



1  
00:00:05,940 --> 00:00:08,960  
>>> GOOD EVENING AND WELCOME.  
I AM DR. LINDSAY HAYS, A

2  
00:00:08,960 --> 00:00:14,340  
POSTDOCTORAL FELLOW HERE AT  
NASA.

3  
00:00:14,340 --> 00:00:17,921  
TONIGHT'S DISCUSSION IS ABOUT  
WHAT WE KNOW ABOUT THE EARLY

4  
00:00:17,921 --> 00:00:21,350  
EARTH AND HOW THAT CAN GUIDE OUR  
SEARCH FOR HABITABLE PLANETS

5  
00:00:21,350 --> 00:00:24,030  
ORBITING OTHER STARS.  
IT WILL BE FOLLOWED BY A

6  
00:00:24,030 --> 00:00:27,160  
QUESTION AND ANSWER PERIOD WITH  
THOSE OF YOU IN THE AUDIENCE AS

7  
00:00:27,160 --> 00:00:31,830  
WELL AS ON SOCIAL MEDIA USING  
HASHTAG #ASKNASA.

8  
00:00:31,830 --> 00:00:41,059  
THIS IS  
FOCUSING ON THE

9  
00:00:41,059 --> 00:00:47,909  
HABITABILITY OF THE EARLY EARTH.  
I'M ONE OF THE CO-ORGANIZERS.

10  
00:00:47,909 --> 00:00:51,319  
I WILL JOIN YOU ALL FOR THE  
QUESTION AND ANSWER PERIOD BUT I

11  
00:00:51,319 --> 00:00:55,390  
WOULD LIKE TO INTRODUCE OUR  
MODERATOR FOR THIS EVENING.

12  
00:00:55,390 --> 00:01:01,840  
A SENIOR SCIENTIST AT PLANETARY  
SCIENCE INSTITUTE, DR. DAVID

13  
00:01:01,840 --> 00:01:07,430  
GRINSPOON.  
>> THANK YOU, LINDSAY.

14  
00:01:07,430 --> 00:01:10,930  
THANK YOU ALL FOR COMING OUT  
THIS AFTERNOON.

15  
00:01:10,930 --> 00:01:14,370  
A BIG HELLO TO ALL YOU PEOPLE  
OUT THERE IN NASA TV LAND.

16  
00:01:14,370 --> 00:01:18,350  
I'M THRILLED TO BE HERE TO  
PRESENT TO YOU THIS DISCUSSION

17  
00:01:18,350 --> 00:01:21,430  
OF SOME REALLY EXCITING NEW  
SCIENCE.

18  
00:01:21,430 --> 00:01:25,020  
WE LIVE IN A REVOLUTIONARY TIME  
IN TERMS OF OUR KNOWLEDGE OF THE

19  
00:01:25,020 --> 00:01:26,870  
UNIVERSE.  
THIS IS THE TIME OF THE EX OH,

20  
00:01:26,870 --> 00:01:31,710  
PLANET REVOLUTION.  
WE KNOW MOST STARS HAVE

21  
00:01:31,710 --> 00:01:38,020  
PLANETARY SYSTEMS OF THEIR OWN.  
IT'S A BIG DISCOVERY.

22  
00:01:38,020 --> 00:01:41,450  
WE'RE ALSO IN A TIME OF RAPID  
DISCOVERY ABOUT THE HISTORY OF

23  
00:01:41,450 --> 00:01:44,710  
LIFE ON EARTH AND THE ORIGIN AND  
EARLY EVOLUTION OF LIFE ON

24  
00:01:44,710 --> 00:01:46,810  
EARTH.  
WE'RE HERE THIS AFTERNOON TO TRY

25  
00:01:46,810 --> 00:01:50,680  
TO BRING ALL THAT TOGETHER.  
I'VE GOT A PANEL OF EXPERTS HERE

26  
00:01:50,680 --> 00:01:54,490  
WHO ARE ALL DOING RESEARCH THAT  
CHIPS AWAY AT THAT PROBLEM OF

27  
00:01:54,490 --> 00:01:57,850  
LIFE ELSEWHERE AND HOW WE CAN  
APPLY OUR KNOWLEDGE OF EARTH

28  
00:01:57,850 --> 00:02:00,520  
HISTORY TO THE QUESTION OF LIFE  
ELSEWHERE.

29  
00:02:00,520 --> 00:02:04,500  
LET ME INTRODUCE THE PANELISTS  
TO YOU.

30  
00:02:04,500 --> 00:02:07,810  
IF I WERE GOING TO GIVE THEM ALL  
THE FULL INTRODUCTION THEY WOULD

31  
00:02:07,810 --> 00:02:10,140  
DESERVE, IT WOULD TAKE THE FULL  
HOUR.

32  
00:02:10,140 --> 00:02:13,420  
THEY'RE ALL VERY ACCOMPLISHED  
PEOPLE AND THE LISTS OF AWARDS

33  
00:02:13,420 --> 00:02:20,690  
AND DEGREES AND PUBLICATIONS  
WOULD FILL AN ENCYCLOPEDIA.

34  
00:02:20,690 --> 00:02:28,560  
BRIEFLY, STARTING ON MY FAR  
RIGHT, WE HAVE CHRIS HOUSE.

35  
00:02:28,560 --> 00:02:30,980  
CHRIS IS THE DIRECTOR OF THE  
PENN STATE ASTRO BIOLOGY

36  
00:02:30,980 --> 00:02:34,380  
RESEARCH CENTER.  
HIS RESEARCH FOCUSES ON

37  
00:02:34,380 --> 00:02:38,490  
MICROBIAL GEO CHEMICAL  
SIGNATURES OF LIFE.

38  
00:02:38,490 --> 00:02:44,620  
THAT MEANS HE STUDIES THE  
TINIEST ORGANISMS AND HOW THEY

39  
00:02:44,620 --> 00:02:50,390  
AFFECT THE ENVIRONMENT AND  
APPLIES THAT TO THE QUESTION OF

40  
00:02:50,390 --> 00:02:53,840  
HOW CAN WE USE THESE CLUES TO  
UNDERSTAND THE ORIGIN AND EARLY

41  
00:02:53,840 --> 00:02:57,940  
EVOLUTION OF LIFE HERE AND  
ELSEWHERE IN THE UNIVERSE.

42  
00:02:57,940 --> 00:03:00,890  
NEXT TO CHRIS IS DR. PHOEBE  
COHEN.

43  
00:03:00,890 --> 00:03:06,170  
SHE'S A PROFESSOR OF GEO  
SCIENCES AT WILLIAMS COLLEGE.

44  
00:03:06,170 --> 00:03:14,060  
HER RESEARCH FOCUSES ON LARGER  
ORGANISMS, THE FOSSIL RECORD,

45  
00:03:14,060 --> 00:03:17,600  
THE INTERACTIONS BETWEEN EARTH  
AND LIFE IN DEEP TIME AND IN

46  
00:03:17,600 --> 00:03:21,420  
PARTICULAR THE ORIGIN OF ANIMALS  
AND THE ORIGIN OF COMPLEXITY ON

47  
00:03:21,420 --> 00:03:28,520  
EARTH AND THE QUESTION OF WHERE  
COMPLEX LIFE MIGHT ARISE IN THE

48  
00:03:28,520 --> 00:03:33,650  
UNIVERSE.  
OVER TO MY LEFT, TIM LYONS IS AT

49  
00:03:33,650 --> 00:03:37,790  
THE DEPARTMENT OF EARTH  
SCIENCES, UNIVERSITY OF

50  
00:03:37,790 --> 00:03:42,760  
CALIFORNIA IN RIVERSIDE.  
TIM STUDIES THE EVOLUTION OF THE

51  
00:03:42,760 --> 00:03:46,730  
OCEAN OF THE ATMOSPHERE AND OF  
LIFE AND HOW THESE ARE COUPLED

52  
00:03:46,730 --> 00:03:48,650  
TOGETHER, HOW THEY AFFECT ONE  
ANOTHER.

53  
00:03:48,650 --> 00:03:52,239  
HE LOOKS AT THE CHEMISTRY OF THE  
MODERN OCEAN AND ASKS HOW CAN

54  
00:03:52,239 --> 00:03:55,680  
THIS HELP US TO UNDERSTAND  
ANCIENT OCEANS AND THE

55  
00:03:55,680 --> 00:03:59,930  
ATMOSPHERE AND THE SEARCH FOR  
EXTRATERRESTRIAL LIFE.

56  
00:03:59,930 --> 00:04:04,610  
NEXT WE HAVE DR. DAWN SUMNER.  
DAWN IS A PROFESSOR OF GEOLOGY

57  
00:04:04,610 --> 00:04:06,760  
AT THE UNIVERSITY OF CALIFORNIA  
DAVIS.

58  
00:04:06,760 --> 00:04:12,209  
SHE STUDIES THE EARLY  
ENVIRONMENT OF EARTH AND MARS

59  
00:04:12,209 --> 00:04:16,310  
AND THE EVOLUTION OF BACTERIA ON  
EARTH AND POTENTIALLY ON MARS

60  
00:04:16,310 --> 00:04:19,530  
AND OTHER ENVIRONMENTS.  
THIS RESEARCH HAS TAKEN HER FROM

61  
00:04:19,530 --> 00:04:24,840  
ANTARCTICA TO THE SURFACE OF  
MARS WHERE SHE'S ONE OF THE MAIN

62  
00:04:24,840 --> 00:04:28,790  
SCIENTISTS WORKING ON A LARGE  
TEAM OF SCIENTISTS RUNNING THE

63  
00:04:28,790 --> 00:04:33,440  
CURIOSITY RECOVER AND TRYING TO  
UNDERSTAND WHAT THAT ENVIRONMENT

64  
00:04:33,440 --> 00:04:37,530  
IS TELLING US ABOUT MARS AND  
ABOUT LIFE IN THE UNIVERSE.

65  
00:04:37,530 --> 00:04:41,460  
FINALLY, WE HAVE DR. SHAWN  
DOMAGAL-GOLDMAN.

66  
00:04:41,460 --> 00:04:45,800  
SHAWN IS A RESEARCH SPACE  
SCIENTIST AT GODDARD SPACE

67  
00:04:45,800 --> 00:04:49,340  
FLIGHT CENTER FOR NASA.  
HE STUDIES THE INTERACTION OF

68  
00:04:49,340 --> 00:04:54,460  
LIFE AND PLANETS AND THINKS  
ABOUT THE SIGNATURES OF LIFE,

69  
00:04:54,460 --> 00:04:58,090  
THE BIOSIGNATURES, HOW WE WOULD  
DETECT LIFE ON ANOTHER PLANET

70  
00:04:58,090 --> 00:05:01,050  
AND USE THAT TO TRACE LIFE'S  
ORIGINS.

71  
00:05:01,050 --> 00:05:07,650  
LATELY HE'S BEEN DESIGNING A NEW  
GENERATION OF TELESCOPES TO FIND

72  
00:05:07,650 --> 00:05:15,180  
THESE BIOSIGNATURES ON SOME OF  
THESE PLANETS WE'VE BEEN

73  
00:05:15,180 --> 00:05:18,220  
DISCOVERING.  
I'M GOING TO START OFF BY

74  
00:05:18,220 --> 00:05:21,870  
PITCHING A\h-- I DON'T KNOW IF  
IT'S A SOFT BALL QUESTION BUT

75  
00:05:21,870 --> 00:05:24,710  
I'M GOING TO ASK YOU EACH TO  
RESPOND TO A QUESTION ABOUT

76  
00:05:24,710 --> 00:05:29,530  
LIFE'S INEVITABILITY.  
WE TALK AND HEAR A LOT ABOUT

77  
00:05:29,530 --> 00:05:34,620  
THIS GOLDIE LOCKS ZONE, THE  
JACKPOT OF SEARCHING FOR LIFE

78  
00:05:34,620 --> 00:05:39,090  
ELSEWHERE IS DEFINED OF A PLANET  
THAT WOULD HAVE LIQUID WATER ON

79  
00:05:39,090 --> 00:05:46,050  
THE SURFACE.  
IF WE FIND SUCH A PLANET, DOES

80  
00:05:46,050 --> 00:05:50,740  
THAT MEAN SHOULD IT HAVE LIFE?  
IS WATER ITSELF A BIOSIGNATURE

81  
00:05:50,740 --> 00:05:55,860  
OR AS ONE OF MY COLLEAGUES SAID  
THIS AFTERNOON, HE SAID IF YOU

82  
00:05:55,860 --> 00:05:58,960  
HAVE A WATER WORLD, HOW DO YOU  
KEEP IT DEAD?

83  
00:05:58,960 --> 00:06:02,720  
>> THANKS, DAVID.  
THAT'S DEFINITELY NOT A SOFT

84  
00:06:02,720 --> 00:06:07,080  
BALL QUESTION.  
I'LL START BY SAYING IT'S REALLY

85  
00:06:07,080 --> 00:06:12,180  
PROFOUND AND WHETHER IT DICTATES  
WHETHER OR NOT LIFE IS COMMON OR

86  
00:06:12,180 --> 00:06:16,690  
RARE AND EITHER RESULT WOULD BE  
TOTALLY PROFOUND FOR OUR PLACE

87  
00:06:16,690 --> 00:06:19,210  
IN THE COSMOS.  
CERTAINLY NOT A SOFT BALL.

88  
00:06:19,210 --> 00:06:25,630  
I ALSO SAY THAT MY OWN PERSONAL  
OPINION ON THIS HAS CHANGED.

89  
00:06:25,630 --> 00:06:31,360  
EARLY ON IN MY CAREER I WAS  
ACTUALLY QUITE OPTIMISTIC THAT

90  
00:06:31,360 --> 00:06:37,260  
WHenever you have liquid water,  
they form the necessary

91  
00:06:37,260 --> 00:06:43,440  
MATERIALS FOR LIFE AND YOU END  
UP FORMING LIFE.

92  
00:06:43,440 --> 00:06:47,280  
BUT LATELY I'VE ACTUALLY STARTED  
TO REALLY BE OPEN TO THE IDEA

93  
00:06:47,280 --> 00:06:52,040  
THAT WE NEED TO CONSIDER THE  
REVERSE POSSIBILITY THAT WHAT WE

94  
00:06:52,040 --> 00:06:55,050  
HAVE HERE IS QUITE SPECIAL AND  
UNIQUE WHICH IS ALSO REALLY

95  
00:06:55,050 --> 00:07:03,800  
PROFOUND AND BASICALLY A LOT OF  
PEOPLE'S FEELINGS ON THIS IS

96  
00:07:03,800 --> 00:07:08,080  
DRIVEN BY THE FACT THAT WE SEE  
LIFE GOES BACK TO THE REALLY

97  
00:07:08,080 --> 00:07:12,310  
VERY BEGINNINGS OF EARTH, SO  
THAT IMPLIES A QUICK ORIGIN.

98  
00:07:12,310 --> 00:07:16,449  
BUT THERE ARE OTHER PIECES OF  
EVIDENCE WE HAVE OUT THERE THAT

99  
00:07:16,449 --> 00:07:20,259  
ALSO BEAR IN THE QUESTION.  
FOR EXAMPLE, WHEN YOU LOOK AT

100  
00:07:20,259 --> 00:07:27,560  
METEORITES, WE KNOW A LOT OF  
RUSHING THROUGH THEM AND THERE

101

00:07:27,560 --> 00:07:31,840

WAS ENERGY GRADIENTS AND THEY  
FORMED A LOT OF ORGANIC MATTER.

102

00:07:31,840 --> 00:07:35,270

SO THAT CAN BE TAKEN AS A VERY  
OPTIMISTIC VIEW, YOU'RE STARTING

103

00:07:35,270 --> 00:07:39,190

TO GET LIFE GOING, BUT YOU CAN  
ALSO CONCLUDE THAT THOSE BODIES

104

00:07:39,190 --> 00:07:45,560

AND SOLAR SYSTEMS THEN DIDN'T  
FORM A BIOSPHERE, THAT THEY

105

00:07:45,560 --> 00:07:52,440

DON'T HAVE CELLS AND METABOLISM.  
WE HAD WATER RUSHING THROUGH AND

106

00:07:52,440 --> 00:07:56,350

ENERGY WAS THERE, BUT WE ONLY  
SEEM TO AT LEAST PRESENTLY HAVE

107

00:07:56,350 --> 00:08:00,650

EVIDENCE FOR LIFE HERE, ONE  
ORIGIN FOR OUR SOLAR SYSTEM.

108

00:08:00,650 --> 00:08:03,120

OF COURSE, THAT COULD CHANGE AS  
WE STUDY MARS AND THAT'S GOING

109

00:08:03,120 --> 00:08:05,250

TO BE EXCITING TO SEE HOW THAT  
PLAYS OUT.

110

00:08:05,250 --> 00:08:10,810

>> YOU THINK THE JURY IS OUT?  
>> THE JURY IS OUT, BUT I'M VERY

111

00:08:10,810 --> 00:08:15,910

OPEN TO THE IDEA THAT WHAT WE  
HAVE IS VERY SPECIAL HERE.

112

00:08:15,910 --> 00:08:19,139

>> PHOEBE.

>> THAT WAS A REALLY GREAT

113

00:08:19,139 --> 00:08:21,980

ANSWER.

YOU CAN'T JUST HAVE LIQUID

114

00:08:21,980 --> 00:08:26,740

WATER, YOU HAVE TO HAVE IT FOR  
AN EXTENDED PERIOD OF TIME.

115

00:08:26,740 --> 00:08:30,389

AS CHRIS ALLUDED TO, YOU ALSO  
NEED OTHER CONDITIONS IN ORDER

116

00:08:30,389 --> 00:08:34,779

FOR LIFE TO EVOLVE, PROBABLY  
SOME SORT OF STABILITY OVER SOME

117

00:08:34,779 --> 00:08:37,719

TIME SCALE THAT WE DIDN'T HAVE A  
HANDLE ON YET WHERE LIQUID WATER

118

00:08:37,719 --> 00:08:41,460

IS EXISTING IN AN ENVIRONMENT  
THAT IS PERMISSIVE FOR LIFE.

119

00:08:41,460 --> 00:08:44,709

I WOULD SAY THAT YOU NEED WATER  
PLUS A BUNCH OF OTHER THINGS.

120

00:08:44,709 --> 00:08:47,339

WHAT THOSE THINGS ARE, I DON'T  
THINK WE HAVE A REALLY GOOD

121  
00:08:47,339 --> 00:08:51,510  
HANDLE ON RIGHT NOW.  
>> I WOULD AGREE THAT THE JURY

122  
00:08:51,510 --> 00:08:53,680  
IS OUT.  
I THINK IT'S THE RIGHT PLACE TO

123  
00:08:53,680 --> 00:08:56,290  
START.  
BUT I'M DRAWN TO THE BACKDROP

124  
00:08:56,290 --> 00:08:58,800  
BEHIND US.  
WHEN I WAS A KID AND I STARTED

125  
00:08:58,800 --> 00:09:02,070  
ALL OF THIS, VISIONS OF THE  
EARLY EARTH WERE VERY DIFFERENT

126  
00:09:02,070 --> 00:09:04,540  
THAN THIS.  
NOW WE SEE WATER AND VOLCANOS

127  
00:09:04,540 --> 00:09:08,290  
AND THERE ARE DATA THAT WATER  
MAY HAVE BEEN ON OUR PLANET MORE

128  
00:09:08,290 --> 00:09:13,550  
THAN 4 BILLION YEARS AGO.  
THE EVIDENCE FOR LIFE IS QUITE A

129  
00:09:13,550 --> 00:09:17,210  
BIT YOUNGER THAN THAT,  
SUGGESTIONS AT 3.7, 3.8 BILLION

130  
00:09:17,210 --> 00:09:22,270  
OR MORE CONVINCING 3.5.  
THAT'S A LOT OF TIME BETWEEN

131

00:09:22,270 --> 00:09:25,470

EVIDENCE OF WATER AND LIFE.

WE DON'T KNOW WHAT HAPPENED

132

00:09:25,470 --> 00:09:27,690

DURING THAT TIME AND WE DON'T

KNOW THAT THAT WOULD BE

133

00:09:27,690 --> 00:09:31,330

INEVITABLE AND PLAY OUT THE SAME

WAY EVERY PLACE WE LOOK.

134

00:09:31,330 --> 00:09:37,190

>> YOU'RE ALL SO CAUTIOUS.

YOU SOUND LIKE SCIENTISTS.

135

00:09:37,190 --> 00:09:41,770

DAWN?

>> I DON'T HAVE A PERSONAL

136

00:09:41,770 --> 00:09:44,850

OPINION.

I SHIFT AROUND BACK AND FORTH

137

00:09:44,850 --> 00:09:46,500

ALL THE TIME.

BUT ONE OF THE MOST EXCITING

138

00:09:46,500 --> 00:09:51,920

THINGS TO ME IS THAT WE ACTUALLY

HAVE TWO ROVERS ON MARS AND

139

00:09:51,920 --> 00:09:55,400

ORBITERS AROUND MARS THAT ARE

TELLING US THERE WAS AN

140

00:09:55,400 --> 00:09:59,920

EXTENSIVE HISTORY OF WATER ON

EARLY MARS.

141

00:09:59,920 --> 00:10:04,820

WE HAVE INSTRUMENTATION WITH THE  
CURIOSITY ROVER HAS DEMONSTRATED

142

00:10:04,820 --> 00:10:09,910

THAT WE HAD LIQUID WATER  
INTERACTIONS BETWEEN THE WATER

143

00:10:09,910 --> 00:10:12,880

AND THE ROCKS WHICH GIVES AN  
ENERGY GRADIENT AND THE ELEMENTS

144

00:10:12,880 --> 00:10:17,350

THAT ARE NECESSARY FOR LIFE.  
WE HAVE NOT FOUND EVIDENCE OF

145

00:10:17,350 --> 00:10:20,470

LIFE.  
WHEN WE LOOK AT EARTH'S FOSSIL

146

00:10:20,470 --> 00:10:24,240

RECORD, IT'S VERY DIFFICULT TO  
FIND THAT EVIDENCE EVEN THOUGH

147

00:10:24,240 --> 00:10:29,110

WE KNOW LIFE WAS PRESENT.  
IT'S A WHOLE PROCESS OF

148

00:10:29,110 --> 00:10:34,450

DISCOVERY AND INVESTIGATION, SO  
AS AN INDIVIDUAL I WANT TO HAVE

149

00:10:34,450 --> 00:10:38,990

AN OPINION, BUT THEN AS I  
SCIENTIST I AM IN THIS WONDERFUL

150

00:10:38,990 --> 00:10:42,529

PLACE WHERE WE CAN ACTUALLY ASK  
THOSE QUESTIONS WITH THE

151

00:10:42,529 --> 00:10:46,640

MISSIONS THAT WE HAVE NOW ON  
MARS AND THE MARS 2020 ROVER

152

00:10:46,640 --> 00:10:51,900

THAT'S BEING PLANNED IS THE NEXT  
STEP TO DO A LITTLE BIT BETTER

153

00:10:51,900 --> 00:10:57,790

SCIENTIFIC INVESTIGATION.  
WE HAVE THE CONDITIONS THAT SHOW

154

00:10:57,790 --> 00:11:01,140

LIQUID WATER WAS PRESENT AND  
MANY OF US THINK FOR A LONG

155

00:11:01,140 --> 00:11:05,529

TIME, AND NOW IS THE QUESTION OF  
WHETHER OR NOT WE CAN FIND

156

00:11:05,529 --> 00:11:08,679

EVIDENCE OF LIFE IF IT WAS  
THERE.

157

00:11:08,679 --> 00:11:10,139

>> GREAT.  
SHAWN?

158

00:11:10,139 --> 00:11:13,790

>> I AGREE WITH DAWN.  
TO ME I FLIP THAT AROUND FROM

159

00:11:13,790 --> 00:11:17,529

THE QUESTION TO A STATEMENT.  
EVERY PLANET THAT HAS HAD WATER

160

00:11:17,529 --> 00:11:20,440

HAS HAD LIFE OR EVERY PLANET  
THAT HAS WATER HAS LIFE, NOT AS

161

00:11:20,440 --> 00:11:22,931

SOMETHING I NECESSARILY BELIEVE  
BUT AS A HYPOTHESIS THAT WE CAN

162

00:11:22,931 --> 00:11:28,000

TEST WITH THE SPACECRAFT THAT WE  
DELIVER TO MARS.

163

00:11:28,000 --> 00:11:31,200

WE KNOW IF WATER THROUGHOUT THE  
SOLAR SYSTEM ON THE MOONS OUT

164

00:11:31,200 --> 00:11:37,680

THERE AND FOR EXO PLANETS WE'RE  
FINDING PLANETS IN THE HAPPY

165

00:11:37,680 --> 00:11:46,540

ZONE WHERE THE CONDITIONS COULD  
ALLOW FOR LIQUID WATER.

166

00:11:46,540 --> 00:11:48,670

THIS IS WHAT'S REALLY GREAT TO  
ME.

167

00:11:48,670 --> 00:11:52,010

WE COULD HAVE PONDERED THIS AS  
NATURAL PHILOSOPHERS 500 OR

168

00:11:52,010 --> 00:11:56,060

1,000 YEARS AGO AND EITHER WERE  
THE FIRST GENERATION OR OUR KIDS

169

00:11:56,060 --> 00:12:03,620

WILL BE THE FIRST GENERATION TO  
RIGOROUSLY TEST THIS.

170

00:12:03,620 --> 00:12:06,990

THAT'S WHAT KEEPS ME WORKING UP  
LATE AT NIGHT AND\h-- WELL, MY

171

00:12:06,990 --> 00:12:14,520

BABY WAKES ME UP EARLY IN THE  
MORNING.

172

00:12:14,520 --> 00:12:17,750

>> IT SEEMS LIKE THE SENSE OF  
THE JURY IS THAT IF WE FIND A

173

00:12:17,750 --> 00:12:21,680

WATER WORLD, IT'S EXCITING BUT  
DOESN'T NECESSARILY TELL US FOR

174

00:12:21,680 --> 00:12:26,760

SURE THAT WE'VE FOUND LIFE.  
BUT AS DAWN SAID, IN A CERTAIN

175

00:12:26,760 --> 00:12:30,930

SENSE ON MARS WE FOUND A WATER  
WORLD OR WE HAVE GOOD EVIDENCE

176

00:12:30,930 --> 00:12:34,690

THAT IT WAS AT ONE TIME A WATER  
WORLD AND THEN MARS PERHAPS

177

00:12:34,690 --> 00:12:39,340

BECOMES AN IMPORTANT TEST.  
IF IT WAS A WATER WORLD AND THIS

178

00:12:39,340 --> 00:12:42,110

IDEA OF INEVITABILITY IS RIGHT  
WE SHOULD BE ABLE TO FIND THE

179

00:12:42,110 --> 00:12:46,890

LIFE THERE EXCEPT IT'S HARD TO  
FIND LIFE IN ANCIENT ROCKS.

180

00:12:46,890 --> 00:12:52,079

THAT LEADS TO THE NEXT QUESTION  
WHICH IS ABOUT SIGNS OF LIFE IN

181  
00:12:52,079 --> 00:12:58,360  
ANCIENT ROCKS OR ANCIENT TRACERS  
OF LIFE ON EARTH.

182  
00:12:58,360 --> 00:13:01,670  
THIS IS A QUESTION FOR ANY OF  
YOU TO ANSWER AND MAYBE ALL OF

183  
00:13:01,670 --> 00:13:05,519  
YOU IF YOU WANT TO CHIME IN.  
WHEN DO YOU THINK IS THE FIRST

184  
00:13:05,519 --> 00:13:11,600  
REALLY GOOD EVIDENCE AND WHAT IS  
THAT EVIDENCE AND THE STATE OF

185  
00:13:11,600 --> 00:13:16,900  
LIFE ON THE PLANET EARTH?  
ANYBODY WANT TO JUMP IN, OR

186  
00:13:16,900 --> 00:13:21,020  
SHOULD I?  
>> I ALLUDED TO THAT.

187  
00:13:21,020 --> 00:13:23,360  
IT'S AN ONGOING STORY.  
OF COURSE LIKE ALL OF THESE

188  
00:13:23,360 --> 00:13:27,860  
THINGS, THERE ARE MANY PEOPLE IN  
THE COMMUNITY THAT ACCEPT GEO

189  
00:13:27,860 --> 00:13:30,760  
CHEMICAL EVIDENCE FOR EARLY LIFE  
AND I HAVE TO MENTION THE I

190  
00:13:30,760 --> 00:13:36,050  
WORD, ISOTOPES.  
THEY'RE NOT FOSSILS.

191

00:13:36,050 --> 00:13:38,730

THEY'RE NOT WELL PRESERVE  
TUESDAY ORGANIC MOLECULES OR

192

00:13:38,730 --> 00:13:42,680

SOMETHING THAT MOST PEOPLE WOULD  
POINT OUT AND SAY THERE'S LIFE,

193

00:13:42,680 --> 00:13:45,839

BUT THERE ARE SIGNATURES WITHIN  
THE GEO CHEMISTRY THAT SUGGEST

194

00:13:45,839 --> 00:13:51,339

METABOLIC PROCESSES.  
THOSE DATE TO 3.7 BILLION YEARS

195

00:13:51,339 --> 00:13:56,720

AGO.  
BY THE TIME WE GET TO 3.5

196

00:13:56,720 --> 00:14:02,970

MILLION YEARS AGO WE HAVE THINGS  
CALLED STROMATOLITES AND OTHERS

197

00:14:02,970 --> 00:14:09,220

THAT ARE MICROBIAL MATS.  
THEY'RE A SEDIMENTARY ORGANIC

198

00:14:09,220 --> 00:14:12,779

MATERIAL THAT'S MEANT TO BE  
TRAPPED BY ORGANIC FILM AND

199

00:14:12,779 --> 00:14:17,339

THERE ARE MICRO FOSSILS THAT I  
THINK MOST PEOPLE AT THIS TIME

200

00:14:17,339 --> 00:14:21,010

ACCEPT.  
SO THE FIRST FOSSIL EVIDENCE IS

201

00:14:21,010 --> 00:14:26,120

ABOUT 3.5 BILLION YEARS AGO.  
THERE HAS BEEN A RECORD ABOUT

202

00:14:26,120 --> 00:14:35,770

2.7 BILLION YEARS AGO OF ORGANIC  
MOLECULES THAT SUGGEST OXYGEN.

203

00:14:35,770 --> 00:14:37,690

IN THE PAST YEAR OR SO THAT'S  
BEEN CHALLENGED BY THE

204

00:14:37,690 --> 00:14:40,980

COLLECTION OF NEW MATERIALS AND  
MORE SOPHISTICATED LEVEL OF

205

00:14:40,980 --> 00:14:44,860

ANALYSIS.  
SO I'M COMFORTABLE PUSHING

206

00:14:44,860 --> 00:14:48,390

THINGS BACK TO 3.5 BILLION YEARS  
AGO, MAYBE FURTHER BACK THAN

207

00:14:48,390 --> 00:14:50,970

THAT.  
BUT THINGS START TO BECOME

208

00:14:50,970 --> 00:14:53,209

CERTAINLY MORE CONVINCING AS WE  
GET YOUNGER.

209

00:14:53,209 --> 00:14:55,800

>> I THINK THAT'S SOMETHING  
REALLY INTERESTING, TOO, IS WHEN

210

00:14:55,800 --> 00:15:00,590

YOU LOOK AT ESPECIALLY THE 3.5  
BILLION YEAR OLD ROCKS THAT WE

211

00:15:00,590 --> 00:15:05,519

HAVE, IT'S NOT JUST ONE TYPE OF  
LIFE.

212

00:15:05,519 --> 00:15:10,019

YOU SEE EVIDENCE FOR A NUMBER OF  
DIFFERENT TYPES OF METABOLISMS.

213

00:15:10,019 --> 00:15:20,051

WE DON'T KNOW ABOUT OXYGEN PHOTO  
SYNTHESIS, SULFATE REDUCTION, SO

214

00:15:20,051 --> 00:15:24,540

IT'S IN THE JUST THE FACT THAT  
LIFE WAS PRESENT AT 3.5 BUT

215

00:15:24,540 --> 00:15:27,459

THERE WERE A LOT OF DIFFERENT  
TYPES OF LIFE AT THAT POINT, AT

216

00:15:27,459 --> 00:15:31,340

LEAST THAT'S MY OPINION.  
>> I WOULD SUGGEST THAT A LOT

217

00:15:31,340 --> 00:15:34,050

MIGHT HAVE GONE ON BEFORE THAT.  
>> RIGHT.

218

00:15:34,050 --> 00:15:39,970

>> YOU HAVE AN ECOLOGY THAT'S  
ESTABLISHED WITH THE ENVIRONMENT

219

00:15:39,970 --> 00:15:44,529

THAT ORGANISMS ARE GROWING IN.  
>> THERE'S EARLY SOLID EVIDENCE

220

00:15:44,529 --> 00:15:47,670

OF WHEN LIFE ACTUALLY STARTED.  
YOU'RE SAYING THAT YOU ARE

221

00:15:47,670 --> 00:15:52,660

SEEING THAT SOLID EVIDENCE THAT  
HAD SOME LONG HISTORY BEFORE IT.

222

00:15:52,660 --> 00:15:54,699

>> RIGHT.

IT'S MUCH EASIER TO FIND GOOD

223

00:15:54,699 --> 00:15:59,290

EVIDENCE FOR LIFE THAT'S FORMING  
A WHOLE ECOLOGY BECAUSE THEN YOU

224

00:15:59,290 --> 00:16:02,460

START TO ACCUMULATE THE  
SIGNATURES AND THEY'RE EASIER TO

225

00:16:02,460 --> 00:16:05,690

PRESERVE IN THE ROCK RECORD.  
IF YOU HAVE ONE OR TWO CELLS

226

00:16:05,690 --> 00:16:09,510

REACTING WITH A MINERAL IN A  
LITTLE ENVIRONMENT, VERY, VERY

227

00:16:09,510 --> 00:16:12,760

HARD TO SEE.

SO THE FIRST GOOD EVIDENCE OF

228

00:16:12,760 --> 00:16:18,540

LIFE IS LIKELYh-- THERE HAS TO  
BE QUITE A BIT OF EVOLUTION

229

00:16:18,540 --> 00:16:22,079

BETWEEN THE TIME WHEN YOU FIRST  
GET LIFE AND YOU HAVE SOMETHING

230

00:16:22,079 --> 00:16:25,490

THAT'S REASONABLE TO PRESERVE IN  
THE ROCK RECORD.

231

00:16:25,490 --> 00:16:28,269

>> THE DIFFERENCE BETWEEN THE  
ORIGIN OF LIFE VERSUS THE ORIGIN

232

00:16:28,269 --> 00:16:32,200

OF A BIOSPHERE, I THINK THAT'S  
SORTS OF WHAT WE'RE TALKING

233

00:16:32,200 --> 00:16:33,790

ABOUT.  
>> WE HAVE TO DEAL WITH THE FACT

234

00:16:33,790 --> 00:16:37,160

THAT WE HAVE ONLY SO MANY ROCKS  
OF THAT TIME PERIOD AND MOST

235

00:16:37,160 --> 00:16:45,389

AREN'T VERY WELL PRESERVED.  
WE'RE ONLY ABLE TO SAMPLE TINY

236

00:16:45,389 --> 00:16:47,589

LITTLE PIECES OF THAT ORIGINAL  
WORLD.

237

00:16:47,589 --> 00:16:50,910

>> DO YOU THINK IF WE GO TO THE  
MOON WE CAN FIND OLD EARTH ROCKS

238

00:16:50,910 --> 00:16:53,810

THAT MIGHT GIVE US THAT ANSWER?  
>> THAT'S INTERESTING.

239

00:16:53,810 --> 00:16:56,440

I'M NOT SURE.  
>> ONE OF THE REASONS IS TO

240

00:16:56,440 --> 00:16:59,520

EXPLORE MARS IS BECAUSE IT  
DOESN'T HAVE THE PLATE

241

00:16:59,520 --> 00:17:02,790

TECTONICS.

ON EARTH THE ROCKS ARE HEATED UP

242

00:17:02,790 --> 00:17:07,019

AND DESTROYED.

MOST OF THE SURFACE OF MARS IS 3

243

00:17:07,019 --> 00:17:11,769

BILLION YEARS OLD AND OLDER.

SO IT GIVES US A CHANCE TO LOOK

244

00:17:11,769 --> 00:17:13,829

AT VERY OLD ROCKS IN THE SOLAR

SYSTEM.

245

00:17:13,829 --> 00:17:18,189

WE HAVE A WHOLE DIFFERENT SET OF

QUESTIONS, BUT MARS HAS A BIG

246

00:17:18,189 --> 00:17:21,569

SUITE OF THESE EARLY ROCKS TO

INVESTIGATE.

247

00:17:21,569 --> 00:17:23,809

>> THE SIMPLE ANSWER TO YOUR

QUESTION, DAVID, THERE IS

248

00:17:23,809 --> 00:17:25,939

DEFINITELY EARTH MATERIAL ON THE

MOON.

249

00:17:25,939 --> 00:17:29,809

GETTING TO IT WOULD BE VERY

DIFFICULT BUT IT SHOULD BE

250

00:17:29,809 --> 00:17:33,519

THERE.

>> THERE'S THAT SAMPLE\h--

251

00:17:33,519 --> 00:17:38,109

>> QUITE A LOT.

>> THE OTHER REASON WE THINK

252

00:17:38,109 --> 00:17:41,190

ABOUT THIS FROM NASA'S  
PERSPECTIVE IS THE EARLIER LIFE

253

00:17:41,190 --> 00:17:44,820

EVOLVED THE IMPLICATION IS THE  
EASIER IT WAS TO EVOLVE IN A

254

00:17:44,820 --> 00:17:46,909

GENERAL SENSE.  
SO THE LIKELIHOOD WOULD BE THAT

255

00:17:46,909 --> 00:17:51,330

LIFE IS SOMEWHERE ELSE OUT  
THERE.

256

00:17:51,330 --> 00:17:55,710

WHEN WE'RE LOOKING IN THE  
EARLIEST PARTS OF EARTH'S ROCK

257

00:17:55,710 --> 00:17:58,679

RECORD FOR SIGNS OF LIFE WE'RE  
LEARNING LESSONS ABOUT HOW TO

258

00:17:58,679 --> 00:18:03,859

LOOK FOR LIFE PERIOD THAT COULD  
BE APPLICABLE TO MARS.

259

00:18:03,859 --> 00:18:05,960

>> AS WE LEARN MORE ABOUT THE  
EARTH, ONE OF THE GREAT

260

00:18:05,960 --> 00:18:19,639

DILEMMAS-- SOMETHING LIKE PHOTO  
SYNTHESIS WAS ALSO DIFFICULT TO

261

00:18:19,639 --> 00:18:23,649

RECONCILE WITH THIS NOTION OF  
HEAVY BOMBARDMENT OF MATERIALS

262

00:18:23,649 --> 00:18:27,929

JUST BEFORE THAT IN A WORLD THAT  
WE IMAGINED THAT DIDN'T HAVE

263

00:18:27,929 --> 00:18:29,409

WATER.  
NOW THAT WE'RE ABLE TO PUSH

264

00:18:29,409 --> 00:18:33,529

WATER BACK AND IN THIS WORKSHOP  
THAT LINDSAY ALLUDED TO, THAT

265

00:18:33,529 --> 00:18:39,830

IDEA OF HEAVY BOMBARDMENT OF  
LIFE IS BEING QUESTIONED.

266

00:18:39,830 --> 00:18:47,730

>> AT SOME POINT CERTAINLY  
THINGS WERE BEING PUMMELED AT

267

00:18:47,730 --> 00:18:50,760

SUCH A PACE THAT YOU PROBABLY  
WOULDN'T HAVE WANTED TO HANG OUT

268

00:18:50,760 --> 00:18:52,249

THERE.  
>> IT'S A QUESTION OF HOW

269

00:18:52,249 --> 00:18:55,389

INTENSE, HOW OFTEN, AND LIFE IS  
RESILIENT.

270

00:18:55,389 --> 00:18:59,470

SO AGAIN, WE DISCUSSED THE  
POSSIBILITY OF REFUCHSIA, PLACES

271

00:18:59,470 --> 00:19:02,970

DEEP WITHIN THE EARTH WHERE LIFE  
CAN POP OUT AND SURVIVE.

272

00:19:02,970 --> 00:19:09,429

AND WE KNOW THAT TODAY, LIFE IS  
DEEP WITHIN THE SUBSURFACE.

273

00:19:09,429 --> 00:19:15,470

>> SPEAKING OF THE EARLY EARTH  
AND THINKING ABOUT EXOPLANETS, I

274

00:19:15,470 --> 00:19:19,850

WANT TO ASK A QUESTION ABOUT  
BIOSIGNATURES.

275

00:19:19,850 --> 00:19:26,460

WHEN WE TALK ABOUT FINDING LIFE,  
WE THINK ABOUT FINDING OXYGEN OR

276

00:19:26,460 --> 00:19:32,710

METHANE OR OTHER SIGNS OF LIFE.  
I'M HEARING THAT LIFE HAS A LONG

277

00:19:32,710 --> 00:19:37,559

HISTORY AND HAS CHANGED  
RADICALLY.

278

00:19:37,559 --> 00:19:43,299

SO THE QUESTION IS IF WE  
DETECTED A PLANET THAT WAS LIKE

279

00:19:43,299 --> 00:19:48,489

THE EARTH, SAY 3 BILLION YEARS  
AGO, WOULD WE RECOGNIZE IT AS AN

280

00:19:48,489 --> 00:19:50,899

INHABITED PLANET?  
WHAT ARE THE BIOSIGNATURES OF

281

00:19:50,899 --> 00:19:54,359

ANCIENT EARTH AND HOW WOULD THEY  
DIFFER FROM THE BIOSIGNATURES

282

00:19:54,359 --> 00:19:57,409

TODAY?

>> CAN I START WITH THE

283

00:19:57,409 --> 00:19:59,669

BIOSIGNATURES OF MODERN EARTH?

>> PLEASE.

284

00:19:59,669 --> 00:20:02,779

>> IF YOU LOOKING AT MODERN  
EARTH THROUGH A TELESCOPE, THE

285

00:20:02,779 --> 00:20:17,389

INDICATOR WOULD BE THE  
SIMULTANEOUS DISCOVERY OF OXYGEN

286

00:20:17,389 --> 00:20:21,370

AND METHANE.

YOU KNOW SOMEONE IS BRINGING THE

287

00:20:21,370 --> 00:20:26,690

METHANE RICH IN OXYGEN.

THE MOST LIKELY EXPLANATION IS

288

00:20:26,690 --> 00:20:30,229

IT'S THE LIFE THAT'S BRINGING IT  
TO THE PARTY.

289

00:20:30,229 --> 00:20:36,780

FOR THE CASE OF ARCHEAN EARTH,  
IF YOU WENT IN A TIME MACHINE,

290

00:20:36,780 --> 00:20:44,239

YOU WOULD SUFFOCATE BECAUSE  
THERE WOULD HAVE BEEN NO OXYGEN

291  
00:20:44,239 --> 00:20:49,100  
TO BREATHE.  
I WAS ACTUALLY THINKING ABOUT

292  
00:20:49,100 --> 00:20:58,080  
THIS QUESTION AS A GRADUATE  
STUDENT AT PENN STATE.

293  
00:20:58,080 --> 00:21:02,129  
THERE WERE THESE AWFUL, AWFUL  
SMELLS COMING OUT OF THE LAB

294  
00:21:02,129 --> 00:21:04,570  
EVERY DAY\h--  
>> NOT EVERY DAY.

295  
00:21:04,570 --> 00:21:08,979  
IT WASN'T HIS STUDENTS AND IT

296  
00:21:08,979 --> 00:21:11,450  
WASN'T THE PIZZA.  
IT WAS MICROBES THAT HIS

297  
00:21:11,450 --> 00:21:13,869  
STUDENTS WERE GROWING IN THE  
LAB.

298  
00:21:13,869 --> 00:21:17,279  
I ASKED WHAT'S GOING ON HERE.  
HE SAID THEY'RE GROWING THESE\h--

299  
00:21:17,279 --> 00:21:19,849  
YOU CAN MAYBE GIVE MORE DETAILS  
ON THE EXPERIMENT BUT THEY'RE

300  
00:21:19,849 --> 00:21:23,279  
GROWING MICROBES IN THESE  
OXYGEN-FREE CONDITIONS SIMILAR

301

00:21:23,279 --> 00:21:26,729  
TO EARLY EARTH AND THEY'RE  
MAKING OTHER GASES.

302  
00:21:26,729 --> 00:21:30,309  
THAT TICKED OFF AN IDEA OF WOULD  
THESE GASES BE DETECTABLE

303  
00:21:30,309 --> 00:21:37,139  
REMOTELY.  
THEY'RE KIND OF SULFUR ATOM WITH

304  
00:21:37,139 --> 00:21:40,470  
THE REST OF A METHANE MOLECULE  
ONTO IT.

305  
00:21:40,470 --> 00:21:43,580  
THEY DON'T LAST IN MODERN  
ENVIRONMENT BECAUSE THEY GET

306  
00:21:43,580 --> 00:21:58,379  
OXIDIZED.  
THERE'S LOTS OF CAVEATS TO THAT

307  
00:21:58,379 --> 00:22:00,019  
STORY.  
THAT'S THE SIMPLE VERSION.

308  
00:22:00,019 --> 00:22:03,570  
I JOKE THAT MAYBE YOU WANT TO  
SMELL FOR LIFE ON OTHER PLANETS

309  
00:22:03,570 --> 00:22:11,190  
INSTEAD OF LOOK FOR LIFE WITH A  
TELESCOPE.

310  
00:22:11,190 --> 00:22:12,369  
>> YOU SHOULD DEVELOP A SMELL  
SCOPE.

311

00:22:12,369 --> 00:22:14,249  
>> PROFESSOR FARNSWORTH.  
>> ONE THING ABOUT THAT

312  
00:22:14,249 --> 00:22:22,070  
PARTICULAR SET OF EXPERIMENTS IS  
THAT THAT IS NOT WHAT WE WERE

313  
00:22:22,070 --> 00:22:26,399  
LOOKING FOR.  
>> IT WASN'T WHAT I WAS LOOKING

314  
00:22:26,399 --> 00:22:29,139  
FOR EITHER.  
>> A LOT OF TIMES SCIENTIFIC

315  
00:22:29,139 --> 00:22:37,019  
DISCOVERIES ARE SERENDIPITOUS.  
IN THAT CASE CARBON MONOXIDE

316  
00:22:37,019 --> 00:22:41,849  
INHABITING ONE OF THE ENZYMES OF  
A CERTAIN ORGANISM AND IT HAD TO

317  
00:22:41,849 --> 00:22:43,600  
SWITCH IT'S METABOLISM TO  
SOMETHING THAT WAS TOTALLY

318  
00:22:43,600 --> 00:22:47,859  
UNKNOWN AT THE TIME.  
WE DISCOVERED MICROBES CAN GIVE

319  
00:22:47,859 --> 00:23:01,940  
ENERGY BY MISTAKE AND THAT'S ONE  
OF THE FUN THINGS IN SCIENCE.

320  
00:23:01,940 --> 00:23:05,039  
>> I ALSO WOULDN'T GIVE UP ON  
OXYGEN.

321

00:23:05,039 --> 00:23:10,690  
FOR THOSE OF YOU WHO DON'T h--  
THERE ARE BIOLOGICAL WAYS OF

322  
00:23:10,690 --> 00:23:16,349  
GETTING OXYGEN OR PRODUCING IT  
TO THE ATMOSPHERE BUT THAT'S NOT

323  
00:23:16,349 --> 00:23:20,659  
VERY MUCH AND YOU REALLY NEED  
PHOTO SYNTHESIS TO DO THAT.

324  
00:23:20,659 --> 00:23:23,419  
ONE OF THE BIG QUESTIONS IN  
STUDIES OF THE EARLY EARTH IS

325  
00:23:23,419 --> 00:23:29,799  
WHEN DID THAT START.  
WE THINK, MOST PEOPLE THAT I

326  
00:23:29,799 --> 00:23:32,409  
KNOW, THINK THAT THAT STARTED  
HAPPENING BEFORE IT STARTED

327  
00:23:32,409 --> 00:23:35,620  
ACCUMULATING IN THE ATMOSPHERE.  
SO THERE'S NOT ONLY THIS

328  
00:23:35,620 --> 00:23:39,149  
QUESTION OF WHEN DID THIS BEGIN  
AND IS IT A VIABLE BIOSIGNATURE

329  
00:23:39,149 --> 00:23:44,609  
WHICH I THINK IT IS BUT WHAT IS  
THE INTERACTION OF THE PLANET

330  
00:23:44,609 --> 00:23:47,029  
THAT ALLOWED TO ACCUMULATE SO IT  
COULD BE DETECTED FROM

331

00:23:47,029 --> 00:23:51,349  
ELSEWHERE.  
IT REMAINS, I THINK, A PRIMARY

332  
00:23:51,349 --> 00:23:55,979  
TARGET AS WELL.  
>> ABSOLUTELY.

333  
00:23:55,979 --> 00:23:58,859  
>> MOVING A LITTLE BIT FARTHER  
FORWARD IN THE EVOLUTION OF

334  
00:23:58,859 --> 00:24:02,470  
EARTH AND POSSIBLY OF OTHER  
PLANETS, I WANT TO ASK PHOEBE

335  
00:24:02,470 --> 00:24:07,880  
ABOUT THE BORING BILLION.  
IN OUR FIELD THERE'S THIS

336  
00:24:07,880 --> 00:24:12,289  
SLIGHTLY SARCASTIC PHRASE THAT  
PEOPLE USE, THE BORING BILLION.

337  
00:24:12,289 --> 00:24:17,059  
REMEMBER, A BILLION YEARS IS A  
LONG, LONG TIME.

338  
00:24:17,059 --> 00:24:21,969  
ARGUABLY HUMAN CIVILIZATION IS  
10,000 YEARS OLD AND HOMINID IS

339  
00:24:21,969 --> 00:24:31,820  
MAYBE A MILLION YEARS OLD.  
WHAT IS THE BORING BILLION AND

340  
00:24:31,820 --> 00:24:36,300  
WAS IT REALLY BORING?  
>> THE BORING BILLION IS A TIME

341

00:24:36,300 --> 00:24:39,379  
IN EARTH HISTORY AFTER WHAT  
WE'VE JUST TALKED ABOUT BUT

342

00:24:39,379 --> 00:24:43,470  
BEFORE COMPLEX LIFE EVOLVED  
WHERE IT APPEARS AS IF NOT VERY

343

00:24:43,470 --> 00:24:46,679  
MUCH IS HAPPENING.  
THAT'S FROM THE GEOLOGICAL AND

344

00:24:46,679 --> 00:24:51,129  
GEO CHEMICAL RECORDS.  
HOWEVER, IT'S PROBABLY NOT AS

345

00:24:51,129 --> 00:24:53,599  
BORING AS WE THINK IT IS, IN  
PART BECAUSE THOSE RECORDS

346

00:24:53,599 --> 00:24:55,649  
AREN'T VERY FULL.  
SO A BILLION YEARS, LIKE YOU

347

00:24:55,649 --> 00:24:59,789  
SAID, IS A HUGE AMOUNT OF TIME  
AND WE HAVEN'T SAMPLED THAT TIME

348

00:24:59,789 --> 00:25:04,259  
PERIOD SO WE'RE SEEING POCKETS  
OF THINGS THAT SORT OF LOOK

349

00:25:04,259 --> 00:25:11,679  
BORING.  
I STUDY FOSSILS OF MICRO SCOPIC

350

00:25:11,679 --> 00:25:15,259  
ORGANISMS DURING THIS TIME  
PERIOD AND MOST OF THEM LOOK

351

00:25:15,259 --> 00:25:19,309

LIKE BEACH BALLS.

THEY HAVE VERY LITTLE SHAPE,

352

00:25:19,309 --> 00:25:21,799

VERY LITTLE TO DISTINGUISH THEM  
FROM OTHER LITTLE BEACH BALLS

353

00:25:21,799 --> 00:25:24,539

THAT I FIND IN A ROCK.

THAT DOESN'T MEAN THEY'RE NOT

354

00:25:24,539 --> 00:25:29,230

EVOLVING.

ORGANISMS ARE ALWAYS EVOLVING,

355

00:25:29,230 --> 00:25:32,080

EVEN IF THEY'RE NOT CHANGING  
THEIR SHAPE OR FORM.

356

00:25:32,080 --> 00:25:37,489

THIS TIME PERIOD THAT APPEARS IN  
THE FOSSIL RECORD TO BE BORING

357

00:25:37,489 --> 00:25:41,369

COULD HAVE BEEN A TIME OF MAJOR  
INNOVATION THAT WE JUST CAN'T

358

00:25:41,369 --> 00:25:45,390

SEE WITH THE TOOLS THAT WE HAVE  
RIGHT NOW.

359

00:25:45,390 --> 00:25:50,029

>> SO IT MAY JUST SEEM BORING  
BECAUSE WE DON'T KNOW WHAT WE'RE

360

00:25:50,029 --> 00:25:51,029

TALKING ABOUT.

>> RIGHT.

361

00:25:51,029 --> 00:25:53,749  
WE DON'T KNOW HOW TO LOOK.  
I THINK WE HAVE SOME IDEAS ABOUT

362  
00:25:53,749 --> 00:25:58,859  
HOW TO BUT WE HAVEN'T YET LOOKED  
IN THE RIGHT PLACES AT THE RIGHT

363  
00:25:58,859 --> 00:26:00,919  
PROXIES TO GET AT THE  
INTERESTING BITS.

364  
00:26:00,919 --> 00:26:05,789  
>> YOU MEAN GENETICALLY IN TERMS  
OF WHAT IS HAPPENING FROM A DNA

365  
00:26:05,789 --> 00:26:06,919  
STANDPOINT?  
>> YEAH.

366  
00:26:06,919 --> 00:26:09,850  
LIFE IS ALWAYS EVOLVING.  
WE CAN'T DO BACK AND SEQUENCE

367  
00:26:09,850 --> 00:26:22,169  
DNA FROM A 2 BILLION YEAR OLD  
ORGANISM.

368  
00:26:22,169 --> 00:26:26,950  
SO ALL YOU HAVE LEFT IS THE  
SHAPE OF THE ORGANISM OR

369  
00:26:26,950 --> 00:26:33,639  
MOLECULAR FOSSILS WHICH MAY HELP  
FLUSH OUT THIS BORING TIME

370  
00:26:33,639 --> 00:26:36,399  
PERIOD.  
>> TO ME THAT'S ONE OF THE

371

00:26:36,399 --> 00:26:40,129  
INTERESTING INTERVALS IN TERMS  
OF GETTING COMPLEX LIFE AND

372

00:26:40,129 --> 00:26:47,559  
WHETHER OR NOT COMPLEX LIFE IS  
INEVITABLE IN EVOLUTION BECAUSE

373

00:26:47,559 --> 00:26:51,409  
COMPLEX LIFE ON EARTH IS MOSTLY  
SUPPORTED BY OXYGEN AND WE HAD

374

00:26:51,409 --> 00:26:56,729  
OXYGEN FOR A LONG PERIOD BEFORE  
WE GET THAT FOSSIL RECORD.

375

00:26:56,729 --> 00:27:00,419  
SO THAT EVEN THOUGH WE DON'T  
KNOW TOO MUCH FROM IT YET, A LOT

376

00:27:00,419 --> 00:27:03,249  
OF TIMES YOU DON'T KNOW MUCH  
ABOUT SOMETHING THAT'S WHERE

377

00:27:03,249 --> 00:27:05,759  
FUTURE DISCOVERIES ARE GOING TO  
BE.

378

00:27:05,759 --> 00:27:09,109  
WE KNOW FROM WHAT WE SEE BEFORE  
AND AFTER THAT IT'S REALLY,

379

00:27:09,109 --> 00:27:11,830  
REALLY IMPORTANT INTERVALS.  
>> SO IT MAY NOT HAVE BEEN

380

00:27:11,830 --> 00:27:14,879  
BORING.  
I'M GLAD TO HEAR THAT BECAUSE

381

00:27:14,879 --> 00:27:18,849  
THAT'S A LONG TIME TO BE BORED.  
NONETHELESS, IT SEEMS LIKE IT

382  
00:27:18,849 --> 00:27:22,460  
DID TAKE A LONG TIME FOR COMPLEX  
LIFE TO APPEAR ON THE EARTH.

383  
00:27:22,460 --> 00:27:27,200  
JUST AS WE DID DISCUSS THE  
INEVITABILITY OF LIFE GIVEN THE

384  
00:27:27,200 --> 00:27:30,759  
RIGHT CONDITIONS AT FIRST, YOU  
MENTIONED THIS QUESTION OF THE

385  
00:27:30,759 --> 00:27:34,849  
INEVITABILITY OF COMPLEXITY.  
WHAT DO YOU GUYS THINK ABOUT

386  
00:27:34,849 --> 00:27:36,789  
THAT?  
CAN WE SAY ANYTHING BASED ON THE

387  
00:27:36,789 --> 00:27:41,149  
TERRESTRIAL RECORD OF WHETHER  
GIVEN LIFE ON THE PLANET IT

388  
00:27:41,149 --> 00:27:46,029  
WOULD GET COMPLEX?  
>> MY FEELING IS THAT BORING IS

389  
00:27:46,029 --> 00:27:49,809  
AN UNFORTUNATE TERM.  
THERE WAS A LOT OF INNOVATION AT

390  
00:27:49,809 --> 00:27:52,229  
THAT TIME.  
IT SET THE STAGE FOR MORE

391

00:27:52,229 --> 00:27:55,460

COMPLEX LIFE, ANIMALS IN  
PARTICULAR.

392

00:27:55,460 --> 00:27:58,019

THE GEO CHEMICAL RECORD  
SUGGESTION THAT THERE WAS A KIND

393

00:27:58,019 --> 00:28:07,109

OF STASIS.  
IT WAS A TIME OF PERHAPS LOW AND

394

00:28:07,109 --> 00:28:12,289

RELATIVELY STABLE LOW OXYGEN.  
TO ME THAT'S NOT BORING AT ALL.

395

00:28:12,289 --> 00:28:14,850

IT'S REMARKABLE THAT YOU COULD  
HAVE A BILLION YEARS OF SUCH

396

00:28:14,850 --> 00:28:16,470

CONDITION.  
IF YOU THINK ABOUT IT, ONCE YOU

397

00:28:16,470 --> 00:28:19,419

HAVE THIS INNOVATION OF OXYGEN  
PRODUCTION AND YOU THINK ABOUT

398

00:28:19,419 --> 00:28:26,509

ALL THE REACTIONS, WHY WOULD IT  
HAVE BEEN SO STABLE.

399

00:28:26,509 --> 00:28:30,300

ONE OF THE FEELINGS THAT IS THAT  
YOU HAVE THIS LONG PERIOD AND IT

400

00:28:30,300 --> 00:28:41,950

MAY HAVE TAKEN SOMETHING TECH  
TONIC THAT BROUGHT YOU CLOSER TO

401

00:28:41,950 --> 00:28:44,499  
COMPLEXITY AND SPECIFICALLY  
ANIMALS.

402  
00:28:44,499 --> 00:28:48,269  
SO IF THERE WERE EXTERNAL  
DRIVERS OR EVEN INTERNAL DRIVERS

403  
00:28:48,269 --> 00:28:51,389  
WITHIN THE EARTH LIKE PLATE  
TECTONICS, MOUNTAIN BUILDING

404  
00:28:51,389 --> 00:28:56,919  
ACTIVITY, IF THAT'S REQUIRED IT  
SEEMS LESS AN INEVITABLE TO ME.

405  
00:28:56,919 --> 00:29:00,499  
>> I CAN IMAGINE A WORLD WHERE  
LIFE HAPPILY CHUGS ALONG BEING

406  
00:29:00,499 --> 00:29:05,059  
MICROBIAL FOR BILLIONS OF YEARS.  
>> NOW THAT WOULD BE BORING.

407  
00:29:05,059 --> 00:29:07,820  
>> BUT THEY WOULD BE DOING COOL  
STUFF.

408  
00:29:07,820 --> 00:29:12,539  
THEY WOULD STILL BE EVOLVING AND  
CHANGING EVEN IF COMPANY CAN'T

409  
00:29:12,539 --> 00:29:19,070  
SEE IT WITH OUR EYES.  
>> I THINK IT WOULD BE A SHAME

410  
00:29:19,070 --> 00:29:22,749  
TO HAVE A UNIVERSE WHERE THERE  
WASN'T SOMETHING\h-- FOR

411

00:29:22,749 --> 00:29:28,169  
INSTANCE, WE WOULDN'T BE HERE  
HAVING THIS CONVERSATION.

412  
00:29:28,169 --> 00:29:34,009  
>> THAT'S TRUE.  
>> THE BACTERIA CAN DO ENOUGH TO

413  
00:29:34,009 --> 00:29:38,529  
THE PLANET TO AFFECT THE  
ATMOSPHERE ENOUGH FOR US TO

414  
00:29:38,529 --> 00:29:42,739  
DETECT.  
>> YOU ACTUALLY MENTIONED

415  
00:29:42,739 --> 00:29:45,440  
SOMETHING A COUPLE MINUTES AGO  
THAT I WANT TO COME BACK TO.

416  
00:29:45,440 --> 00:29:47,960  
IT'S STUCK IN MY MIND AND IT  
BOTHERED ME A LITTLE BIT.

417  
00:29:47,960 --> 00:29:52,989  
YOU SAID THERE ARE NONBIOLOGICAL  
WAYS TO MAKE OXYGEN ON THE

418  
00:29:52,989 --> 00:29:54,269  
EARTH.  
ALL THIS TALK ABOUT

419  
00:29:54,269 --> 00:29:58,830  
BIOSIGNATURES AND THE FACT THAT  
WHEN WE DO LEARN ABOUT EXO

420  
00:29:58,830 --> 00:30:01,820  
PLANETS IT'S SO HARD TO LEARN  
ANYTHING, WE'RE GOING TO HAVE

421

00:30:01,820 --> 00:30:06,340  
VERY LIMITED CLUES AND WE HAVE  
THIS CRITERION.

422  
00:30:06,340 --> 00:30:08,989  
HOW DO WE KNOW WE'RE NOT GOING  
TO FIND FALSE POSITIVES IF

423  
00:30:08,989 --> 00:30:12,509  
OXYGEN IS THE KEY TO FINDING  
LIFE AND THERE ARE WAYS TO MAKE

424  
00:30:12,509 --> 00:30:17,629  
OXYGEN THAT DON'T NEED LIFE AND  
ARE THERE OTHER KINDS OF FALSE

425  
00:30:17,629 --> 00:30:21,179  
POSITIVES AND DO YOU WORRY ABOUT  
THAT AND HOW DO WE GUARD AGAINST

426  
00:30:21,179 --> 00:30:24,289  
THAT?  
>> I CAN TAKE THIS ONE.

427  
00:30:24,289 --> 00:30:27,839  
WE ACTUALLY JUST HAD A PAPER  
ACCEPTED.

428  
00:30:27,839 --> 00:30:33,269  
I TALKED EARLIER ABOUT HOW WOULD  
WE LOOK FOR LIFE ON A PLANET

429  
00:30:33,269 --> 00:30:38,919  
THAT DIDN'T HAVE THE SAME  
BIOSIGNATURES AS MODERN DAY

430  
00:30:38,919 --> 00:30:46,019  
EARTH.  
TO ANSWER THAT, I LITERALLY DO

431

00:30:46,019 --> 00:30:49,080  
NOT KNOW HOW WE WOULD HAVE  
STARTED TO ANSWER THAT QUESTION

432  
00:30:49,080 --> 00:30:52,930  
IF WE DIDN'T HAVE SOME PICTURE  
LIKE THIS OF WHAT THE EARLY

433  
00:30:52,930 --> 00:30:55,210  
EARTH LOOKED LIKE.  
THESE QUESTIONS OF WHY DID

434  
00:30:55,210 --> 00:30:58,969  
OXYGEN RISE TO BEGIN WITH LED A  
LOT OF SCIENTISTS INCLUDING SOME

435  
00:30:58,969 --> 00:31:02,089  
OF THE PEOPLE HERE IN THE ROOM  
TO DO A LOT OF WORK FIGURING OUT

436  
00:31:02,089 --> 00:31:09,349  
HOW TO VERY FINELY BALANCE REOX  
ON A PLANET TO CAUSE A PLANET TO

437  
00:31:09,349 --> 00:31:11,509  
BE MORE OXIDIZED AND LESS  
OXIDIZED.

438  
00:31:11,509 --> 00:31:16,450  
WHEN YOU ADD ALL THOSE UP AND  
YOU KNOW WHICH PARTS BIOLOGY

439  
00:31:16,450 --> 00:31:20,109  
CONTRIBUTES TO, YOU CAN TAKE A  
MODEL WITH ALL THAT STUFF IN AND

440  
00:31:20,109 --> 00:31:22,669  
PLUNK THE BIOLOGY OUT AND THEN  
YOU HAVE A MODEL FOR A

441

00:31:22,669 --> 00:31:26,539

NONBIOLOGICAL PLANET.  
I KNOW, IT'S HARD, RIGHT?

442

00:31:26,539 --> 00:31:28,789

>> RIGHT.  
SO THE CONVERSE SIDE OF THAT IS

443

00:31:28,789 --> 00:31:32,960

THE MODEL THAT BUILDS ON EARTH  
AND MOST OF US AGREE THAT WE HAD

444

00:31:32,960 --> 00:31:35,999

ECOSYSTEMS 3.5 BILLION YEARS  
AGO.

445

00:31:35,999 --> 00:31:39,210

OUR OLDEST ROCKS ARE 4 BILLION  
YEARS OLD AND IT'S ENTIRELY

446

00:31:39,210 --> 00:31:45,539

POSSIBLE THAT A LARGE PART OF  
WHAT WE UNDERSTAND IS INFLUENCED

447

00:31:45,539 --> 00:31:49,679

BY BIOLOGY.  
>> OUR MODELS ARE BUILD ON A

448

00:31:49,679 --> 00:31:51,429

WORLD IN WHICH THERE WAS  
BIOLOGY.

449

00:31:51,429 --> 00:31:55,299

WE ASSUME THAT WE KNOW THE  
THINGS THAT WERE CONTRIBUTING

450

00:31:55,299 --> 00:32:00,219

WELL ENOUGH TO TAKE THEM BACK  
OUT OF THE MODELS.

451

00:32:00,219 --> 00:32:04,359  
THERE ARE FALSE POSITIVES BUT  
THE WAY YOU MEASURE OR ACCOUNT

452  
00:32:04,359 --> 00:32:06,379  
FOR THEM, DISCRIMINATE BETWEEN  
THE FALSE POSITIVES AND THE TRUE

453  
00:32:06,379 --> 00:32:09,409  
POSITIVES IS LOOK FOR SOMETHING  
OTHER THAN OXYGEN.

454  
00:32:09,409 --> 00:32:12,319  
THIS IS WHERE METHANE BECOMES  
IMPORTANT.

455  
00:32:12,319 --> 00:32:15,139  
>> IT COMES DOWN TO THE  
SCIENTIFIC PROCESS AS WELL.

456  
00:32:15,139 --> 00:32:20,729  
AS SOON AS YOU FIND SOMETHING  
THAT YOU THINK MIGHT BE A

457  
00:32:20,729 --> 00:32:25,509  
BIOSIGNATURE, THERE IS ALWAYS  
THE QUESTIONS.

458  
00:32:25,509 --> 00:32:29,619  
WE HAVE A LOT OF ARGUMENTS IN  
THE COMMUNITY ABOUT WHAT

459  
00:32:29,619 --> 00:32:32,480  
DIFFERENT THINGS MEAN, BUT  
THAT'S A VERY PRODUCTIVE WAY.

460  
00:32:32,480 --> 00:32:38,790  
YOU GO FROM A POSITIVE DETECTION  
TO MAYBE SOME DAY SOMETHING THAT

461

00:32:38,790 --> 00:32:43,039  
MOST PEOPLE AGREE IS A DETECTION  
OF LIFE ELSEWHERE.

462  
00:32:43,039 --> 00:32:47,669  
>> THE EARLY EARTH IS UNBIASED.  
IT'S OUR GREAT NATURAL LAB.

463  
00:32:47,669 --> 00:32:52,139  
SO WE HAVE ROCKS AND WE HAVE  
FOSSILS IN MANY CASES AND WE CAN

464  
00:32:52,139 --> 00:32:55,820  
GO AND LOOK AT THESE AND WE CAN  
START FROM THE ASSUMPTION THAT

465  
00:32:55,820 --> 00:33:00,659  
THEY'RE NOT BIOLOGICAL FOSSILS.  
THE GEO CHEMISTRY IS OFTEN A

466  
00:33:00,659 --> 00:33:03,580  
CHALLENGE.  
WE KEEP TESTING THAT AND

467  
00:33:03,580 --> 00:33:09,820  
CONVINCE OURSELVES AND FROM THAT  
WE CAN START TO MODEL AN

468  
00:33:09,820 --> 00:33:12,049  
ATMOSPHERE.  
THAT'S ALL YEAR GOING TO GET FOR

469  
00:33:12,049 --> 00:33:15,799  
A LONG TIME FROM AN EXO PLANET.  
WE CAN THINK ABOUT HOW THAT

470  
00:33:15,799 --> 00:33:17,539  
CHANGES.  
>> THIS IS SOMETHING WE'VE ALSO

471

00:33:17,539 --> 00:33:20,950  
LEARNED FROM MARS BY LOOKING AT  
PAST CLAIMS OF EVIDENCE FOR LIFE

472  
00:33:20,950 --> 00:33:25,019  
ON MARS, WHETHER IT WAS THE  
VIKING, ONCE THE COMMUNITY

473  
00:33:25,019 --> 00:33:28,169  
STARTED LOOKING AT IT AND  
RAISING THE STANDARD OF PROOF

474  
00:33:28,169 --> 00:33:31,309  
FOR THOSE CLAIMS, WE REALIZED  
THAT IT'S NOT JUST A SINGLE LINE

475  
00:33:31,309 --> 00:33:33,820  
OF EVIDENCE.  
IT'S THE MULTIPLE LINES OF

476  
00:33:33,820 --> 00:33:37,299  
EVIDENCE THAT YOU REALLY NEED.  
WE WOULD LIKE TO TAKE THAT TO

477  
00:33:37,299 --> 00:33:41,570  
EXO PLANET BUT EVERY SINGLE  
MEASUREMENT I WANT TO ADD TO

478  
00:33:41,570 --> 00:33:44,229  
THAT TELESCOPE, IT ADDS COST, IT  
ADDS COMPLEXITY.

479  
00:33:44,229 --> 00:33:48,169  
>> IT'S A GOOD THING WE HAVE THE  
EARLY EARTH.

480  
00:33:48,169 --> 00:33:55,690  
WITHOUT IT WE WOULD BE HOSED AS  
FAR AS IDEAS ABOUT FROM EXTRA

481

00:33:55,690 --> 00:33:59,599  
TERRESTRIAL LIFE.  
PEOPLE SOMETIMES SAY THAT'S THE

482  
00:33:59,599 --> 00:34:02,799  
FIELD THAT DOESN'T HAVE DATA OR  
EVIDENCE.

483  
00:34:02,799 --> 00:34:08,681  
IN REALITY WE'VE GOT TONS OF  
DATA AND EVIDENCE AND OUR

484  
00:34:08,681 --> 00:34:15,440  
GROWING KNOWLEDGE OF PLANETS IN  
OUR SOLAR SYSTEM AND ELSEWHERE.

485  
00:34:15,440 --> 00:34:19,510  
HERE'S A QUESTION FOR YOU GUYS.  
IS THERE A DANGER IN BEING TOO

486  
00:34:19,510 --> 00:34:22,580  
EARTH CENTERED IN OUR THINKING  
SINCE WE HAVE THIS ONE BIOSPHERE

487  
00:34:22,580 --> 00:34:26,679  
AND CLING TO IT TO EXTRAPOLATE  
ELSEWHERE.

488  
00:34:26,679 --> 00:34:33,429  
IS IT POSSIBLE THAT WE'RE WRONG  
THAT LIFE DOESN'T NEED

489  
00:34:33,429 --> 00:34:37,549  
BIOMOLECULES AND IT DOESN'T EVEN  
NEED TO BE CARBON BASED AND IF

490  
00:34:37,549 --> 00:34:43,190  
SO DO WE HAVE A PROSPECT FOR  
FINDING LIFE AND HOW DO WE EVEN

491

00:34:43,190 --> 00:34:46,070  
THINK ABOUT THAT QUESTION?  
>> FIRST OF ALL, IT'S REALLY

492  
00:34:46,070 --> 00:34:51,309  
CLEAR FOR EXPLORATION IN OUR OWN  
SOLAR SYSTEM THAT WE ABSOLUTELY

493  
00:34:51,309 --> 00:34:57,990  
HAVE TO BE OPEN TO LIFE THAT'S  
NOT LIKE EARTH.

494  
00:34:57,990 --> 00:35:01,230  
THAT'S BECAUSE WE CAN LOOK  
THROUGH THE SOLAR SYSTEM AND WE

495  
00:35:01,230 --> 00:35:05,780  
CAN CERTAINLY SEE PLACES OF  
INTEREST THAT ARE WORTH

496  
00:35:05,780 --> 00:35:08,700  
EXPLORING.  
CERTAINLY THE ONES MENTIONED,

497  
00:35:08,700 --> 00:35:13,390  
EUROPA, TITAN, BOTH HAVE  
PARALLELS TO EARTH AND DIFFERENT

498  
00:35:13,390 --> 00:35:21,799  
FROM EARTH.  
THE

499  
00:35:21,799 --> 00:35:26,400  
SERIES IS OUTGASSING WATER  
TO THE SOLAR SYSTEM.

500  
00:35:26,400 --> 00:35:30,440  
AND OF COURSE MARS.  
SO WE HAVE A NUMBER OF TARGETS

501

00:35:30,440 --> 00:35:36,250  
AND ALL OF THOSE ARE GOING TO  
REQUIRE TO SOME DEGREE THINKING

502  
00:35:36,250 --> 00:35:39,790  
OUTSIDE THE EARTH CENTRIC BOX.  
I THINK WE'RE ALL COMFORTABLE

503  
00:35:39,790 --> 00:35:43,270  
WITH THAT FROM TRYING TO FIGURE  
OUT HOW A BIOSPHERE COULD

504  
00:35:43,270 --> 00:35:46,750  
OPERATE, BUT IT'S CHALLENGING  
WHEN YOU START TO THINK ABOUT

505  
00:35:46,750 --> 00:35:50,170  
THE BURDEN OF PROOF OF DETECTING  
LIFE AND TRYING TO AVOID FALSE

506  
00:35:50,170 --> 00:35:52,589  
POSITIVES.  
ON EARTH WE HAVE THE BURDEN OF

507  
00:35:52,589 --> 00:35:56,029  
PROOF OF TRYING TO FIGURE OUT IF  
LIFE WASN'T THERE BECAUSE LIFE

508  
00:35:56,029 --> 00:35:58,690  
HAS BEEN SO PERVASIVE FOR  
BILLIONS OF YEARS AND NOW WE

509  
00:35:58,690 --> 00:36:02,339  
HAVE THE CHALLENGE OF HAVING TO  
EXPLORE WHEN THE PRESUMPTION HAS

510  
00:36:02,339 --> 00:36:05,910  
TO BE NO HYPOTHESIS THAT THIS  
ISN'T LIFE.

511

00:36:05,910 --> 00:36:08,470  
>> ONE OF THE AMAZING THINGS  
ABOUT THE EXO PLANET REVOLUTION

512  
00:36:08,470 --> 00:36:14,170  
IS IT HAS PROVIDED US WITH  
CREATIVE IDEAS.

513  
00:36:14,170 --> 00:36:17,260  
SO YOU HEAR ABOUT THESE PLANETS  
AROUND OTHER STARS THAT LOOK

514  
00:36:17,260 --> 00:36:20,029  
DIFFERENT THAN EARTH.  
AS A SCIENTIST THAT'S SUPER

515  
00:36:20,029 --> 00:36:22,460  
EXCITING.  
YOU CAN SAY, OKAY, NOW I HAVE

516  
00:36:22,460 --> 00:36:25,349  
SOMETHING TO WORK WITH HERE.  
WHAT MIGHT LIFE LOOK LIKE ON A

517  
00:36:25,349 --> 00:36:30,280  
PLANET THE SIZE OF SATURN OR A  
PLANET THAT'S MUCH, MUCH CLOSER

518  
00:36:30,280 --> 00:36:34,150  
TO ITS STARS.  
IN A WAY I THINK THAT'S HELPED

519  
00:36:34,150 --> 00:36:37,500  
US MOVE AWAY FROM AN EARTH  
CENTRIC VIEW BY PROVIDING US

520  
00:36:37,500 --> 00:36:40,690  
WITH OPPORTUNITIES TO EXPLORE  
OTHER WAYS THAT LIFE COULD

521

00:36:40,690 --> 00:36:45,010  
EVOLVE ON PLANETS THAT HAVE NO  
SIMILARITY OR VERY LITTLE

522

00:36:45,010 --> 00:36:49,349  
SIMILARITY TO EARTH.

>> IT'S SHOCKED OUR MODELS OF

523

00:36:49,349 --> 00:36:53,559  
HOW PLANETS EVOLVE OVER TIME IN  
A SYSTEM OF PLANETS.

524

00:36:53,559 --> 00:36:58,420  
WE HAVEN'T MADE THE BIOLOGICAL  
AND CHEMICAL MEASUREMENTS YET.

525

00:36:58,420 --> 00:37:04,819  
I CAN'T WAIT TO BE SCRATCHING MY  
HEAD OVER THOSE DATA AND SAY HOW

526

00:37:04,819 --> 00:37:10,690  
DID THAT HAPPEN.  
THAT'S THE MOMENT I'M WAITING

527

00:37:10,690 --> 00:37:12,500  
ON.  
>> IT'S GOING TO BE AN EXCITING

528

00:37:12,500 --> 00:37:16,670  
NEXT DECADE OR TWO AS WE START  
TO LEARN ABOUT THESE EXOPLANETS

529

00:37:16,670 --> 00:37:19,740  
AND EXPLORE THE SOLAR SYSTEM  
FURTHER.

530

00:37:19,740 --> 00:37:26,260  
I THINK AT THIS POINT WE WANT TO  
GET YOUR OPINIONS AND YOUR

531

00:37:26,260 --> 00:37:28,799

QUESTIONS.

WE COULD KEEP DISCUSSING AMONGST

532

00:37:28,799 --> 00:37:31,819

OURSELVES FOR A LONG TIME AND  
CLEARLY GO ON FOR HOURS.

533

00:37:31,819 --> 00:37:35,019

BUT AT THIS POINT I THINK IT  
WOULD BE GREAT TO SEE IF THERE

534

00:37:35,019 --> 00:37:38,289

ARE ANY QUESTIONS FROM THE  
AUDIENCE AND ONLINE.

535

00:37:38,289 --> 00:37:41,390

SO I'M GOING TO TURN IT OVER TO  
LINDSAY NOW WHO WILL RUN THE

536

00:37:41,390 --> 00:37:43,569

QUESTION AND ANSWER PORTION.  
>> THANKS, DAVID.

537

00:37:43,569 --> 00:37:46,069

I SEE WE HAVE A FEW QUESTIONS  
HERE IN THE AUDIENCE.

538

00:37:46,069 --> 00:37:49,819

WE'LL GET TO THOSE IN A MOMENT.  
I'D LIKE TO REMIND THOSE OF YOU

539

00:37:49,819 --> 00:37:54,490

WATCHING AND THOSE FOLLOWING US  
ON SOCIAL MEDIA TO USE [ASKNASA](mailto:ASKNASA).

540

00:37:54,490 --> 00:37:58,900

WE'LL BE LOOKING FOR QUESTIONS  
FROM YOU GUYS AS WELL.

541

00:37:58,900 --> 00:38:03,589  
>> THAT WAS GREAT.  
I'M GOING TO OPERATE UNDER THE

542  
00:38:03,589 --> 00:38:06,539  
OPTIMISTIC PHILOSOPHY THAT WE  
WILL MAKE THIS DISCOVERY AT

543  
00:38:06,539 --> 00:38:09,269  
LEAST SOME TIME IN MY LIFETIME  
HOPEFULLY.

544  
00:38:09,269 --> 00:38:13,440  
WHEN WE MAKE THIS DISCOVERY AND  
WE DECIDE THAT THERE'S ENOUGH

545  
00:38:13,440 --> 00:38:16,170  
EVIDENCE TO PROVE THE  
BIOSIGNATURES TELL US THERE'S

546  
00:38:16,170 --> 00:38:20,560  
ENOUGH EVIDENCE TO PROVE LIFE ON  
AN EXO PLANET.

547  
00:38:20,560 --> 00:38:26,450  
BESIDES OBVIOUSLY FURTHER  
SCRUTINY OF THAT DATA AND OF

548  
00:38:26,450 --> 00:38:28,910  
COURSE I WOULD EXPECT THAT AND  
HOPE THAT THERE ARE PEOPLE WHO

549  
00:38:28,910 --> 00:38:36,529  
DISAGREE, BUT WHAT COMES NEXT?  
>> GREAT QUESTION.

550  
00:38:36,529 --> 00:38:40,160  
CHANCES ARE THAT DISCOVERY IS  
NOT GOING TO COME JUST IN A

551

00:38:40,160 --> 00:38:47,480  
MOMENT BECAUSE IT'S OFTEN A GRAD  
WALL PROCESS WHERE YOU DO MORE

552  
00:38:47,480 --> 00:38:50,670  
OBSERVATION.  
SO IT MIGHT NOT BE AN AHA BUT AN

553  
00:38:50,670 --> 00:38:53,740  
EXTENDED LET'S PAY MORE  
ATTENTION TO THIS ONE AND SORT

554  
00:38:53,740 --> 00:38:56,079  
OF A GRADUAL DAWNING OF  
APPRECIATION.

555  
00:38:56,079 --> 00:39:01,450  
WHAT COMES NEXT IS VERY TRICKY.  
DO ANY OF YOU HAVE THOUGHTS ON

556  
00:39:01,450 --> 00:39:02,910  
THAT?  
WHAT'S THE NEXT STEP?

557  
00:39:02,910 --> 00:39:06,010  
>> CELEBRATION.  
>> FIRST WE'RE GOING TO

558  
00:39:06,010 --> 00:39:10,950  
CELEBRATE, AT LEAST FOR A NIGHT.  
BUT THEN WE'RE GOING TO HAVE ALL

559  
00:39:10,950 --> 00:39:14,130  
KINDS OF QUESTIONS ABOUT WHAT  
HAS HAPPENED TO THAT PLANET OVER

560  
00:39:14,130 --> 00:39:16,420  
TIME.  
DOES THAT PLANET HAS SEASONS AND

561

00:39:16,420 --> 00:39:20,250  
IF IT HAS SEASONS IS THE LIFE  
RESPONDING TO THE SEASONAL

562  
00:39:20,250 --> 00:39:23,790  
CYCLES IN THAT PLANET'S ORBIT.  
WHAT IS HAPPENING OVER THE

563  
00:39:23,790 --> 00:39:25,970  
DECADES.  
IS THAT PLANET EVOLVING OR THE

564  
00:39:25,970 --> 00:39:28,530  
SPHERE OF THAT PLANET EVOLVING.  
WHAT IS HAPPENING TO THE CARBON

565  
00:39:28,530 --> 00:39:31,579  
DIOXIDE SIGNAL.  
THINGS LIKE THAT ARE WHAT WE

566  
00:39:31,579 --> 00:39:38,790  
WANT TO LOOK AT.  
ALL WE'RE GOING TO GET AT FIRST

567  
00:39:38,790 --> 00:39:45,360  
ARE SPECTRAL SIGNALS.  
IF WE REALLY WANT TO KNOW MORE

568  
00:39:45,360 --> 00:39:48,869  
ABOUT THAT PLANET I'VE HEARD  
IDEAS OF PUTTING A FLEET OF

569  
00:39:48,869 --> 00:39:57,430  
TELESCOPES THAT CAN GET YOU A  
MAP OF THE PLANET AND IF THE

570  
00:39:57,430 --> 00:39:59,589  
FORESTS ARE BIG ENOUGH WHERE  
THEY CAN HAVE A COLOR SIGNATURE

571

00:39:59,589 --> 00:40:02,680  
AND YOU CAN START TO LOOK FOR  
THAT SORT OF THING, TOO.

572  
00:40:02,680 --> 00:40:10,099  
>> SOMEONE IS GOING TO WANT TO  
SEND A FLY-BY EVENTUALLY BUT I'M

573  
00:40:10,099 --> 00:40:14,359  
NOT THAT PATIENT.  
>> ANOTHER POINT IS THAT WE KEEP

574  
00:40:14,359 --> 00:40:17,500  
TALKING ABOUT THAT ONE.  
REALLY WE'RE TALKING ABOUT A

575  
00:40:17,500 --> 00:40:20,319  
POPULATION.  
WE'LL CELEBRATE EVERY SINGLE

576  
00:40:20,319 --> 00:40:27,499  
TIME THIS HAPPENS, BUT LET'S  
HOPE IT'S DOZENS OF DISCOVERIES.

577  
00:40:27,499 --> 00:40:30,700  
>> IT'S MY VIEW THAT ONCE THE  
EXO PLANET REVOLUTION SINKS IN

578  
00:40:30,700 --> 00:40:33,410  
AND THE PEOPLE GET ABOUT WHAT  
WE'RE DISCOVERING THAT THERE

579  
00:40:33,410 --> 00:40:36,819  
WILL BE PUBLIC SORT TO FUND THE  
KIND OF INSTRUMENTS THAT SHAWN

580  
00:40:36,819 --> 00:40:45,000  
IS TRYING TO BUILD TO LEARN MORE  
ABOUT THESE PLANETS AND THEN I

581

00:40:45,000 --> 00:40:48,510  
THINK THERE WILL BE PUBLIC SORT  
TO BUILD THAT NEXT GENERATION OF

582  
00:40:48,510 --> 00:40:52,750  
INSTRUMENTS WHERE WE CAN REALLY  
LEARN MORE ABOUT IT BY SOME

583  
00:40:52,750 --> 00:40:56,489  
FUTURISTIC OBSERVATIONAL  
PLATFORMS AND CONCEPTS.

584  
00:40:56,489 --> 00:41:01,990  
>> I THINK ONE OF THE KEY THINGS  
IS WHEN YOU MAKE A DISCOVERY,

585  
00:41:01,990 --> 00:41:04,510  
THE QUESTIONS BLOSSOM OUT FROM  
THAT.

586  
00:41:04,510 --> 00:41:09,039  
IT'S HARD TO PREDICT NOW WHAT  
WOULD BE NEXT, BUT EVERY MAJOR

587  
00:41:09,039 --> 00:41:13,750  
SCIENTIFIC DISCOVERY HAS LED TO  
MANY MORE QUESTIONS AND DETAILED

588  
00:41:13,750 --> 00:41:21,119  
OBSERVATIONS.  
>> YOU'LL WANT TO PUT A ROVER ON

589  
00:41:21,119 --> 00:41:24,630  
IT.  
>> THE ANALOGY IS EFFORTS TO

590  
00:41:24,630 --> 00:41:28,799  
LOOK AT MICROBIOLOGY IN THE  
SUBSET OF THE EARTH.

591

00:41:28,799 --> 00:41:32,480  
YOU GET AWAY FROM THE SURFACE OF  
THE EARTH, WE LOOK AT HOW IT

592  
00:41:32,480 --> 00:41:39,820  
WORKS, WE GOT IT, THERE'S  
ORGANIC MATTER.

593  
00:41:39,820 --> 00:41:42,519  
WE HAVE THIS COMFORTABLE  
UNDERSTANDING OF HOW MICROBES

594  
00:41:42,519 --> 00:41:45,819  
WORK, AND NOW ALL OF A SUDDEN WE  
START TO LOOK AT MICROBES THAT

595  
00:41:45,819 --> 00:41:51,230  
ARE STEMMING DOWN, GOOD EVIDENCE  
TO A KILOMETER AND ACTUALLY

596  
00:41:51,230 --> 00:41:54,500  
SEVERAL KILOMETERS WHEN YOU  
CONSIDER GOLD MINES.

597  
00:41:54,500 --> 00:41:58,670  
SO WE HAVE A BIOSPHERE THAT'S  
SEVERAL KILOMETERS INTO THE

598  
00:41:58,670 --> 00:42:01,770  
EARTH AND THE RULES ARE VERY  
DIFFERENT IN TERMS OF HOW THE

599  
00:42:01,770 --> 00:42:04,640  
MICROBES OPERATE, HOW MUCH  
ENERGY THEY NEED TO ACTUALLY

600  
00:42:04,640 --> 00:42:07,559  
DUPLICATE.  
IT'S REALLY WILD.

601

00:42:07,559 --> 00:42:10,700  
SO THAT'S A GOOD ANALOGY OF WHEN  
YOU HAVE A VERY, VERY DIFFERENT

602  
00:42:10,700 --> 00:42:17,130  
BIOSPHERE, YOU START TO LEARN  
RULES THAT YOU DIDN'T REALIZE\h--

603  
00:42:17,130 --> 00:42:18,731  
YOU LEARN QUESTIONS YOU DIDN'T  
KNOW YOU HAD.

604  
00:42:18,731 --> 00:42:23,770  
>> I'VE HEARD IT SAID THIS WEEK  
THAT THE ANCIENT EARTH IS AN EXO

605  
00:42:23,770 --> 00:42:27,079  
PLANET.  
YOU'RE SAYING THE DEEP EARTH IS

606  
00:42:27,079 --> 00:42:29,839  
AN EXO PLANET IN SOME SENSE.  
IS THERE ANOTHER QUESTION?

607  
00:42:29,839 --> 00:42:34,299  
>> IF YOU HAD THIS DREAM  
TELESCOPE AND YOU COULD TURN IT

608  
00:42:34,299 --> 00:42:40,430  
AROUND AND POINT IT AT EARTH,  
HOW FAR BACK COULD YOU GO IN

609  
00:42:40,430 --> 00:42:44,060  
EARTH'S HISTORY AND SAY WE'VE  
GOT LIFE THERE AND IF YOU WENT

610  
00:42:44,060 --> 00:42:50,980  
BACK FARTHER, COULD YOU SAY NOT  
YET BUT IF WE WAIT A BILLION

611

00:42:50,980 --> 00:42:54,430  
YEARS, MAYBE.  
>> SO COULD WE SEE THE POTENTIAL

612  
00:42:54,430 --> 00:43:00,009  
FOR LIFE ON A PLANET THAT  
DOESN'T HAVE LIFE?

613  
00:43:00,009 --> 00:43:03,599  
>> YES.  
WHAT KIND OF A SHOT IN THE DARK

614  
00:43:03,599 --> 00:43:06,150  
ARE WE LOOKING AT HERE.  
EVEN IF WE WERE LOOKING AT EARTH

615  
00:43:06,150 --> 00:43:11,759  
WHERE WE KNOW IT'S FULL OF LIFE,  
HOW FAR BACK IN HISTORY COULD WE

616  
00:43:11,759 --> 00:43:15,430  
GO ON THIS PLANET AND SEE IT  
EVEN WITH YOUR DREAM TELESCOPE?

617  
00:43:15,430 --> 00:43:26,630  
>> I'LL START WITH AN OXYGEN  
CENTRIC RESPONSE.

618  
00:43:26,630 --> 00:43:30,140  
IF WE LOOK AT EARTH'S HISTORY,  
AGAIN THERE ARE MANY PEOPLE THAT

619  
00:43:30,140 --> 00:43:32,789  
THINK THAT THE PRODUCTION OF  
OXYGEN MAY HAVE GONE BACK 3

620  
00:43:32,789 --> 00:43:36,349  
BILLION YEARS AGO.  
BUT THERE ARE SOME VERY

621

00:43:36,349 --> 00:43:39,119  
SOPHISTICATED ANALYTICAL  
TECHNIQUES THAT WE CAN PULL OUT

622  
00:43:39,119 --> 00:43:42,920  
OF THE ROCK RECORD THAT SUGGEST  
THAT IT MAY NOT HAVE ACCUMULATED

623  
00:43:42,920 --> 00:43:48,210  
IN APPRECIABLE AMOUNTS TO 2.3  
BILLION YEARS AGO.

624  
00:43:48,210 --> 00:43:51,529  
IF YOU JUST WANT TO TAKE THE  
PERSPECTIVE OF OXYGEN, PERHAPS

625  
00:43:51,529 --> 00:43:55,849  
YOU COULD GO BACK 2.3 BILLION  
YEARS AGO AND POINT YOUR

626  
00:43:55,849 --> 00:43:58,319  
TELESCOPE AND SEE THAT.  
MAYBE YOU WANT TO SPEAK TO OTHER

627  
00:43:58,319 --> 00:44:01,920  
GASES.  
>> OTHER GASES WOULD BE POSSIBLE

628  
00:44:01,920 --> 00:44:06,869  
BUT THE OTHER THING THAT YOU  
ALLUDED TO BRIEFLY, IT'S

629  
00:44:06,869 --> 00:44:10,049  
POSSIBLE THAT FOR THIS BORING  
BILLION WE TALKED ABOUT, THAT

630  
00:44:10,049 --> 00:44:13,049  
OXYGEN LEVELS WERE A LITTLE  
LOWER, METHANE WAS A LITTLE

631

00:44:13,049 --> 00:44:16,269  
HIGHER AND IT MAY BE THE  
COMBINATION OF THOSE TWO IS

632  
00:44:16,269 --> 00:44:19,710  
EASIER TO DETECT FOR A BILLION  
OR 2 BILLION YEARS OF EARTH'S

633  
00:44:19,710 --> 00:44:23,750  
HISTORY THAN THOSE GASES ARE TO  
DETECT NOW.

634  
00:44:23,750 --> 00:44:30,599  
THE BIOSPHERE MIGHT HAVE BEEN  
MORE DETECTABLE IN THE HISTORY

635  
00:44:30,599 --> 00:44:34,980  
THAN IT IS TODAY.  
>> IF YOU ACCEPT THAT METHANE IS

636  
00:44:34,980 --> 00:44:39,550  
A GOOD BIOSIGNATURE, THERE'S A  
POPULAR NOTION THAT THE EARLY

637  
00:44:39,550 --> 00:44:42,730  
SUN WAS FAINTER THAN IT IS  
TODAY.

638  
00:44:42,730 --> 00:44:46,430  
WE'RE STRESSED WITH THIS IDEA OF  
HOW YOU MAINTAIN LIQUID WATER ON

639  
00:44:46,430 --> 00:44:50,490  
THE EARTH'S SURFACE GOING BACK  
MORE THAN 4 BILLION YEARS.

640  
00:44:50,490 --> 00:44:53,150  
MOST PEOPLE ACKNOWLEDGE THAT  
THAT'S PROBABLY SOME COMBINATION

641

00:44:53,150 --> 00:45:00,380  
OF GREENHOUSE GASES.  
SO CARBON DIOXIDEh--

642  
00:45:00,380 --> 00:45:09,650  
>> THE PALE ORANGE DOT.  
>> A PART OF THAT ANSWER, TOO,

643  
00:45:09,650 --> 00:45:14,790  
IRRESPECTIVE OF YOUR TECHNOLOGY,  
IF YOU LOOKED AT THE ANCIENT

644  
00:45:14,790 --> 00:45:18,289  
EARTH, WHEN WOULD YOU SEE THE  
BIOSPHERE BEING AS COMPLETELY

645  
00:45:18,289 --> 00:45:24,349  
DOMINANT AS IT IS TODAY AND  
REALLY GIVEN HOW DIFFICULT

646  
00:45:24,349 --> 00:45:30,460  
HORROR HOW RARE ROCKS BECOME  
THAT ARE THAT OLD, IT'S REALLY

647  
00:45:30,460 --> 00:45:35,009  
KIND OF AMAZING THAT YOU FIND  
EVIDENCE FOR LIFE IN ALL OF THE

648  
00:45:35,009 --> 00:45:37,560  
BEST PRESERVED ROCKS THAT ARE  
QUITE OLD.

649  
00:45:37,560 --> 00:45:41,720  
IF WE HAVE THE TECHNOLOGY TO SEE  
LIFE BECAUSE OF THE METHANE IT

650  
00:45:41,720 --> 00:45:49,720  
PRODUCES EVEN IN THE ABSENCE OF  
ANOXIC SPHERE, IT'S A LARGE

651

00:45:49,720 --> 00:45:54,980  
PORTION OF THE EARTH'S HISTORY  
THAT MICROBES MAKE A BIG EFFECT

652  
00:45:54,980 --> 00:45:58,740  
ON THE PLANET.  
THE EARLIEST PERIOD MIGHT BE

653  
00:45:58,740 --> 00:46:03,569  
HARD.  
>> HOW LONG HAS EARTH BEEN A

654  
00:46:03,569 --> 00:46:09,339  
PALE BLUE DOT, DID YOU FEEL?  
>> ABOUT 4.2, 4.3.

655  
00:46:09,339 --> 00:46:15,069  
>> SOME PEOPLE ARE SAYING THE  
PRESSURE WASN'T AS HIGH.

656  
00:46:15,069 --> 00:46:19,289  
I WOULD SAY AT LEAST TWO AND A  
HALF YEARS, MAYBE UP TO FOUR\h--

657  
00:46:19,289 --> 00:46:24,940  
I'M SORRY, BILLION YEARS.  
WITH MAYBE SOME SPORADIC ORANGE

658  
00:46:24,940 --> 00:46:28,990  
IN THERE AND SOME SPORADIC  
WHITE.

659  
00:46:28,990 --> 00:46:34,099  
>> CARL SEGUIN WAS RIGHT AT  
LEAST FOR THE LAST COUPLE

660  
00:46:34,099 --> 00:46:37,280  
BILLION YEARS.  
>> RIGHT.

661

00:46:37,280 --> 00:46:40,760

>> I THINK WE HAVE ANOTHER  
QUESTION IN THE AUDIENCE.

662

00:46:40,760 --> 00:46:43,339

>> IT'S CLEAR THAT THE EARTH IS  
THE GOLD STANDARD FOR

663

00:46:43,339 --> 00:46:45,880

HABITABILITY FOR OBVIOUS  
REASONS.

664

00:46:45,880 --> 00:46:49,180

IF WE'RE INTERESTED IN THE  
HABITABILITY OF EXOPLANETS IS

665

00:46:49,180 --> 00:46:57,450

THIS FAIR.  
KNOWING WHAT YOU KNOW ABOUT THE

666

00:46:57,450 --> 00:47:00,710

CURRENT EARTH AND THE EARLY  
EARTH, WOULD IT BE DIFFERENT

667

00:47:00,710 --> 00:47:07,880

THAN WE SEE IT IN THE PAST.  
>> HOW WOULD YOU MAKE A MORE

668

00:47:07,880 --> 00:47:13,849

HABIT PLANET?  
>> THIS REALLY GETS AT HOW YOU

669

00:47:13,849 --> 00:47:18,160

CAN ACTUALLY, TO ME, ASK THE  
SCIENTIFIC QUESTIONS.

670

00:47:18,160 --> 00:47:24,950

WE ONLY HAVE ONE EXAMPLE OF LIFE  
AND FOR THE COMPLEX LIFE WE NEED

671

00:47:24,950 --> 00:47:28,369  
HIGH ENERGY SOURCE WHICH IS  
MOLECULAR OXYGEN.

672  
00:47:28,369 --> 00:47:33,269  
BUT FOR A LOT OF EARTH'S  
HISTORY, BEFORE 2.5 BILLION

673  
00:47:33,269 --> 00:47:37,859  
YEARS OR SO, WE HAD LIFE THAT  
WAS USING OTHER ENERGY SOURCES,

674  
00:47:37,859 --> 00:47:43,470  
AND SOME OF IT WAS SUNLIGHT THAT  
MAY HAVE PRODUCED OXYGEN BUT

675  
00:47:43,470 --> 00:47:46,029  
THERE ARE OTHER WAYS TO COLLECT  
THAT.

676  
00:47:46,029 --> 00:47:50,269  
I THINK IT REALLY DEPENDS ON  
WHAT TYPE OF BIOSPHERE YOU

677  
00:47:50,269 --> 00:47:56,859  
CONSIDER BEING MOST SUCCESSFUL.  
IF YOU NEED LARGE ORGANISMS, WE

678  
00:47:56,859 --> 00:48:02,569  
NEED A VERY INTENSE ENERGY  
SOURCE AND THAT FOR PLANTS IS

679  
00:48:02,569 --> 00:48:09,630  
LIGHT BUT FOR US WE NEED THIS  
CHEMICAL.

680  
00:48:09,630 --> 00:48:14,859  
OUR CURRENT EARTH CREATES A  
REALLY GOOD MODEL WE CAN USE.

681

00:48:14,859 --> 00:48:19,720  
WHEN YOU START TALKING ABOUT  
OTHER THINGS, YOU HAVE TO START

682  
00:48:19,720 --> 00:48:23,319  
MAKING SO MANY ASSUMPTIONS THAT  
IT'S REALLY HARD TO SAY ANYTHING

683  
00:48:23,319 --> 00:48:26,270  
WOULD BE BETTER.  
>> THAT'S RIGHT.

684  
00:48:26,270 --> 00:48:28,160  
THE EARTH IS AN EXTRAORDINARY  
PLACE.

685  
00:48:28,160 --> 00:48:31,329  
OUR DISTANCE FROM THE SUN OR THE  
COMBINATION OF GAS IS SOMETHING

686  
00:48:31,329 --> 00:48:35,410  
THAT WE HAVEN'T MENTIONED IS THE  
FACT THAT OUR HISTORY WE WERE

687  
00:48:35,410 --> 00:48:38,349  
DEALT A GOOD HAND IN TERMS OF  
RADIOACTIVE MATERIALS AND THE

688  
00:48:38,349 --> 00:48:41,509  
HEAT THAT WAS GENERATED WITHIN  
THE EARTH WHICH ULTIMATELY LED

689  
00:48:41,509 --> 00:48:44,259  
TO PLATE TECTONICS, THE MOVEMENT  
OF PLATES ON THE EARTH'S

690  
00:48:44,259 --> 00:48:47,720  
SURFACE.  
THAT'S A CENTRAL THING AND

691

00:48:47,720 --> 00:48:56,990  
PERHAPS TIPPING POINT.  
HARD TO MAINTAIN A PHOSPHOROUS

692  
00:48:56,990 --> 00:49:01,970  
BALANCE WHICH IS CRITICAL TO  
LIFE AS WE KNOW IT ON EARTH.

693  
00:49:01,970 --> 00:49:04,349  
IT'S A WONDERFUL COMBINATION.  
THE QUESTION IS WHETHER THAT

694  
00:49:04,349 --> 00:49:06,869  
SAME COMBINATION HAS TO PLAY OUT  
EVERYWHERE.

695  
00:49:06,869 --> 00:49:11,760  
>> HERE'S A FOR INSTANCE JUST TO  
FOCUS ON YOUR QUESTION.

696  
00:49:11,760 --> 00:49:14,030  
THERE'S A QUESTION THAT CAME UP  
EARLIER WHY IT TOOK SO LONG FOR

697  
00:49:14,030 --> 00:49:25,039  
COMPLEX RISE TO TAKE PLACE ON  
EARTH.

698  
00:49:25,039 --> 00:49:28,029  
THERE IS THIS IDEA THAT IT TOOK  
A WHILE FOR OXYGEN TO BUILD UP

699  
00:49:28,029 --> 00:49:32,809  
AND WE NEEDED TO ENERGETIC  
SOURCE TO POWER ANIMAL LIFE.

700  
00:49:32,809 --> 00:49:36,150  
COULD YOU IMAGINE A PLANET  
SOMEWHAT LIKE EARTH BUT WITH

701

00:49:36,150 --> 00:49:41,049  
DIFFERENT CHEMISTRY SO THAT IT  
DIDN'T TAKE AS LONG FOR OXYGEN

702  
00:49:41,049 --> 00:49:43,900  
TO BUILD UP SO THAT THERE  
WASN'T\h-- PEOPLE TALK ABOUT ALL

703  
00:49:43,900 --> 00:49:46,710  
THIS IRON THAT THE OXYGEN HAD TO  
REACT TO.

704  
00:49:46,710 --> 00:49:49,740  
WHAT IF\h-- I DON'T WANT TO USE  
THE WORD REDUCING, A LESS

705  
00:49:49,740 --> 00:49:52,529  
REDUCING PLANET.  
WHAT IF THERE WAS LESS STUFF

706  
00:49:52,529 --> 00:49:56,029  
THAT THE OXYGEN HAD TO REACT  
WITH BEFORE IT COULD BUILD UP SO

707  
00:49:56,029 --> 00:50:01,830  
YOU HAD A PLANET CHEMICALLY  
PRIMED FOR OXYGEN TO BUILD UP

708  
00:50:01,830 --> 00:50:06,089  
EARLIER.  
MIGHT GOTTEN AN EARLIER START TO

709  
00:50:06,089 --> 00:50:09,390  
COMPLEX LIFE AND BY NOW WE WOULD  
ALREADY BE INHABITING OTHER

710  
00:50:09,390 --> 00:50:14,930  
GALAXIES?  
>> WE'RE VERY GOOD AT FIGURING

711

00:50:14,930 --> 00:50:16,589  
OUT WHAT WE MISSED.  
WE CERTAINLY MISSED PLATE

712  
00:50:16,589 --> 00:50:24,339  
TECTONICS.  
IF YOU DID THAT, THERE WOULD BE

713  
00:50:24,339 --> 00:50:27,810  
A LONGER TERM CONSEQUENCE  
BECAUSE YOU DO STILL CONTINUE TO

714  
00:50:27,810 --> 00:50:30,880  
LOSE HYDROGEN AND OXIDIZE OVER  
LONGER PERIODS OF TIME.

715  
00:50:30,880 --> 00:50:34,900  
IF YOU MOVE THAT EVENT UP, YOU  
ACTUALLY ON SOME LEVEL SHORTEN

716  
00:50:34,900 --> 00:50:39,310  
HABITABILITY SOME DAY IN THE  
FUTURE, NOT KNOWING EXACTLY WHEN

717  
00:50:39,310 --> 00:50:42,289  
THAT IS, WHICH BRINGS UP ANOTHER  
POINT.

718  
00:50:42,289 --> 00:50:47,089  
IF YOU WANT TO FIND AN OPTIMAL  
FOR LIFETIME, SMALLER STARS, BUT

719  
00:50:47,089 --> 00:50:54,050  
NOW WE'RE TALKING ABOUT SCIENCE  
FICTION AT THIS POINT.

720  
00:50:54,050 --> 00:50:57,839  
>> THIS TIES IN VERY WELL TO A  
QUESTION WE HAVE ON SOCIAL MEDIA

721

00:50:57,839 --> 00:51:01,549  
WHICH IS IF WE FIND LIFE VERY  
UNLIKE OUR OWN, HOW WOULD WE BE

722

00:51:01,549 --> 00:51:07,900  
ABLE TO TELL?  
>> THIS GETS AT HOW YOU ACTUALLY

723

00:51:07,900 --> 00:51:13,359  
RECOGNIZE SOMETHING AS LIFE AND  
IT GETS BACK TO THE DEFINITION

724

00:51:13,359 --> 00:51:18,109  
OF WHAT LIFE IS.  
WE USUALLY THINK OF IT AS HAVING

725

00:51:18,109 --> 00:51:26,910  
A METABOLISM AND REPRODUCTION.  
WE COULD EASILY\h-- IT'S

726

00:51:26,910 --> 00:51:29,380  
CONCEIVABLE TO ME THAT THERE  
COULD BE A LIFE THAT'S VERY

727

00:51:29,380 --> 00:51:33,170  
DIFFERENT THAN THAT ON EARTH AND  
WE WOULDN'T RECOGNIZE IT BECAUSE

728

00:51:33,170 --> 00:51:37,700  
WE DON'T HAVE THE RIGHT MODELS  
FOR IDENTIFYING THOSE

729

00:51:37,700 --> 00:51:39,920  
CHARACTERISTICS.  
IN SOME SENSE WE COULD END UP

730

00:51:39,920 --> 00:51:44,619  
WITH A FALSE NEGATIVE IF THE  
LIFE IS SO DIFFERENT IT DOESN'T

731

00:51:44,619 --> 00:51:48,180  
ACTUALLY FIT WITH OUR MODEL FOR  
HOW WE DETECT LIFE.

732  
00:51:48,180 --> 00:51:54,319  
>> YOU AND SHAWN BOTH MENTIONED  
THE NOTION OF EQUILIBRIUM AND

733  
00:51:54,319 --> 00:52:05,029  
DISEQUILIBRIUM.  
SO WOULD YOU THINK IT WOULD BE

734  
00:52:05,029 --> 00:52:08,779  
REASONABLE TO SAY THAT ANY KIND  
OF LIFE WILL AT LEAST BE DOING

735  
00:52:08,779 --> 00:52:12,210  
SOMETHING CHEMICALLY, EATING  
SOMETHING, EXCRETING SOMETHING

736  
00:52:12,210 --> 00:52:19,010  
AND WILL LEAVE SOMETHING IN THE  
MIX OF GASES OR IS THAT TOO MUCH

737  
00:52:19,010 --> 00:52:22,859  
OF AN ASSUMPTION?  
>> BIOTIC PROCESSES CAN GIVE YOU

738  
00:52:22,859 --> 00:52:33,420  
A SIMILAR EQUILIBRIUM.  
IT'S ONE OF THOSE CRITICAL

739  
00:52:33,420 --> 00:52:38,760  
QUESTIONS THAT I THINK AS A  
SCIENTIST I WANT TO MODEL TO

740  
00:52:38,760 --> 00:52:41,869  
COMPARE AND TEST THINGS AGAINST,  
BUT I ALSO WANT TO KEEP IN MIND

741

00:52:41,869 --> 00:52:46,499  
THAT MY MODELS ARE LIMITED AND  
RESTRICTED AND I DON'T KNOW ALL

742  
00:52:46,499 --> 00:52:50,710  
THESE OTHER THINGS.  
>> I WOULD FOLLOW THAT WE HAVE

743  
00:52:50,710 --> 00:52:54,170  
CHEMICAL PRINCIPLES AND WE HOPE  
THAT THOSE ARE UNIVERSAL

744  
00:52:54,170 --> 00:52:58,599  
THROUGHOUT THE UNIVERSE.  
SO THIS SENSE OF DISEQUILIBRIUM,

745  
00:52:58,599 --> 00:53:05,069  
LIFE IS ABOUT THE FLOW OF  
ELECTRONS.

746  
00:53:05,069 --> 00:53:08,980  
SO IF YOU HAVE A SENSE FOR THE  
CHEMISTRY ON THAT PLANET, YOU

747  
00:53:08,980 --> 00:53:11,400  
COULD START TO ENVISION  
REACTIONS THAT COULD LEAD TO

748  
00:53:11,400 --> 00:53:14,529  
THAT CHEMISTRY THAT COULD BE A  
SOURCE OF ENERGY.

749  
00:53:14,529 --> 00:53:17,400  
>> I THINK THAT'S WHY STUDYING  
THE EARLY EARTH IS SO IMPORTANT

750  
00:53:17,400 --> 00:53:22,079  
BECAUSE THAT WHAT WE'RE DOING ON  
OUR PLANET.

751

00:53:22,079 --> 00:53:24,890  
WE KNOW LIFE EVOLVED AND WE CAN  
LOOK AT THE CHEMISTRY ON THE

752

00:53:24,890 --> 00:53:34,119  
EARLY EARTH AND SEE HOW IT  
CHANGED OVER TIME.

753

00:53:34,119 --> 00:53:36,180  
>> IF WE WANT TO LOOK FOR THE  
REALLY WEIRD STUFF, WE SHOULD

754

00:53:36,180 --> 00:53:39,059  
START WITH THE WEIRD STUFF THAT  
WE HAVE DATA ON WHICH ARE THESE

755

00:53:39,059 --> 00:53:42,780  
EARLY VERSIONS OF EARTH.  
BY LOOKING AT THOSE VERSIONS OF

756

00:53:42,780 --> 00:53:46,140  
EARTH WE CAN DERIVE THESE  
PRINCIPLES AND TEST THEM AND

757

00:53:46,140 --> 00:53:49,230  
HOPEFULLY COME UP WITH A  
FUNDAMENTAL THEORY OF BIOGEO

758

00:53:49,230 --> 00:53:53,230  
CHEMISTRY.  
>> OR REQUIRE OBSERVATION OF

759

00:53:53,230 --> 00:53:57,630  
THIS OTHER PLANET AND TRY TO  
UNDERSTAND ITS HISTORY BEFORE WE

760

00:53:57,630 --> 00:54:00,920  
CAN DEFINITELY SAY IT WAS IN  
THIS EQUILIBRIUM.

761

00:54:00,920 --> 00:54:12,000

>> I LIKE THAT ANSWER.

IT GOES BACK TO SOMETHING THAT

762

00:54:12,000 --> 00:54:15,619

DAWN SAID EARLIER WHERE WE WERE  
TALKING ABOUT THE EVIDENCE OF

763

00:54:15,619 --> 00:54:19,220

LIFE AT 3.5, THAT THE REASON  
THAT WE GET ALL COMFORTABLE WITH

764

00:54:19,220 --> 00:54:23,269

IT IS THAT WE SEE SO MANY  
COMPONENTS OF IT.

765

00:54:23,269 --> 00:54:25,609

THAT COULD BE TRUE OF AN EXO  
PLANET EVEN IF THE LIFE IS

766

00:54:25,609 --> 00:54:28,549

COMPLETELY DIFFERENT OF LIFE ON  
EARTH, THAT YOU MIGHT ACTUALLY

767

00:54:28,549 --> 00:54:32,470

SEE EVIDENCE OF AN ECOSYSTEM  
BEFORE YOU RECOGNIZED ANY LIFE

768

00:54:32,470 --> 00:54:35,420

FORM.  
>> IF YOU SAW THOSE GASES AND

769

00:54:35,420 --> 00:54:40,300

SAW THEM CHANGING ON SEASONAL  
TIME SCALES OR CALCULATE THEIR

770

00:54:40,300 --> 00:54:43,440

LIFE TIMES AND THEY'RE NOT  
DISAPPEARING FAST ENOUGH.

771

00:54:43,440 --> 00:54:48,670  
>> WE THINK IT'S SEASONAL  
VARIATIONS IN CO 2 TODAY.

772  
00:54:48,670 --> 00:54:58,920  
>> AND A CO-VARIATIONS OF O2.  
>> THE SIGNS OF LIFE ON EARTH IS

773  
00:54:58,920 --> 00:55:01,180  
NOT SUBTLE.  
IF YOU WERE AN ALIEN AND YOU

774  
00:55:01,180 --> 00:55:07,269  
WERE LOOKING AT MARS YOU WOULD  
SAY SOME CO2 AND OTHER STUFF AND

775  
00:55:07,269 --> 00:55:12,509  
THEN YOU WOULD LOOK AT EARTH AND  
GO WHOA, WE GOT A LIVE ONE HERE

776  
00:55:12,509 --> 00:55:19,989  
AND IT MAY BE THAT THAT THE  
CHARACTERISTICS OF LIFE ON OTHER

777  
00:55:19,989 --> 00:55:22,420  
PLANETS.  
>> >> I THINK WE HAVE ONE MORE

778  
00:55:22,420 --> 00:55:28,329  
QUESTION FROM THE AUDIENCE.  
>> HOW MUCH OF OUR HISTORY HAVE

779  
00:55:28,329 --> 00:55:31,589  
WE LOST TO PLATE TECTONICS AND  
HOW WELL HAVE WE PUT THE STORY

780  
00:55:31,589 --> 00:55:35,690  
BACK TOGETHER AND ALSO HOW LUCKY  
ARE WE TO HAVE INDIRECT ACCESS

781

00:55:35,690 --> 00:55:48,980  
TO THE ROCKS ON MARS?  
>> WE'VE LOST TOO MUCH TO PLATE

782  
00:55:48,980 --> 00:55:51,299  
TECTONICS.  
>> STUDYING OTHER PLANETS FILL

783  
00:55:51,299 --> 00:55:54,109  
SOME OF THAT GAP.  
OUR RECORD FOR THE FIRST HALF A

784  
00:55:54,109 --> 00:55:57,869  
BILLION YEARS IS REALLY SPARSE.  
WHEN I GOT STARTED THERE WAS

785  
00:55:57,869 --> 00:56:01,130  
NOTHING.  
NOW WE HAVE GRAINS AND EVEN

786  
00:56:01,130 --> 00:56:04,490  
ROCKS THAT GO BEYOND 4 BILLION  
YEARS.

787  
00:56:04,490 --> 00:56:07,510  
THE SEA FLOOR IS LOST CONSTANTLY  
BECAUSE OF PLATE TECTONICS

788  
00:56:07,510 --> 00:56:09,380  
THROUGH TIME.  
ONE OF THE CHALLENGES THAT WE'RE

789  
00:56:09,380 --> 00:56:11,960  
FACED IS WITH TRYING TO  
RECONSTRUCT AN OCEAN CHEMISTRY

790  
00:56:11,960 --> 00:56:15,760  
FOR WHICH THERE IS NO SEA FLOOR  
RECORDED.

791

00:56:15,760 --> 00:56:21,820  
WE LOOK AT PLACES LIKE EARLY  
CONTINENTS AND OR THE MARGIN OF

792  
00:56:21,820 --> 00:56:23,730  
CONTINENTS THAT ARE STILL  
PRESERVED.

793  
00:56:23,730 --> 00:56:27,569  
THERE ARE RISK IN THAT BUT IT'S  
THE BEST THAT WE HAVE BECAUSE WE

794  
00:56:27,569 --> 00:56:31,509  
HAVE AN EARTH THAT'S CONSTANTLY  
RECYCLING.

795  
00:56:31,509 --> 00:56:34,310  
WE'VE LOST MUCH OF THE RECORD  
AND THE FURTHER YOU GO BACK, THE

796  
00:56:34,310 --> 00:56:37,450  
LESS THERE IS.  
>> HOW LUCKY ARE WE TO BE

797  
00:56:37,450 --> 00:56:44,170  
EXPLORING MARS?  
VERY LUCKY.

798  
00:56:44,170 --> 00:56:48,789  
>> IT'S REALLY GREAT TO BE ABLE  
TO LOOK AT THESE OLD ROCKS AND

799  
00:56:48,789 --> 00:56:54,059  
SO WHEN I FIRST GOT INTERESTED  
IN MARS, A LOT OF IT WAS WE HAVE

800  
00:56:54,059 --> 00:56:58,269  
A CHANCE TO LOOK AT THE EARLY  
STAGES OF A PLANET AND EARLY

801

00:56:58,269 --> 00:57:03,890  
STAGES OF EARTH, BUT THEN WE  
ALSO HAVE THE ISSUE THAT IT IS A

802  
00:57:03,890 --> 00:57:07,069  
DIFFERENT PLANET AND IT CLEARLY  
HAS A VERY DIFFERENT

803  
00:57:07,069 --> 00:57:11,240  
EVOLUTIONARY HISTORY.  
SO YOU'RE IN THIS REALLY

804  
00:57:11,240 --> 00:57:14,249  
INTERESTING PLACE WHERE WE CAN  
LOOK AT THE ROCKS THAT THE

805  
00:57:14,249 --> 00:57:22,509  
CURIOSITY IS SEEING AND WE CAN  
FIND EVIDENCE THAT RIVERS FLOWED

806  
00:57:22,509 --> 00:57:26,059  
AND LOOK AT SOME OF THE MINERAL  
REACTIONS AND UNDERSTAND THE

807  
00:57:26,059 --> 00:57:30,410  
WATER/ROCK INTERACTIONS BUT WE  
DON'T KNOW ENOUGH YET TO TIE

808  
00:57:30,410 --> 00:57:40,359  
THAT BACK TO EARLY EARTH.  
BUT WITH THE INCREASED DATA AND

809  
00:57:40,359 --> 00:57:45,910  
THE COMBINATION OF THE CHEMICAL  
AND IMAGE DATA FROM ORBIT WITH

810  
00:57:45,910 --> 00:57:49,109  
THE DATA WE'RE GETTING FROM  
ROVERS ON THE GROUND IS

811

00:57:49,109 --> 00:57:55,039  
PROVIDING THIS WHOLE NEW VIEW OF  
THE COMPLEXITY OF MARS AS A

812  
00:57:55,039 --> 00:57:57,789  
PLANET.  
WE WILL BE SEARCHING FOR

813  
00:57:57,789 --> 00:58:01,980  
EVIDENCE OF LIFE, AND WE WILL BE  
TRYING TO UNDERSTAND THE

814  
00:58:01,980 --> 00:58:04,930  
ENVIRONMENT, UNDERSTAND THE GEO  
CHEMICAL EVOLUTION AND WE DON'T

815  
00:58:04,930 --> 00:58:10,749  
KNOW WHICH PARTS ARE GOING TO  
HELP US UNDERSTAND EARTH.

816  
00:58:10,749 --> 00:58:14,119  
>> ANOTHER QUESTION?  
>> I JUST WANTED TO SEE IF

817  
00:58:14,119 --> 00:58:17,690  
ANYBODY HAD ANY LAST FINAL  
COMMENTS THAT WE WANTED TO MAKE?

818  
00:58:17,690 --> 00:58:23,079  
THERE WAS SOME INTEREST IN THE  
DIFFERENT ENVIRONMENTS OFTEN THE

819  
00:58:23,079 --> 00:58:26,119  
EARLY EARTH THAT MAY BE  
APPLICABLE TO THE NEW

820  
00:58:26,119 --> 00:58:35,709  
OBSERVATIONS OF MARINE PLANKTON  
ON THE ISS?

821

00:58:35,709 --> 00:58:41,700

>> I THINK WHAT YOU TOLD ME TO  
SAY WAS IT WAS TOOTHPASTE.

822

00:58:41,700 --> 00:58:50,349

DIATOMS AND TOOTHPASTE.

>> IN THIS FIELD THERE ARE NEWS

823

00:58:50,349 --> 00:58:53,160

STORIES, SOME OF WHICH TURN OUT  
TO BE TRUE.

824

00:58:53,160 --> 00:58:58,619

WE READ TODAY THAT THEY FOUND  
PLANKTON ON THE INTERNATIONAL

825

00:58:58,619 --> 00:59:03,489

SPACE STATION, THE PROPER  
RESPONSE IS TO SAY OH, REALLY?

826

00:59:03,489 --> 00:59:06,369

SO WE JUST LEARNED ABOUT THIS  
AND WE'RE SKEPTICAL BUT OF

827

00:59:06,369 --> 00:59:08,650

COURSE WE'RE INTERESTED IN  
HEARING MORE.

828

00:59:08,650 --> 00:59:14,069

>> THAT'S ABOUT IT.  
I JUST WANTED TO SAY THANK YOU

829

00:59:14,069 --> 00:59:17,599

GUYS ALL FOR JOINING US TONIGHT.  
IF YOU WOULD LIKE TO LEARN MORE,

830

00:59:17,599 --> 00:59:22,850

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