1
00:00:00,166 --> 00:00:00,700
[Music]

2
00:00:00,700 --> 00:00:05,133
When considering the possibility of life beyond Earth,
we look for three main ingredients:

3
00:00:05,133 --> 00:00:09,933
the first one is key elements such as carbon,
hydrogen, oxygen, and sulfur.

4
00:00:09,933 --> 00:00:12,766
The second one is a source of energy,

5
00:00:12,766 --> 00:00:16,866
and the third, and perhaps most important,
is the existence of liquid water.

6
00:00:16,866 --> 00:00:21,100
Water is a necessary solvent in all chemical
reactions that have to do with life.

7
00:00:21,100 --> 00:00:24,266
Energy is required to drive these chemical reactions

8
00:00:24,266 --> 00:00:28,333
and organic matter is the material from which
all life that we know of is made.

9
00:00:28,333 --> 00:00:30,833
Life as we know it requires liquid water.

10
00:00:30,833 --> 00:00:34,200
Scientists believe that life on Earth started in our oceans.

11
00:00:34,200 --> 00:00:38,066
Now through our exploration of the Solar System,
we’ve realized that the moons

12
00:00:38,066 --> 00:00:42,333
around the giant planets have the right conditions
that there could be liquid water

13
00:00:42,333 --> 00:00:43,800
underneath their surfaces.

14
00:00:43,800 --> 00:00:48,566
So that really sort of expands our whole concept
of where you could have a habitat

15
00:00:48,566 --> 00:00:50,300
where we might find life.

16
00:00:50,300 --> 00:00:54,633
[Music]

17
00:00:54,633 --> 00:00:56,400
Water is fairly common in the universe.

18
00:00:56,400 --> 00:01:00,466
We’ve seen traces of water in large molecular clouds between stars.

19
00:01:00,466 --> 00:01:03,633
We’ve seen traces of water in protoplanetary disks.

20
00:01:03,633 --> 00:01:07,866
We’ve also seen traces of water as water vapor
in the atmospheres of giant planets

21
00:01:07,866 --> 00:01:11,900
around other stars, and we know that water is
in the atmospheres and interiors

22
00:01:11,900 --> 00:01:14,300
of our Solar System’s giant planets.

23
00:01:14,300 --> 00:01:17,366

So, we know that water is ubiquitous throughout
the universe.

24
00:01:17,366 --> 00:01:20,500
As far as liquid water, that’s a little less common.

25
00:01:20,500 --> 00:01:24,800
Earth is the only planet in the Solar System
where we see water at our surface.

26
00:01:24,800 --> 00:01:29,833
Moons such as Enceladus and Europa may
have liquid water beneath layers of ice.

27
00:01:29,833 --> 00:01:33,866
We’re really expanding our understanding of
what makes a place habitable.

28
00:01:33,866 --> 00:01:39,266
Instead of just looking for an Earthlike, terrestrial
planet that’s a very specific distance

29
00:01:39,266 --> 00:01:42,866
from its star, we’re learning that there can be
hidden habitats

30
00:01:42,866 --> 00:01:44,966
that are underneath icy layers,

31
00:01:44,966 --> 00:01:47,700
and they can be a lot further out from the Sun.

32
00:01:47,700 --> 00:01:53,366
So we believe icy moons in the Solar System
actually harbor kilometers thick oceans

33
00:01:53,366 --> 00:01:55,566
underneath their icy surfaces.

34

00:01:55,566 --> 00:01:59,500
These icy moons and their subsurface oceans
may be some of

35
00:01:59,500 --> 00:02:03,633
the best places to search for life elsewhere
in our Solar System.

36
00:02:04,184 --> 00:02:08,333
[Music]

37
00:02:08,333 --> 00:02:12,733
Enceladus is one of Saturn’s many moons,
and it’s a very small moon

38
00:02:12,733 --> 00:02:14,900
that people tend to kind of ignore because it is so small

39
00:02:14,900 --> 00:02:16,800
about 500 kilometers in diameter.

40
00:02:16,800 --> 00:02:20,333
But decades ago, in the 1980s from ground-based observing,

41
00:02:20,333 --> 00:02:24,100
we found out that the location of Enceladus relative to Saturn

42
00:02:24,100 --> 00:02:27,400
happened to coincide nicely with Saturn’s E ring

43
00:02:27,400 --> 00:02:31,066
and so we were thinking that Enceladus had
something to do with the E ring

44
00:02:31,066 --> 00:02:34,233
particulates, that icy material, but we weren’t sure.

45
00:02:34,233 --> 00:02:38,533
What we later find from Cassini was that we

directly determined

46
00:02:38,533 --> 00:02:42,800
that there are indeed plumes jetting out of
the south polar region from cracks

47
00:02:42,800 --> 00:02:45,266
in the south pole of Enceladus in the crust.

48
00:02:45,266 --> 00:02:49,066
And it’s dominantly water-rich material
just jetting out into space.

49
00:02:49,066 --> 00:02:54,233
And so the way we saw it, Cassini happened to
be located where Enceladus was backlit

50
00:02:54,233 --> 00:02:58,700
from the Sun, and so you saw this curtain
of beautiful, diffuse material

51
00:02:58,700 --> 00:03:02,400
jetting out of the south polar region –
quite breathtaking actually.

52
00:03:02,400 --> 00:03:05,400
Even more, we were able to use the different
compliments of instruments

53
00:03:05,400 --> 00:03:09,666
onboard Cassini to go after the chemical
composition of the plumes,

54
00:03:09,666 --> 00:03:14,866
and that’s where things got really interesting.
So number one, that’s because of liquid water.

55
00:03:14,866 --> 00:03:20,333
There’s definitely a liquid water reservoir subsurface
below the icy crust that is there.

56
00:03:20,333 --> 00:03:25,433
Number two, the chemical composition of the plumes
told us that there is a lot of organics

57
00:03:25,433 --> 00:03:29,133
things that make up amino acids and things
on life that are very interesting.

58
00:03:29,133 --> 00:03:33,600
And number three, what we were really
looking for was a source of energy.

59
00:03:33,600 --> 00:03:37,800
On Enceladus, photons from the Sun aren’t going
to work because you can’t penetrate

60
00:03:37,800 --> 00:03:42,600
the tens of kilometers of icy crust to get down
to where the liquid water reservoir is.

61
00:03:42,600 --> 00:03:46,600
But, what Enceladus does have is hydrothermal vents.

62
00:03:46,600 --> 00:03:51,400
It’s very hot with the liquid water, that has a lot
of analogies with the ocean floor

63
00:03:51,400 --> 00:03:57,000
where we have a form of releasing chemical energy
via something called serpentinization.

64
00:03:57,000 --> 00:04:00,100
And so we think that Enceladus might have that potential

65
00:04:00,100 --> 00:04:04,400
to have an energy source being chemical, not sunlight.

66
00:04:04,400 --> 00:04:08,900

And so you put all that together and Enceladus
has all the ingredients,

67
00:04:08,900 --> 00:04:11,600
or most of what we need for life.

68
00:04:11,600 --> 00:04:15,800
. That makes it a very astrobiologically
interesting object to study.

69
00:04:15,800 --> 00:04:22,933
[Music]

70
00:04:22,933 --> 00:04:27,000
Europa is one of the largest moons of Jupiter,
and we believe that Europa has

71
00:04:27,000 --> 00:04:31,500
a subsurface ocean tens to hundreds
of kilometers thick

72
00:04:31,500 --> 00:04:37,200
And so this ocean may be one of the best places
to search for life in the Solar System.

73
00:04:37,200 --> 00:04:41,300
There’s been three space missions that have
provided evidence for

74
00:04:41,300 --> 00:04:43,433
Europa harboring liquid water.

75
00:04:43,433 --> 00:04:49,066
The first one is Voyager in the late 70's,
the second one is the Galileo mission

76
00:04:49,066 --> 00:04:54,700
in the late 90s, and most recently Hubble,
which detected plume-like emission

77
00:04:54,700 --> 00:04:59,500
from hydrogen and oxygen which is closely
related to the existence of water

78
00:04:59,500 --> 00:05:01,500
beneath its surface.

79
00:05:01,500 --> 00:05:06,233
These plumes may be directly ejected through
cracks in the surface of the moon,

80
00:05:06,233 --> 00:05:09,066
and therefore what we are seeing in water vapor plumes

81
00:05:09,066 --> 00:05:13,300
is the actual ocean water from the subsurface of the moon.

82
00:05:13,300 --> 00:05:18,833
As these plume particles are ejected to space,
solar radiation is going to excite these

83
00:05:18,833 --> 00:05:24,733
water particles, creating vibrational modes.
Now, these vibrational modes are signatures

84
00:05:24,733 --> 00:05:29,600
that can be detected at infrared wavelengths by
the Keck Observatory.

85
00:05:29,600 --> 00:05:35,866
So, we observe Europa on seventeen dates.
What we found is that the majority

86
00:05:35,866 --> 00:05:41,600
of observations have no presence of water;
however, on one of those dates

87
00:05:41,600 --> 00:05:45,833
we detected water. We detected H2O.

88
00:05:45,833 --> 00:05:51,633
In the past, Hubble provided indirect measurements
of water by detecting hydrogen and oxygen,

89
00:05:51,633 --> 00:05:56,000
but now we have directly detected water
for the first time.

90
00:05:56,000 --> 00:05:58,866
Both the Webb Telescope and the Europa Clipper
mission will give us

91
00:05:58,866 --> 00:06:05,166
us a much more detailed picture of the surface
of Europa, its cracks and crevices,

92
00:06:05,166 --> 00:06:09,900
detailed pictures of the water vapor, as well as
other molecules that may also

93
00:06:09,900 --> 00:06:12,866
be emanating from the subsurface of Europa.

94
00:06:12,866 --> 00:06:18,133
So both of these missions will give us a great
picture of whether Europa is truly habitable.

95
00:06:18,133 --> 00:06:27,133
[Music]

96
00:06:27,133 --> 00:06:29,266
Titan is a moon of Saturn.

97
00:06:29,266 --> 00:06:34,533
It’s the second largest moon in the Solar System
and it is about two times larger

98
00:06:34,533 --> 00:06:38,333

than Earth’s Moon and actually bigger than
the planet Mercury.

99
00:06:38,333 --> 00:06:42,433
Titan is also interesting – it’s the only moon in
our Solar System with an atmosphere.

100
00:06:42,433 --> 00:06:45,900
It’s surrounded by sort of an envelope of
gaseous nitrogen

101
00:06:45,900 --> 00:06:47,733
just like our own Earth is.

102
00:06:47,733 --> 00:06:52,633
Titan was first discovered by telescope
observations back in the mid-1600s.

103
00:06:52,633 --> 00:06:56,700
The first spacecraft observations were made of
Titan during flybys through

104
00:06:56,700 --> 00:07:00,633
the outer Solar System – that was in the late
seventies and in the eighties.

105
00:07:00,633 --> 00:07:04,800
But we really were able to explore Titan in-depth
with the Cassini-Huygens Mission.

106
00:07:04,800 --> 00:07:08,700
The Huygens probe was dropped into the
atmosphere of Titan,

107
00:07:08,700 --> 00:07:13,000
and it made measurements of chemistry, and it
took images as it fell to the surface,

108
00:07:13,000 --> 00:07:14,900
and that was back in 2005.

109
00:07:14,900 --> 00:07:19,033
. And since then, the Cassini Orbiter made over
a hundred close flybys of Titan.

110
00:07:19,033 --> 00:07:23,333
Cassini in its design with the different
instruments – we purposely were picking

111
00:07:23,333 --> 00:07:26,533
instruments that could go into longer
wavelengths into the infrared

112
00:07:26,533 --> 00:07:29,300
so we could really understand the moon.

113
00:07:29,300 --> 00:07:33,433
We were able to basically peel back the
layers of Titan

114
00:07:33,433 --> 00:07:38,866
to really see what was below, and it was
remarkable – very Earthlike.

115
00:07:38,866 --> 00:07:44,400
The landscape is similar to Earth’s in many,
many ways, but with a little bit of a twist.

116
00:07:44,400 --> 00:07:49,800
So on Titan, you can find dunes, you find lakes,
there are river channels,

117
00:07:49,800 --> 00:07:55,500
the atmosphere is very dense and you can get
clouds and smog and you even get rain.

118
00:07:55,500 --> 00:08:01,800
We saw winds, we saw seasons, and one really
important thing we saw was liquids

119
00:08:01,800 --> 00:08:05,266
pooling in the polar regions on the surface –
a lot of it.

120
00:08:05,266 --> 00:08:10,633
But because Titan is so cold, those features are
all made of very exotic materials

121
00:08:10,633 --> 00:08:13,033
compared to what we would find on Earth.

122
00:08:13,033 --> 00:08:17,766
So the lakes and the rain are made of liquid
methane, the crust that forms

123
00:08:17,766 --> 00:08:22,366
the surface of Titan is actually water ice, but it’s
so cold that it is as hard as rock,

124
00:08:22,366 --> 00:08:26,766
and in the atmosphere we get this organic
chemistry that forms large

125
00:08:26,766 --> 00:08:29,866
organic molecules and particulates – they
fall down to the surface

126
00:08:29,866 --> 00:08:32,466
and then behave like dust or like sand does.

127
00:08:32,466 --> 00:08:36,066
So it makes us want to go back to really
understand the complex,

128
00:08:36,066 --> 00:08:39,600
organic environment of that surface and what it means

129
00:08:39,600 --> 00:08:42,133
for either past life or future life.

130
00:08:42,133 --> 00:08:44,900
[Music]

131
00:08:44,900 --> 00:08:49,500
Dragonfly is a mission that was just selected by
NASA to fly to Titan

132
00:08:49,500 --> 00:08:51,933
Titan and arrive in the mid-2030's.

133
00:08:51,933 --> 00:08:55,166
Dragonfly is going to make a whole bunch of
measurements to help us understand

134
00:08:55,166 --> 00:08:58,500
the environment on Titan and its potential for habitability.

135
00:08:58,500 --> 00:09:01,033
We'll be taking measurements of the atmosphere –
that includes

136
00:09:01,033 --> 00:09:03,933
things like pressure, temperature, winds.

137
00:09:03,933 --> 00:09:08,500
We'll probe the surface to try to understand
what materials the surface is made out of.

138
00:09:08,500 --> 00:09:12,500
We'll also be drilling into the surface to look for
the types of organic molecules

139
00:09:12,500 --> 00:09:17,033
that are present and to see if we can find any
examples of compounds that mimic

140
00:09:17,033 --> 00:09:20,133
the types of building blocks that we know we

need for life on Earth.

141
00:09:20,133 --> 00:09:24,300
We don’t really know how life started on Earth.
We don’t exactly know what the chemical

142
00:09:24,300 --> 00:09:30,500
was like before life started. So, with Titan we
have this really unique opportunity

143
00:09:30,500 --> 00:09:34,200
There are times in Titan’s past where there
could be liquid water on the surface.

144
00:09:34,200 --> 00:09:39,200
Impact craters can generate impact melt, and
there’s a potential for possible cryovolcanism

145
00:09:39,200 --> 00:09:41,633
cryovolcanism to erupt some liquid water
onto the surface.

146
00:09:41,633 --> 00:09:45,033
And so we know that there’s a rich organic
chemistry going on in the atmosphere

147
00:09:45,033 --> 00:09:47,066
we know that’s depositing to the surface.

148
00:09:47,066 --> 00:09:51,500
If there were times where those organics in the
liquid water environments were mixing,

149
00:09:51,500 --> 00:09:54,533
then there may be some really interesting
chemistry taking place.

150
00:09:54,533 --> 00:09:58,033
When you have these processes operating for
hundreds of millions of years,

151
00:09:58,033 --> 00:10:01,166
how far can they get you down that path of
chemical complexity

152
00:10:01,166 --> 00:10:04,966
and can we see reactions and molecules that
start to look something like

153
00:10:04,966 --> 00:10:09,800
what we think of as essential elements for our
biochemistry for life on Earth.

154
00:10:09,800 --> 00:10:13,700
In the future, looking forward as opposed to
looking back and thinking about Titan

155
00:10:13,700 --> 00:10:16,333
as a chemical laboratory for the pre-biotic Earth,

156
00:10:16,333 --> 00:10:20,200
I like to look forward thinking about what’s
going to happen when the Sun evolves

157
00:10:20,200 --> 00:10:25,266
and warms up and the habitable zone actually
moves outward to where Titan is, and it will.

158
00:10:25,266 --> 00:10:28,133
You have all the organics, you’re going to have
a source of energy,

159
00:10:28,133 --> 00:10:32,466
all we have to do is melt the frozen water and
we’re going to have a pool of organics

160
00:10:32,466 --> 00:10:33,933
just embedded in liquid.

161

00:10:33,933 --> 00:10:37,566
Titan might actually have a chance at that
point to harbor life.

162
00:10:37,566 --> 00:10:43,200
[Music]

163
00:10:43,200 --> 00:10:45,800
So when we think about ocean worlds, it's
good to compare them to what

164
00:10:45,800 --> 00:10:50,533
we know about Earth. In total proportion, Earth
is about point-one-percent water.

165
00:10:50,533 --> 00:10:54,433
An ocean world is a body that has, in
proportion, about ten times more water

166
00:10:54,433 --> 00:10:55,400
than Earth does.

167
00:10:55,400 --> 00:10:59,666
And when we think of the TRAPPIST planets,
those planets have about fifty times

168
00:10:59,666 --> 00:11:02,266
more water in proportion to what Earth does.

169
00:11:02,266 --> 00:11:06,566
Ocean worlds do appear to be common in our
galaxy. As far back as the early 2000's,

170
00:11:06,566 --> 00:11:10,200
We had astronomers, some of them still here at
NASA Goddard who suggested that we would

171
00:11:10,200 --> 00:11:13,366
have ocean worlds orbiting low-mass stars.

172
00:11:13,366 --> 00:11:18,566
Recently we've looked at about fifty-two
exoplanets, and these are low-mass exoplanets

173
00:11:18,566 --> 00:11:23,200
and what we've found is, of these fifty-two
planets one out of every four

174
00:11:23,200 --> 00:11:24,900
may be an ocean planet.

175
00:11:24,900 --> 00:11:29,766
And when it comes to these ocean planets,
over half of them may be ice-covered

176
00:11:29,766 --> 00:11:34,000
ocean worlds, and so Enceladus and Europa
may serve as small-scale analogues

177
00:11:34,000 --> 00:11:35,633
of these planets.

178
00:11:35,633 --> 00:11:41,033
So there are a number of different ways to
search for life on planets around other stars,

179
00:11:41,033 --> 00:11:44,766
but the key method is the study of the atmospheres.

180
00:11:44,766 --> 00:11:49,833
We can search for signs of life - biosignatures,
we call them, things like oxygen,

181
00:11:49,833 --> 00:11:54,133
water vapor, carbon dioxide, even more
unusual biosignatures -

182
00:11:54,133 --> 00:11:59,266
things like chlorofluorocarbons, or other things

that are only produced by intelligent life.

183
00:11:59,266 --> 00:12:03,666
By looking for these key constituents of
planetary atmospheres that signal life,

184
00:12:03,666 --> 00:12:09,233
We can discover lifeforms on other planets
that we could never actually visit in our lifetime.

185
00:12:09,233 --> 00:12:13,366
So this is very analogous to how we study the
atmospheres of moons and planets

186
00:12:13,366 --> 00:12:17,366
in our own solar system, and really makes the
connection between studying the plumes

187
00:12:17,366 --> 00:12:21,300
of Europa, and the atmospheres of planets
around other stars.

188
00:12:21,300 --> 00:12:26,133
What I would like to see is the definition
of a habitable zone expanded

189
00:12:26,133 --> 00:12:31,333
We don't want to keep thinking too narrow
about liquid on the surface, broaden the scope

190
00:12:31,333 --> 00:12:35,766
and really try to embrace other worlds that might seem too far from their host star,

191
00:12:35,766 --> 00:12:40,300
and frozen out, when they really aren't frozen
at all. At great depths, they harbor