



1
00:00:01,768 --> 00:00:03,603
>> Announcer: NASA's Jet
Propulsion Laboratory

2
00:00:03,603 --> 00:00:06,906
presents the von Karman Lecture.

3
00:00:06,906 --> 00:00:09,743
A series of talks by
scientists and engineers

4
00:00:09,743 --> 00:00:13,313
who are exploring our
planet, our solar system,

5
00:00:13,313 --> 00:00:14,914
and all that lies beyond.

6
00:00:22,055 --> 00:00:23,890
>> Good evening everybody.

7
00:00:23,890 --> 00:00:25,325
I'm Brian White from JPL's

8
00:00:25,325 --> 00:00:27,394
Office of Communications
and Education.

9
00:00:27,394 --> 00:00:29,863
Welcome to the
von Karman series.

10
00:00:29,863 --> 00:00:31,431
Before we get started,
I want to talk about

11
00:00:31,431 --> 00:00:33,800
a teacher I had in college
who on the very first,

12

00:00:33,800 --> 00:00:36,669

great teacher, on the
very first day of class,

13

00:00:36,669 --> 00:00:39,939

he drew this itty-bitty tiny
little circle on the board,

14

00:00:39,939 --> 00:00:42,776

and he said "this is
everything you know."

15

00:00:42,776 --> 00:00:44,244

[laughter]

16

00:00:44,244 --> 00:00:45,345

Exactly that's what we
thought as college students.

17

00:00:45,345 --> 00:00:46,880

We thought we knew everything.

18

00:00:46,880 --> 00:00:48,281

We thought we knew more
than a tiny little circle.

19

00:00:48,281 --> 00:00:49,783

He says "it's fine
because everything

20

00:00:49,783 --> 00:00:52,018

"that circle is
touching, is everything

21

00:00:52,018 --> 00:00:54,120

"you now know you don't know."

22

00:00:55,722 --> 00:00:57,223

He said "by the
end of the class,"

23

00:00:57,223 --> 00:00:59,259
and drew this much bigger
circle all the way around it,

24

00:00:59,259 --> 00:01:00,627
and he said "I hope this is you,

25

00:01:00,627 --> 00:01:02,529
"and I hope it's a lot scarier,

26

00:01:02,529 --> 00:01:05,298
"because everything
that circle is touching

27

00:01:05,298 --> 00:01:09,169
"is everything you now
know you don't know."

28

00:01:09,169 --> 00:01:10,503
[laughter]

29

00:01:10,503 --> 00:01:13,206
Ocean worlds are a
rich and vibrant part

30

00:01:13,206 --> 00:01:15,308
of our solar system that
intrigue both scientists

31

00:01:15,308 --> 00:01:16,643
and the public alike.

32

00:01:16,643 --> 00:01:18,478
Obviously you're
all here tonight.

33

00:01:18,478 --> 00:01:21,014

But what exactly
are we looking for,

34

00:01:21,014 --> 00:01:25,485

and how will we know we've
found it, whatever it is?

35

00:01:25,485 --> 00:01:26,986

Tonight we'll take a
look at some things

36

00:01:26,986 --> 00:01:29,923

that we know we don't know and
how we go about figuring out

37

00:01:29,923 --> 00:01:31,858

which questions to ask.

38

00:01:31,858 --> 00:01:33,827

Now this evening's speaker,
Doctor Morgan Cable

39

00:01:33,827 --> 00:01:36,129

is a research
scientist here at JPL.

40

00:01:36,129 --> 00:01:39,265

While earning her PhD
in chemistry at Caltech,

41

00:01:39,265 --> 00:01:41,367

she designed receptor
sites for the detection

42

00:01:41,367 --> 00:01:44,504

of bacterial spores, the
toughest form of life.

43

00:01:44,504 --> 00:01:46,940

She and colleagues were the first to discover a cocrystal,

44

00:01:46,940 --> 00:01:49,909

the equivalent of hydrated mineral made exclusively

45

00:01:49,909 --> 00:01:52,912

of organics that may exist on Titan's surface.

46

00:01:52,912 --> 00:01:55,181

This work has led to the inception of a new field,

47

00:01:55,181 --> 00:01:57,150

Titan petrology, and she can correct me

48

00:01:57,150 --> 00:01:59,385

if I screwed that one up.

49

00:01:59,385 --> 00:02:01,955

She conducts fieldwork in extreme environments on Earth,

50

00:02:01,955 --> 00:02:05,625

searching for life in places such as the Atacama Desert,

51

00:02:05,625 --> 00:02:06,926

the summit of Mount Kilimanjaro

52

00:02:06,926 --> 00:02:08,661

and the lava fields of Iceland.

53

00:02:08,661 --> 00:02:11,030

She is an extreme unicyclist.

54

00:02:12,499 --> 00:02:15,301

She's a surfer who worked
on the Cassini mission as

55

00:02:15,301 --> 00:02:19,172

a project science
systems engineer,

56

00:02:19,172 --> 00:02:20,607

is currently a
co-investigator on

57

00:02:20,607 --> 00:02:22,342

the Dragonfly mission to Titan,

58

00:02:22,342 --> 00:02:24,344

and a member of the
project science team

59

00:02:24,344 --> 00:02:25,678

for the Europa lander.

60

00:02:25,678 --> 00:02:28,214

Ladies and gentlemen,
Doctor Morgan Cable.

61

00:02:28,214 --> 00:02:30,450

[applause]

62

00:02:34,554 --> 00:02:36,089

>> Thank you.

63

00:02:36,089 --> 00:02:38,491

Can you all hear me all right?

64

00:02:38,491 --> 00:02:39,993

All right.

65

00:02:39,993 --> 00:02:42,328

Thanks so much for coming,
for braving the coronavirus.

66

00:02:42,328 --> 00:02:44,564

Make sure you're all
washing your hands.

67

00:02:44,564 --> 00:02:46,232

We've been doing the
chemistry hi-five,

68

00:02:46,232 --> 00:02:47,467

which is with the elbow.

69

00:02:47,467 --> 00:02:49,202

I've also seen some
with the foot, you know,

70

00:02:49,202 --> 00:02:51,304

instead of shaking hands.

71

00:02:51,304 --> 00:02:53,406

It's such a pleasure
to be here tonight.

72

00:02:53,406 --> 00:02:55,808

I'm so excited to
tell you a bit about

73

00:02:55,808 --> 00:02:58,444

the work that we're
doing here at JPL

74

00:02:58,444 --> 00:03:00,680

and other NASA
centers to explore

75

00:03:00,680 --> 00:03:03,583

this ultimate
question, are we alone.

76

00:03:03,583 --> 00:03:05,285

So before we get started,

77

00:03:05,285 --> 00:03:07,554

I'd like you all to
do a little exercise.

78

00:03:07,554 --> 00:03:09,756

Now it's kind of
late here, 7 p.m.

79

00:03:09,756 --> 00:03:10,990

For those of you
watching online,

80

00:03:10,990 --> 00:03:12,091

it might be a little bit later,

81

00:03:12,091 --> 00:03:14,060

but I'd like you
to take a minute

82

00:03:14,060 --> 00:03:17,931

to take a breath
and close your eyes.

83

00:03:17,931 --> 00:03:20,133

And I want you to
picture yourself,

84

00:03:20,133 --> 00:03:24,103

in your mind's eye,
standing on an alien world.

85

00:03:24,103 --> 00:03:26,105

All right, picture it.

86

00:03:26,105 --> 00:03:29,175

Look up into the sky.

87

00:03:29,175 --> 00:03:31,144

How many suns are there?

88

00:03:31,144 --> 00:03:33,446

Is there a single star
like we have here,

89

00:03:33,446 --> 00:03:35,715

or is it more like Tatooine?

90

00:03:35,715 --> 00:03:38,685

Binary star systems are
actually pretty common.

91

00:03:38,685 --> 00:03:40,320

Maybe it's night time.

92

00:03:40,320 --> 00:03:43,456

Do you see different
constellations in the sky?

93

00:03:43,456 --> 00:03:44,390

Look down.

94

00:03:44,390 --> 00:03:45,992

What are you standing on?

95

00:03:45,992 --> 00:03:47,527

Is it rock?

96

00:03:47,527 --> 00:03:49,028

Is it ice?

97

00:03:49,028 --> 00:03:50,430

Sand?

98

00:03:50,430 --> 00:03:51,798
Maybe you're floating.

99
00:03:51,798 --> 00:03:54,000
Maybe it's a boat
in your own liquid.

100
00:03:54,000 --> 00:03:57,537
Is that liquid water or
is it something else?

101
00:03:57,537 --> 00:04:00,840
Picture yourself there
on your alien world.

102
00:04:00,840 --> 00:04:02,675
Is there a lot of gravity?

103
00:04:02,675 --> 00:04:06,246
Is it larger than Earth and
so it's pulling you down,

104
00:04:06,246 --> 00:04:07,747
or are you kind of floating?

105
00:04:07,747 --> 00:04:10,883
Would you skip around like the
astronauts did on the moon?

106
00:04:10,883 --> 00:04:12,685
Think about this place.

107
00:04:12,685 --> 00:04:14,687
And now I'm going to
give you a mission.

108
00:04:14,687 --> 00:04:17,490
Your mission, if you
choose to accept it,

109

00:04:17,490 --> 00:04:19,092

is to collect one sample.

110

00:04:19,092 --> 00:04:20,260

Well, not even one.

111

00:04:20,260 --> 00:04:22,795

Anything that your
arms can carry to prove

112

00:04:22,795 --> 00:04:26,332

that there is life
on your alien world.

113

00:04:26,332 --> 00:04:27,934

Think about what you might grab.

114

00:04:29,135 --> 00:04:31,604

Okay and now I'd like
you to open your eyes.

115

00:04:33,039 --> 00:04:37,644

This is our only example of
a place that has life, right?

116

00:04:38,244 --> 00:04:39,045

Our home planet.

117

00:04:39,045 --> 00:04:40,280

Our pale blue dot.

118

00:04:40,280 --> 00:04:41,814

The Earth.

119

00:04:41,814 --> 00:04:45,518

And you may think that in
a world teeming with life,

120

00:04:45,518 --> 00:04:47,553

doing that exercise
that I just asked

121

00:04:47,553 --> 00:04:49,589

of you would be easy, right?

122

00:04:49,589 --> 00:04:51,624

This would be super simple.

123

00:04:51,624 --> 00:04:52,959

But is it?

124

00:04:52,959 --> 00:04:55,128

Well it depends
on where you land.

125

00:04:55,128 --> 00:04:57,430

If you land here, super easy.

126

00:04:57,430 --> 00:04:59,432

This is the Amazon
rainforest, right?

127

00:04:59,432 --> 00:05:01,301

You could just go grab a leaf,

128

00:05:01,301 --> 00:05:02,735

maybe a monkey if
you're quick enough.

129

00:05:02,735 --> 00:05:04,003

You know, you
could get something

130

00:05:04,003 --> 00:05:07,040

really easy and obvious
that there's life there.

131

00:05:07,040 --> 00:05:08,408
Okay that's great.

132
00:05:08,408 --> 00:05:10,276
But if I were an
engineer trying to design

133
00:05:10,276 --> 00:05:14,580
a spacecraft to land here, do
you see a safe place to land?

134
00:05:14,580 --> 00:05:16,082
Not so much.

135
00:05:16,082 --> 00:05:18,918
Chances are I would want to
land in a nice flat place.

136
00:05:18,918 --> 00:05:22,322
This is the Atacama
Desert in northern Chile.

137
00:05:22,322 --> 00:05:24,290
It's one of the driest
deserts in the world,

138
00:05:24,290 --> 00:05:26,959
and we actually love
this here at NASA,

139
00:05:26,959 --> 00:05:29,295
because this makes an
excellent analog for Mars.

140
00:05:29,295 --> 00:05:31,331
A lot of the salts,
the water activity,

141
00:05:31,331 --> 00:05:32,965
other things about

this environment

142

00:05:32,965 --> 00:05:35,702
make it a good analog for Mars.

143

00:05:35,702 --> 00:05:38,037
But if you were to try
to look for life here,

144

00:05:38,037 --> 00:05:41,708
there is life here, but it's
not quite as easy to find.

145

00:05:41,708 --> 00:05:43,976
You might need a
microscope for example.

146

00:05:43,976 --> 00:05:47,246
You might need a tool
to dig down underneath

147

00:05:47,246 --> 00:05:50,016
the surface a little
bit to find that life.

148

00:05:51,184 --> 00:05:53,820
Now what if you went
to a place like here.

149

00:05:53,820 --> 00:05:55,621
Does anyone recognize
the skyline?

150

00:05:55,621 --> 00:05:58,124
Yeah, this is Los Angeles.

151

00:05:58,124 --> 00:06:00,827
Now this gets into a different
kind of bio-signature,

152

00:06:00,827 --> 00:06:02,895

something that we call
a techno-signature,

153

00:06:02,895 --> 00:06:05,965

and we're going to save that
discussion for another time.

154

00:06:05,965 --> 00:06:07,767

That would be amazing,
and if we find something

155

00:06:07,767 --> 00:06:09,302

like this somewhere checking

156

00:06:09,302 --> 00:06:11,838

that life box would
be pretty easy.

157

00:06:11,838 --> 00:06:15,641

But chances are if we were to
land anywhere here on Earth,

158

00:06:15,641 --> 00:06:17,877

we would land here, right?

159

00:06:17,877 --> 00:06:21,914

About 70% of Earth's
surface is covered in water.

160

00:06:21,914 --> 00:06:26,853

And if you were to design
a container to collect life

161

00:06:26,853 --> 00:06:29,655

to bring back, you would
design it differently

162

00:06:29,655 --> 00:06:32,692

if you were going to land
someplace like an ocean

163

00:06:32,692 --> 00:06:34,093

then you would if
you were landing in

164

00:06:34,093 --> 00:06:36,662

a desert or in a rainforest,

165

00:06:36,662 --> 00:06:40,333

and so depending on where you go

166

00:06:40,333 --> 00:06:43,870

and what you're looking
for, may define the type

167

00:06:43,870 --> 00:06:48,641

of things that you would bring
with you to your alien world.

168

00:06:48,641 --> 00:06:51,210

And it's appropriate
that we end on water,

169

00:06:51,210 --> 00:06:54,280

because for NASA this is
one of the key ingredients

170

00:06:54,280 --> 00:06:56,416

that we look for when
we're searching for life.

171

00:06:56,416 --> 00:06:57,917

It's not the only thing.

172

00:06:57,917 --> 00:07:01,387

Of course there could be life
that is not aqueous based,

173

00:07:01,387 --> 00:07:03,356

that's not based
on liquid water.

174

00:07:03,356 --> 00:07:05,958

But this is our
sample size, right?

175

00:07:05,958 --> 00:07:06,959

Sample size of one.

176

00:07:06,959 --> 00:07:09,629

One world and here we find

177

00:07:09,629 --> 00:07:13,032

that life needs three
key ingredients.

178

00:07:13,032 --> 00:07:15,234

One of them is liquid water.

179

00:07:15,234 --> 00:07:18,638

Liquid helps you
transport nutrients in,

180

00:07:18,638 --> 00:07:20,440

transport waste out.

181

00:07:20,440 --> 00:07:22,208

It gives, it sort of greases

182

00:07:22,208 --> 00:07:26,045

the molecular machinery
of life it lubricates it.

183

00:07:26,045 --> 00:07:28,815

So we know that
life needs water.

184

00:07:28,815 --> 00:07:31,717

We also know that it needs
what I call chemistry.

185

00:07:31,717 --> 00:07:32,952

Basically building blocks.

186

00:07:32,952 --> 00:07:35,688

You need something to
make those molecules

187

00:07:35,688 --> 00:07:37,623

that you are made up of.

188

00:07:37,623 --> 00:07:39,392

You need something
to make those out of,

189

00:07:39,392 --> 00:07:42,395

and that can be carbon,
hydrogen, nitrogen,

190

00:07:42,395 --> 00:07:44,096

like we have here abundantly.

191

00:07:44,096 --> 00:07:46,132

Typically it'll be something
that's pretty common.

192

00:07:46,132 --> 00:07:50,403

If we were all based on, I
don't know, titanium or iridium,

193

00:07:50,403 --> 00:07:51,971

there's not a lot
of that around,

194

00:07:51,971 --> 00:07:53,739

so there wouldn't

be very many of us.

195

00:07:53,739 --> 00:07:55,208

Which I guess means
we wouldn't have

196

00:07:55,208 --> 00:07:58,311

as many coronavirus distributor,
which would be good.

197

00:07:58,311 --> 00:08:03,115

But you typically use building
blocks that are common.

198

00:08:03,115 --> 00:08:04,317

So that's the second thing.

199

00:08:04,317 --> 00:08:05,985

We need the building
blocks of life.

200

00:08:05,985 --> 00:08:08,788

And the third thing
we need is energy.

201

00:08:08,788 --> 00:08:10,556

Something to metabolize.

202

00:08:10,556 --> 00:08:12,925

Something to drive the
chemical reactions,

203

00:08:12,925 --> 00:08:16,128

the biochemical reactions
that keep us alive.

204

00:08:16,128 --> 00:08:18,264

And so any place on
Earth where we find

205

00:08:18,264 --> 00:08:21,133

those three things,
we find life.

206

00:08:21,133 --> 00:08:22,568

Every time.

207

00:08:22,568 --> 00:08:25,004

And so these are the things
that we will look for

208

00:08:25,004 --> 00:08:28,040

when we try to explore our
solar system and beyond

209

00:08:28,040 --> 00:08:29,609

and search for life there.

210

00:08:31,310 --> 00:08:34,180

So let's go a little bit
further out from Earth,

211

00:08:34,180 --> 00:08:38,718

we're going to go about 480
million miles to Jupiter.

212

00:08:38,718 --> 00:08:41,854

Jupiter's our largest planet
in our solar system, right?

213

00:08:41,854 --> 00:08:43,122

It's kind of the bouncer.

214

00:08:43,122 --> 00:08:46,125

It sorta kept a lot of
major meteoritic events

215

00:08:46,125 --> 00:08:47,994

from happening here on

Earth, at least not too many.

216

00:08:47,994 --> 00:08:50,530

So we're 65 million years and
counting since the last one.

217

00:08:50,530 --> 00:08:51,931

That's great.

218

00:08:51,931 --> 00:08:53,466

Jupiter is amazing.

219

00:08:53,466 --> 00:08:55,301

It's beautiful and I love it.

220

00:08:55,301 --> 00:08:57,603

But I love its moons even more.

221

00:08:57,603 --> 00:09:00,606

Jupiter has four what
we call Galilean moons,

222

00:09:00,606 --> 00:09:02,441

'cause Galileo discovered them,

223

00:09:02,441 --> 00:09:03,876

should get some credit.

224

00:09:03,876 --> 00:09:06,679

And three of them are locked

225

00:09:06,679 --> 00:09:09,282

in what's called
the tidal resonance.

226

00:09:09,282 --> 00:09:13,152

And this one, Europa,
is in the middle.

227

00:09:13,152 --> 00:09:17,456

So in between Europa and
Jupiter is a world called Io.

228

00:09:17,456 --> 00:09:20,860

It's the most volcanically
active body in the solar system.

229

00:09:20,860 --> 00:09:24,030

It's a really cool place
and it's really hot because

230

00:09:24,030 --> 00:09:27,433

of its interaction with
Europa and also with

231

00:09:27,433 --> 00:09:30,603

the third moon out which
is called Ganymede.

232

00:09:30,603 --> 00:09:33,973

So it goes Io, Europa, Ganymede.

233

00:09:33,973 --> 00:09:38,978

And for every one orbit
Europa does, Io does two.

234

00:09:40,313 --> 00:09:43,449

For every orbit that Ganymede
does, Europa does two.

235

00:09:43,449 --> 00:09:45,585

And so what happens
is, it's kind of like,

236

00:09:45,585 --> 00:09:47,286

you remember on the playground
when you were a kid,

237

00:09:47,286 --> 00:09:49,956

if you pushed your friend
or maybe your sister,

238

00:09:49,956 --> 00:09:51,357

brother on the swing set,

239

00:09:51,357 --> 00:09:52,925

and you wanted them
to go really high,

240

00:09:52,925 --> 00:09:55,628

you had to time that pushes
just right, you know,

241

00:09:55,628 --> 00:09:57,997

and if you did that you could
get them go maybe higher

242

00:09:57,997 --> 00:10:00,166

than your parents
thought was safe.

243

00:10:00,166 --> 00:10:02,902

That's what's happening
here with these worlds.

244

00:10:02,902 --> 00:10:05,371

So they're locked in this
gravitational tug-of-war

245

00:10:05,371 --> 00:10:07,306

and because of this resonance,

246

00:10:07,306 --> 00:10:08,708

every time they orbit
around they give

247

00:10:08,708 --> 00:10:10,743

each other this energetic kick.

248

00:10:10,743 --> 00:10:13,546

And here that kick turns into
this friction that causes

249

00:10:13,546 --> 00:10:16,616

the worlds to move like this.

250

00:10:16,616 --> 00:10:19,619

And so that flexing
we call tidal flexing,

251

00:10:19,619 --> 00:10:21,020

that generates heat.

252

00:10:21,020 --> 00:10:23,656

And that's why Europa has a lot

253

00:10:23,656 --> 00:10:26,525

of liquid underneath
this icy shell.

254

00:10:26,525 --> 00:10:28,628

And it's why it's one
of my favorite places

255

00:10:28,628 --> 00:10:30,262

in the entire solar system.

256

00:10:30,262 --> 00:10:34,767

Europa actually has two to
three times the volume of all

257

00:10:34,767 --> 00:10:38,204

of Earth's oceans
combined in liquid water.

258

00:10:38,204 --> 00:10:39,672

That's a lot of water.

259

00:10:39,672 --> 00:10:42,208

Now it's under a shell of ice.

260

00:10:42,208 --> 00:10:45,945

But it's really interesting
because you can learn

261

00:10:45,945 --> 00:10:48,280

a lot about this
world, we think,

262

00:10:48,280 --> 00:10:50,483

from studying Europa's surface.

263

00:10:50,483 --> 00:10:53,953

Now you may notice that
it's got some cracks

264

00:10:53,953 --> 00:10:57,089

and some grooves and they
seem to be a darker color.

265

00:10:57,089 --> 00:10:59,125

We're not sure exactly
what that dark color is,

266

00:10:59,125 --> 00:11:01,961

we think it could either be
salts or organic molecules,

267

00:11:01,961 --> 00:11:03,863

maybe a little bit of both.

268

00:11:03,863 --> 00:11:07,033

But one thing is kind
of missing from this.

269

00:11:07,033 --> 00:11:08,534

Does anyone know?

270

00:11:08,534 --> 00:11:10,169

I'll give you a hint, our moon has a lot of these.

271

00:11:10,169 --> 00:11:11,003

Yes.

272

00:11:11,003 --> 00:11:12,204

Craters.

273

00:11:12,204 --> 00:11:14,040

Turns out Europa only has this many.

274

00:11:14,040 --> 00:11:16,509

It's got about seven big craters.

275

00:11:16,509 --> 00:11:17,710

You know that's important,

276

00:11:17,710 --> 00:11:19,912

because this is how we date objects

277

00:11:19,912 --> 00:11:22,148

in our solar system, by crater counting.

278

00:11:22,148 --> 00:11:23,582

And this tells us that the surface

279

00:11:23,582 --> 00:11:26,485

of Europa is relatively young.

280

00:11:26,485 --> 00:11:27,420

Now this is cool.

281

00:11:27,420 --> 00:11:29,655

It's about 50 million years.

282

00:11:29,655 --> 00:11:31,857

So even younger
than the dinosaurs,

283

00:11:31,857 --> 00:11:35,528

which means something must
be refreshing it somehow.

284

00:11:35,528 --> 00:11:39,331

We think that there could be
some activity from the ocean,

285

00:11:39,331 --> 00:11:41,067

maybe some localized heating.

286

00:11:41,067 --> 00:11:43,135

We see these things
called lenticulae,

287

00:11:43,135 --> 00:11:45,337

which is Greek or
Latin for freckles.

288

00:11:45,337 --> 00:11:47,907

Some places where it looks
like there're little hot spots.

289

00:11:47,907 --> 00:11:51,310

We see these smooth bands
where it looks like some of

290

00:11:51,310 --> 00:11:55,915

the surface has split open
and water has been sucked up

291

00:11:55,915 --> 00:11:58,551
or ice has been sucked up
and filled in the gaps.

292

00:11:58,551 --> 00:12:00,519
And so we see these
places on the surface

293

00:12:00,519 --> 00:12:02,755
where it looks like
there's a lot of activity,

294

00:12:02,755 --> 00:12:04,390
and that gets us really excited,

295

00:12:04,390 --> 00:12:06,025
because we would want,

296

00:12:06,025 --> 00:12:08,594
if we send something
to explore this place,

297

00:12:08,594 --> 00:12:11,630
to search those fresher regions.

298

00:12:11,630 --> 00:12:14,066
Those may have more
organics in them,

299

00:12:14,066 --> 00:12:15,868
they may have better evidence

300

00:12:15,868 --> 00:12:19,038
of what's in that
ocean underneath.

301

00:12:19,038 --> 00:12:21,941
And boy, wouldn't it be great
to send a spacecraft here

302

00:12:21,941 --> 00:12:26,045
and look for life or look
for evidence of habitability?

303

00:12:26,045 --> 00:12:26,979
Yes it would.

304

00:12:26,979 --> 00:12:28,214
And we're going to do that.

305

00:12:29,682 --> 00:12:32,551
Europa is incredible, right?

306

00:12:32,551 --> 00:12:35,121
We think that underneath
this ice shell,

307

00:12:35,121 --> 00:12:37,356
we know that it has
a liquid water ocean,

308

00:12:37,356 --> 00:12:39,425
we're not sure exactly
how deep it is.

309

00:12:39,425 --> 00:12:40,626
That's one of the things

310

00:12:40,626 --> 00:12:43,129
that our next mission
is going to study.

311

00:12:43,129 --> 00:12:44,363
But we do know that there's

312

00:12:44,363 --> 00:12:46,832
a lot of radiation
at the surface.

313

00:12:46,832 --> 00:12:49,535

This is because
Jupiter is really big.

314

00:12:49,535 --> 00:12:51,771

It acts as the bouncer for
the rest of our solar system,

315

00:12:51,771 --> 00:12:55,174

which is great, but it also
has some negative effects

316

00:12:55,174 --> 00:12:56,475

for some of the moons around it.

317

00:12:56,475 --> 00:12:58,544

Because it's so large
it sucks in a lot of

318

00:12:58,544 --> 00:13:01,080

the charged particles
from the solar winds

319

00:13:01,080 --> 00:13:02,314

and it whips them around with

320

00:13:02,314 --> 00:13:03,883

its really strong
magnetic field,

321

00:13:03,883 --> 00:13:05,918

and it slams them into Europa.

322

00:13:05,918 --> 00:13:07,686

Now Europa doesn't
have an atmosphere,

323

00:13:07,686 --> 00:13:10,289

and so these things
will interact directly

324

00:13:10,289 --> 00:13:12,358

with that water
ice on the surface.

325

00:13:12,358 --> 00:13:14,293

And water ice is H₂O right?

326

00:13:14,293 --> 00:13:15,294

That's water.

327

00:13:15,294 --> 00:13:16,428

It'll break that up.

328

00:13:16,428 --> 00:13:17,897

It'll kick off the hydrogens

329

00:13:17,897 --> 00:13:19,498

and since they're super
light they float away,

330

00:13:19,498 --> 00:13:21,734

and so you'll end up
with this tenuous oxygen,

331

00:13:21,734 --> 00:13:23,936

we don't even call
it an atmosphere.

332

00:13:23,936 --> 00:13:26,572

We call it in exosphere
'cause it's so thin.

333

00:13:26,572 --> 00:13:30,309

And that oxygen is
really rich in electrons.

334

00:13:30,309 --> 00:13:33,312

Now down at the
seafloor where we think

335

00:13:33,312 --> 00:13:36,415

there could be hydrothermal
activity, heating,

336

00:13:36,415 --> 00:13:38,617

geothermal activity,
things like that,

337

00:13:38,617 --> 00:13:41,487

we are pretty sure based
on examples here on Earth

338

00:13:41,487 --> 00:13:43,656

that that place
is electron poor.

339

00:13:43,656 --> 00:13:45,925

So if you've got a lot of
electrons in one place,

340

00:13:45,925 --> 00:13:49,562

a few electrons in another
place, you know what that is?

341

00:13:49,562 --> 00:13:51,997

That's a battery,
basically right?

342

00:13:51,997 --> 00:13:54,967

You just need to connect the
two and there's a lot of types

343

00:13:54,967 --> 00:13:58,671

of life here on Earth
that we call a chemotroph.

344

00:13:58,671 --> 00:13:59,572
Chemoautotrophs.

345
00:13:59,572 --> 00:14:01,006
Chemo- means chemistry,

346
00:14:01,006 --> 00:14:02,775
auto means it does it by
itself, it doesn't need help,

347
00:14:02,775 --> 00:14:05,377
and it uses those types
of energy sources,

348
00:14:05,377 --> 00:14:07,279
just shuttling the
electrons around.

349
00:14:07,279 --> 00:14:09,815
Takes a little tax, a
little bit off the top,

350
00:14:09,815 --> 00:14:12,151
and that's what it
uses to be alive.

351
00:14:12,151 --> 00:14:13,853
And so there are all
sorts of organisms

352
00:14:13,853 --> 00:14:16,088
that could exist in
environments like this.

353
00:14:16,088 --> 00:14:19,859
And the Europa Clipper Mission
is going to study this world.

354
00:14:19,859 --> 00:14:21,460
So Europa Clipper is a mission

355

00:14:21,460 --> 00:14:23,963
that NASA's building right now.

356

00:14:23,963 --> 00:14:27,633
It's going to have nine
different instruments

357

00:14:27,633 --> 00:14:30,202
that will be able
to study Europa,

358

00:14:30,202 --> 00:14:32,204
its surface, its interior,

359

00:14:32,204 --> 00:14:34,907
and all of these properties
to help us understand

360

00:14:34,907 --> 00:14:37,209
whether or not it's
habitable and whether or not

361

00:14:37,209 --> 00:14:40,679
there could be life there
today, or maybe in the past.

362

00:14:40,679 --> 00:14:43,282
Europa Clipper is
going to be ready

363

00:14:43,282 --> 00:14:46,485
for launch in about 2025, as
I said we're building it now.

364

00:14:46,485 --> 00:14:48,354
And depending on
which rocket we go on,

365

00:14:48,354 --> 00:14:52,291
we'll reach the Jupiter system
maybe sixish years later,

366
00:14:52,291 --> 00:14:55,895
and we'll bring all of
these instruments to bear.

367
00:14:55,895 --> 00:14:58,530
We're going to have some
very sensitive cameras

368
00:14:58,530 --> 00:15:00,132
that will be able
to take incredibly

369
00:15:00,132 --> 00:15:03,269
high resolution images
of Europa's surface.

370
00:15:03,269 --> 00:15:05,771
We will have basically
a fancy compass,

371
00:15:05,771 --> 00:15:08,807
magnetometer that can
tell us by studying

372
00:15:08,807 --> 00:15:13,379
the magnetic field properties
of that ocean and its depth.

373
00:15:13,379 --> 00:15:16,015
We'll have a radar
sounder that could do

374
00:15:16,015 --> 00:15:18,083
the same thing we do
here when we fly radar

375

00:15:18,083 --> 00:15:20,452
over Antarctica to get at
the thickness of the ice

376
00:15:20,452 --> 00:15:23,522
and if there are any
pockets of water in there.

377
00:15:23,522 --> 00:15:27,860
It will also have an instrument
called a mass spectrometer.

378
00:15:27,860 --> 00:15:29,895
And we actually have
two different kinds.

379
00:15:29,895 --> 00:15:31,196
One that can get at the gas.

380
00:15:31,196 --> 00:15:32,531
It's sort of like your nose.

381
00:15:32,531 --> 00:15:33,999
It'll sniff what's there.

382
00:15:33,999 --> 00:15:35,467
Things that are coming
off the surface,

383
00:15:35,467 --> 00:15:37,903
to tell us if there are
any interesting gases

384
00:15:37,903 --> 00:15:39,805
like hydrogen or methane,

385
00:15:39,805 --> 00:15:41,006
things that we could tie

386

00:15:41,006 --> 00:15:43,509
to some sort of
geothermal activity.

387
00:15:43,509 --> 00:15:45,778
And we'll also have
one that it's kind

388
00:15:45,778 --> 00:15:48,981
of like sticking out your
tongue and tasting snowflakes,

389
00:15:48,981 --> 00:15:51,817
except doing it, you know,
five kilometers a second.

390
00:15:51,817 --> 00:15:53,585
Would not recommend doing
that with your tongue,

391
00:15:53,585 --> 00:15:56,422
but with the instrument
aboard that's a dust detector,

392
00:15:56,422 --> 00:16:00,125
that is actually the perfect
speed to pick up dust grains,

393
00:16:00,125 --> 00:16:03,195
ice grains, you smash them
open and you can determine

394
00:16:03,195 --> 00:16:05,731
what kind of organic
molecules are present.

395
00:16:05,731 --> 00:16:08,300
And so we can do
that for bits of ice

396

00:16:08,300 --> 00:16:09,768
that are sputtered
off the surface

397
00:16:09,768 --> 00:16:12,838
from micrometeoroid impacts
and things like that,

398
00:16:12,838 --> 00:16:15,808
and get an idea what that
surface composition is,

399
00:16:15,808 --> 00:16:17,309
even without landing.

400
00:16:17,309 --> 00:16:19,878
So the Europa Clipper
Mission is going to be in

401
00:16:19,878 --> 00:16:21,680
the Jupiter system
for several years,

402
00:16:21,680 --> 00:16:24,783
but we decided to not
have it orbit Europa

403
00:16:24,783 --> 00:16:26,618
because of the
intense radiation.

404
00:16:26,618 --> 00:16:29,188
It's not so good for us
if we were standing on

405
00:16:29,188 --> 00:16:30,723
the surface of Europa,
you probably get

406
00:16:30,723 --> 00:16:33,258

a lethal dose of
radiation in a few hours,

407

00:16:33,258 --> 00:16:34,660

it's not good for
spacecraft either.

408

00:16:34,660 --> 00:16:37,830

It can cause things
like single-event upsets

409

00:16:37,830 --> 00:16:40,499

in your electronics
and make them function,

410

00:16:40,499 --> 00:16:42,935

turn on and off in ways
that you don't expect.

411

00:16:42,935 --> 00:16:44,737

And so what Europa
Clipper's going to do

412

00:16:44,737 --> 00:16:46,238

is it's going to
get close to Europa,

413

00:16:46,238 --> 00:16:48,474

take lots of data and
then come back out,

414

00:16:48,474 --> 00:16:51,310

cool off, send the data
back give us some time

415

00:16:51,310 --> 00:16:53,445

to interpret it,
think about it before

416

00:16:53,445 --> 00:16:56,015

it goes back in again
for its next pass.

417
00:16:56,015 --> 00:16:59,084
And this is something that
we're really excited about,

418
00:16:59,084 --> 00:17:01,453
because we'll be able
to get images that

419
00:17:01,453 --> 00:17:05,591
every time we send a powerful
spacecraft somewhere,

420
00:17:05,591 --> 00:17:07,826
and we bring advanced
instruments like cameras,

421
00:17:07,826 --> 00:17:12,398
detectors, the electronic
tongue I was talking about,

422
00:17:12,398 --> 00:17:14,466
we always find things
that surprise us.

423
00:17:14,466 --> 00:17:17,169
And I can't imagine the
things that we will find here

424
00:17:17,169 --> 00:17:19,204
that will surprise us.

425
00:17:19,204 --> 00:17:22,107
Now when NASA does missions,
typically we like to send

426
00:17:22,107 --> 00:17:25,377
an orbiter or a

flyby mission first.

427

00:17:25,377 --> 00:17:26,779

Now there's some reasons for that.

428

00:17:26,779 --> 00:17:28,847

This can give us a lot of great images

429

00:17:28,847 --> 00:17:30,582

and maps of the surface.

430

00:17:30,582 --> 00:17:32,217

One of the other instruments aboard Clipper

431

00:17:32,217 --> 00:17:34,420

is basically like a really fancy camera.

432

00:17:34,420 --> 00:17:37,556

For every picture that it takes, each pixel

433

00:17:37,556 --> 00:17:40,092

of that image will actually be a spectrum.

434

00:17:40,092 --> 00:17:41,693

That will give us information about

435

00:17:41,693 --> 00:17:43,462

what the surface is made of.

436

00:17:43,462 --> 00:17:45,397

Those kinds of details are really important,

437

00:17:45,397 --> 00:17:47,499

'cause ultimately
if we want to answer

438

00:17:47,499 --> 00:17:50,202

the life question,
we need to land,

439

00:17:50,202 --> 00:17:53,172

and we're working
right now on a concept.

440

00:17:53,172 --> 00:17:55,174

This is called
the Europa Lander.

441

00:17:55,174 --> 00:17:58,077

This is something that
would come after Clipper

442

00:17:58,077 --> 00:18:00,245

and be able to take
all of that information

443

00:18:00,245 --> 00:18:03,649

to help us pick just the
right spot to land, right?

444

00:18:03,649 --> 00:18:06,685

We want to go to a safe place
but an interesting place

445

00:18:06,685 --> 00:18:09,755

that could potentially
have signatures of life.

446

00:18:09,755 --> 00:18:12,257

It will have the ability
to communicate directly

447

00:18:12,257 --> 00:18:15,627

with Earth through
its high gain antenna,

448

00:18:15,627 --> 00:18:18,063

and it will have
an arm, it would,

449

00:18:18,063 --> 00:18:21,166

that would be able to
cut into the surface.

450

00:18:21,166 --> 00:18:24,636

Now the surface of
Europa is pretty cold.

451

00:18:24,636 --> 00:18:27,673

It's about a hundred
and fifty Kelvin.

452

00:18:27,673 --> 00:18:31,276

Which, let's see in celsius
that's what -130 degrees C.

453

00:18:31,276 --> 00:18:33,345

I don't know what it is in
fahrenheit I'm a scientist.

454

00:18:33,345 --> 00:18:34,713

We don't work in fahrenheit.

455

00:18:34,713 --> 00:18:36,748

But it's really cold.

456

00:18:36,748 --> 00:18:39,718

And it turns out that
ice at those temperatures

457

00:18:39,718 --> 00:18:43,188

has a lot of similar properties
to rock, like granite.

458

00:18:43,188 --> 00:18:45,157

And some of our
engineers here at JPL

459

00:18:45,157 --> 00:18:47,893

who are designing types of
cutting tools to be able

460

00:18:47,893 --> 00:18:51,363

to slice into that
really hard ice,

461

00:18:51,363 --> 00:18:53,065

boy they are really interesting.

462

00:18:53,065 --> 00:18:54,233

One of the guys was telling me

463

00:18:54,233 --> 00:18:55,701

"yeah I was on my
treadmill this morning,

464

00:18:55,701 --> 00:18:57,870

"I was thinking about what
is the toughest sample

465

00:18:57,870 --> 00:18:59,404

"that we could come up with."

466

00:18:59,404 --> 00:19:01,373

And he ended up,
this was really mean.

467

00:19:01,373 --> 00:19:04,209

He took cotton, and he
stretched out the cotton balls

468

00:19:04,209 --> 00:19:06,879

until you get like that
really fibrous kind of stuff,

469

00:19:06,879 --> 00:19:08,947

and then he put
that in water ice,

470

00:19:08,947 --> 00:19:10,749

and then dunked that
and liquid nitrogen.

471

00:19:10,749 --> 00:19:13,619

And he said that broke about
half of their prototypes,

472

00:19:13,619 --> 00:19:17,122

because of the fibers, you
know, tripped up all the blades.

473

00:19:17,122 --> 00:19:20,159

But the reason that we do that
is because we want to be sure

474

00:19:20,159 --> 00:19:22,528

that we have
over-engineered everything,

475

00:19:22,528 --> 00:19:24,396

such that even if the
surface is something

476

00:19:24,396 --> 00:19:26,798

we wouldn't necessarily expect,

477

00:19:26,798 --> 00:19:29,234

we can still do our science.

478

00:19:29,234 --> 00:19:32,037

Even if we land in a place
where there's something,

479

00:19:32,037 --> 00:19:34,506

there're bigger rocks
than we expected,

480

00:19:34,506 --> 00:19:35,707

there might be some
weird fibrous things,

481

00:19:35,707 --> 00:19:37,843

that we could still cut
some of that sample,

482

00:19:37,843 --> 00:19:40,746

hopefully not destroy some
really sensitive organism,

483

00:19:40,746 --> 00:19:44,316

and bring it in and look
at it with our instruments.

484

00:19:44,316 --> 00:19:46,685

And so that's what this
type of mission concept

485

00:19:46,685 --> 00:19:48,120

would be able to do.

486

00:19:48,120 --> 00:19:50,789

So Europa is a
fascinating place.

487

00:19:50,789 --> 00:19:52,424

But it's not the only place.

488

00:19:52,424 --> 00:19:53,592

There are a few
other worlds I'd like

489

00:19:53,592 --> 00:19:55,460
to tell you about tonight.

490

00:19:55,460 --> 00:19:56,962
So let's go a
little bit further,

491

00:19:56,962 --> 00:19:59,865
actually a lot further, out
further away from the sun.

492

00:19:59,865 --> 00:20:02,734
So you know how you've got
those like nice diagrams

493

00:20:02,734 --> 00:20:05,070
of the solar system and it
shows like the sun and then

494

00:20:05,070 --> 00:20:08,307
Mercury, Venus and they're
all kind of evenly spaced out.

495

00:20:08,307 --> 00:20:10,409
You know they're not
actually like that, right?

496

00:20:10,409 --> 00:20:13,412
Like the distance from
the sun to Jupiter,

497

00:20:13,412 --> 00:20:16,081
you've got to do that
again to get to Saturn.

498

00:20:16,081 --> 00:20:17,516
Space is big, okay.

499

00:20:17,516 --> 00:20:20,953

So if you're here at
Saturn now, the sun is,

500

00:20:20,953 --> 00:20:23,722

it's not 10 times dimmer.

501

00:20:23,722 --> 00:20:25,257

The distance is 10 times,

502

00:20:25,257 --> 00:20:26,925

but the light intensity varies,

503

00:20:26,925 --> 00:20:28,827

do you guys remember this
from from high school?

504

00:20:28,827 --> 00:20:29,895

One over R squared.

505

00:20:29,895 --> 00:20:32,164

100 times dimmer, right?

506

00:20:32,164 --> 00:20:33,398

Because it's 10 squared.

507

00:20:33,398 --> 00:20:36,068

So things are very
different around Saturn.

508

00:20:36,068 --> 00:20:39,471

We were fortunate to
have a spacecraft in

509

00:20:39,471 --> 00:20:41,473

the Saturn system
called Cassini,

510

00:20:41,473 --> 00:20:42,708

which if you're here in the room

511

00:20:42,708 --> 00:20:45,544

is right over there,
the scale model.

512

00:20:45,544 --> 00:20:48,547

Cassini launched
in, let's see, '97,

513

00:20:48,547 --> 00:20:51,817

it arrived in the
Saturn system in 2004.

514

00:20:51,817 --> 00:20:53,085

Space is big.

515

00:20:53,085 --> 00:20:55,053

And was there for
about 13 years.

516

00:20:55,053 --> 00:20:57,489

And I was lucky enough
to be involved in

517

00:20:57,489 --> 00:20:59,791

the Cassini mission
right near the end

518

00:20:59,791 --> 00:21:02,027

of its time in
the Saturn system.

519

00:21:02,027 --> 00:21:06,698

We learned so much about Saturn,
its rings, and its moons.

520

00:21:06,698 --> 00:21:11,370

And one of the ones
that surprised us the

most was this one.

521

00:21:11,370 --> 00:21:12,838

This is one of my
favorite places.

522

00:21:12,838 --> 00:21:14,273

This is Enceladus.

523

00:21:14,273 --> 00:21:16,441

Small things can
be mighty, I know.

524

00:21:16,441 --> 00:21:18,477

Enceladus is relatively small.

525

00:21:18,477 --> 00:21:20,545

It's about the size of Arizona.

526

00:21:20,545 --> 00:21:23,849

But really amazing things are
packed in this tiny package.

527

00:21:23,849 --> 00:21:28,854

It is the whitest and brightest
body in the solar system,

528

00:21:29,721 --> 00:21:31,156

which tells us that the surface

529

00:21:31,156 --> 00:21:33,992

is mostly just really
reflective snow, water ice.

530

00:21:33,992 --> 00:21:38,163

And you see that cool thing
spewing out of the south pole?

531

00:21:38,163 --> 00:21:41,967

Yes, that is a plume and
that surprised all of us.

532

00:21:41,967 --> 00:21:44,436

When we built Cassini,
we didn't think there

533

00:21:44,436 --> 00:21:46,371

was liquid water out this far.

534

00:21:46,371 --> 00:21:48,940

So we cleaned it but
we didn't sterilize it.

535

00:21:48,940 --> 00:21:51,109

That's actually why
Cassini ended up doing

536

00:21:51,109 --> 00:21:54,713

its swan dive into
Saturn when we reached

537

00:21:54,713 --> 00:21:56,181

the end of the
spacecraft's life,

538

00:21:56,181 --> 00:21:59,084

'cause we didn't want to
contaminate places like this.

539

00:21:59,084 --> 00:22:03,822

Enceladus, in its south pole,
has these four big cracks.

540

00:22:03,822 --> 00:22:05,324

They're called tiger stripes,

541

00:22:05,324 --> 00:22:08,093

'cause it looks like a giant
tiger just went like that.

542

00:22:08,093 --> 00:22:09,628

But these are really
big, it'd have to be

543

00:22:09,628 --> 00:22:11,863

a very large tiger there about,

544

00:22:11,863 --> 00:22:13,031

let's see, three marathons long.

545

00:22:13,031 --> 00:22:15,634

A marathon's what's
42 kilometers?

546

00:22:15,634 --> 00:22:17,302

42, answer to everything.

547

00:22:17,302 --> 00:22:18,470

Yes.

548

00:22:18,470 --> 00:22:20,072

And they're a
little bit less than

549

00:22:20,072 --> 00:22:22,207

a marathon in
between each of them.

550

00:22:22,207 --> 00:22:24,509

So these are really
large cracks,

551

00:22:24,509 --> 00:22:28,013

and coming out from
them is a lot of water.

552

00:22:28,013 --> 00:22:29,781

It starts out as

liquid, this has

553

00:22:29,781 --> 00:22:32,517

a liquid water ocean
just like Europa,

554

00:22:32,517 --> 00:22:35,020

and when that water comes
out into space it freezes,

555

00:22:35,020 --> 00:22:37,122

and then it can reflect
light beautifully

556

00:22:37,122 --> 00:22:38,523

from the sun which are what

557

00:22:38,523 --> 00:22:41,593

some of these gorgeous back-lit
or front-lit images are.

558

00:22:41,593 --> 00:22:45,597

And it's spewing out
tons of just free sample

559

00:22:45,597 --> 00:22:46,832

from its ocean into space.

560

00:22:46,832 --> 00:22:48,367

No need to dig or drill,

561

00:22:48,367 --> 00:22:50,135

just like "NASA, you want
to find life somewhere?"

562

00:22:50,135 --> 00:22:54,106

"Come on down, get your
free sample right here."

563

00:22:54,106 --> 00:22:56,341
Now when we built Cassini,
we didn't think there

564
00:22:56,341 --> 00:22:57,576
was liquid water out this far,

565
00:22:57,576 --> 00:22:59,277
and we sure didn't
think that there could

566
00:22:59,277 --> 00:23:01,113
be life this far out,

567
00:23:01,113 --> 00:23:04,649
and so Cassini did not have
life detection instruments

568
00:23:04,649 --> 00:23:08,387
on board, but it was
still able to fly through

569
00:23:08,387 --> 00:23:11,256
this plume multiple times
and use its instruments

570
00:23:11,256 --> 00:23:14,493
to give us some hints of
what we think is there.

571
00:23:14,493 --> 00:23:18,430
Just like Europa Clipper,
Cassini also had that tongue

572
00:23:18,430 --> 00:23:20,632
that could stick out and
collect some ice grains

573
00:23:20,632 --> 00:23:22,601
and figure out if there are

organic molecules there,

574

00:23:22,601 --> 00:23:24,069
and it found some.

575

00:23:24,069 --> 00:23:26,938
It had a sniffing instrument
so we could sniff gases,

576

00:23:26,938 --> 00:23:29,107
and it found
hydrogen and methane,

577

00:23:29,107 --> 00:23:32,077
two things that we
know organisms either
eat or poop out.

578

00:23:32,077 --> 00:23:34,379
Either way it's exciting
that they're there,

579

00:23:34,379 --> 00:23:38,583
and it also found evidence
of hydrothermal vents,

580

00:23:38,583 --> 00:23:40,952
like we think are also
present on Europa.

581

00:23:40,952 --> 00:23:43,054
We found three separate
lines of evidence

582

00:23:43,054 --> 00:23:46,858
that tell us there could
be places at the seafloor

583

00:23:46,858 --> 00:23:49,394
where water from the

ocean goes underneath,

584

00:23:49,394 --> 00:23:52,130

gets heated up and
then comes back out.

585

00:23:52,130 --> 00:23:55,133

Now this is a video of a
hydrothermal vent here on Earth.

586

00:23:55,133 --> 00:23:57,035

I would love if this
was taken at Enceladus,

587

00:23:57,035 --> 00:23:59,404

we're not quite there yet
but we're working on it.

588

00:23:59,404 --> 00:24:04,042

These places are very
rich ecosystems of life.

589

00:24:04,042 --> 00:24:08,180

Not just bacteria,
but crabs octopus,

590

00:24:08,180 --> 00:24:11,616

octopods I think is a plural
officially of octopus,

591

00:24:11,616 --> 00:24:15,053

we see tubeworms, all sorts
of advanced organisms.

592

00:24:15,053 --> 00:24:17,389

And their living as far
removed from sunlight

593

00:24:17,389 --> 00:24:20,125

as you can get here on Earth.

594

00:24:20,125 --> 00:24:21,626

Now this is important, right?

595

00:24:21,626 --> 00:24:23,962

'Cause all of these ocean
worlds I'm showing you have

596

00:24:23,962 --> 00:24:26,698

a thick layer of
ice that's shielding

597

00:24:26,698 --> 00:24:28,467

that ocean from sunlight.

598

00:24:28,467 --> 00:24:31,303

Almost all life here on
Earth needs sunlight,

599

00:24:31,303 --> 00:24:32,871

directly or indirectly.

600

00:24:32,871 --> 00:24:34,906

If you are a plant, it's direct.

601

00:24:34,906 --> 00:24:36,408

If you eat a plant,
it's indirect.

602

00:24:36,408 --> 00:24:41,279

And so we seek evidence
in communities like this,

603

00:24:42,647 --> 00:24:45,617

these rare places where sunlight
doesn't seem to be needed,

604

00:24:45,617 --> 00:24:49,855

to give us clues to what we

might look for in these worlds.

605

00:24:49,855 --> 00:24:52,324

And so a lot of NASA
scientists will study

606

00:24:52,324 --> 00:24:54,526

these hydrothermal
systems here on Earth,

607

00:24:54,526 --> 00:24:57,762

or ask our oceanographer
buddies to give us some hints

608

00:24:57,762 --> 00:24:59,498

and some clues as to
what we might look for

609

00:24:59,498 --> 00:25:02,467

and where we might
get tripped up

610

00:25:02,467 --> 00:25:05,937

if we're trying to design an
experiment to look for life.

611

00:25:05,937 --> 00:25:08,540

So Enceladus is another
fascinating place.

612

00:25:08,540 --> 00:25:10,542

But I want to tell
you about one more.

613

00:25:10,542 --> 00:25:13,311

This is one of the bigger
moons in our solar system.

614

00:25:13,311 --> 00:25:14,779

It looks tiny next to Saturn,

615

00:25:14,779 --> 00:25:17,349

you see that little
sorta golden dot.

616

00:25:17,349 --> 00:25:19,484

That's Titan.

617

00:25:19,484 --> 00:25:22,888

Titan is the second largest
moon in our solar system.

618

00:25:22,888 --> 00:25:25,790

If you count its atmosphere,
it's actually the biggest.

619

00:25:25,790 --> 00:25:27,259

But we'll give Ganymede a win,

620

00:25:27,259 --> 00:25:29,594

'cause otherwise it's
not quite as fascinating.

621

00:25:29,594 --> 00:25:31,496

Titan has an atmosphere,

622

00:25:31,496 --> 00:25:34,332

an atmosphere that's actually
thicker than Earth's.

623

00:25:34,332 --> 00:25:36,868

And thanks to a
collaboration between NASA

624

00:25:36,868 --> 00:25:39,638

and the European
Space Agency, the ESA,

625

00:25:39,638 --> 00:25:42,607

we were able to land
the Huygens probe on

626

00:25:42,607 --> 00:25:46,411

the surface of Titan, and this
is the image that it took.

627

00:25:46,411 --> 00:25:48,480

Now it kind of looks
like Earth, right?

628

00:25:48,480 --> 00:25:49,915

You see some dirt there,

629

00:25:49,915 --> 00:25:52,083

it's probably a really
hazy day here in LA, right?

630

00:25:52,083 --> 00:25:53,952

It's kinda yellowish brown.

631

00:25:53,952 --> 00:25:56,788

And you see some pebbles
there, some rocks.

632

00:25:56,788 --> 00:25:58,623

Those are not rocks
as we know it.

633

00:25:58,623 --> 00:26:01,359

Those we think are
made out of water ice,

634

00:26:01,359 --> 00:26:04,863

and that brown stuff
we think is a mixture

635

00:26:04,863 --> 00:26:06,765

of complex organic molecules

636
00:26:06,765 --> 00:26:08,833
that are made in the atmosphere.

637
00:26:08,833 --> 00:26:10,335
Actually similar to smog.

638
00:26:10,335 --> 00:26:11,603
We think it's photochemistry,

639
00:26:11,603 --> 00:26:13,271
it's the same way smog is made.

640
00:26:13,271 --> 00:26:15,473
So light interacts
with some gases,

641
00:26:15,473 --> 00:26:17,676
those gases start to
link their atoms together

642
00:26:17,676 --> 00:26:19,878
to make bigger molecules,
and those continue,

643
00:26:19,878 --> 00:26:21,646
those reactions
continue to happen

644
00:26:21,646 --> 00:26:23,548
and you get bigger
and bigger aerosols

645
00:26:23,548 --> 00:26:25,016
that eventually get big enough

646
00:26:25,016 --> 00:26:27,819
that they rain down or
snow down on the surface.

647

00:26:27,819 --> 00:26:29,788

We think that's
what's happening.

648

00:26:29,788 --> 00:26:34,459

But there's still
a lot of unanswered
questions about Titan.

649

00:26:34,459 --> 00:26:37,395

One of the coolest
things about Titan

650

00:26:37,395 --> 00:26:40,031

is that it's not just rocks,
it's not just, you know,

651

00:26:40,031 --> 00:26:42,667

it has clouds, it
has an atmosphere,

652

00:26:42,667 --> 00:26:45,570

but it also has
liquid on its surface.

653

00:26:45,570 --> 00:26:47,572

Titan is even colder
than Europa though.

654

00:26:47,572 --> 00:26:51,076

Its -183 degrees C,
which is 90 kelvin

655

00:26:51,076 --> 00:26:52,477

and I don't know what
that is in fahrenheit,

656

00:26:52,477 --> 00:26:53,979

but it's even colder.

657

00:26:53,979 --> 00:26:56,915

However if you were standing
on the surface of Titan,

658

00:26:56,915 --> 00:26:58,183

you would not actually need

659

00:26:58,183 --> 00:27:00,085

a spacesuit because
of that atmosphere.

660

00:27:00,085 --> 00:27:01,319

You'd need a heck of a parka.

661

00:27:01,319 --> 00:27:02,587

Like a really thick one.

662

00:27:02,587 --> 00:27:04,089

You know frostbite
would be a thing.

663

00:27:04,089 --> 00:27:07,292

But you could walk
around without

664

00:27:07,292 --> 00:27:09,127

that pressurized spacesuit.

665

00:27:09,127 --> 00:27:11,196

This is, the pressure is
about one and a half times

666

00:27:11,196 --> 00:27:16,034

our pressure here on
Earth at sea level.

667

00:27:16,034 --> 00:27:17,669

And so because of that,

668

00:27:17,669 --> 00:27:20,805

a lot of really cool
things are possible.

669

00:27:20,805 --> 00:27:25,210

We also see rain
happening on Titan,

670

00:27:25,210 --> 00:27:27,612

but because it's so cold
it's not liquid water.

671

00:27:27,612 --> 00:27:29,247

Water is frozen solid.

672

00:27:29,247 --> 00:27:32,517

We see lakes that are made
out of liquid hydrocarbons.

673

00:27:32,517 --> 00:27:33,985

Methane and ethane.

674

00:27:33,985 --> 00:27:35,453

When I give talks to kids,

675

00:27:35,453 --> 00:27:37,088

I say liquid farts and they
all get really excited.

676

00:27:37,088 --> 00:27:38,456

Sometimes adults do too.

677

00:27:38,456 --> 00:27:40,091

[laughter]

678

00:27:40,091 --> 00:27:40,925

I love it.

679

00:27:40,925 --> 00:27:42,027

It's great.

680

00:27:42,027 --> 00:27:43,395

But this is fascinating, right?

681

00:27:43,395 --> 00:27:46,364

Because if you remember
from like maybe

682

00:27:46,364 --> 00:27:48,033

middle or high school chemistry,

683

00:27:48,033 --> 00:27:50,769

water is a polar solvent, right?

684

00:27:50,769 --> 00:27:53,405

Methane and ethane
are the opposite.

685

00:27:53,405 --> 00:27:55,106

They are nonpolar.

686

00:27:55,106 --> 00:27:57,709

And you may recall
like dissolves like.

687

00:27:57,709 --> 00:28:00,545

Anything that dissolves in
liquid water is not going to

688

00:28:00,545 --> 00:28:04,416

in these liquid
hydrocarbons, and vice versa.

689

00:28:04,416 --> 00:28:07,285

And so we have these huge
seas, they're as big as

690

00:28:07,285 --> 00:28:08,820
the Great Lakes, and bigger,

691

00:28:08,820 --> 00:28:12,657
that are filled with this
liquid that couldn't be,

692

00:28:12,657 --> 00:28:17,095
it could not grease the
machinery of life as we know it.

693

00:28:17,095 --> 00:28:18,730
But it could potentially do that

694

00:28:18,730 --> 00:28:22,467
for some other weird alien
chemistry that would have to be

695

00:28:22,467 --> 00:28:26,404
by definition very different
from any biochemistry here

696

00:28:26,404 --> 00:28:28,973
on Earth just to be
able to stay dissolved

697

00:28:28,973 --> 00:28:31,076
and work in a liquid like this.

698

00:28:31,076 --> 00:28:32,977
So just in our own
cosmic backyard,

699

00:28:32,977 --> 00:28:35,814
we have this wild
example of something that

700

00:28:35,814 --> 00:28:37,982
boy would be really
nice if we could go here

701

00:28:37,982 --> 00:28:39,684
and study this world more.

702

00:28:39,684 --> 00:28:42,087
So it's got this cool
stuff on its surface,

703

00:28:42,087 --> 00:28:45,490
but people always forget
this Titan also has

704

00:28:45,490 --> 00:28:47,025
a liquid water
ocean underneath all

705

00:28:47,025 --> 00:28:49,260
of the cool stuff
happening on the surface.

706

00:28:49,260 --> 00:28:51,663
You got those liquid
hydrocarbon lakes,

707

00:28:51,663 --> 00:28:54,165
that cool organicy stuff that
we don't know what it is,

708

00:28:54,165 --> 00:28:57,635
and then you go down through
the ice, which is the shell,

709

00:28:57,635 --> 00:28:59,771
and you hit liquid water also.

710

00:28:59,771 --> 00:29:02,173
Now this is really
exciting to me,

711

00:29:02,173 --> 00:29:04,142

for someone who is a
chemist by training,

712

00:29:04,142 --> 00:29:07,445

I study organic chemistry
because we've tried

713

00:29:07,445 --> 00:29:11,483

to replicate some places
in Titans environment,

714

00:29:11,483 --> 00:29:13,151

here in the laboratory.

715

00:29:13,151 --> 00:29:15,019

We can do that
same photochemistry

716

00:29:15,019 --> 00:29:17,489

that makes that gunk
in the atmosphere.

717

00:29:17,489 --> 00:29:19,257

Carl Sagan was actually
one of the first people

718

00:29:19,257 --> 00:29:22,060

to do this in the lab
and he named that stuff,

719

00:29:22,060 --> 00:29:25,964

he called it tholin, which is
from the Greek word tholos,

720

00:29:25,964 --> 00:29:28,266

which means muddy or not clear.

721

00:29:28,266 --> 00:29:29,768

Which is really great

it's a double meaning.

722

00:29:29,768 --> 00:29:31,002

Because the stuff,
when you make it,

723

00:29:31,002 --> 00:29:32,871

it's like that brownish
orangeish color,

724

00:29:32,871 --> 00:29:34,139

so it's sort of mud colored.

725

00:29:34,139 --> 00:29:36,074

And we also don't know
what it's made of.

726

00:29:36,074 --> 00:29:37,776

'Cause you stick it
into an instrument,

727

00:29:37,776 --> 00:29:39,410

and you get this
forest of peaks.

728

00:29:39,410 --> 00:29:41,212

It's like anything
that you can think of

729

00:29:41,212 --> 00:29:44,048

that's made out of carbon,
hydrogen and nitrogen.

730

00:29:44,048 --> 00:29:46,618

Those three elements, you mix
'em together whatever way,

731

00:29:46,618 --> 00:29:48,486

do you have your chemistry
set at home, anybody?

732

00:29:48,486 --> 00:29:49,420

I do.

733

00:29:49,420 --> 00:29:51,156

No, you don't do that for fun?

734

00:29:51,156 --> 00:29:54,058

But you can make small
things, big things, every,

735

00:29:54,058 --> 00:29:56,194

it's all in there,
in the tholin,

736

00:29:56,194 --> 00:29:59,230

and the really cool thing
is if you take that tholin

737

00:29:59,230 --> 00:30:01,132

and you dissolve
it in liquid water,

738

00:30:01,132 --> 00:30:04,169

you make amino acids, like that.

739

00:30:04,169 --> 00:30:08,473

So if any of that organicy
goopy stuff that's made on,

740

00:30:08,473 --> 00:30:10,208

in the atmosphere that
stuck on the surface,

741

00:30:10,208 --> 00:30:11,342

if any of that gets pulled down

742

00:30:11,342 --> 00:30:13,444

into that liquid water ocean,

743

00:30:13,444 --> 00:30:16,181
boy you've got a lot of
interesting molecules now

744

00:30:16,181 --> 00:30:18,750
that life could use potentially.

745

00:30:18,750 --> 00:30:20,718
And so this is why
I think Titan is

746

00:30:20,718 --> 00:30:23,788
a really fascinating
world, worthy of study.

747

00:30:23,788 --> 00:30:25,256
Boy, wouldn't it be great
if we were working on

748

00:30:25,256 --> 00:30:27,025
a mission to go there?

749

00:30:27,025 --> 00:30:28,259
We are.

750

00:30:28,259 --> 00:30:30,261
This is Dragonfly.

751

00:30:30,261 --> 00:30:32,997
This is a brand new mission,

752

00:30:32,997 --> 00:30:37,168
it was just selected in July
of last year, and it is big.

753

00:30:37,168 --> 00:30:41,706
This is eight-bladed
rotorcraft that can move,

754

00:30:41,706 --> 00:30:43,408

remember I said the
atmosphere is thick?

755

00:30:43,408 --> 00:30:45,743

The gravity on
Titan is a lot less.

756

00:30:45,743 --> 00:30:48,613

It turns out it's more
efficient to fly around

757

00:30:48,613 --> 00:30:50,081

than it would be to drive,

758

00:30:50,081 --> 00:30:52,617

like our typical
rovers do on Mars.

759

00:30:52,617 --> 00:30:53,852

And this thing is large.

760

00:30:53,852 --> 00:30:55,620

Like our first
science team meeting,

761

00:30:55,620 --> 00:30:57,689

they had the VR headset so
we can see how big it is,

762

00:30:57,689 --> 00:30:59,724

and like okay, I'm not
normal-sized human,

763

00:30:59,724 --> 00:31:00,892

so picture little
bit bigger than me,

764

00:31:00,892 --> 00:31:02,594
but it's like I put out my arms

765
00:31:02,594 --> 00:31:04,329
and I can't quite reach as wide.

766
00:31:04,329 --> 00:31:05,597
Like it's big.

767
00:31:05,597 --> 00:31:07,765
That antenna, the
direct to Earth antenna,

768
00:31:07,765 --> 00:31:10,034
that thing that folds up in
back, is like taller than me,

769
00:31:10,034 --> 00:31:11,336
I was looking up at it.

770
00:31:11,336 --> 00:31:12,904
This thing is big.

771
00:31:12,904 --> 00:31:14,672
But because of all
the advancements

772
00:31:14,672 --> 00:31:18,877
in rotorcraft technology,
in autonomous navigation,

773
00:31:18,877 --> 00:31:21,479
this type of thing is
possible to do now,

774
00:31:21,479 --> 00:31:23,147
which is super exciting,

775
00:31:23,147 --> 00:31:25,416

'cause this means we
can land in one spot,

776

00:31:25,416 --> 00:31:27,452
study that place
and then pick up

777

00:31:27,452 --> 00:31:29,053
and go somewhere
else interesting.

778

00:31:29,053 --> 00:31:32,123
So we can study these
dunes that we see in

779

00:31:32,123 --> 00:31:33,591
the equatorial region of Titan,

780

00:31:33,591 --> 00:31:34,759
that's where we're
going to start.

781

00:31:34,759 --> 00:31:36,261
We're going to
start near a crater.

782

00:31:36,261 --> 00:31:38,296
Titan also doesn't
have very many craters,

783

00:31:38,296 --> 00:31:39,530
but it's got a few,

784

00:31:39,530 --> 00:31:40,999
and it's a great place
'cause it looks like

785

00:31:40,999 --> 00:31:43,468
that impact excavated
some stuff out and some of

786

00:31:43,468 --> 00:31:45,470

the water ice may be
really accessible,

787

00:31:45,470 --> 00:31:46,971

and so we're gonna go there too,

788

00:31:46,971 --> 00:31:48,940

and we're going to just
hop around for a few years.

789

00:31:48,940 --> 00:31:51,776

This is going to
launch we hope in 2026,

790

00:31:51,776 --> 00:31:54,178

land on Titan in 2034.

791

00:31:54,178 --> 00:31:55,413

Space is big.

792

00:31:55,413 --> 00:31:56,648

And don't count how
old you will be,

793

00:31:56,648 --> 00:31:58,116

because you might get depressed,

794

00:31:58,116 --> 00:32:01,786

but I'm really excited
about this mission.

795

00:32:01,786 --> 00:32:05,657

So the future is really
bright when it comes to

796

00:32:05,657 --> 00:32:07,926

the types of missions

that we're working on,

797

00:32:07,926 --> 00:32:09,894

that we're building
to answer some of

798

00:32:09,894 --> 00:32:12,697

these critical questions
about ocean worlds

799

00:32:12,697 --> 00:32:14,265

and whether or not we're alone.

800

00:32:14,265 --> 00:32:17,402

But this is just in our
own cosmic backyard.

801

00:32:17,402 --> 00:32:19,270

What about further than that?

802

00:32:19,270 --> 00:32:22,407

I'd like to introduce you
to the TRAPPIST system.

803

00:32:22,407 --> 00:32:24,976

So this is about
12 parsecs out in

804

00:32:24,976 --> 00:32:27,111

the Aquarius
constellation, so if you're

805

00:32:27,111 --> 00:32:28,513

a really good pilot
like Han Solo,

806

00:32:28,513 --> 00:32:30,548

this is one Kessel Run away.

807

00:32:30,548 --> 00:32:31,783
[laughter]

808
00:32:31,783 --> 00:32:33,418
I'm glad you went
with me on that one.

809
00:32:33,418 --> 00:32:36,020
It's got about seven planets

810
00:32:36,020 --> 00:32:38,456
in orbit around
a red dwarf star.

811
00:32:38,456 --> 00:32:41,726
Now this is a place that we
are just starting to study,

812
00:32:41,726 --> 00:32:45,263
but there are a handful of
worlds even in this system

813
00:32:45,263 --> 00:32:47,999
that are in what we
call the habitable zone.

814
00:32:47,999 --> 00:32:49,033
Now what is that?

815
00:32:49,033 --> 00:32:50,301
Well that's where Earth is.

816
00:32:50,301 --> 00:32:52,070
If you're too close
to your host star,

817
00:32:52,070 --> 00:32:54,572
things get a little bit
hot and liquid water

818

00:32:54,572 --> 00:32:57,241

is not stable at the surface,
it would all boil away.

819

00:32:57,241 --> 00:32:59,477

If you're too far
you end up with

820

00:32:59,477 --> 00:33:00,645

the opposite problem, right?

821

00:33:00,645 --> 00:33:02,080

Things get frozen solid.

822

00:33:02,080 --> 00:33:05,149

Earth is in just that
right happy place,

823

00:33:05,149 --> 00:33:07,452

where liquid water can
be stable on the surface,

824

00:33:07,452 --> 00:33:09,387

and when we look at exoplanets,

825

00:33:09,387 --> 00:33:10,888

that's what we
call these planets

826

00:33:10,888 --> 00:33:12,757

in orbit around other stars,

827

00:33:12,757 --> 00:33:15,994

We start off looking
in that habitable zone,

828

00:33:15,994 --> 00:33:19,964

because those worlds
may be similar to Earth.

829

00:33:19,964 --> 00:33:22,433

And we've started a
catalog and just in

830

00:33:22,433 --> 00:33:25,003

a few years of looking
we've already found a bunch.

831

00:33:25,003 --> 00:33:26,838

You can see some
that say TRAPPIST-1,

832

00:33:26,838 --> 00:33:28,506

whatever there's a
letter at the end,

833

00:33:28,506 --> 00:33:30,475

that's typically how
we name exoplanets.

834

00:33:30,475 --> 00:33:32,310

We start with the
telescope that found them,

835

00:33:32,310 --> 00:33:35,513

so the TRAPPIST, or the mission
that found them is first,

836

00:33:35,513 --> 00:33:37,982

then we give it a number for
the star that we observed,

837

00:33:37,982 --> 00:33:41,219

and then the planets all
get letters, so A-B-C-D-E,

838

00:33:41,219 --> 00:33:42,954

so you can figure
out where it is,

839

00:33:42,954 --> 00:33:44,922

how close it is
to its host star.

840

00:33:44,922 --> 00:33:48,393

And so you can see
TRAPPIST D, E and F and G

841

00:33:48,393 --> 00:33:51,329

all seem to be in
that habitable zone,

842

00:33:51,329 --> 00:33:53,331

and that's just around one star,

843

00:33:53,331 --> 00:33:54,832

and we've just started looking.

844

00:33:54,832 --> 00:33:56,367

This thing is probably
already out of date,

845

00:33:56,367 --> 00:33:57,635

it's from September of last year

846

00:33:57,635 --> 00:33:59,037

but I'm sure we
found a few more.

847

00:33:59,037 --> 00:34:02,440

And this just blows
your mind, right?

848

00:34:02,440 --> 00:34:04,876

These are just the ones
in the habitable system.

849

00:34:04,876 --> 00:34:07,478

We haven't even started
looking for exo-Europas

850

00:34:07,478 --> 00:34:10,515
and exo-Titans and exo-Enceladi?

851

00:34:10,515 --> 00:34:11,349
Enceladi.

852

00:34:12,750 --> 00:34:16,854
Now we know that liquid water
can exist even further out

853

00:34:16,854 --> 00:34:19,957
than this habitable zone
that Earth resides in.

854

00:34:19,957 --> 00:34:22,293
It's an incredibly
exciting time to be

855

00:34:22,293 --> 00:34:25,930
a planetary scientist, to
be studying these worlds.

856

00:34:25,930 --> 00:34:28,099
But looking for life on a place

857

00:34:28,099 --> 00:34:30,701
this far away is
challenging, right?

858

00:34:30,701 --> 00:34:33,638
If we wanted to send
a spacecraft there,

859

00:34:33,638 --> 00:34:35,606
it would take a very long time.

860

00:34:35,606 --> 00:34:37,075

We're working on
concepts like that.

861

00:34:37,075 --> 00:34:39,510

There's some spacecraft
that we're working

862

00:34:39,510 --> 00:34:42,413

on using things like
solar electric propulsion

863

00:34:42,413 --> 00:34:44,315

or even lasers to
accelerate them to

864

00:34:44,315 --> 00:34:46,751

a significant percentage
of the speed of light,

865

00:34:46,751 --> 00:34:48,953

which is nuts, 'cause
then how do you slow down.

866

00:34:48,953 --> 00:34:50,588

But we're working on that, too.

867

00:34:50,588 --> 00:34:52,957

And to get to these world
so that we can study them.

868

00:34:52,957 --> 00:34:54,492

We can still do a lot

869

00:34:54,492 --> 00:34:57,161

with powerful telescopes
here on Earth.

870

00:34:57,161 --> 00:34:59,330

One of the nice things

we can do is if some of

871

00:34:59,330 --> 00:35:01,332

these worlds are
just the right angle

872

00:35:01,332 --> 00:35:04,635

where they pass between
us and their host star,

873

00:35:04,635 --> 00:35:06,404

we can do spectroscopy.

874

00:35:06,404 --> 00:35:11,409

Spectro- is lights,
-scopy is study,

875

00:35:12,577 --> 00:35:13,811

so we're studying
light, spectroscopy.

876

00:35:13,811 --> 00:35:16,080

So we can break that
down into the rainbow

877

00:35:16,080 --> 00:35:18,182

and look at what
wavelengths are missing,

878

00:35:18,182 --> 00:35:21,185

and by doing that we can tell
what kind of gases are in

879

00:35:21,185 --> 00:35:23,254

the atmospheres of
some of these worlds,

880

00:35:23,254 --> 00:35:25,056

which is pretty amazing.

881

00:35:25,056 --> 00:35:29,160

But the search for life
can have challenges, right?

882

00:35:29,160 --> 00:35:30,495

It can be tough.

883

00:35:30,495 --> 00:35:32,096

Who recognizes this image?

884

00:35:33,464 --> 00:35:35,800

Yeah, this is, does anyone
know the name of the meteorite?

885

00:35:35,800 --> 00:35:39,070

Very good, it's ALH84001.

886

00:35:39,070 --> 00:35:41,205

Which do you want to know
how meteorites are named?

887

00:35:41,205 --> 00:35:42,073

I'm going to tell you.

888

00:35:42,073 --> 00:35:43,574

Guess what.

889

00:35:43,574 --> 00:35:46,010

All right so this was a Mars
meteorite that was discovered

890

00:35:46,010 --> 00:35:49,647

in Allan Hills Antarctica,
that's where the ALH comes from,

891

00:35:49,647 --> 00:35:52,750

the 84 is from 1984,
'cause that was the year

892

00:35:52,750 --> 00:35:55,553

that it was discovered,
and then the 001 is it was

893

00:35:55,553 --> 00:35:58,523

the first meteorite that was
found that year in this place.

894

00:35:58,523 --> 00:35:59,957

They leave a couple
extra digits,

895

00:35:59,957 --> 00:36:01,659

'cause I guess they're hoping
they'll find, you know,

896

00:36:01,659 --> 00:36:03,628

maybe 100 or more,
that would be great.

897

00:36:03,628 --> 00:36:05,997

We haven't found that many
Mars meteorites though.

898

00:36:05,997 --> 00:36:08,065

We found about 30 so far,

899

00:36:08,065 --> 00:36:10,601

and most of them we
do find in Antarctica,

900

00:36:10,601 --> 00:36:12,270

because it's nice and white,

901

00:36:12,270 --> 00:36:14,805

there's not a lot of snow
or anything else happening,

902

00:36:14,805 --> 00:36:18,075

and so these black meteorites
show up brilliantly.

903

00:36:18,075 --> 00:36:20,444
They're very easy to find.

904

00:36:20,444 --> 00:36:23,981
So this one ALH84001 is

905

00:36:23,981 --> 00:36:27,151
the oldest Mars meteorite
that we've found.

906

00:36:27,151 --> 00:36:29,887
We think that it's from
a time in Mars's history

907

00:36:29,887 --> 00:36:31,756
when it was much
warmer and wetter.

908

00:36:31,756 --> 00:36:33,591
Now the reason we know
it's from Mars is because

909

00:36:33,591 --> 00:36:35,793
there were some
trapped gases inside

910

00:36:35,793 --> 00:36:37,728
that we were able to
sample, and those gases are

911

00:36:37,728 --> 00:36:40,565
the same as in
Mars's atmosphere.

912

00:36:40,565 --> 00:36:42,700
We also some other
evidence to show us,

913

00:36:42,700 --> 00:36:45,670

to prove to ourselves
as scientists that
this is from Mars.

914

00:36:45,670 --> 00:36:48,105

And when we sliced it open
and looked at it under

915

00:36:48,105 --> 00:36:51,175

a scanning electron microscope,
this is what we saw.

916

00:36:51,175 --> 00:36:54,679

And of course we all immediately
got very excited, right?

917

00:36:54,679 --> 00:36:56,814

Because that thing
looks like a worm.

918

00:36:56,814 --> 00:36:58,449

Well it's not.

919

00:36:58,449 --> 00:37:01,285

It's about 1/100 the
width of a human hair,

920

00:37:01,285 --> 00:37:02,853

which is incredibly small,

921

00:37:02,853 --> 00:37:04,655

very few cells are
even that small,

922

00:37:04,655 --> 00:37:07,959

much less a multicellular
organism like this.

923

00:37:07,959 --> 00:37:12,964

But it gives us some
lessons as to when life can,

924

00:37:14,398 --> 00:37:18,469

or when evidence that we
think as biased humans

925

00:37:18,469 --> 00:37:20,438

that we see looks like life,

926

00:37:20,438 --> 00:37:23,007

whether or not it is
actually life or not.

927

00:37:23,007 --> 00:37:25,243

So we study the chemical
signatures that were in

928

00:37:25,243 --> 00:37:28,512

this meteorite and there
is still to this day,

929

00:37:28,512 --> 00:37:31,182

some scientists, a small
subset of the community

930

00:37:31,182 --> 00:37:34,285

that are convinced that this
is actually evidence of life.

931

00:37:34,285 --> 00:37:37,622

But the problem is it's hard
to convince the rest of us,

932

00:37:37,622 --> 00:37:39,457

and the reason for
that is because there

933

00:37:39,457 --> 00:37:42,493

are abiotic
explanations for all of

934

00:37:42,493 --> 00:37:43,894

the things that we see here.

935

00:37:43,894 --> 00:37:46,297

We see some carbonate globules.

936

00:37:46,297 --> 00:37:49,467

Carbonate typically is
associated with life,

937

00:37:49,467 --> 00:37:51,869

especially fossilized life,

938

00:37:51,869 --> 00:37:54,605

but you can also make
it without life, too.

939

00:37:54,605 --> 00:37:57,742

We see magnetite crystals
inside of this meteorite.

940

00:37:57,742 --> 00:38:00,578

Now some bacteria will
actually use magnetite,

941

00:38:00,578 --> 00:38:02,613

kind of like little compasses
to sort of navigate around,

942

00:38:02,613 --> 00:38:05,283

but the amount of
magnetite that we saw

943

00:38:05,283 --> 00:38:07,351

was inconsistent with what

944
00:38:07,351 --> 00:38:09,320
we would expect
for most organisms.

945
00:38:09,320 --> 00:38:11,222
The amount that we
saw would have meant

946
00:38:11,222 --> 00:38:13,891
that Mars's magnetic field
would be super strong,

947
00:38:13,891 --> 00:38:15,393
like way stronger than Earth's,

948
00:38:15,393 --> 00:38:17,161
and that's doesn't make
sense 'cause it's smaller,

949
00:38:17,161 --> 00:38:18,996
how could it, that
doesn't make sense.

950
00:38:18,996 --> 00:38:22,800
And you can also deposit
that abiotically, too.

951
00:38:22,800 --> 00:38:25,436
So Carl Sagan said once that

952
00:38:25,436 --> 00:38:29,106
"life has to be the
hypothesis of last resort."

953
00:38:29,106 --> 00:38:32,476
You must have eliminated all
other possible explanations,

954
00:38:32,476 --> 00:38:34,779

and if you can do that and the
only thing you're left with

955

00:38:34,779 --> 00:38:37,248

is life then you
can be convinced.

956

00:38:37,248 --> 00:38:40,217

And the problem with this
meteorite is there are still

957

00:38:40,217 --> 00:38:43,387

enough abiotic
explanations for this

958

00:38:43,387 --> 00:38:46,991

that all of us
can't be convinced.

959

00:38:46,991 --> 00:38:49,126

And this is something that
we have here, on Earth.

960

00:38:49,126 --> 00:38:50,394

So we can bring to bear all

961

00:38:50,394 --> 00:38:52,129

of our most sensitive
instruments,

962

00:38:52,129 --> 00:38:54,265

some of the microscopes
and spectrometers

963

00:38:54,265 --> 00:38:56,567

that fill a room, right?

964

00:38:56,567 --> 00:38:59,370

What if you want to take
that and now put it on

965

00:38:59,370 --> 00:39:00,838

a spacecraft, miniaturize it

966

00:39:00,838 --> 00:39:02,807

and then send it somewhere else?

967

00:39:04,275 --> 00:39:07,044

Some of the instrumentation,
it gets challenging, right?

968

00:39:07,044 --> 00:39:09,547

You may not be able
to be as sensitive,

969

00:39:09,547 --> 00:39:13,684

but now you can be sure that
you know exactly what happened

970

00:39:13,684 --> 00:39:16,087

to your sample in between
when it was there on Mars,

971

00:39:16,087 --> 00:39:18,122

for example like with Viking,

972

00:39:18,122 --> 00:39:19,724

and when you reached
out your robotic arm

973

00:39:19,724 --> 00:39:22,093

and grabbed it and then
looked at what was inside.

974

00:39:22,093 --> 00:39:25,329

With meteorites we can
guess at when they formed,

975

00:39:25,329 --> 00:39:27,231

that meteorite that
I was showing you,

976

00:39:27,231 --> 00:39:29,800

it probably was ejected
from Mars millions,

977

00:39:29,800 --> 00:39:32,703

maybe billions of years ago,
when it was warmer and wetter,

978

00:39:32,703 --> 00:39:34,605

and then it just kind of
circled around in space for

979

00:39:34,605 --> 00:39:38,042

a while we think until
about 16,000 years ago.

980

00:39:38,042 --> 00:39:40,311

And that's when it
crashed here on Earth.

981

00:39:40,311 --> 00:39:42,546

We don't really know what
was happening to it during

982

00:39:42,546 --> 00:39:46,217

that time and that
uncertainty can lead us

983

00:39:46,217 --> 00:39:48,919

to question anything we
might find inside it.

984

00:39:48,919 --> 00:39:51,689

That's why we want to go
and land on these places,

985

00:39:51,689 --> 00:39:53,491

where we have a
better understanding

986
00:39:53,491 --> 00:39:56,360
of what we call the
provenance of that sample,

987
00:39:56,360 --> 00:39:59,563
the history, where it's
been, how it got there,

988
00:39:59,563 --> 00:40:01,365
so that if we find
a signature in it

989
00:40:01,365 --> 00:40:04,101
we can say for sure that
came from this place,

990
00:40:04,101 --> 00:40:05,336
it's not contamination.

991
00:40:05,336 --> 00:40:07,505
It's not something
it picked up later.

992
00:40:07,505 --> 00:40:09,540
That's really important
for being sure

993
00:40:09,540 --> 00:40:13,144
when we finally answer this
key question are we alone,

994
00:40:13,144 --> 00:40:14,712
we can be sure of our answer.

995
00:40:16,247 --> 00:40:17,515
So the Viking landers,

996
00:40:17,515 --> 00:40:19,183
there were two of
them in the 1970s.

997
00:40:19,183 --> 00:40:21,218
These landed on the
surface of Mars,

998
00:40:21,218 --> 00:40:24,255
and this was the first
mission that explicitly had

999
00:40:24,255 --> 00:40:27,625
the goal of looking for
life somewhere else.

1000
00:40:27,625 --> 00:40:29,360
On Mars in this case.

1001
00:40:29,360 --> 00:40:32,196
The Viking landers, they
had identical instruments

1002
00:40:32,196 --> 00:40:35,232
and they went to two different
places on Mars's surface,

1003
00:40:35,232 --> 00:40:39,970
and they had three biology
detection instruments.

1004
00:40:39,970 --> 00:40:41,739
They also had a
chemical analyzer called

1005
00:40:41,739 --> 00:40:43,374
a mass spectrometer,
remember the tongue,

1006

00:40:43,374 --> 00:40:45,376
it's like similar to that.

1007
00:40:45,376 --> 00:40:48,312
Of the three
biology experiments,

1008
00:40:48,312 --> 00:40:50,915
one gave a positive
result for life,

1009
00:40:50,915 --> 00:40:53,784
one was negative and
one was ambiguous.

1010
00:40:53,784 --> 00:40:57,521
Now this isn't because the
scientists did a poor job,

1011
00:40:57,521 --> 00:41:00,090
they did the best job
that they could designing

1012
00:41:00,090 --> 00:41:01,759
an experiment that they
thought would give them

1013
00:41:01,759 --> 00:41:04,628
that absolute yes or no answer.

1014
00:41:04,628 --> 00:41:06,130
But all three of
these techniques

1015
00:41:06,130 --> 00:41:08,866
were based off of
metabolic assays.

1016
00:41:08,866 --> 00:41:11,502
Basically what they did is

they scooped up some Mars soil,

1017

00:41:11,502 --> 00:41:13,938

some Mars regolith,
they put it in a bin

1018

00:41:13,938 --> 00:41:17,074

and then they dropped
either water or liquid water

1019

00:41:17,074 --> 00:41:20,277

or some nutrients on it
or both and sealed it up

1020

00:41:20,277 --> 00:41:23,180

and they looked at the gases
that came off or they looked

1021

00:41:23,180 --> 00:41:25,883

at whether or not it could
take some of the nutrients

1022

00:41:25,883 --> 00:41:30,387

that it was given and be
able to turn that into

1023

00:41:30,387 --> 00:41:33,824

other molecules that could
give us evidence of life.

1024

00:41:33,824 --> 00:41:37,194

So these tests were
based off of them going

1025

00:41:37,194 --> 00:41:38,429

to different places
here on Earth

1026

00:41:38,429 --> 00:41:40,130

and trying those

same experiments,

1027

00:41:40,130 --> 00:41:42,233

and they thought that they
were very confident that

1028

00:41:42,233 --> 00:41:44,435

these types of
things could give us

1029

00:41:44,435 --> 00:41:47,238

an absolute yes or no
answer, are we alone.

1030

00:41:47,238 --> 00:41:50,975

Well it turns out that
we didn't have as deep of

1031

00:41:50,975 --> 00:41:54,879

a knowledge of the surface
chemistry of Mars at that time.

1032

00:41:54,879 --> 00:41:56,380

Since then we've
discovered that there

1033

00:41:56,380 --> 00:41:59,617

are things like perchlorates,
very reactive salts,

1034

00:41:59,617 --> 00:42:02,286

that can give the
same types of answers.

1035

00:42:02,286 --> 00:42:04,555

It turns out that a
scientist recently was able

1036

00:42:04,555 --> 00:42:07,858

to replicate very

well, not perfectly,

1037

00:42:07,858 --> 00:42:11,195

but really closely those
same false positives,

1038

00:42:11,195 --> 00:42:13,030

what we call it, when
you see something

1039

00:42:13,030 --> 00:42:14,798

that you think is
real but its not.

1040

00:42:14,798 --> 00:42:16,967

Those false positive
measurements,

1041

00:42:16,967 --> 00:42:18,836

if you take perchlorate
and you sort of give it

1042

00:42:18,836 --> 00:42:20,304

a light dusting of gamma rays,

1043

00:42:20,304 --> 00:42:21,605

and then you do that same

1044

00:42:21,605 --> 00:42:22,873

sort of life
detection measurement,

1045

00:42:22,873 --> 00:42:24,508

you dump some water and
some nutrients on it,

1046

00:42:24,508 --> 00:42:26,677

you'd get the same gases off.

1047

00:42:26,677 --> 00:42:29,980

And so, as Carl
said, life has to be

1048

00:42:29,980 --> 00:42:32,149

that hypothesis of last resort,

1049

00:42:32,149 --> 00:42:34,351

and in the case of the
Viking experiments,

1050

00:42:34,351 --> 00:42:38,923

we still have abiotic
explanations that could explain

1051

00:42:38,923 --> 00:42:40,925

the data that we see.

1052

00:42:40,925 --> 00:42:42,626

But we have learned
a lot since then.

1053

00:42:42,626 --> 00:42:45,496

When we were building and
launching the Viking landers,

1054

00:42:45,496 --> 00:42:47,865

we didn't know about the
third branch of life.

1055

00:42:47,865 --> 00:42:50,167

We knew about
bacteria and fungi,

1056

00:42:52,269 --> 00:42:53,671

but we didn't know
about archaea.

1057

00:42:53,671 --> 00:42:55,706

That haven't been

discovered yet.

1058

00:42:55,706 --> 00:42:58,142

We know a lot more
now than we did then.

1059

00:42:58,142 --> 00:43:00,945

It doesn't mean though that
we won't make new mistakes

1060

00:43:00,945 --> 00:43:03,180

whenever we search
for life elsewhere.

1061

00:43:03,180 --> 00:43:04,982

And that's something
that as scientists

1062

00:43:04,982 --> 00:43:06,350

we always need to keep in mind.

1063

00:43:06,350 --> 00:43:08,986

We will do our best to design

1064

00:43:08,986 --> 00:43:10,754

the most foolproof experiments.

1065

00:43:10,754 --> 00:43:13,691

But we have to prepare
ourselves for the fact

1066

00:43:13,691 --> 00:43:16,093

that we will likely make
new and different mistakes.

1067

00:43:16,093 --> 00:43:18,996

We'll still learn something,
and we still have to go.

1068

00:43:18,996 --> 00:43:20,898
Because we need to know.

1069
00:43:20,898 --> 00:43:25,369
But we need to make sure that
we're prepared for an answer.

1070
00:43:25,369 --> 00:43:27,571
And so that's something
that I always try

1071
00:43:27,571 --> 00:43:29,073
to keep in mind
when we're having

1072
00:43:29,073 --> 00:43:31,609
these endless discussions
about what experiments

1073
00:43:31,609 --> 00:43:33,477
we should do, how
sure we can be,

1074
00:43:33,477 --> 00:43:36,313
how many tests we can
do here to be positive

1075
00:43:36,313 --> 00:43:38,382
that we're spending
our taxpayer dollars,

1076
00:43:38,382 --> 00:43:40,184
your dollars, as well
as we can, right?

1077
00:43:40,184 --> 00:43:42,519
Because that's what NASA does.

1078
00:43:42,519 --> 00:43:44,855
And we can take a

lot of lessons from

1079

00:43:44,855 --> 00:43:47,524

the types of life that
we have here on Earth.

1080

00:43:47,524 --> 00:43:50,661

Does anyone recognize
this little guy?

1081

00:43:50,661 --> 00:43:51,495

The tardigrade.

1082

00:43:51,495 --> 00:43:52,696

The water bear.

1083

00:43:52,696 --> 00:43:54,398

This little guy can
survive in space, right?

1084

00:43:54,398 --> 00:43:55,833

I think he's super cute.

1085

00:43:55,833 --> 00:43:58,035

One of my friends said
"boy, it would be terrifying

1086

00:43:58,035 --> 00:43:59,870

"if that was like
large enough to ride."

1087

00:43:59,870 --> 00:44:01,105

I think that'd be amazing.

1088

00:44:01,105 --> 00:44:02,272

Could you imagine
like riding around.

1089

00:44:02,272 --> 00:44:03,974

It's be awesome.

1090

00:44:03,974 --> 00:44:05,576

So we have examples of life

1091

00:44:05,576 --> 00:44:07,778

that can survive really
extreme conditions.

1092

00:44:07,778 --> 00:44:10,114

How would you look
for a tardigrade?

1093

00:44:10,114 --> 00:44:11,515

Would a microscope be enough?

1094

00:44:11,515 --> 00:44:14,885

That would just be a
morphology type of measurement.

1095

00:44:14,885 --> 00:44:15,919

What if you saw it move?

1096

00:44:15,919 --> 00:44:17,254

That would be better.

1097

00:44:17,254 --> 00:44:19,823

Maybe if you also were
able to study some of

1098

00:44:19,823 --> 00:44:22,960

the molecules that
the tardigrade is
consuming or producing,

1099

00:44:22,960 --> 00:44:25,829

or maybe sad to
say, maybe just take

1100

00:44:25,829 --> 00:44:27,297

the tardigrade itself
and stick it into

1101

00:44:27,297 --> 00:44:29,199

an instrument and see
what it's made of.

1102

00:44:29,199 --> 00:44:31,468

These are types of
things that we could do

1103

00:44:31,468 --> 00:44:32,903

if we expect this kind of life.

1104

00:44:32,903 --> 00:44:35,172

But we see some other
weird things too.

1105

00:44:35,172 --> 00:44:37,408

This kind of organism, I
can't remember its name,

1106

00:44:37,408 --> 00:44:39,209

but it doesn't need oxygen.

1107

00:44:39,209 --> 00:44:41,445

It's one of the few animals,
even though it's microscopic,

1108

00:44:41,445 --> 00:44:44,515

it's an animal that doesn't
need oxygen to be alive.

1109

00:44:44,515 --> 00:44:46,750

This is a brand-new sea
slug that's new to science,

1110

00:44:46,750 --> 00:44:48,285

discovered just last year.

1111

00:44:48,285 --> 00:44:50,821

So we're still finding even
on our own planet all sorts

1112

00:44:50,821 --> 00:44:54,692

of wacky and wild forms of
what look like alien life,

1113

00:44:54,692 --> 00:44:56,393

and this guy, this
is something we call

1114

00:44:56,393 --> 00:44:57,661

the immortal jellyfish.

1115

00:44:57,661 --> 00:44:59,530

It's about the size
of your pinky nail,

1116

00:44:59,530 --> 00:45:00,998

and it does this weird thing.

1117

00:45:00,998 --> 00:45:03,300

When conditions get bad,
it reverts back to its sort

1118

00:45:03,300 --> 00:45:06,403

of primordial polyp form and
it just kind of chills out,

1119

00:45:06,403 --> 00:45:07,671

and then again when
conditions get good again,

1120

00:45:07,671 --> 00:45:10,207

it makes itself back
into a jellyfish.

1121

00:45:10,207 --> 00:45:12,376

So we think this thing
could potentially live for

1122

00:45:12,376 --> 00:45:14,011

a really long time,
maybe forever.

1123

00:45:14,011 --> 00:45:16,313

Forever is a long time, but
at least for a very long time.

1124

00:45:16,313 --> 00:45:19,883

So we try to take lessons
from the extreme forms

1125

00:45:19,883 --> 00:45:23,687

of life that we see here
to help inform those tests

1126

00:45:23,687 --> 00:45:25,956

that we might perform
somewhere else,

1127

00:45:25,956 --> 00:45:28,092

to answer that pivotal question.

1128

00:45:28,092 --> 00:45:30,394

'Cause this is what
we're going for, right?

1129

00:45:30,394 --> 00:45:32,062

At least, you know,
it'd be great,

1130

00:45:32,062 --> 00:45:34,898

to write my speech, to go in
and collect the Nobel Prize

1131

00:45:34,898 --> 00:45:38,769

for finding life for the
first time in human history.

1132
00:45:38,769 --> 00:45:42,706
This is something we call
civilization level science.

1133
00:45:42,706 --> 00:45:44,408
You only get to make
this discovery once,

1134
00:45:44,408 --> 00:45:48,412
and it would
revolutionize, I think,

1135
00:45:48,412 --> 00:45:52,049
our opinion of who
we are as a species.

1136
00:45:52,049 --> 00:45:54,151
Whether or not we're alone.

1137
00:45:54,151 --> 00:45:57,888
Is the Earth just this this
precious terribly alone ball,

1138
00:45:57,888 --> 00:46:01,058
or is it one of millions and
billions that are out there,

1139
00:46:01,058 --> 00:46:03,927
that could potentially all
have different various forms

1140
00:46:03,927 --> 00:46:06,497
of life that we
couldn't even imagine?

1141
00:46:06,497 --> 00:46:09,032
This kind, we have the

technology to answer

1142

00:46:09,032 --> 00:46:12,302

this question now, and
we're building missions

1143

00:46:12,302 --> 00:46:13,904

to go and find these answers.

1144

00:46:13,904 --> 00:46:17,441

It's an incredibly exciting
time to work for NASA,

1145

00:46:17,441 --> 00:46:21,278

to be a planetary scientist,
and I don't even need that.

1146

00:46:21,278 --> 00:46:24,882

I would just be so happy to
be part of this question,

1147

00:46:24,882 --> 00:46:26,483

of trying to find the answer.

1148

00:46:27,651 --> 00:46:29,753

But there is that
other potential,

1149

00:46:29,753 --> 00:46:31,789

that maybe we
search for life here

1150

00:46:31,789 --> 00:46:34,057

in our own cosmic
backyard and elsewhere

1151

00:46:34,057 --> 00:46:35,492

and we come up empty.

1152

00:46:35,492 --> 00:46:37,194
Do you recognize this image?

1153
00:46:37,194 --> 00:46:39,029
This is the 30-year
anniversary, actually,

1154
00:46:39,029 --> 00:46:40,998
of the pale blue dot,

1155
00:46:40,998 --> 00:46:43,100
which was taken by
Voyager One spacecraft,

1156
00:46:43,100 --> 00:46:44,868
the last von Karman
lecture I believe

1157
00:46:44,868 --> 00:46:46,804
focused heavily on this.

1158
00:46:46,804 --> 00:46:49,606
What if this is all there is?

1159
00:46:49,606 --> 00:46:52,409
I find that terrifying,
but in a way it could also

1160
00:46:52,409 --> 00:46:55,445
be really gratifying to think
that we are this precious.

1161
00:46:55,445 --> 00:46:57,948
That this world
just happened to be

1162
00:46:57,948 --> 00:47:00,551
the magical place
where life can happen,

1163

00:47:00,551 --> 00:47:02,519

and boy it really
makes you think about

1164

00:47:02,519 --> 00:47:07,524

how we want to preserve
that and keep it going,

1165

00:47:08,959 --> 00:47:10,194

maybe go over to Mars and you
know, set up a colony there,

1166

00:47:10,194 --> 00:47:13,096

just in case the next
65 million year meteor.

1167

00:47:13,096 --> 00:47:15,766

We don't want that to happen.

1168

00:47:15,766 --> 00:47:19,036

But that would be a
revolutionary discovery, too.

1169

00:47:19,036 --> 00:47:22,105

And either way as a
scientist, I want to know.

1170

00:47:22,105 --> 00:47:23,707

I want to ask the question.

1171

00:47:23,707 --> 00:47:26,610

I want to design that
experiment or help to design

1172

00:47:26,610 --> 00:47:28,579

that experiment
where we end up with

1173

00:47:28,579 --> 00:47:31,281

that single hypothesis
of last resort,

1174
00:47:31,281 --> 00:47:33,851
that the only explanation
could be life.

1175
00:47:33,851 --> 00:47:36,186
it could not be
made abiotically.

1176
00:47:36,186 --> 00:47:39,022
And then I want to go and
figure out what that life is.

1177
00:47:39,022 --> 00:47:42,826
Right now we only have
a sample size of one.

1178
00:47:42,826 --> 00:47:44,828
That's it, right?

1179
00:47:44,828 --> 00:47:46,496
This could be all there is,

1180
00:47:46,496 --> 00:47:48,899
or it could be one
small grain of sand in

1181
00:47:48,899 --> 00:47:52,202
an immense universe of worlds

1182
00:47:52,202 --> 00:47:55,038
that could all have
life of their own.

1183
00:47:55,038 --> 00:47:58,041
I want to be part of
finding that answer.

1184

00:47:59,576 --> 00:48:01,178

So I want you to go back
now, close your eyes again.

1185

00:48:01,178 --> 00:48:03,847

I know it's like 45 minutes
later, but you can do it.

1186

00:48:03,847 --> 00:48:05,315

I believe in you.

1187

00:48:05,315 --> 00:48:07,951

I haven't heard any snoring
yet, you guys have done so well.

1188

00:48:07,951 --> 00:48:11,088

And go back to that
alien world again.

1189

00:48:11,088 --> 00:48:14,057

Except this time it's
not you standing there,

1190

00:48:14,057 --> 00:48:15,959

it's a robotic version of you.

1191

00:48:15,959 --> 00:48:18,562

It's a robotic
exploration spacecraft.

1192

00:48:18,562 --> 00:48:21,465

So now when you look up at
that sun or those suns in

1193

00:48:21,465 --> 00:48:24,401

the sky, it's not just a light
that you see now you have

1194

00:48:24,401 --> 00:48:27,271

a spectrometer, and you
can break down that light

1195
00:48:27,271 --> 00:48:29,706
and figure out what
that energy profile is

1196
00:48:29,706 --> 00:48:32,242
and how that light
might be utilized

1197
00:48:32,242 --> 00:48:33,977
by life that's on your world.

1198
00:48:33,977 --> 00:48:35,479
Now whenever you look down,

1199
00:48:35,479 --> 00:48:38,548
you can figure out what
the rock distribution is,

1200
00:48:38,548 --> 00:48:40,517
and which one is most
likely to have maybe

1201
00:48:40,517 --> 00:48:42,552
a microbe hiding underneath it.

1202
00:48:42,552 --> 00:48:45,255
Now you have instruments
inside of you and your belly

1203
00:48:45,255 --> 00:48:47,457
that when you take a sample
and you put it in there,

1204
00:48:47,457 --> 00:48:51,161
you can be sure that that
has the signatures of life.

1205

00:48:52,329 --> 00:48:53,130

For the first time
in human history of

1206

00:48:53,130 --> 00:48:55,132

an alien somewhere else.

1207

00:48:55,132 --> 00:48:57,301

That's what we do at NASA.

1208

00:48:57,301 --> 00:49:00,337

That's what I'm helping to
work on with my colleagues,

1209

00:49:00,337 --> 00:49:04,341

is to be able to extend
our senses further out into

1210

00:49:04,341 --> 00:49:06,276

the solar system and beyond.

1211

00:49:06,276 --> 00:49:08,779

I want to be able
to take that circle

1212

00:49:08,779 --> 00:49:11,949

and expand it out further
than I can possibly imagine,

1213

00:49:11,949 --> 00:49:14,117

to stretch it out
as far as I can

1214

00:49:14,117 --> 00:49:16,253

during my time here as a human

1215

00:49:16,253 --> 00:49:21,258

and that's just why I
love terribly what I do.

1216

00:49:21,992 --> 00:49:23,560

Thank you very much.

1217

00:49:23,560 --> 00:49:25,796

[applause]

1218

00:49:36,406 --> 00:49:37,374

>> Folks, we are
going to open up

1219

00:49:37,374 --> 00:49:39,309

for some questions right now.

1220

00:49:39,309 --> 00:49:40,911

If you are in the house
and you've got a question,

1221

00:49:40,911 --> 00:49:41,979

you're going to
line up right behind

1222

00:49:41,979 --> 00:49:42,980

that microphone over there.

1223

00:49:42,980 --> 00:49:44,281

We also have some questions from

1224

00:49:44,281 --> 00:49:46,817

our online audience as well.

1225

00:49:46,817 --> 00:49:48,885

So while you're all
thinking about maybe

1226

00:49:48,885 --> 00:49:49,820

a question you're going to ask,

1227

00:49:49,820 --> 00:49:51,254
I'm going to go online here to

1228
00:49:51,254 --> 00:49:53,657
the great Mosasaur
from YouTube asks

1229
00:49:53,657 --> 00:49:56,927
"although there isn't a
concrete answer for this,

1230
00:49:56,927 --> 00:49:59,997
"in your opinion, your opinion,

1231
00:49:59,997 --> 00:50:02,132
"do you think we can find
life on these worlds?

1232
00:50:02,132 --> 00:50:04,968
"Can we expect to see
it in our lifetime?"

1233
00:50:06,169 --> 00:50:07,437
>> I think so, otherwise I would

1234
00:50:07,437 --> 00:50:09,506
be spending my energy
doing something else.

1235
00:50:09,506 --> 00:50:13,643
Again with just the
sample size of one,

1236
00:50:13,643 --> 00:50:15,278
we have some guesstimates of

1237
00:50:15,278 --> 00:50:16,780
the types of life we would find,

1238

00:50:16,780 --> 00:50:19,750
chances are they're going
to be small microorganisms,

1239
00:50:19,750 --> 00:50:21,918
just based on the
energy that's there,

1240
00:50:21,918 --> 00:50:23,387
and we have some estimates of

1241
00:50:23,387 --> 00:50:26,590
how many organisms we might
expect in some of these oceans.

1242
00:50:26,590 --> 00:50:29,026
So we have some idea
of the types of life

1243
00:50:29,026 --> 00:50:31,261
and the amounts of
life we might find,

1244
00:50:31,261 --> 00:50:33,497
and some of the instruments
that we are working

1245
00:50:33,497 --> 00:50:36,867
on miniaturizing and sticking
on spacecraft right now

1246
00:50:36,867 --> 00:50:39,069
have limits of detection
that are sensitive enough

1247
00:50:39,069 --> 00:50:40,771
that they could
find those things.

1248
00:50:40,771 --> 00:50:42,806

That's why I think that
we have the ability

1249
00:50:42,806 --> 00:50:44,174
to answer this question now.

1250
00:50:45,675 --> 00:50:48,912
>> Another one from
online, from Space Debris

1251
00:50:48,912 --> 00:50:52,382
on YouTube, it's kind of similar

1252
00:50:52,382 --> 00:50:53,917
to what you were just answering

1253
00:50:53,917 --> 00:50:54,985
and what the last part of
what you were talking about,

1254
00:50:54,985 --> 00:50:57,154
"besides knowing
we're not alone,

1255
00:50:57,154 --> 00:50:58,722
"what is the best
value for humans

1256
00:50:58,722 --> 00:51:00,657
"in finding life
on another world?"

1257
00:51:01,825 --> 00:51:05,228
>> For me it's
knowing that there are

1258
00:51:05,228 --> 00:51:07,798
so many other
possibilities out there.

1259

00:51:07,798 --> 00:51:11,268

I mean if we're not asking
these big questions,

1260

00:51:11,268 --> 00:51:16,006

the things that when we were
much earlier on in our history

1261

00:51:16,006 --> 00:51:18,475

of just starting to be
humans and we looked up from

1262

00:51:18,475 --> 00:51:20,610

that campfire up into
the stars at night

1263

00:51:20,610 --> 00:51:22,145

and wondered about them.

1264

00:51:22,145 --> 00:51:23,947

That's what sets
us apart, right?

1265

00:51:23,947 --> 00:51:25,415

Otherwise we're just what,

1266

00:51:25,415 --> 00:51:28,452

like eat, sleep, reproduce
and die and that's it?

1267

00:51:28,452 --> 00:51:29,686

You know?

1268

00:51:29,686 --> 00:51:31,354

This is the thing
that drives us,

1269

00:51:31,354 --> 00:51:34,758

that makes us human is to

ask these questions why,

1270

00:51:34,758 --> 00:51:37,828

and because of that we want
to strive to know the answers.

1271

00:51:37,828 --> 00:51:39,830

And as soon as we know the
answer to that question,

1272

00:51:39,830 --> 00:51:41,498

we're going to
have so many more.

1273

00:51:41,498 --> 00:51:44,000

It's going to be this
amazing beautiful cycle

1274

00:51:44,000 --> 00:51:46,136

and I want to kick
off some more of that.

1275

00:51:47,904 --> 00:51:50,807

>> I think we've got a
question here in the house.

1276

00:51:52,876 --> 00:51:54,711

>> This is a very very
interesting lecture.

1277

00:51:54,711 --> 00:51:55,645

I really like it.

1278

00:51:57,147 --> 00:52:02,052

So you talked about the the
nonpolar versus the polar

1279

00:52:04,254 --> 00:52:09,025

and how if those mix I
guess it was on Europa?

1280

00:52:09,025 --> 00:52:09,960

>> Titan.

1281

00:52:09,960 --> 00:52:11,595

>> It was on Titan that we mix.

1282

00:52:11,595 --> 00:52:14,731

Because there's what
is actually water

1283

00:52:14,731 --> 00:52:16,299

under Titan even though.

1284

00:52:16,299 --> 00:52:21,304

So my question is, so you
have all this carbon on Titan,

1285

00:52:24,641 --> 00:52:28,245

why, do we have any idea
why we have a planet,

1286

00:52:28,245 --> 00:52:33,083

satellite at Saturn
that's heavily carbon,

1287

00:52:33,083 --> 00:52:36,720

and then we have Io at
Jupiter that's heavily sulfur.

1288

00:52:36,720 --> 00:52:41,658

Why do we have, why don't
we have one of each on both,

1289

00:52:41,658 --> 00:52:44,027

circling both
Jupiter and Saturn?

1290

00:52:44,027 --> 00:52:45,228

>> That's a great question.

1291

00:52:45,228 --> 00:52:46,463

Well a lot of these
worlds probably

1292

00:52:46,463 --> 00:52:47,764

do have a lot of
carbon and sulfur,

1293

00:52:47,764 --> 00:52:49,733

but it may be in different forms

1294

00:52:49,733 --> 00:52:54,571

where it's trapped in the crust
or underneath the ice shell.

1295

00:52:54,571 --> 00:52:57,774

Titan we're lucky,
because of its atmosphere.

1296

00:52:57,774 --> 00:53:00,810

It's outgassing methane
from its interior.

1297

00:53:00,810 --> 00:53:03,580

We're actually not sure
why it's still doing that,

1298

00:53:03,580 --> 00:53:04,981

because if you
look at the amount

1299

00:53:04,981 --> 00:53:06,216

of methane that should be there,

1300

00:53:06,216 --> 00:53:07,617

it should have run
out in oh, you know,

1301
00:53:07,617 --> 00:53:09,119
a hundred million years.

1302
00:53:09,119 --> 00:53:11,087
So there's probably some
funky cycle that's going on

1303
00:53:11,087 --> 00:53:12,923
and we're catching
it at a good time.

1304
00:53:12,923 --> 00:53:16,293
But that methane is
what's broken up by light.

1305
00:53:16,293 --> 00:53:17,260
Methane and nitrogen.

1306
00:53:17,260 --> 00:53:19,229
So we've got CH₄ and N₂,

1307
00:53:19,229 --> 00:53:20,964
and you break those apart
and you make all sorts

1308
00:53:20,964 --> 00:53:23,300
of other different
C, H, N things,

1309
00:53:23,300 --> 00:53:25,936
and that's what the
photo chemistry is making

1310
00:53:25,936 --> 00:53:28,271
that's depositing
on the surface.

1311
00:53:28,271 --> 00:53:31,408
There are other worlds where

you still have reservoirs

1312

00:53:31,408 --> 00:53:33,743
of carbon maybe as methane ice,

1313

00:53:33,743 --> 00:53:36,479
like Pluto is very rich in
methane ice for an example.

1314

00:53:36,479 --> 00:53:39,716
As you step further
into the solar system,

1315

00:53:39,716 --> 00:53:42,419
closer to the sun you don't
have as many volatiles.

1316

00:53:42,419 --> 00:53:45,355
Those, the things
that are gases here

1317

00:53:45,355 --> 00:53:47,824
freeze out as ices further out,

1318

00:53:47,824 --> 00:53:49,993
but you have other
complex organic molecules.

1319

00:53:49,993 --> 00:53:51,294
Like we have here on Earth.

1320

00:53:51,294 --> 00:53:53,330
A lot of the organics
that are here probably

1321

00:53:53,330 --> 00:53:55,699
were deposited by comets

1322

00:53:55,699 --> 00:53:58,535

and meteoritic impacts
over a millennia,

1323

00:53:58,535 --> 00:54:00,770

and so that's another
great source of carbon.

1324

00:54:01,972 --> 00:54:03,473

>> Audience Member: Thank you.

1325

00:54:03,473 --> 00:54:05,442

>> All right and this will be
our last question in the house.

1326

00:54:05,442 --> 00:54:08,111

If we don't get a chance
to ask your question,

1327

00:54:08,111 --> 00:54:10,547

Morgan is going to
stick around for awhile,

1328

00:54:10,547 --> 00:54:13,283

answer, she said she'll
answer everything

1329

00:54:13,283 --> 00:54:14,117

that comes up here.

1330

00:54:14,117 --> 00:54:15,819

So good luck to that.

1331

00:54:15,819 --> 00:54:17,454

But our last question in here.

1332

00:54:17,454 --> 00:54:18,922

>> Yes.

1333

00:54:18,922 --> 00:54:20,924

What promising technologies
do we have at this point

1334
00:54:20,924 --> 00:54:23,526
for getting through
the layers of ice into

1335
00:54:23,526 --> 00:54:26,930
the oceans of
these water worlds?

1336
00:54:26,930 --> 00:54:28,098
>> Okay.

1337
00:54:28,098 --> 00:54:29,833
I could do a whole
other talk just on that.

1338
00:54:29,833 --> 00:54:32,002
So there are a few
different architectures

1339
00:54:32,002 --> 00:54:34,804
that NASA scientists and
a bunch of engineers both

1340
00:54:34,804 --> 00:54:37,040
at NASA centers and universities

1341
00:54:37,040 --> 00:54:39,509
and other companies
are working on.

1342
00:54:39,509 --> 00:54:42,279
There's one that we
call it a melt probe,

1343
00:54:42,279 --> 00:54:44,381
it's something that
would have a heated tip,

1344

00:54:44,381 --> 00:54:46,349

there are a bunch of different
ways you can do that,

1345

00:54:46,349 --> 00:54:48,084

that would slowly melt away

1346

00:54:48,084 --> 00:54:50,053

or sublime if you're
in a vacuum, right?

1347

00:54:50,053 --> 00:54:52,789

The solid would just turn
into water vapor and go away.

1348

00:54:52,789 --> 00:54:54,491

You can use that to get down.

1349

00:54:54,491 --> 00:54:56,860

There are also some
robotic techniques.

1350

00:54:56,860 --> 00:55:00,096

There's a concept that
I'm working on with

1351

00:55:00,096 --> 00:55:02,499

some colleagues here
at JPL called EELS,

1352

00:55:02,499 --> 00:55:04,234

Enceladus Extant Life Surveyor,

1353

00:55:04,234 --> 00:55:06,569

it also is like snake
like, so eels, get it.

1354

00:55:06,569 --> 00:55:08,772

We love acronyms if
you haven't noticed.

1355

00:55:08,772 --> 00:55:12,876

That could maneuver down
through those open tiger stripes

1356

00:55:12,876 --> 00:55:15,679

on Enceladus, and potentially
reach the ocean that way,

1357

00:55:15,679 --> 00:55:17,113

and so there are a bunch
of different things

1358

00:55:17,113 --> 00:55:19,582

we're working on, 'cause
getting to that ocean would be

1359

00:55:19,582 --> 00:55:22,619

the ideal place
to look for life,

1360

00:55:22,619 --> 00:55:24,087

'cause then you could
take in your sensor

1361

00:55:24,087 --> 00:55:26,256

and you could just
filter water for as long

1362

00:55:26,256 --> 00:55:29,159

as you wanted until you got
the concentrations high enough

1363

00:55:29,159 --> 00:55:32,429

to be sure that if there
was even one cell in like,

1364

00:55:32,429 --> 00:55:34,230

you know, gallons
and gallons of water,

1365

00:55:34,230 --> 00:55:36,132
that you would find it.

1366

00:55:36,132 --> 00:55:37,767
>> And how would we get the
information back from the probe?

1367

00:55:37,767 --> 00:55:39,436
>> How would we get
the information back?

1368

00:55:39,436 --> 00:55:40,770
So there are some
theories about that.

1369

00:55:40,770 --> 00:55:42,372
You could have a tether,

1370

00:55:42,372 --> 00:55:47,377
but if there are some
geophysical tidal flexing things

1371

00:55:48,778 --> 00:55:50,013
that could break the tether
you could deposit pucks

1372

00:55:50,013 --> 00:55:51,614
that could communicate,
that would have their

1373

00:55:51,614 --> 00:55:54,084
own little power supplies
that you could connect.

1374

00:55:54,084 --> 00:55:56,052
So there are a bunch
of different ways

that we're looking

1375

00:55:56,052 --> 00:55:58,154
to try to answer that question,

1376

00:55:58,154 --> 00:56:00,123
because that kind of
engineering is super fun,

1377

00:56:00,123 --> 00:56:02,058
the really challenging things.

1378

00:56:02,058 --> 00:56:03,960
>> Do we know enough
about the cracks on Europa

1379

00:56:03,960 --> 00:56:08,264
to know if a similar
type of eel like device

1380

00:56:08,264 --> 00:56:09,899
could get through
the cracks there?

1381

00:56:09,899 --> 00:56:11,301
>> That's a good question.

1382

00:56:11,301 --> 00:56:12,902
There is some
preliminary evidence

1383

00:56:12,902 --> 00:56:15,905
that Europa may have
a plume as well.

1384

00:56:15,905 --> 00:56:17,440
It hasn't been verified yet.

1385

00:56:17,440 --> 00:56:19,442

We've seen some
funky things with

1386
00:56:19,442 --> 00:56:20,910
the Hubble Space Telescope.

1387
00:56:20,910 --> 00:56:23,179
We've seen some, it
looks like water vapor

1388
00:56:23,179 --> 00:56:24,581
in places it shouldn't be,

1389
00:56:24,581 --> 00:56:26,683
and we, some
scientists went back

1390
00:56:26,683 --> 00:56:28,585
and looked at the Galileo data.

1391
00:56:28,585 --> 00:56:31,988
Galileo was a spacecraft that
went to the Jupiter system in

1392
00:56:31,988 --> 00:56:35,492
the '90s and early 2000s,
and the magnetometer,

1393
00:56:35,492 --> 00:56:37,560
that fancy compass,
found some weird readings

1394
00:56:37,560 --> 00:56:40,597
that might be consistent
with a plume of water vapor.

1395
00:56:40,597 --> 00:56:42,932
But my understanding of
talking to the geologists

1396

00:56:42,932 --> 00:56:45,335

and the geophysicists
is that a crack,

1397

00:56:45,335 --> 00:56:47,771

since Europe is bigger and
its ice shell is thicker,

1398

00:56:47,771 --> 00:56:50,273

might not propagate all
the way to the ocean,

1399

00:56:50,273 --> 00:56:52,509

instead if there is a
plume, which Clipper,

1400

00:56:52,509 --> 00:56:54,811

Europa Clipper would confirm,

1401

00:56:54,811 --> 00:56:56,446

if there is one
it's probably from

1402

00:56:56,446 --> 00:56:57,847

a near surface reservoir.

1403

00:56:57,847 --> 00:57:01,151

And if that's true, well
could life get up there,

1404

00:57:01,151 --> 00:57:03,019

if it could would
it still be alive?

1405

00:57:03,019 --> 00:57:04,821

Chances are it
might be very salty.

1406

00:57:04,821 --> 00:57:06,256

Will that affect things?

1407

00:57:06,256 --> 00:57:07,690

There are a bunch of things that we would need

1408

00:57:07,690 --> 00:57:09,959

to think about to understand the provenance, right?

1409

00:57:09,959 --> 00:57:12,228

The history of that sample.

1410

00:57:12,228 --> 00:57:13,696

>> Thank you.

1411

00:57:13,696 --> 00:57:15,465

>> That's all the time that we have for tonight.

1412

00:57:15,465 --> 00:57:17,967

Real quick, join us next month, April 16th and 17th,

1413

00:57:17,967 --> 00:57:20,837

where we kind of what we're looking at right here,

1414

00:57:20,837 --> 00:57:24,073

how NASA observe Earth from air and orbit.

1415

00:57:24,073 --> 00:57:25,642

But before we go, let's give our speaker

1416

00:57:25,642 --> 00:57:27,110

another great big round of applause.

1417

00:57:27,110 --> 00:57:29,379

[applause]

1418

00:57:34,317 --> 00:57:35,752

Thank you for joining
us this evening.