1

00:00:00,000 --> 00:00:29,000

The Earth, home to millions of species.

2

00:00:30,000 --> 00:00:38,000

But what might live beyond?

3

00:00:42,000 --> 00:00:48,000

Astronomers have discovered thousands of planets outside our solar system.

4

00:00:50,000 --> 00:00:54,000

They believe there are trillions more.

5

00:00:55,000 --> 00:01:06,000

If life exists on only a fraction of them, then the universe must be alive.

6

00:01:06,000 --> 00:01:32,000

All living things have the same needs to feed, reproduce.

7

00:01:36,000 --> 00:01:40,000

And evolve.

8

00:01:41,000 --> 00:01:48,000

By applying the laws of life on Earth to the rest of the universe,

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00:01:48,000 --> 00:01:56,000

it's possible to imagine what could live on alien worlds.

10

00:02:06,000 --> 00:02:29,000

The Earth, home to millions of species.

11

00:02:29,000 --> 00:02:38,000

Planets beyond our solar system are known to astronomers as exoplanets.

12

00:02:38,000 --> 00:02:45,000

They are all trillions of miles from Earth.

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00:02:45,000 --> 00:02:52,000

And yet, it might be possible to detect a faint signature of life.

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00:02:52,000 --> 00:02:57,000

From the light of the stars, they orbit.

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00:02:57,000 --> 00:03:02,000

Every star is sending to us light of all different colors.

16

00:03:02,000 --> 00:03:09,000

So if we can catch that light in our telescope and put it through an instrument that spreads the light out into a rainbow,

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00:03:09,000 --> 00:03:18,000

and we look in great detail at that rainbow, we will find the chemical fingerprints of the elements in the atmosphere of that star.

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00:03:19,000 --> 00:03:27,000

This is one of those rainbows captured by the telescope of a distant star about 12 light years away, the star Tau Setti.

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00:03:27,000 --> 00:03:32,000

We can see these dark lines like from hydrogen in the star's atmosphere.

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00:03:32,000 --> 00:03:37,000

Down here, we see these three characteristic lines of magnesium.

21

00:03:37,000 --> 00:03:45,000

So this is the atmosphere of the star, but what we want to do is catch light that passes through the atmosphere of an exoplanet

22

00:03:45,000 --> 00:03:52,000

to capture the chemical fingerprint of that atmosphere in exactly the same way.

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00:03:52,000 --> 00:04:03,000

In 2012, this sort of fingerprint was visible in our own solar system.

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00:04:03,000 --> 00:04:13,000

When Venus passed in front of the Sun, it was silhouetted against it.

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00:04:13,000 --> 00:04:21,000

For a moment, a tiny halo appeared, the atmosphere of Venus.

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00:04:21,000 --> 00:04:30,000

It's this sliver of light astronomers are looking for.

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00:04:30,000 --> 00:04:40,000

If they can analyze the atmosphere of distant exoplanets, silhouetted against distant stars,

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00:04:40,000 --> 00:04:45,000

they might find proof of life.

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00:04:56,000 --> 00:05:02,000

We've thought very carefully about what the signs of life will be.

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00:05:02,000 --> 00:05:11,000

So we look around and we look at what's in the atmosphere that could be remotely detectable from light years away.

31

00:05:11,000 --> 00:05:24,000

And it always leads us back to the same gas, oxygen.

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00:05:24,000 --> 00:05:31,000

50 to 70% of oxygen in our atmosphere is actually coming from the ocean,

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00:05:31,000 --> 00:05:38,000

which is the lungs of planet Earth.

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00:05:38,000 --> 00:05:53,000

The process that drives the growth of the giant kelp in the oceans and in fact all the forests that we see on the land is photosynthesis.

35

00:05:53,000 --> 00:05:58,000

What interests me most about photosynthesis is the waste product that gets tossed away,

36

00:05:58,000 --> 00:06:08,000

and that's the oxygen that goes into the atmosphere.

37

00:06:08,000 --> 00:06:20,000

We think that almost all of the oxygen in our atmosphere is produced by photosynthesis, by life here on planet Earth.

38

00:06:20,000 --> 00:06:36,000

And if you see it in abundance, you know that the planet is a living world.

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00:06:36,000 --> 00:06:51,000

Among trillions of worlds out there, those with more oxygen are more likely to sustain life.

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00:06:51,000 --> 00:07:07,000

Imagine a planet like Earth orbiting not one star, but two.

41

00:07:07,000 --> 00:07:19,000

This is Eden.

42

00:07:19,000 --> 00:07:46,000

The light from its twin stars powers photosynthesis, pumping oxygen into the atmosphere, allowing life to thrive.

43

00:07:46,000 --> 00:08:01,000

Grazers feed on low-lying fungus, but they're constantly alert to danger.

44

00:08:01,000 --> 00:08:30,000

The canopy is home to predators, perfectly evolved to live among the trees, waiting for their moment to strike.

45

00:08:32,000 --> 00:08:45,000

On the ground, the grazer has the edge. It's faster in a chase.

46

00:08:45,000 --> 00:08:58,000

But the predator has evolved a special weapon.

47

00:09:02,000 --> 00:09:21,000

This time, the grazer escapes, and the predator conserves its energy.

48

00:09:21,000 --> 00:09:29,000

On any planet, energy is precious.

49

00:09:29,000 --> 00:09:44,000

Starlight is a virtually infinite source, but the trick is to turn that light into life.

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00:09:44,000 --> 00:09:49,000

We are in the tropical rainforest.

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00:09:49,000 --> 00:10:08,000

There are more types of plants and animals here than anywhere else in Earth.

52

00:10:08,000 --> 00:10:17,000

The trees and plants are soaking up the sun's energy. By the magic of photosynthesis, they convert sunlight into glucose energy, in other words, sugar.

53

00:10:17,000 --> 00:10:28,000

You can see it and even taste it.

54

00:10:28,000 --> 00:10:34,000

You can actually taste the energy from the sun.

55

00:10:34,000 --> 00:10:43,000

Plants act like batteries, capturing the sun's energy as glucose.

56

00:10:43,000 --> 00:10:51,000

Herbivores eat plants. Carnivores eat herbivores.

57

00:10:51,000 --> 00:11:02,000

Every link in the food chain depends on the transfer of this glucose energy.

58

00:11:02,000 --> 00:11:10,000

And in this forest, one animal can't get enough of the stuff.

59

00:11:10,000 --> 00:11:14,000

The hummingbird.

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00:11:14,000 --> 00:11:23,000

Hummbirds can move their wings over a hundred times a second.

61

00:11:23,000 --> 00:11:34,000

You can feel how much energy they are spending just by being there.

62

00:11:34,000 --> 00:11:44,000

This frenzy of activity is fueled by glucose-rich nectar.

63

00:11:44,000 --> 00:11:49,000

This is a device that from the front looks like a flower.

64

00:11:49,000 --> 00:11:59,000

A hummingbird comes and it feeds from it.

65

00:11:59,000 --> 00:12:04,000

There is one. It's going back and forth.

66

00:12:04,000 --> 00:12:07,000

You can do it.

67

00:12:07,000 --> 00:12:13,000

Okay, so now it's drinking.

68

00:12:13,000 --> 00:12:21,000

This measures the nectar the bird is drinking and the oxygen it is breathing.

69

00:12:21,000 --> 00:12:26,000

We calculate the energy intake from the nectar and the energy output from the oxygen

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00:12:26,000 --> 00:12:34,000

and we can calculate very accurately how much energy the bird is using.

71

00:12:34,000 --> 00:12:40,000

A hovering hummingbird consumes oxygen at an incredible rate.

72

00:12:40,000 --> 00:12:48,000

Ten times faster than an Olympic sprinter.

73

00:12:48,000 --> 00:12:55,000

The more oxygen it can get into its cells, the faster it can burn glucose,

74

00:12:55,000 --> 00:13:05,000

which unlocks the energy within.

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00:13:05,000 --> 00:13:30,000

On Earth, 21% of the atmosphere is oxygen, fueling the diversity of life around us.

76

00:13:30,000 --> 00:13:39,000

On Eden, there's 10% more oxygen than on Earth.

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00:13:39,000 --> 00:13:56,000

So life here can be more diverse, more energetic, more competitive.

78

00:14:01,000 --> 00:14:16,000

Summer is breeding season for grazers.

79

00:14:16,000 --> 00:14:23,000

Always fearful of predators. They don't spend time finding a mate.

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00:14:23,000 --> 00:14:29,000

Instead, they produce worm-like spawn.

81

00:14:29,000 --> 00:14:40,000

Each needs to fuse with another to create an embryo.

82

00:14:40,000 --> 00:14:56,000

For protection, they form a cocoon.

83

00:14:56,000 --> 00:15:19,000

Suspended above the ground, the embryos can grow away from predators.

84

00:15:19,000 --> 00:15:30,000

Here on Earth, the threat of death is a huge factor in the evolution of life.

85

00:15:30,000 --> 00:15:39,000

Predation is everywhere. There's not an organism out there that doesn't run a risk of being eaten by another organism.

86

00:15:39,000 --> 00:15:54,000

The aspect that I'm interested in is how predation shapes reproduction.

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00:15:54,000 --> 00:15:59,000

They're going to be coming in here.

88

00:15:59,000 --> 00:16:08,000

This river is perfect for studying guppyfish and their patterns of reproduction.

89

00:16:08,000 --> 00:16:14,000

This is an easy neighborhood.

90

00:16:14,000 --> 00:16:18,000

Here, guppies live with only one other species of fish.

91

00:16:18,000 --> 00:16:22,000

It's a fish that rarely eats guppies or harasses guppies.

92

00:16:22,000 --> 00:16:32,000

They can swim wherever they want without any risk of somebody trying to eat them.

93

00:16:32,000 --> 00:16:36,000

Here we have some babies that we just caught. We have five of them here.

94

00:16:36,000 --> 00:16:43,000

They may look small to you, but that's really big for a newborn baby guppy.

95

00:16:43,000 --> 00:16:51,000

The guppies here invest a lot of effort in relatively few offspring.

96

00:16:51,000 --> 00:16:57,000

Downstream, it's a different story.

97

00:16:57,000 --> 00:17:06,000

Wow!

98

00:17:06,000 --> 00:17:15,000

This boulder is a natural barrier dividing the river.

99

00:17:15,000 --> 00:17:21,000

Below it lurks danger.

100

00:17:21,000 --> 00:17:25,000

A guppy life down here is pretty much like the life of a fugitive.

101

00:17:25,000 --> 00:17:27,000

You're always on the run from predators.

102

00:17:27,000 --> 00:17:36,000

If a guppy were to swim out here, it wouldn't last a second.

103

00:17:36,000 --> 00:17:49,000

The only defense that guppies have is to produce lots of offspring in the hope that some will survive to adulthood.

104

00:17:49,000 --> 00:17:54,000

I have two babies from up there where guppies live without predators

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00:17:54,000 --> 00:17:57,000

and four from down here where guppies live with predators.

106

00:17:57,000 --> 00:17:59,000

There's a dramatic difference in size.

107

00:17:59,000 --> 00:18:07,000

Those that are from here are much, much smaller than the ones that I caught above the barrier.

108

00:18:07,000 --> 00:18:12,000

Moms don't have a big prospect of living to the future no matter what they do.

109

00:18:12,000 --> 00:18:19,000

So the best strategy down here is to make many small babies.

110

00:18:19,000 --> 00:18:25,000

The guppies have evolved two different ways of breeding.

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00:18:25,000 --> 00:18:34,000

Having a few large babies or lots of small ones.

112

00:18:34,000 --> 00:18:45,000

The deciding factor is the threat from predators.

113

00:18:45,000 --> 00:18:50,000

If you're one of the prey items, you're going to die young so you better live fast.

114

00:18:50,000 --> 00:19:01,000

You better put a lot into having babies because if you don't, you'll go extinct.

115

00:19:01,000 --> 00:19:18,000

Such a strategy would apply on any planet, wherever one species preys on another.

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00:19:18,000 --> 00:19:26,000

On Eden, the grazers have evolved to breed fast.

117

00:19:26,000 --> 00:19:47,000

They produce as many offspring as quickly as possible to ensure the survival of the species.

118

00:19:47,000 --> 00:19:56,000

But in the forest, they're never truly safe.

119

00:19:56,000 --> 00:20:10,000

As summer ends, the fungi grow orange-colored fruit, which attract grazers.

120

00:20:10,000 --> 00:20:29,000

Spores within the fruit spread an infection.

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00:20:29,000 --> 00:20:52,000

Now, when predators attack, infected grazers don't run. They've lost their fear instinct.

122

00:20:52,000 --> 00:21:05,000

It's an easy meal, but a poisonous one.

123

00:21:05,000 --> 00:21:28,000

The fungi have used the grazers to infect and kill the predators.

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00:21:28,000 --> 00:21:44,000

Such complex relationships between species exist on Earth. But not all are so lethal.

125

00:21:44,000 --> 00:21:50,000

The Hadza are hunter-gatherers, living off the land.

126

00:22:20,000 --> 00:22:33,000

One high-calorie food is prized above all else. Honey.

127

00:22:33,000 --> 00:22:40,000

But finding fresh honey is difficult.

128

00:22:40,000 --> 00:22:47,000

The bees move their nests from season to season.

129

00:22:47,000 --> 00:22:57,000

So the Hadza call on help.

130

00:23:28,000 --> 00:23:34,000

The honey guide has lived up to its name.

131

00:23:34,000 --> 00:23:47,000

It's led them to a bee's nest in the forest.

132

00:23:48,000 --> 00:24:03,000

The honey guide has lived up to its name. It's led them to a bee's nest in a baobab tree.

133

00:24:03,000 --> 00:24:14,000

The hunters need the bird to find the bees. And the bird needs the hunters to access the honey.

134

00:24:45,000 --> 00:24:58,000

That's dangerous■ä.

135

00:24:58,000 --> 00:25:00,660

All was very sad.

136

00:25:00,660 --> 00:25:10,400

I know.

137

00:25:28,000 --> 00:25:40,320

The risk is worth it.

138

00:25:40,320 --> 00:25:54,200

Fresh, rich honey.

139

00:25:54,200 --> 00:26:00,200

The lango makes sure the bird gets its share.

140

00:26:00,200 --> 00:26:08,840

It's a win-win situation.

141

00:26:08,840 --> 00:26:21,640

A complex relationship between species is known as symbiosis.

142

00:26:21,640 --> 00:26:38,080

The richer the ecosystem, the more complex the relationship.

143

00:26:38,080 --> 00:26:44,880

On Eden, a deadly three-way symbiosis has evolved.

144

00:26:44,880 --> 00:26:53,880

They are centered around the fungi.

145

00:26:53,880 --> 00:26:59,880

First, they feed the grazers.

146

00:26:59,880 --> 00:27:05,880

Then they infect them.

147

00:27:05,880 --> 00:27:24,880

They season the predators.

148

00:27:24,880 --> 00:27:49,880

The fungi do all this to grow their next generation, which feeds on the bodies of the dead predators.

149

00:27:49,880 --> 00:27:58,880

On Earth, fungi play a crucial but invisible role in the life of any forest.

150

00:27:58,880 --> 00:28:13,880

Behind the scenes.

151

00:28:13,880 --> 00:28:20,880

Most people think the first complex life on our planet was something like insects or even dinosaurs.

152

00:28:20,880 --> 00:28:30,880

Hundreds of millions of years before that, the first complex multicellular organisms were these things.

153

00:28:30,880 --> 00:28:35,880

Fungi.

154

00:28:35,880 --> 00:28:48,880

We know of at least 140,000 species, but that's likely to be less than 10% of the real total.

155

00:28:48,880 --> 00:29:05,880

There's probably thousands of different fungal species just in this forest alone.

156

00:29:05,880 --> 00:29:13,880

Okay, so we've actually got three mushrooms here, and you can actually see these dotted all throughout the forest.

157

00:29:13,880 --> 00:29:18,880

But what's amazing is that these mushrooms are really just the tip of the iceberg.

158

00:29:18,880 --> 00:29:27,880

When we look below the surface, most of the fungus is actually in these tiny little threads that go all throughout the soil.

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00:29:27,880 --> 00:29:34,880

This is called the mycelium, and it connects all of the other mushrooms in this area.

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00:29:34,880 --> 00:29:42,880

There can be tens of kilometers of these tiny microscopic fungi spreading throughout the entire soil.

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00:29:42,880 --> 00:29:53,880

The tree needs those fibers to survive, because the tree can capture carbon from the atmosphere, and it provides that carbon to the fungus.

162

00:29:53,880 --> 00:30:00,880

In contrast, the fungi access nitrogen and phosphorus from the soil, which they give in exchange for that carbon.

163

00:30:00,880 --> 00:30:11,880

So really, it's a mutualism that benefits both of the organisms.

164

00:30:11,880 --> 00:30:19,880

Possibly the most extraordinary thing about this mycelial system is just how connected it is.

165

00:30:19,880 --> 00:30:28,880

So the fungi that are attached to the roots of this tree will also be attached to the roots of that tree, and that tree over there.

166

00:30:28,880 --> 00:30:44,880

And they will also be connected to their neighbors via the same mycelial system that is really going tree to tree to tree.

167

00:30:44,880 --> 00:30:54,880

The mycelial network is like a circuit of wires and nodes through which information can flow.

168

00:30:54,880 --> 00:31:02,880

And with it, fungi can maintain the forest.

169

00:31:02,880 --> 00:31:13,880

So if we have one tree over there that's dying, it might reallocate more nutrients towards that tree so that the tree can do better, and as a result, the fungal system does better.

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00:31:13,880 --> 00:31:24,880

Similarly, if there's disturbance at some part of the fungal network, it will remove nutrients away so that it can minimize the impact of that disturbance.

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00:31:24,880 --> 00:31:40,880

It's these invisible ecosystem engineers that are keeping the entire system functioning in a really healthy way.

172

00:31:40,880 --> 00:32:01,880

This system has become known as the Wood Wide Web, and it sounds like a bit of a joke, but really it doesn't function so differently from the internet, keeping all of the organisms connected in the forest system.

173

00:32:01,880 --> 00:32:11,880

This process is happening all across the planet in every ecosystem we can imagine.

174

00:32:11,880 --> 00:32:23,880

So if we're going to get a lush ecosystem on some alien planet out there, I bet you that it's underpinned by something like this massive mycelial system.

175

00:32:32,880 --> 00:32:44,880

Life in the forests of Eden is a trade-off between fungi, grazers and predators.

176

00:32:44,880 --> 00:33:05,880

But there are greater celestial forces at play.

177

00:33:05,880 --> 00:33:20,880

Eden has stronger seasons than on Earth. Greater fluctuations of light and warmth from its twin stars.

178

00:33:21,880 --> 00:33:40,880

As winter approaches, the remaining predators migrate, chasing the light.

179

00:33:40,880 --> 00:33:46,880

The remaining grazers die.

180

00:33:46,880 --> 00:34:06,880

It's the same every winter. Nothing grows in the dark forest, except the embryos in their cocoons.

181

00:34:06,880 --> 00:34:30,880

Just as the season starts to change, the grazers hatch, taking their cue from the return of the twin stars.

182

00:34:30,880 --> 00:34:43,880

On Earth, life does the same thing, using the seasons as a clock.

183

00:34:43,880 --> 00:34:57,880

It's mid-summer, the longest day of the year.

184

00:34:57,880 --> 00:35:04,880

There's a lot of fly fishermen out this time of year because this is the time of year that the fish are biting.

185

00:35:04,880 --> 00:35:12,880

Because there's an abundant food source in the river, and that food source are all these guys, the mayfly nymph.

186

00:35:12,880 --> 00:35:24,880

So we think of mayflies as flying around on the land with us, but they spend the vast majority of their life cycle living down on the bottom of the river, developing, growing.

187

00:35:24,880 --> 00:35:36,880

And it's all really building up to this one time in the year where they're all going to emerge.

188

00:35:36,880 --> 00:35:46,880

Yellow Breeches River feeds the Sasquahana.

189

00:35:46,880 --> 00:35:58,880

Beneath these waters, millions of mayflies are primed and ready to go.

190

00:35:58,880 --> 00:36:12,880

And when the sun sets, they emerge on mass.

191

00:36:12,880 --> 00:36:19,880

There's just so many insects that seemingly came out of nowhere.

192

00:36:19,880 --> 00:36:29,880

It really almost feels like an alien invasion.

193

00:36:29,880 --> 00:36:34,880

Mayflies live at most for two days.

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00:36:34,880 --> 00:36:43,880

In that time, they must find a mate to pass on their genes.

195

00:36:43,880 --> 00:36:51,880

They have one shot, they have one chance, and if they miss it, it's game over for that mayfly.

196

00:36:59,880 --> 00:37:10,880

Once they've mated, the females return to the river to lay their eggs and then die.

197

00:37:10,880 --> 00:37:17,880

Each of these little white dots is a mayfly that successfully made it back to the water and has laid eggs.

198

00:37:17,880 --> 00:37:21,880

They are floating down by the thousands, by the hundreds of thousands.

199

00:37:21,880 --> 00:37:35,880

They have started the next generation that will continue on and do this again next year in this really precisely timed event.

200

00:37:35,880 --> 00:37:48,880

The rhythm of the seasons is always dictated by the tilt of a planet towards its star.

201

00:37:48,880 --> 00:37:59,880

Earth is tilted at an angle of 23.5 degrees.

202

00:37:59,880 --> 00:38:05,880

On Eden, that angle is 40 degrees.

203

00:38:05,880 --> 00:38:13,880

So more light spreads across more of the planet's surface.

204

00:38:13,880 --> 00:38:23,880

And more light means more life.

205

00:38:23,880 --> 00:38:29,880

It's spring and there's food to eat.

206

00:38:29,880 --> 00:38:40,880

But the new grazers need to grow as fast as possible.

207

00:38:40,880 --> 00:38:48,880

Before the predators return.

208

00:38:48,880 --> 00:39:03,880

And the life cycle repeats.

209

00:39:03,880 --> 00:39:08,880

Wanderous creatures.

210

00:39:08,880 --> 00:39:17,880

Fed by glucose.

211

00:39:17,880 --> 00:39:22,880

Powered by oxygen.

212

00:39:22,880 --> 00:39:34,880

Washed by starlight.

213

00:39:34,880 --> 00:39:42,880

What is true on Eden may be true throughout the universe.

214

00:39:42,880 --> 00:39:59,880

That all life depends on the flow of energy.

215

00:39:59,880 --> 00:40:04,880

How might life adapt on a different world?

216

00:40:04,880 --> 00:40:09,880

Inhabited by intelligent beings.

217

00:40:09,880 --> 00:40:21,880

Intelligent enough to make a new home among the stars.