:23,166

So K2 enables us to do that.

688

00:28:23,166 --> 00:28:25,300

We can do things
we couldn't do with Kepler

689

00:28:25,300 --> 00:28:27,400

because of the way
the spacecraft operates.

690

00:28:27,400 --> 00:28:30,433

Here are just some
examples of things

691

00:28:30,433 --> 00:28:31,766

that we didn't do with Kepler.

692

00:28:31,766 --> 00:28:33,566

This is M35.

693

00:28:33,566 --> 00:28:35,833

This is a cluster of stars.

694

00:28:35,833 --> 00:28:38,633

Clusters of stars

are fantastic laboratories

695

00:28:38,633 --> 00:28:40,100

to study astrophysics.

696

00:28:40,100 --> 00:28:42,200

All the stars formed

at the same time

697

00:28:42,200 --> 00:28:43,700

or roughly the same time;

698

00:28:43,700 --> 00:28:46,366

therefore, they probably all

have the same composition.

699

00:28:46,366 --> 00:28:50,433

So you have stars of the same

composition, same age.

700

00:28:50,433 --> 00:28:51,700

Why do they differ?

701

00:28:51,700 --> 00:28:53,766

And their differences

should tell you something

702

00:28:53,766 --> 00:28:55,800

about how old they are,

703

00:28:55,800 --> 00:28:59,600

how massive they are,

what their radius is,

704

00:28:59,600 --> 00:29:01,500

what their evolution history is.

705

00:29:01,500 --> 00:29:03,200

Are binaries more common?

706

00:29:03,200 --> 00:29:04,566

Are binaries less common?

707

00:29:04,566 --> 00:29:06,633

What are planets like
in clusters?

708

00:29:06,633 --> 00:29:08,966

So you can learn
about how things form

709

00:29:08,966 --> 00:29:10,333

as the universe goes on

710

00:29:10,333 --> 00:29:12,633

by looking at different clusters
at different ages.

711

00:29:12,633 --> 00:29:14,366

Kepler didn't look
at many clusters.

712

00:29:14,366 --> 00:29:16,833

We can look at lots because
we look along the ecliptic.

713

00:29:16,833 --> 00:29:18,400

Ecliptic's full of clusters.

714

00:29:18,400 --> 00:29:20,600

We look at--
Kepler looked at one field.

715

00:29:20,600 --> 00:29:22,833

We're gonna look at 18 fields.

716

00:29:22,833 --> 00:29:26,466

So we get 18 times the amount of area that Kepler saw.

717

00:29:26,466 --> 00:29:29,100

This is star-forming regions.

718

00:29:29,100 --> 00:29:31,533

Kepler intentionally didn't look at star-forming regions.

719

00:29:31,533 --> 00:29:32,766

Why is that?

720

00:29:32,766 --> 00:29:34,666

Because star-forming regions are full of dust,

721

00:29:34,666 --> 00:29:36,833

and dust absorbs optical light.

722

00:29:36,833 --> 00:29:39,300

And if you absorb optical light, you don't see as many stars,

723

00:29:39,300 --> 00:29:40,933

you don't find as many planets,

724

00:29:40,933 --> 00:29:43,300

and you can't find Earth-like things.

725

00:29:43,300 --> 00:29:46,000

With K2, that's not a limitation anymore.

726

00:29:46,000 --> 00:29:47,633

We look at a single field
for 80 days.

727

00:29:47,633 --> 00:29:49,133

If it's got lots of dust,

728

00:29:49,133 --> 00:29:52,033

we'll just look at somewhere
with less dust in three months.

729

00:29:52,033 --> 00:29:54,666

And now we can start to study
these younger stars.

730

00:29:54,666 --> 00:29:56,833

We can study how stars form.

731

00:29:56,833 --> 00:29:58,666

We can study how planets form.

732

00:29:58,666 --> 00:30:00,700

We can study when planets form.

733

00:30:00,700 --> 00:30:03,433

Do planets form right away
at the same time as the star?

734

00:30:03,433 --> 00:30:05,600

Do they take a few million years
after the star?

735

00:30:05,600 --> 00:30:07,433

Do they form close to the star?

736

00:30:07,433 --> 00:30:09,166

Do they form far out
from the star?

737

00:30:09,166 --> 00:30:11,566

These are questions K2
can answer

738

00:30:11,566 --> 00:30:13,366

that Kepler
wasn't able to answer.

739

00:30:13,366 --> 00:30:15,400

These are new science
we're learning.

740

00:30:15,400 --> 00:30:17,400

And something I'll show you
a little bit of--

741

00:30:17,400 --> 00:30:20,300

a movie of--
this is a comet here.

742

00:30:20,300 --> 00:30:22,933

The ecliptic plane,
as we learned very quickly

743

00:30:22,933 --> 00:30:25,133

when we started getting
our commissioning data,

744

00:30:25,133 --> 00:30:26,866

is full of moving objects,

745

00:30:26,866 --> 00:30:29,066

because it looks at where
our own solar system is.

746

00:30:29,066 --> 00:30:30,866

Our solar system forms
in a disk,

747

00:30:30,866 --> 00:30:33,700
and so K2 is looking
into this disk,

748
00:30:33,700 --> 00:30:36,566
and so we see thousands
and thousands of asteroids,

749
00:30:36,566 --> 00:30:38,333
and we see planets.

750
00:30:38,333 --> 00:30:40,933
But planets closer to home
than what we're used to.

751
00:30:43,666 --> 00:30:45,466
This is a little bit
out of focus,

752
00:30:45,466 --> 00:30:48,866
but this is a cover image
from a proposal we put in.

753
00:30:48,866 --> 00:30:50,033
But this is showing you

754
00:30:50,033 --> 00:30:52,166
all the constellations
along our ecliptic,

755
00:30:52,166 --> 00:30:53,800
and things that either
we have observed

756
00:30:53,800 --> 00:30:56,566
or will observe
in those constellations.

757
00:30:56,566 --> 00:31:00,766
And you can see this huge

variety from galaxies,

758

00:31:00,766 --> 00:31:03,466

to planets,
to clusters,

759

00:31:03,466 --> 00:31:04,866

to planetary nebula,

760

00:31:04,866 --> 00:31:07,100

all different science
and all different fields.

761

00:31:07,100 --> 00:31:09,566

Depending on where you look,
you find different things.

762

00:31:09,566 --> 00:31:12,133

You have different science.

763

00:31:12,133 --> 00:31:15,466

So I think K2
has really far exceeded

764

00:31:15,466 --> 00:31:18,300

our expectations of the breadth
of science it's doing.

765

00:31:18,300 --> 00:31:22,066

It's really changed from this
somewhat narrow mission

766

00:31:22,066 --> 00:31:24,266

of Kepler into this
extremely broad mission

767

00:31:24,266 --> 00:31:27,466

of a general astrophysics
observatory.

768

00:31:27,466 --> 00:31:28,766

In addition to astrophysics,

769

00:31:28,766 --> 00:31:30,500

we also do some
planetary science work.

770

00:31:30,500 --> 00:31:32,133

Planetary science
is looking at things

771

00:31:32,133 --> 00:31:34,800

in our own solar system.

772

00:31:34,800 --> 00:31:37,933

Here is just a quick movie
of an object

773

00:31:37,933 --> 00:31:39,366

from our own solar system.

774

00:31:39,366 --> 00:31:41,533

This is the planet Neptune,

775

00:31:41,533 --> 00:31:43,433

and you can see something
going around Neptune.

776

00:31:43,433 --> 00:31:46,000

That's the moon Triton.

777

00:31:46,000 --> 00:31:49,000

This is, I think,
about 60 days of data,

778

00:31:49,000 --> 00:31:51,466

and you can see
this planet moving.

779

00:31:51,466 --> 00:31:53,266

You see a smear
because the planet--

780

00:31:53,266 --> 00:31:54,966

a bleed of the brightness,

781

00:31:54,966 --> 00:31:56,366

because the planet's
very bright.

782

00:31:56,366 --> 00:31:59,066

But you can see very nicely
the moon, the motion,

783

00:31:59,066 --> 00:32:00,666

and the orbital dynamics.

784

00:32:00,666 --> 00:32:03,000

You know, a lot of us learned
orbital dynamics

785

00:32:03,000 --> 00:32:05,333

in undergraduate
and in high school

786

00:32:05,333 --> 00:32:07,866

and PhD at different levels.

787

00:32:07,866 --> 00:32:09,533

I certainly had never seen

788

00:32:09,533 --> 00:32:11,733

orbital dynamics happen
in real time

789

00:32:11,733 --> 00:32:13,766

or in a movie like this

790
00:32:13,766 --> 00:32:16,733
as the moon
goes around the planet here.

791
00:32:16,733 --> 00:32:19,066
You can see
Kepler's laws in action

792
00:32:19,066 --> 00:32:20,900
in a single movie.

793
00:32:20,900 --> 00:32:23,300
And the reason that Neptune
is moving so much

794
00:32:23,300 --> 00:32:25,066
isn't that Neptune's
moving fast.

795
00:32:25,066 --> 00:32:27,166
It's that the parallactic angle

796
00:32:27,166 --> 00:32:31,466
of Kepler to Neptune here
is changing.

797
00:32:31,466 --> 00:32:35,000
As the spacecraft
moves around the Sun,

798
00:32:35,000 --> 00:32:37,900
the position of Neptune

799
00:32:37,900 --> 00:32:39,933
compared to
the background stars moves.

800
00:32:39,933 --> 00:32:42,866
We call this a parallax,

and that's what's going on here.

801

00:32:42,866 --> 00:32:45,000

This is just showing you
some of the other

802

00:32:45,000 --> 00:32:46,633

solar system stuff we're doing.

803

00:32:46,633 --> 00:32:48,800

This is the brightness change

804

00:32:48,800 --> 00:32:51,166

of some trans-Neptunian objects,

805

00:32:51,166 --> 00:32:53,733

things in the same orbit
as Pluto.

806

00:32:53,733 --> 00:32:56,933

You can see this little wiggle
in brightness as they rotate.

807

00:32:56,933 --> 00:32:59,900

We can learn
the shapes of bodies

808

00:32:59,900 --> 00:33:01,100

in the outer solar system.

809

00:33:01,100 --> 00:33:02,566

We can learn how they rotate.

810

00:33:02,566 --> 00:33:05,300

We can learn
how bright they are.

811

00:33:05,300 --> 00:33:08,633

This can help us learn

how the solar system formed.

812

00:33:08,633 --> 00:33:10,533

The reason I'm showing
planetary science stuff

813

00:33:10,533 --> 00:33:12,500

is because I think
nobody predicted

814

00:33:12,500 --> 00:33:14,966

that we would do a lot
of planetary science work,

815

00:33:14,966 --> 00:33:17,533

but it's actually become a very
important part of the mission

816

00:33:17,533 --> 00:33:19,600

as we learn about
our own solar system.

817

00:33:19,600 --> 00:33:21,366

And that informs us
of our exoplanets

818

00:33:21,366 --> 00:33:23,366

and vice versa.

819

00:33:23,366 --> 00:33:24,900

I like this movie because
it's the faintest thing

820

00:33:24,900 --> 00:33:26,833

we ever observed with K2.

821

00:33:26,833 --> 00:33:28,733

This is something--for those
who understand magnitudes,

822

00:33:28,733 --> 00:33:31,766

23rd magnitude
is extremely faint.

823

00:33:31,766 --> 00:33:33,966

You can see something
going up and down.

824

00:33:33,966 --> 00:33:35,533

Do you see that?

825

00:33:35,533 --> 00:33:37,233

That's a trans-Neptunian object.

826

00:33:37,233 --> 00:33:40,433

I don't know if you can
see that in the movie.

827

00:33:40,433 --> 00:33:41,733

You have to get your eye in.

828

00:33:41,733 --> 00:33:43,966

There we go.
Up and down.

829

00:33:43,966 --> 00:33:46,500

The faintest thing
we've ever observed.

830

00:33:46,500 --> 00:33:48,366

Kepler observed from--or K2,

831

00:33:48,366 --> 00:33:50,266

we observe objects
from the extremely bright

832

00:33:50,266 --> 00:33:51,566

to the extremely faint.

833

00:33:51,566 --> 00:33:54,166

We have this huge
dynamical range in brightness.

834

00:33:56,066 --> 00:33:58,433

Okay, so I mentioned clusters.

835

00:33:58,433 --> 00:33:59,866

Clusters is extremely important.

836

00:33:59,866 --> 00:34:02,400

This is an image
of the Pleiades.

837

00:34:02,400 --> 00:34:04,500

I show Hubble images
because Hubble's beautiful,

838

00:34:04,500 --> 00:34:05,533

as I mentioned earlier.

839

00:34:05,533 --> 00:34:07,066

This is a Hubble image
of the Pleiades.

840

00:34:07,066 --> 00:34:09,700

This is actually our image
of the Pleiades,

841

00:34:09,700 --> 00:34:13,766

the Seven Sisters as many
of you will know it.

842

00:34:13,766 --> 00:34:15,533

And the seven bright stars here,

843

00:34:15,533 --> 00:34:17,666

which are used really heavily

844
00:34:17,666 --> 00:34:19,200
in astrophysics
to try and understand

845
00:34:19,200 --> 00:34:21,833
how stars operate.

846
00:34:21,833 --> 00:34:23,566
Zoom in here, and this is
showing you--

847
00:34:23,566 --> 00:34:25,033
this is the shape of our CCDs.

848
00:34:25,033 --> 00:34:27,566
This is showing you where--

849
00:34:27,566 --> 00:34:30,300
where we looked
for a given campaign.

850
00:34:30,300 --> 00:34:33,100
And then we put masks around
these, we put masks around them,

851
00:34:33,100 --> 00:34:36,800
and we can observe
these bright stars

852
00:34:36,800 --> 00:34:38,766
in this field of view.

853
00:34:38,766 --> 00:34:40,766
You can see them actually
because I'm moving here.

854
00:34:40,766 --> 00:34:42,033
That's the movement
of the spacecraft

855

00:34:42,033 --> 00:34:43,633

I mentioned,
the six-hour roll.

856

00:34:43,633 --> 00:34:45,033

So by looking at these,

857

00:34:45,033 --> 00:34:47,666

we can look how their
brightness changes over time.

858

00:34:47,666 --> 00:34:50,633

We can look at seismology
inside of these stars

859

00:34:50,633 --> 00:34:51,866

as they oscillate,

860

00:34:51,866 --> 00:34:53,700

as gas moves up and down

861

00:34:53,700 --> 00:34:55,800

and convects inside them.

862

00:34:55,800 --> 00:34:57,733

And we can understand
the internal structure

863

00:34:57,733 --> 00:35:02,366

of these stars that people have
been observing for millennia.

864

00:35:02,366 --> 00:35:05,500

Give new insights on them.

865

00:35:05,500 --> 00:35:07,866

This is just--
I just thought I'd show you

866

00:35:07,866 --> 00:35:11,566
some of the full frame images,
as we call them.

867

00:35:11,566 --> 00:35:13,500
This is our full frame.

868

00:35:13,500 --> 00:35:15,500
You'll see that there
are 2 CCDs

869

00:35:15,500 --> 00:35:17,033
that are no longer operating,

870

00:35:17,033 --> 00:35:21,666
but the rest of the area
really is vast

871

00:35:21,666 --> 00:35:25,866
and can teach us a huge amount
about our galaxy.

872

00:35:25,866 --> 00:35:28,033
And so this is
where the Pleiades is.

873

00:35:28,033 --> 00:35:29,533
This is another cluster,
the Hyades,

874

00:35:29,533 --> 00:35:30,866
that many of you heard of.

875

00:35:30,866 --> 00:35:33,066
Praesepe,
or the Beehive Cluster,

876

00:35:33,066 --> 00:35:35,933

falls into things.

877

00:35:35,933 --> 00:35:38,233

So this is a hugely
diverse field

878

00:35:38,233 --> 00:35:40,933

and hugely new things
that we can look into.

879

00:35:40,933 --> 00:35:43,300

Of course, K2's still
an exoplanet powerhouse.

880

00:35:43,300 --> 00:35:46,033

Exoplanets really is
what the mission

881

00:35:46,033 --> 00:35:48,033

primarily seems to do.

882

00:35:48,033 --> 00:35:49,533

While we're
a general observatory,

883

00:35:49,533 --> 00:35:52,133

people propose
to do science,

884

00:35:52,133 --> 00:35:55,733

and exoplanets is obviously
a very big part of this.

885

00:35:55,733 --> 00:35:58,466

There are 50 confirmed--

886

00:35:58,466 --> 00:36:01,500

more than 50 confirmed planets
from K2.

887

00:36:01,500 --> 00:36:03,533

I think there's about
a thousand planet candidates

888

00:36:03,533 --> 00:36:04,933

as of yesterday.

889

00:36:04,933 --> 00:36:08,133

There was an announcement of
about 800 new planet candidates.

890

00:36:08,133 --> 00:36:11,633

So K2 is pushing up there

891

00:36:11,633 --> 00:36:14,900

towards the sort of Kepler
numbers of things detected.

892

00:36:14,900 --> 00:36:16,600

And crucially,
we're finding planets

893

00:36:16,600 --> 00:36:18,033

around the nearest stars,

894

00:36:18,033 --> 00:36:20,133

around the nearest
and brightest stars.

895

00:36:20,133 --> 00:36:22,566

Things that perhaps we can hope
to characterize with missions

896

00:36:22,566 --> 00:36:24,333

like James Webb.

897

00:36:24,333 --> 00:36:26,466

So this is the--
as of a month ago,

898

00:36:26,466 --> 00:36:27,933

the number of planets
we're finding.

899

00:36:27,933 --> 00:36:30,200

You see this actually
mirrors Kepler quite nicely.

900

00:36:30,200 --> 00:36:32,666

Very few bigger things,

901

00:36:32,666 --> 00:36:34,966

many more of these
smaller things,

902

00:36:34,966 --> 00:36:37,233

peaking at
the super-Earth-sized regime

903

00:36:37,233 --> 00:36:38,766

where we're most sensitive.

904

00:36:42,900 --> 00:36:45,500

So this is just showing you
some of the reasons

905

00:36:45,500 --> 00:36:47,000

why we differ from Kepler.

906

00:36:47,000 --> 00:36:49,133

This is a popular handout image

907

00:36:49,133 --> 00:36:52,766

that we gave to many people
as opposed to for Kepler,

908

00:36:52,766 --> 00:36:54,066

and then we made one for K2.

909

00:36:54,066 --> 00:36:56,633

And with Kepler, you thought
how small the Sun is.

910

00:36:56,633 --> 00:36:58,766

And with K2, you think
how big the Sun is.

911

00:36:58,766 --> 00:37:02,400

That's 'cause K2 looks
at lots of nearby stars,

912

00:37:02,400 --> 00:37:05,300

trying to find planets
around the smallest stars,

913

00:37:05,300 --> 00:37:07,033

these M-dwarfs, as we call them.

914

00:37:07,033 --> 00:37:10,266

The reason being, small stars
have a bigger transit depth.

915

00:37:10,266 --> 00:37:13,533

Transit is a function
of the area of the planet

916

00:37:13,533 --> 00:37:15,666

divided by the area
of the star blocked

917

00:37:15,666 --> 00:37:17,333

or the area of the star.

918

00:37:17,333 --> 00:37:19,433

And therefore,
if you shrink the star,

919

00:37:19,433 --> 00:37:22,600

you find smaller planets
more easily.

920

00:37:22,600 --> 00:37:24,200

So that's what we're
doing with K2.

921

00:37:24,200 --> 00:37:26,866

We're finding these planets
around the smallest stars.

922

00:37:28,766 --> 00:37:30,466

So Kepler's taught us a lot

923

00:37:30,466 --> 00:37:32,466

about the inner part
of the solar system,

924

00:37:32,466 --> 00:37:33,766

of solar systems.

925

00:37:33,766 --> 00:37:35,300

It's taught us
about the occurrence

926

00:37:35,300 --> 00:37:38,033

of things interior,
basically of Earth's

927

00:37:38,033 --> 00:37:39,866

orbit around the stars.

928

00:37:39,866 --> 00:37:41,233

But if you look at this graph,

929

00:37:41,233 --> 00:37:42,800

this shows you how--

930

00:37:42,800 --> 00:37:47,633

where the inner system
of our solar system

931

00:37:47,633 --> 00:37:49,133

and where Kepler's sensitive.

932

00:37:49,133 --> 00:37:51,833

The blue region here
is showing Kepler sensitivity

933

00:37:51,833 --> 00:37:55,266

as a function of distance
from a star.

934

00:37:55,266 --> 00:37:58,433

And it tails off as you
get towards Earth's orbit.

935

00:37:58,433 --> 00:38:01,433

And then if you shrink
that region down

936

00:38:01,433 --> 00:38:03,866

and look at how big
our solar system is,

937

00:38:03,866 --> 00:38:05,266

you realize that Kepler,

938

00:38:05,266 --> 00:38:08,133

while teaching us so much
about other planetary systems,

939

00:38:08,133 --> 00:38:12,533

is just a tiny window
into even our own solar system.

940

00:38:12,533 --> 00:38:14,300

In fact, if you think of what

941
00:38:14,300 --> 00:38:16,866
Kepler could detect
in our own solar system,

942
00:38:16,866 --> 00:38:18,333
Kepler might find one,

943
00:38:18,333 --> 00:38:21,033
perhaps two planets
in our own solar system,

944
00:38:21,033 --> 00:38:24,033
of which our own system
has many.

945
00:38:24,033 --> 00:38:26,500
So we just probed
this tiny regime.

946
00:38:26,500 --> 00:38:28,666
Fortunately, there's something
called microlensing

947
00:38:28,666 --> 00:38:31,000
that may come out to inform us

948
00:38:31,000 --> 00:38:35,700
of other regions
around other stars.

949
00:38:35,700 --> 00:38:39,533
Teach us things about Neptune,
Saturn, Uranus

950
00:38:39,533 --> 00:38:43,433
and their frequency that we
simply don't know right now.

951

00:38:43,433 --> 00:38:45,800

And K2 is gonna be
an important part of this.

952

00:38:45,800 --> 00:38:48,300

So what is gravitational
microlensing?

953

00:38:48,300 --> 00:38:49,733

Very, very simply,

954

00:38:49,733 --> 00:38:51,600

gravitational microlensing uses

955

00:38:51,600 --> 00:38:54,866

the fact that gravity
warps space-time.

956

00:38:54,866 --> 00:38:56,566

So if you have
a lot of gravity,

957

00:38:56,566 --> 00:38:58,166

and you have a background star,

958

00:38:58,166 --> 00:39:00,400

the light from that
background galaxy

959

00:39:00,400 --> 00:39:02,433

as traditional microlensing--

960

00:39:02,433 --> 00:39:05,566

the light from that galaxy
is gonna be bent.

961

00:39:05,566 --> 00:39:07,566

It's gonna be focused.

962

00:39:07,566 --> 00:39:11,600

And so you see that light
in these background galaxies

963

00:39:11,600 --> 00:39:13,200

is brighter than they
would actually be.

964

00:39:13,200 --> 00:39:15,366

This is the traditional
gravitational microlensing.

965

00:39:15,366 --> 00:39:17,366

It's been used for a long time

966

00:39:17,366 --> 00:39:20,033

to weigh foreground galaxies.

967

00:39:20,033 --> 00:39:21,533

You can understand
the mass of things

968

00:39:21,533 --> 00:39:23,500

by how much
they bend the light.

969

00:39:27,166 --> 00:39:31,033

Microlensing--
that was gravitational lensing.

970

00:39:31,033 --> 00:39:33,866

Microlensing uses this effect

971

00:39:33,866 --> 00:39:36,466

but on the much,
much smaller scale.

972

00:39:36,466 --> 00:39:39,566

If you take a background star,
a star in our galactic bulge,

973

00:39:39,566 --> 00:39:42,333

say, in the center
of our galaxy,

974

00:39:42,333 --> 00:39:44,233

and then you have that light
coming towards you,

975

00:39:44,233 --> 00:39:46,300

and then you have
a foreground star,

976

00:39:46,300 --> 00:39:48,300

perhaps even a star
that's too faint to see,

977

00:39:48,300 --> 00:39:49,766

but the light
of that background star

978

00:39:49,766 --> 00:39:51,766

is bent around
the foreground star.

979

00:39:51,766 --> 00:39:54,566

So as that foreground star
moves past--

980

00:39:54,566 --> 00:39:55,800

because everything is moving--

981

00:39:55,800 --> 00:39:58,133

moves past the background star,

982

00:39:58,133 --> 00:39:59,800

you see the background star
get brighter,

983

00:39:59,800 --> 00:40:02,133
because the light
is focused towards us.

984
00:40:02,133 --> 00:40:04,033
We call this a microlens.

985
00:40:04,033 --> 00:40:05,666
And so that's what
you're seeing here.

986
00:40:05,666 --> 00:40:07,666
Background star,
foreground star moving.

987
00:40:07,666 --> 00:40:10,966
You see this shape
of the brightening.

988
00:40:10,966 --> 00:40:14,166
But what if this foreground
star had a planet?

989
00:40:14,166 --> 00:40:16,200
You'd see two dips.
You'd see first the main

990
00:40:16,200 --> 00:40:18,233
dip of the microlensing
of the star,

991
00:40:18,233 --> 00:40:19,633
and then a little dip caused

992
00:40:19,633 --> 00:40:22,400
by the lensing of the planet,
the planet's causing.

993
00:40:22,400 --> 00:40:24,066
And this is

the microlensing event.

994

00:40:24,066 --> 00:40:26,900

So this goes up, and you can
see the secondary dip.

995

00:40:26,900 --> 00:40:30,166

And that lasts, you know,
a few hours to a day,

996

00:40:30,166 --> 00:40:34,700

and the main event
might last a few weeks.

997

00:40:34,700 --> 00:40:38,633

We have detected
a few planets like this,

998

00:40:38,633 --> 00:40:39,900

but very few.

999

00:40:39,900 --> 00:40:41,166

And the Kepler mission

1000

00:40:41,166 --> 00:40:42,933

is gonna help us
detect many more of these.

1001

00:40:42,933 --> 00:40:46,733

This is a brief movie
I'm gonna show,

1002

00:40:46,733 --> 00:40:48,933

showing you
how this effect works,

1003

00:40:48,933 --> 00:40:50,633

not just for stars of planets

1004

00:40:50,633 --> 00:40:52,900
but also perhaps
for free-floating planets.

1005
00:40:52,900 --> 00:40:56,400
The idea is that there's planets
orbiting no star,

1006
00:40:56,400 --> 00:40:59,100
wandering planets
or rogue planets.

1007
00:40:59,100 --> 00:41:00,766
I call them
free-floating planets.

1008
00:41:00,766 --> 00:41:03,033
So in addition
to finding planets around--

1009
00:41:03,033 --> 00:41:04,833
distant around their own star--

1010
00:41:04,833 --> 00:41:09,500
we can also find planets
that orbit with no star.

1011
00:41:09,500 --> 00:41:11,600
So this is just
the microlensing effect.

1012
00:41:20,166 --> 00:41:22,200
This is the lens here
move across--

1013
00:41:22,200 --> 00:41:24,433
this is the--
this is the foreground star

1014
00:41:24,433 --> 00:41:26,566

that you can't see
warping the lights.

1015
00:41:26,566 --> 00:41:27,900
And then you see this ring

1016
00:41:27,900 --> 00:41:29,633
as it focused
the light towards you.

1017
00:41:29,633 --> 00:41:31,166
And then when you add up
all that light,

1018
00:41:31,166 --> 00:41:34,533
you see this brightening.

1019
00:41:36,000 --> 00:41:38,266
So K2's gonna look
towards the center of the galaxy

1020
00:41:38,266 --> 00:41:39,500
where there are
the most stars.

1021
00:41:39,500 --> 00:41:41,300
You have the most chance
of something passing

1022
00:41:41,300 --> 00:41:44,400
in front of a background star.

1023
00:41:44,400 --> 00:41:47,266
And it's gonna try and find
these events by looking

1024
00:41:47,266 --> 00:41:51,533
at a large patch
of the sky towards there.

1025

00:41:51,533 --> 00:41:53,766

If we just look
at what Kepler probed

1026

00:41:53,766 --> 00:41:56,666

in its tiny region,
we can see that

1027

00:41:56,666 --> 00:41:59,466

that in comparison is very small
compared to where

1028

00:41:59,466 --> 00:42:01,233

the microlensing region
is gonna probe.

1029

00:42:01,233 --> 00:42:04,466

The microlensing region has a
much more higher volume of space

1030

00:42:04,466 --> 00:42:07,766

where can find events towards
the center of the galaxy,

1031

00:42:07,766 --> 00:42:10,933

looking for these
very faint stars

1032

00:42:10,933 --> 00:42:12,866

that pass in front
of these background things.

1033

00:42:12,866 --> 00:42:15,000

So--but why K2?

1034

00:42:15,000 --> 00:42:18,000

These microlensing events have
been observed from the ground.

1035

00:42:18,000 --> 00:42:20,466
Some wonderful ground-based
observing projects

1036
00:42:20,466 --> 00:42:22,400
to detect them,
and they've found planets.

1037
00:42:22,400 --> 00:42:26,366
They have found a few--
low tens of planets.

1038
00:42:26,366 --> 00:42:27,700
Kepler gives you
something else.

1039
00:42:27,700 --> 00:42:30,233
Kepler isn't orbiting Earth.

1040
00:42:30,233 --> 00:42:31,900
It's far from the Earth,
in fact.

1041
00:42:31,900 --> 00:42:35,066
As I mentioned, it's about
8/10 of the way to the Sun,

1042
00:42:35,066 --> 00:42:37,466
is the distance
that Kepler's away.

1043
00:42:37,466 --> 00:42:39,566
So that means
that Kepler and Earth

1044
00:42:39,566 --> 00:42:41,433
look at a different angle

1045
00:42:41,433 --> 00:42:43,266
towards these

microlensing events.

1046

00:42:43,266 --> 00:42:47,433

And these microlensing events
are extremely precisely tuned,

1047

00:42:47,433 --> 00:42:50,633

and the shape of this
brightening is very precise

1048

00:42:50,633 --> 00:42:53,100

and very sensitive to the angle
that you're looking at it.

1049

00:42:53,100 --> 00:42:55,733

So if both of them look
at a slightly different angle,

1050

00:42:55,733 --> 00:42:57,400

they see different things.

1051

00:42:57,400 --> 00:42:59,833

The events look
slightly different.

1052

00:42:59,833 --> 00:43:01,600

This is just an example

1053

00:43:01,600 --> 00:43:03,166

of what something
would look like here.

1054

00:43:03,166 --> 00:43:05,933

You see the microlensing
event from Earth,

1055

00:43:05,933 --> 00:43:08,200

and you see a slightly
different time of center

1056

00:43:08,200 --> 00:43:10,100

and a slightly different
magnification

1057

00:43:10,100 --> 00:43:11,800

from what the spacecraft--

1058

00:43:11,800 --> 00:43:15,033

the K2 mission would detect
with the Kepler spacecraft.

1059

00:43:15,033 --> 00:43:17,366

And you can use
these differences in the shape

1060

00:43:17,366 --> 00:43:20,566

to learn things
about the unseen lens star,

1061

00:43:20,566 --> 00:43:23,233

primarily on the unseen
lens planet, hopefully.

1062

00:43:23,233 --> 00:43:26,100

Primarily you learn
about its mass.

1063

00:43:26,100 --> 00:43:28,366

You learn how massive
these planets are.

1064

00:43:28,366 --> 00:43:30,333

Without the extra line of sight,

1065

00:43:30,333 --> 00:43:32,900

it's very hard to
uniquely determine the mass.

1066

00:43:34,833 --> 00:43:36,266

I'll skip that one.

1067

00:43:36,266 --> 00:43:38,700

Of course, doing this requires

1068

00:43:38,700 --> 00:43:41,933

a lot of ground-based observing.

1069

00:43:41,933 --> 00:43:45,966

The Earth is a challenging place
to look at continuously.

1070

00:43:45,966 --> 00:43:48,433

K2 can look at a place
continuously fairly easily.

1071

00:43:48,433 --> 00:43:49,500

We just point.

1072

00:43:49,500 --> 00:43:51,033

On the Earth,
there are two reasons.

1073

00:43:51,033 --> 00:43:53,733

One, the Earth rotates,
and you have daytime.

1074

00:43:53,733 --> 00:43:55,233

Two, you have weather.

1075

00:43:55,233 --> 00:43:56,600

You have clouds.

1076

00:43:56,600 --> 00:43:59,166

So because we wanted
to observe this region

1077

00:43:59,166 --> 00:44:00,933

simultaneously from Earth

and space

1078

00:44:00,933 --> 00:44:03,666

for three months
with no break,

1079

00:44:03,666 --> 00:44:06,500

we put together
a huge network

1080

00:44:06,500 --> 00:44:08,833

of telescopes to observe.

1081

00:44:08,833 --> 00:44:10,666

This is just some
of the telescopes

1082

00:44:10,666 --> 00:44:14,500

that are observing these regions
of sky continuously,

1083

00:44:14,500 --> 00:44:17,033

both doing observing
of large regions

1084

00:44:17,033 --> 00:44:19,800

and also follow-up
of events that are found.

1085

00:44:19,800 --> 00:44:22,366

These telescopes--I think
most of them are observing

1086

00:44:22,366 --> 00:44:24,600

every single night
for the campaign,

1087

00:44:24,600 --> 00:44:28,533

Campaign 9, which ended
a few days ago.

1088

00:44:28,533 --> 00:44:29,866

And most of these are manual,

1089

00:44:29,866 --> 00:44:32,466

so you needed people
observing at the telescopes

1090

00:44:32,466 --> 00:44:35,633

for three months straight
for all these telescopes.

1091

00:44:35,633 --> 00:44:38,733

I like to think that we actually
observed the microlensing region

1092

00:44:38,733 --> 00:44:40,633

for more than 24 hours a day

1093

00:44:40,633 --> 00:44:42,066

because we had
multiple telescopes

1094

00:44:42,066 --> 00:44:45,533

going simultaneously
for three months.

1095

00:44:45,533 --> 00:44:47,333

And so that meant that
when there's weather

1096

00:44:47,333 --> 00:44:49,333

and when there's daytime,
there wasn't a break.

1097

00:44:49,333 --> 00:44:51,666

This is just the first image

1098

00:44:51,666 --> 00:44:54,600

that we pulled down
from the spacecraft.

1099
00:44:54,600 --> 00:44:55,800
This is our full frame image.

1100
00:44:55,800 --> 00:44:57,966
This was made courtesy
of Doug Caldwell,

1101
00:44:57,966 --> 00:44:59,733
who works within the project.

1102
00:44:59,733 --> 00:45:02,233
And I just wanted to show you
what this looks like.

1103
00:45:02,233 --> 00:45:05,166
It looks nothing like any of
our previous full frame images,

1104
00:45:05,166 --> 00:45:07,500
and that's because
it's just packed with stars.

1105
00:45:07,500 --> 00:45:08,966
There's stars everywhere.

1106
00:45:08,966 --> 00:45:11,000
And, you know, this is like
looking at the Milky Way.

1107
00:45:11,000 --> 00:45:12,900
In fact, if any of you
have been lucky enough to be

1108
00:45:12,900 --> 00:45:15,400
in the Southern Hemisphere, it's
like looking in the Milky Way

1109
00:45:15,400 --> 00:45:16,500
in the Southern Hemisphere,

1110
00:45:16,500 --> 00:45:18,733
where you see more stars.

1111
00:45:18,733 --> 00:45:20,333
And so this is a region--
the dark regions

1112
00:45:20,333 --> 00:45:21,400
where there's lots of dust.

1113
00:45:21,400 --> 00:45:23,400
And here you see
huge numbers of stars.

1114
00:45:23,400 --> 00:45:24,566
And this is where we do

1115
00:45:24,566 --> 00:45:26,600
some of our microlensing
experiments.

1116
00:45:28,366 --> 00:45:29,833
And as of today,

1117
00:45:29,833 --> 00:45:32,300
there are about 500
microlensing events

1118
00:45:32,300 --> 00:45:33,966
detected from the ground

1119
00:45:33,966 --> 00:45:35,766
and from the spacecraft,

1120
00:45:35,766 --> 00:45:38,100

which we hope
to find planets in.

1121
00:45:38,100 --> 00:45:39,266
It's still a work in progress.

1122
00:45:39,266 --> 00:45:41,666
The campaign stopped
over the weekend,

1123
00:45:41,666 --> 00:45:43,233
but we're gonna
be working hard

1124
00:45:43,233 --> 00:45:46,833
to find more events
as time goes on.

1125
00:45:46,833 --> 00:45:48,700
I'm just gonna stop here
in saying

1126
00:45:48,700 --> 00:45:50,333
that this isn't the end
of the story.

1127
00:45:50,333 --> 00:45:53,866
Microlensing we understand
as an agency

1128
00:45:53,866 --> 00:45:56,200
to be an extremely valuable way

1129
00:45:56,200 --> 00:45:59,266
to determine what other
planetary systems are like.

1130
00:45:59,266 --> 00:46:01,700
Kepler told us
about the hot planets,

1131

00:46:01,700 --> 00:46:04,466

the planets that are hotter
than Earth and equal to Earth.

1132

00:46:04,466 --> 00:46:07,033

K2 and a WFIRST in the future

1133

00:46:07,033 --> 00:46:09,466

are telling us
about the cold planets.

1134

00:46:09,466 --> 00:46:11,466

WFIRST will launch in 2024

1135

00:46:11,466 --> 00:46:15,433

and will be detecting thousands
of Jupiter-like planets

1136

00:46:15,433 --> 00:46:16,966

and Neptune-like planets

1137

00:46:16,966 --> 00:46:19,100

and maybe cold,
Earth-like planets

1138

00:46:19,100 --> 00:46:22,566

orbiting their distant stars.

1139

00:46:22,566 --> 00:46:24,700

And hopefully lots
of free-floating planets

1140

00:46:24,700 --> 00:46:27,333

orbiting no star,
rogue planets.

1141

00:46:27,333 --> 00:46:30,833

So all I say is just thanks

for coming and stay tuned

1142

00:46:30,833 --> 00:46:33,400

for early estimates
of microlensing events

1143

00:46:33,400 --> 00:46:34,966

when we find them
that will be coming out

1144

00:46:34,966 --> 00:46:36,633

over the next 12 months.

1145

00:46:36,633 --> 00:46:37,633

Thank you.

1146

00:46:37,633 --> 00:46:40,633

[applause]

1147

00:46:43,366 --> 00:46:45,166

- Very good.

Thank you.

1148

00:46:45,166 --> 00:46:47,700

So we have time
for some questions.

1149

00:46:47,700 --> 00:46:49,633

If you have a question,
please raise your hand

1150

00:46:49,633 --> 00:46:50,866

and wait for the microphone.

1151

00:46:50,866 --> 00:46:52,500

Ask one question only.

1152

00:46:52,500 --> 00:46:53,933

Thank you.

1153

00:47:02,366 --> 00:47:04,733

- Hi. Richard,
University of Colorado.

1154

00:47:04,733 --> 00:47:06,233

Thank you for that great talk.

1155

00:47:06,233 --> 00:47:07,600

I have a question regarding

1156

00:47:07,600 --> 00:47:10,800

the regions of planets
that are detected.

1157

00:47:10,800 --> 00:47:14,433

You had mentioned that
there's an issue of sensitivity

1158

00:47:14,433 --> 00:47:16,933

in terms of noise
versus detection,

1159

00:47:16,933 --> 00:47:19,900

and it's in this sort of
Earth analog--

1160

00:47:19,900 --> 00:47:24,066

sorry, Earth--
Earth region.

1161

00:47:24,066 --> 00:47:27,233

I'm wondering if you are aware
of the Starshade Project,

1162

00:47:27,233 --> 00:47:29,633

and I'm wondering if you have
any information regarding that

1163

00:47:29,633 --> 00:47:31,266
and how it's proceeding.

1164
00:47:31,266 --> 00:47:32,566
If it's proceeding.

1165
00:47:32,566 --> 00:47:34,833
- Yeah, so yeah,

1166
00:47:34,833 --> 00:47:38,100
our limits of sensitivity
of Earth-size

1167
00:47:38,100 --> 00:47:41,533
came because when you build
a spacecraft,

1168
00:47:41,533 --> 00:47:46,000
you tend not to fund it
to do things far

1169
00:47:46,000 --> 00:47:49,266
and beyond your actual--
what you want to do.

1170
00:47:49,266 --> 00:47:52,033
You know, you want to come in
as cheap as possible,

1171
00:47:52,033 --> 00:47:53,666
but still do amazing science.

1172
00:47:53,666 --> 00:47:56,433
So you make what you want
to do just possible.

1173
00:47:56,433 --> 00:47:58,133
And so that's why
we're not detecting many,

1174

00:47:58,133 --> 00:47:59,666

'cause it's extremely hard,

1175

00:47:59,666 --> 00:48:03,500

and our mission ended
after just four years.

1176

00:48:03,500 --> 00:48:06,666

However, we are finding things,
which is really fantastic.

1177

00:48:06,666 --> 00:48:10,666

The Starshade Project
is just mind-blowing.

1178

00:48:10,666 --> 00:48:11,866

It really is.

1179

00:48:11,866 --> 00:48:14,733

You launch a spacecraft
to look at a star.

1180

00:48:14,733 --> 00:48:17,500

You then launch
this huge thing that can be,

1181

00:48:17,500 --> 00:48:19,633

you know, tens of meters across.

1182

00:48:19,633 --> 00:48:21,633

Looks like petals of a flower

1183

00:48:21,633 --> 00:48:23,666

to block light from the star.

1184

00:48:23,666 --> 00:48:25,833

And by blocking light
from the star,

1185

00:48:25,833 --> 00:48:28,433

you can start to see
the planets around the star.

1186

00:48:28,433 --> 00:48:30,466

The reason--if you look
at a star in the sky,

1187

00:48:30,466 --> 00:48:31,666

you can't see planets,

1188

00:48:31,666 --> 00:48:33,800

even if your eyes
were incredibly sensitive,

1189

00:48:33,800 --> 00:48:37,166

because you're swamped by light
from the--

1190

00:48:37,166 --> 00:48:38,866

light from the star
swamps any light

1191

00:48:38,866 --> 00:48:39,866

coming from the planet.

1192

00:48:39,866 --> 00:48:42,966

But if you use
very clever optics

1193

00:48:42,966 --> 00:48:44,500

to block out light
from the star,

1194

00:48:44,500 --> 00:48:46,366

you can see the planets.

1195

00:48:46,366 --> 00:48:49,000

These starshades are gonna orbit

millions of miles

1196

00:48:49,000 --> 00:48:50,766
from the spacecraft.

1197

00:48:50,766 --> 00:48:52,700
It's an incredible undertaking,

1198

00:48:52,700 --> 00:48:54,766
but certainly there are plans

1199

00:48:54,766 --> 00:48:57,700
that the Starshade's
gonna be launched

1200

00:48:57,700 --> 00:48:59,533
perhaps in the 2020s.

1201

00:48:59,533 --> 00:49:01,066
There are certainly
investigations

1202

00:49:01,066 --> 00:49:02,466
going on right now.

1203

00:49:02,466 --> 00:49:07,266
Perhaps even as part
of the WFIRST experiment.

1204

00:49:07,266 --> 00:49:11,400
It's very much an exciting
new area of research,

1205

00:49:11,400 --> 00:49:13,666
but it's very
challenging to do.

1206

00:49:13,666 --> 00:49:16,666
One of the reasons is, you

can look at one star over here,

1207

00:49:16,666 --> 00:49:20,600

and then you have to move
your starshade millions of miles

1208

00:49:20,600 --> 00:49:23,666

in order to look at another star
in another part of the sky.

1209

00:49:23,666 --> 00:49:26,500

That and the optics are
incredibly hard to create.

1210

00:49:26,500 --> 00:49:28,633

But I think coronagraphs,

1211

00:49:28,633 --> 00:49:31,266

which are much smaller things
to block the light,

1212

00:49:31,266 --> 00:49:34,166

and starshades,
which are much bigger things

1213

00:49:34,166 --> 00:49:35,766

that orbit far
from the spacecraft,

1214

00:49:35,766 --> 00:49:38,466

are gonna be how
we're gonna find

1215

00:49:38,466 --> 00:49:41,166

and understand life

1216

00:49:41,166 --> 00:49:42,866

outside our own solar system,

1217

00:49:42,866 --> 00:49:45,833
because you can actually
image the planets themselves.

1218
00:49:45,833 --> 00:49:49,133
You can see directly the light
coming from these planets.

1219
00:49:49,133 --> 00:49:50,633
You can understand perhaps

1220
00:49:50,633 --> 00:49:53,100
what's in the atmospheres
of these planets.

1221
00:49:55,166 --> 00:49:57,300
- Hi, I'm Morgan
from Florida Tech,

1222
00:49:57,300 --> 00:50:00,633
and I was wondering
what the most common

1223
00:50:00,633 --> 00:50:03,666
solar system configuration is
for exoplanets

1224
00:50:03,666 --> 00:50:07,566
and if we have enough data
to speculate about that?

1225
00:50:10,300 --> 00:50:12,300
- Kepler really, you know,

1226
00:50:12,300 --> 00:50:14,200
it probes the inner
solar systems.

1227
00:50:14,200 --> 00:50:15,866
It doesn't probe

the outer solar systems,

1228

00:50:15,866 --> 00:50:17,333

but other things do.

1229

00:50:17,333 --> 00:50:22,766

I think the average solar system
doesn't have many giant planets.

1230

00:50:22,766 --> 00:50:25,166

The average solar system
probably has planets

1231

00:50:25,166 --> 00:50:26,833

closer in than ours.

1232

00:50:26,833 --> 00:50:29,433

We're probably a little unusual

1233

00:50:29,433 --> 00:50:32,400

in that we don't have
anything interior to Mercury.

1234

00:50:32,400 --> 00:50:37,033

That said, the universe is
so large that I think if you--

1235

00:50:37,033 --> 00:50:39,866

and--but the number
of parameters so high

1236

00:50:39,866 --> 00:50:42,466

that if you looked
at any planetary system,

1237

00:50:42,466 --> 00:50:45,766

you'd say this one's unique
for reason X.

1238

00:50:45,766 --> 00:50:47,600

But because there's
so many parameters,

1239

00:50:47,600 --> 00:50:49,433

every planetary system
is unique.

1240

00:50:49,433 --> 00:50:51,733

And we can point to things
in our solar system

1241

00:50:51,733 --> 00:50:53,133

that are unusual,

1242

00:50:53,133 --> 00:50:57,266

but unusual things
happen all the time.

1243

00:50:58,266 --> 00:50:59,700

I think one thing we have--

1244

00:50:59,700 --> 00:51:02,833

you know, as we increase
our knowledge as a species,

1245

00:51:02,833 --> 00:51:04,366

we learn how
insignificant we are.

1246

00:51:04,366 --> 00:51:05,800

And we're just
learning that again.

1247

00:51:05,800 --> 00:51:09,633

Planetary systems like ours
are likely common.

1248

00:51:09,633 --> 00:51:12,500

Maybe not--

maybe not the most common,

1249

00:51:12,500 --> 00:51:14,766

but they're certainly not rare.

1250

00:51:16,533 --> 00:51:20,000

- Hi, I'm Karima,

and thank you for your talk.

1251

00:51:20,000 --> 00:51:22,066

You mentioned earlier

that there's a focus

1252

00:51:22,066 --> 00:51:24,066

on refining algorithms

to find planets

1253

00:51:24,066 --> 00:51:25,366

that are the same size as Earth,

1254

00:51:25,366 --> 00:51:26,900

and I was wondering

why the priority is

1255

00:51:26,900 --> 00:51:29,600

on finding same size

instead of, like,

1256

00:51:29,600 --> 00:51:31,333

maybe the same energy or--

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00:51:31,333 --> 00:51:34,800

like, why does size make

a planet more inhabitable?

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00:51:34,800 --> 00:51:37,400

Why can't we inhabit bigger

or smaller planets?

1259

00:51:37,400 --> 00:51:40,633
- Yeah, so the Kepler mission

1260
00:51:40,633 --> 00:51:43,233
was focused
on finding planets like ours.

1261
00:51:43,233 --> 00:51:45,466
So orbiting stars like ours,

1262
00:51:45,466 --> 00:51:49,200
orbiting planets
at distances like ours

1263
00:51:49,200 --> 00:51:50,933
and sizes like ours.

1264
00:51:50,933 --> 00:51:54,833
The reason being is,
we have a sample of one,

1265
00:51:54,833 --> 00:51:56,533
one planet with life,

1266
00:51:56,533 --> 00:51:58,466
and we extrapolate from there.

1267
00:51:58,466 --> 00:52:00,333
I think probably anybody,

1268
00:52:00,333 --> 00:52:02,733
if you explained that
you've discovered one thing

1269
00:52:02,733 --> 00:52:04,800
and you're going to extrapolate
to the universe,

1270
00:52:04,800 --> 00:52:06,633

any kind of statistical person

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00:52:06,633 --> 00:52:10,833

will critique that method,
somewhat harshly.

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00:52:10,833 --> 00:52:13,200

But that's all we have,
and that's what we do.

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00:52:13,200 --> 00:52:16,333

We know life on our planet
needs liquid water,

1274

00:52:16,333 --> 00:52:19,800

and we need our solid surface.

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00:52:19,800 --> 00:52:23,400

We don't have life that just--

1276

00:52:23,400 --> 00:52:24,866

or at least not much life

1277

00:52:24,866 --> 00:52:26,600

that floats around
with no surface.

1278

00:52:26,600 --> 00:52:29,066

Perhaps it exists, but
it's probably hard to detect.

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00:52:29,066 --> 00:52:33,266

It wouldn't be complex life
like we have, probably.

1280

00:52:33,266 --> 00:52:36,300

So the reason being is
because we know that we exist,

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00:52:36,300 --> 00:52:39,366

therefore we look for places
that look like our own.

1282

00:52:39,366 --> 00:52:41,000

It's probably not
a very good strategy,

1283

00:52:41,000 --> 00:52:43,700

but it's the least worst
right now.

1284

00:52:51,300 --> 00:52:53,766

- So please join me
in thanking Dr. Tom Barclay

1285

00:52:53,766 --> 00:52:55,866

for an excellent talk.

1286

00:52:55,866 --> 00:52:57,866

[applause]