



1
00:00:01,264 --> 00:00:02,382
>>>NASA'S JET PROPULSION

2
00:00:02,382 --> 00:00:08,388
LABORATORY PRESENTS THE VON
KARMAN LECTURES, A SERIES OF

3
00:00:08,388 --> 00:00:12,042
TALKS BY SCIENTISTS AND
ENGINEERS WHO ARE EXPLORING OUR

4
00:00:12,042 --> 00:00:30,377
PLANET, OUR SOLAR SYSTEM AND ALL
THAT LIES BEYOND.

5
00:00:30,377 --> 00:00:32,329
>> HEY, GOOD EVENING, LADIES AND
GENTLEMEN.

6
00:00:32,329 --> 00:00:34,214
HOW'S EVERYONE TONIGHT?

7
00:00:34,214 --> 00:00:35,265
PACKED THE HOUSE TONIGHT.

8
00:00:35,265 --> 00:00:36,333
THANKS FOR COMING OUT IN
DECEMBER.

9
00:00:36,333 --> 00:00:38,134
THIS IS COOL.

10
00:00:38,134 --> 00:00:39,402
ALL RIGHT, SHALL WE?

11
00:00:39,402 --> 00:00:42,422
THE INSIGHT MISSION TO MARS, THE
12th IN NASA'S DISCOVERY

12
00:00:42,422 --> 00:00:48,261
PROGRAM, WILL LAUNCH IN MARCH OF
2016, LANDING SIX MONTHS LATER

13
00:00:48,261 --> 00:00:51,198
IN ELYSIUM PLANITIA.

14
00:00:51,198 --> 00:00:54,284
UNLIKE RECENT MISSIONS TO MARS,
INSIGHT PLANS TO EXPLORE THE

15
00:00:54,284 --> 00:00:57,387
INTERIOR OF THE PLANET DOWN TO
ITS VERY CORE, INVESTIGATING THE

16
00:00:57,387 --> 00:01:00,357
PROCESSES OF TERRESTRIAL PLANET
FORMATION AND EVOLUTION BY

17
00:01:00,357 --> 00:01:03,310
PERFORMING THE FIRST
COMPREHENSIVE SURFACE-BASED

18
00:01:03,310 --> 00:01:04,461
GEOPHYSICAL MEASUREMENTS ON
MARS.

19
00:01:04,461 --> 00:01:08,398
INSIGHT WILL PURSUE THESE GOALS
USING SEISMOLOGY, PRECISION

20
00:01:08,398 --> 00:01:10,200
TRACKING AND HEAT FLOW
MEASUREMENTS.

21
00:01:10,200 --> 00:01:15,338
TONIGHT'S LECTURE WILL DISCUSS
THE MISSION GOALS AND THE

22

00:01:15,338 --> 00:01:17,374
CHALLENGES FACED WHEN TRYING TO
STUDY THESE PLANETARY PHENOMENA

23
00:01:17,374 --> 00:01:20,093
FROM A SINGLE LOCATION.

24
00:01:20,093 --> 00:01:25,232
TONIGHT'S GUEST IS A PHYSICIST
IN THE SCIENCE DIVISION SINCE

25
00:01:25,232 --> 00:01:25,382
1977.

26
00:01:25,382 --> 00:01:28,101
HIS RESEARCH FOCUSSED ON THE
GEOLOGICAL HISTORY OF THE PLANET

27
00:01:28,101 --> 00:01:30,487
MARS AND GEOPHYSICAL
INVESTIGATIONS OF THE INTERIORS

28
00:01:30,487 --> 00:01:32,289
OF TERRESTRIAL PLANETS.

29
00:01:32,289 --> 00:01:35,375
HE HAS PARTICIPATED IN SEVERAL
PLANETARY FLIGHT INSTRUMENT

30
00:01:35,375 --> 00:01:42,432
TEAMS, INCLUDING THE MARS
ORBITER LASER ALTIMETERS ON MARS

31
00:01:42,432 --> 00:01:48,405
GLOBAL AND THE MAGELLAN MISSION
TO VENUS, THE SEISMOMETER ON THE

32
00:01:48,405 --> 00:01:54,144
MISSION TO MARS CANCELED TWO
YEARS BEFORE LAUNCH AND THE

33

00:01:54,144 --> 00:01:56,413
SESAME ACOUSTIC.

34

00:01:56,413 --> 00:01:59,432
IN ADDITION, TO SERVED AS
SCIENTIST FOR THE SPIRIT AND

35

00:01:59,432 --> 00:02:01,234
OPPORTUNITY ROVERS FOR SIX
YEARS.

36

00:02:01,234 --> 00:02:04,087
HE HELPED DEVELOP A BROADBAND
SPACE-QUALIFIED SEISMOMETER AND

37

00:02:04,087 --> 00:02:07,440
HAS BEEN WORKING FOR THE PAST 25
YEARS TO SEND SEISMOMETERS TO

38

00:02:07,440 --> 00:02:10,010
OTHER PLANETS, PARTICULARLY
MARS.

39

00:02:10,010 --> 00:02:16,116
HE HOLDS A BS IN PHYSICS AND
PH.D IN GEOPHYSICS FROM THE

40

00:02:16,116 --> 00:02:18,134
UNIVERSITY OF SOUTHERN
CALIFORNIA, HAS SERVED ON MANY

41

00:02:18,134 --> 00:02:21,338
NASA AND ACADEMY OF SCIENCES
ADVISORY PANELS AND HAS

42

00:02:21,338 --> 00:02:23,406
PUBLISHED OVER 60 JOURNAL
ARTICLES, REPORTS AND BOOK

43

00:02:23,406 --> 00:02:24,257

CHAPTERS.

44

00:02:24,257 --> 00:02:26,376

CURRENTLY, HE IS THE PRINCIPAL
INVESTIGATOR OF THE INSIGHT

45

00:02:26,376 --> 00:02:27,193

DISCOVERY MISSION.

46

00:02:27,193 --> 00:02:30,330

WITH THIS LAUNCH COMING UP SOON,
WE'RE REALLY GLAD HE COULD MAKE

47

00:02:30,330 --> 00:02:33,383

SOME TIME FOR US TONIGHT, SO,
PLEASE HELP ME WELCOME TONIGHT'S

48

00:02:33,383 --> 00:02:36,202

GUEST, DR. BRUCE BANERDT.

49

00:02:37,087 --> 00:02:41,107

[APPLAUSE]

>> OKAY, WELL, THANK YOU, MARK.

50

00:02:45,412 --> 00:02:49,516

SO, I'M HERE TODAY TO TELL YOU
ABOUT THE INSIGHT MISSION.

51

00:02:49,516 --> 00:02:50,367

LET'S SEE.

52

00:02:50,367 --> 00:02:54,254

SO, ONE THING I WANT TO SAY
RIGHT UP FRONT IS THAT THIS IS A

53

00:02:54,254 --> 00:02:57,307

VERY INTERNATIONAL
COLLABORATION.

54

00:02:57,307 --> 00:03:01,244

THIS MISSION HAS A PAYLOAD WHICH
IS BEING BUILT ALL OVER THE

55

00:03:01,244 --> 00:03:01,411

WORLD.

56

00:03:01,411 --> 00:03:05,231

THESE ARE SOME OF THE LOGOS OF
THE INSTITUTIONS.

57

00:03:05,231 --> 00:03:10,353

WE'VE GOT LOGOS FROM THE UNITED
STATES, GERMANY, FRANCE,

58

00:03:10,353 --> 00:03:12,455

SWITZERLAND, UNITED KINGDOM,
POLAND, SPAIN.

59

00:03:12,455 --> 00:03:15,125

WE'VE GOT PIECES COMING FROM ALL
OVER THE WORLD.

60

00:03:15,125 --> 00:03:19,029

WE'VE REALLY TRIED TO TAP SORT
OF THE BEST SCIENTIFIC AND

61

00:03:19,029 --> 00:03:22,248

ENGINEERING TALENT FROM THE
ENTIRE WORLD TO DO THIS MISSION.

62

00:03:22,248 --> 00:03:27,120

AND SO, I'M REALLY PROUD TO BE
THE LEADER OF THIS MISSION, AND

63

00:03:27,120 --> 00:03:30,240

I THINK WE'RE GOING TO GET SOME
REALLY COOL RESULTS THAT I'M

64
00:03:30,240 --> 00:03:32,092
GOING TO TELL YOU ABOUT TONIGHT.

65
00:03:32,092 --> 00:03:34,310
SO, LET'S START IN.

66
00:03:34,310 --> 00:03:38,081
SO, WHAT'S -- THE GOAL OF THIS
MISSION, AS MARK ALREADY

67
00:03:38,081 --> 00:03:40,333
ALLUDED, WE REALLY WANT TO
UNDERSTAND IN A FUNDAMENTAL

68
00:03:40,333 --> 00:03:44,120
SENSE, WE'D LIKE TO UNDERSTAND
THE METHODS BY WHICH THE

69
00:03:44,120 --> 00:03:49,392
TERRESTRIAL PLANETS, THE ROCKY
PLANETS FORM, AND THOSE ARE THE

70
00:03:49,392 --> 00:03:53,313
INNER PLANETS OF THE SOLAR
SYSTEM -- MERCURY, VENUS, EARTH,

71
00:03:53,313 --> 00:03:57,467
MARS, THE MOON -- AS WELL AS
ROCKY PLANETS AROUND OTHER

72
00:03:57,467 --> 00:04:02,338
STARS, EXOPLANETS THAT WE'RE
JUST STARTING TO INVESTIGATE.

73
00:04:02,338 --> 00:04:07,143
AND UNDERSTANDING HOW THOSE
PLANETS BEGAN, HOW THEY WERE

74
00:04:07,143 --> 00:04:13,249

FORMED, HOW THEY EVOLVED TO WHAT
THEY ARE TODAY IS I THINK ONE OF

75

00:04:13,249 --> 00:04:18,254

THE FUNDAMENTAL QUESTIONS THAT
HUMANS HAVE.

76

00:04:18,254 --> 00:04:23,426

IT'S SOMETHING THAT GOES BACK TO
JUST UNDERSTANDING WHERE WE CAME

77

00:04:23,426 --> 00:04:28,114

FROM, BOTH BIOLOGICALLY AND IN
TERMS OF THE WORLD AND THE

78

00:04:28,114 --> 00:04:29,165

UNIVERSE WE LIVE IN.

79

00:04:29,165 --> 00:04:31,484

SO, THIS MISSION I THINK IS
GOING TO PUT IN PLACE SOME OF

80

00:04:31,484 --> 00:04:35,138

THE BUILDING BLOCKS OR PUT SOME
OF THE PIECES OF THE PUZZLE

81

00:04:35,138 --> 00:04:36,306

TOGETHER TO UNDERSTAND THAT.

82

00:04:36,306 --> 00:04:38,391

SO, HOW ARE WE GOING TO DO THIS
INVESTIGATION?

83

00:04:38,391 --> 00:04:41,494

WE'RE GOING TO USE GEOPHYSICAL
TECHNIQUES.

84

00:04:41,494 --> 00:04:46,199

IN PARTICULAR, WE'RE GOING TO
USE SEISMOLOGY, THE STUDY OF

85
00:04:46,199 --> 00:04:50,386
EARTHQUAKE WAVES OR MARSQUAKE
WAVES IN THIS CASE, PRECISION

86
00:04:50,386 --> 00:04:55,141
TRACKING OF THE SPACECRAFT --
AND I'LL TALK MORE ABOUT WHAT

87
00:04:55,141 --> 00:04:57,060
THAT MEANS -- AND MEASURING THE
HEAT FLOW COMING OUT OF THE

88
00:04:57,060 --> 00:04:59,412
PLANET.

89
00:04:59,412 --> 00:05:03,383
SO, WHY DO WE WANT US TO STUDY
PLANETARY INTERIORS?

90
00:05:03,383 --> 00:05:08,304
THIS IS MOSTLY WHAT I DO IS
STUDY PLANETARY INTERIORS.

91
00:05:08,304 --> 00:05:13,093
AND THAT'S MAYBE NOT THE MOST
OBVIOUS THING TO DO, BUT IT

92
00:05:13,093 --> 00:05:18,431
TURNS OUT THAT PLANETARY
INTERIORS ARE REALLY

93
00:05:18,431 --> 00:05:21,401
FUNDAMENTALLY CONNECTED TO JUST
ABOUT EVERYTHING THAT WE SEE AND

94
00:05:21,401 --> 00:05:23,186
EVERYTHING THAT WE DO.

95

00:05:23,186 --> 00:05:29,142
THE INTERIOR OF THE PLANET'S
REALLY A BIG HEAT ENGINE.

96
00:05:29,142 --> 00:05:34,247
IT'S AN ENGINE THAT'S MOVING,
IT'S BEING POWERED BY INTERNAL

97
00:05:34,247 --> 00:05:39,068
HEAT, AND THAT HEAT HAS COME
FROM ITS EARLIEST FORMATION, AND

98
00:05:39,068 --> 00:05:44,174
IT'S BEING GENERATED BY THE
RADIOACTIVE DECAY OF THINGS LIKE

99
00:05:44,174 --> 00:05:49,345
URANIUM AND THORIUM IN THE
ROCKS AND THE HEAT IS DRIVING

100
00:05:49,345 --> 00:05:51,281
ALL OF THE GEOLOGY THAT YOU SEE
ON THE SURFACE.

101
00:05:51,281 --> 00:05:54,217
IT'S FORMING THE MOUNTAINS THAT
YOU SEE, IT FORMS THE VALLEYS

102
00:05:54,217 --> 00:05:58,338
THAT YOU SEE, THE CANYONS, ON
SOME SENSE EVEN EROSION, WHICH

103
00:05:58,338 --> 00:06:00,140
IS SORT OF POWERED BY THE SUN.

104
00:06:00,140 --> 00:06:03,309
THE SUN'S WHAT LIFTS THE WATER
AND DRIVES THE WINDS AND ERODES

105
00:06:03,309 --> 00:06:06,095

THINGS DOWN, BUT THOSE THINGS
DON'T HAPPEN UNLESS YOU HAVE

106

00:06:06,095 --> 00:06:07,163

ELEVATION DIFFERENCES.

107

00:06:07,163 --> 00:06:09,232

AND ALL OF THE ELEVATION
DIFFERENCES ON THE EARTH ARE

108

00:06:09,232 --> 00:06:14,420

DRIVEN IN SOME FUNDAMENTAL SENSE
BY THE HEAT ENGINE OF THE

109

00:06:14,420 --> 00:06:16,039

INTERIOR OF THE EARTH.

110

00:06:16,039 --> 00:06:18,424

AS WELL AS MOVING THINGS AROUND
ON THE SURFACE GEOLOGICALLY,

111

00:06:18,424 --> 00:06:22,462

IT'S ALSO A SOURCE AND SYNC OF
AL OF THE VOLATILES OF THE

112

00:06:22,462 --> 00:06:25,231

ATMOSPHERE THAT WE HAVE AROUND
US THAT WE BREATHE.

113

00:06:25,231 --> 00:06:27,217

THAT'S WHERE THE OCEANS CAME
FROM.

114

00:06:27,217 --> 00:06:30,420

THEY BASICALLY CAME FROM VAPOR
THAT COMES UP IN VOLCANIC

115

00:06:30,420 --> 00:06:33,473

ERUPTIONS AND FROM THE SPREADING
THAT GOES ON IN THE MIDDLE OF

116

00:06:33,473 --> 00:06:34,257

THE OCEAN.

117

00:06:34,257 --> 00:06:38,044

AND SO, IT REALLY PROVIDES A LOT
OF THE NECESSARY CONDITIONS FOR

118

00:06:38,044 --> 00:06:41,264

A PLANET TO BECOME AND REMAIN
HABITABLE.

119

00:06:41,264 --> 00:06:44,467

BUT FOR OUR PURPOSES TONIGHT,
THE COOL THING ABOUT THE

120

00:06:44,467 --> 00:06:49,455

INTERIOR IS IT RETAINS THE
FINGERPRINTS OF ITS INITIAL

121

00:06:49,455 --> 00:06:54,143

ORIGIN, OVERPRINTED SOMEWHAT BY
THE STUFF THAT HAPPENS

122

00:06:54,143 --> 00:06:54,327

AFTERWARD.

123

00:06:54,327 --> 00:06:56,312

SO, WE CAN LOOK AT THE INTERIOR,
WE CAN LOOK AT THE STRUCTURE, WE

124

00:06:56,312 --> 00:06:59,182

CAN LOOK AT THE PROCESSES GOING
ON IN THERE AND SORT OF USE THAT

125

00:06:59,182 --> 00:07:02,418

AS A WINDOW BACK IN TIME, BACK
4 1/2 BILLION YEARS AGO TO LOOK

126

00:07:02,418 --> 00:07:09,175
AT THE VERY EARLIEST PROCESSES
THAT PUT THIS PLANET TOGETHER.

127
00:07:09,175 --> 00:07:13,062
SO, WHAT DOES A TERRESTRIAL
PLANET LOOK LIKE ON THE INSIDE?

128
00:07:13,062 --> 00:07:16,099
TURNS OUT THAT ALL OF THE
TERRESTRIAL PLANETS -- AND BY

129
00:07:16,099 --> 00:07:18,434
THAT, I MEAN THE ROCKY
PLANETS -- ALL HAVE THE SAME

130
00:07:18,434 --> 00:07:19,986
BASIC STRUCTURE.

131
00:07:19,986 --> 00:07:24,073
THEY ALL HAVE A CORE AT THE
CENTER WHICH IS MADE OF MOSTLY

132
00:07:24,073 --> 00:07:27,343
IRON AND NICKEL, THE HEAVY
METALS.

133
00:07:27,343 --> 00:07:33,249
IT'S SURROUNDED BY A MANTLE OF
SILICOT ROCKS, BUT DENSER THAN

134
00:07:33,249 --> 00:07:35,385
YOU PICK UP ON THE SURFACE OF
THE PLANET BECAUSE THEY'RE UNDER

135
00:07:35,385 --> 00:07:38,354
A LOT OF PRESSURE, AND SO THE
ATOMS HAVE ARRANGED THEMSELVES

136
00:07:38,354 --> 00:07:42,141

INTO A MUCH DENSER STRUCTURE, SO
THERE ARE MINERALS THAT WE DON'T

137

00:07:42,141 --> 00:07:43,243

USUALLY FIND ON THE SURFACE.

138

00:07:43,243 --> 00:07:49,215

AND THEN ON THE VERY OUTER PART
OF THE PLANET, WE HAVE A CRUST

139

00:07:49,215 --> 00:07:51,351

WHICH IS MADE UP OF LIGHTER
MINERALS, LIGHTER ROCKS THAT

140

00:07:51,351 --> 00:07:54,454

HAVE A LITTLE BIT DIFFERENT
COMPOSITION THAN THE MANTLE, AND

141

00:07:54,454 --> 00:07:57,457

THOSE ARE THE ROCKS THAT WE
INTERACT WITH ON A DAILY BASIS.

142

00:07:57,457 --> 00:08:01,244

ALL THE PLANETS HAVE THE SAME
BASIC STRUCTURE, BUT THE

143

00:08:01,244 --> 00:08:04,197

RELATIVE SIZES OF THOSE
DIFFERENT PIECES ARE DIFFERENT

144

00:08:04,197 --> 00:08:07,383

FOR THE DIFFERENT PLANETS, AND
THERE ARE DETAILED DIFFERENCES

145

00:08:07,383 --> 00:08:11,154

IN THE CHEMISTRY.

146

00:08:11,154 --> 00:08:13,289

THERE ARE A LOT OF FINE
DIFFERENCES, AND THOSE

147

00:08:13,289 --> 00:08:16,142

DIFFERENCES ARE VERY IMPORTANT
IN SORT OF THE EVOLUTIONARY

148

00:08:16,142 --> 00:08:18,344

PATHS THAT PLANETS CAN TAKE.

149

00:08:18,344 --> 00:08:23,032

SO, WE'D LIKE TO UNDERSTAND THAT
PROCESS.

150

00:08:23,032 --> 00:08:26,152

ONE COULD SAY IF YOU WANT TO
UNDERSTAND HOW A TERRESTRIAL

151

00:08:26,152 --> 00:08:29,022

PLANET IS BUILT, WE'VE GOT A
PERFECTLY GOOD TERRESTRIAL

152

00:08:29,022 --> 00:08:30,273

PLANET RIGHT UNDER OUR FEET.

153

00:08:30,273 --> 00:08:31,391

WHY NOT STUDY THAT ONE?

154

00:08:31,391 --> 00:08:36,045

AND WE DO STUDY THAT ONE A LOT,
BUT THERE ARE SOME DRAWBACKS TO

155

00:08:36,045 --> 00:08:39,232

TRYING TO UNDERSTAND THE VERY
EARLIEST PROCESSES ON THE EARTH.

156

00:08:39,232 --> 00:08:42,201

AND TURNS OUT THAT MUCH OF THE
EVIDENCE THAT WE'D LIKE TO SEE

157

00:08:42,201 --> 00:08:45,421

ON THE EARTH HAS BEEN SORT OF
SCRAMBLED UP AND ERASED BY THE

158

00:08:45,421 --> 00:08:51,110

FACT THAT EARTH IS A VERY
VIGOROUS HEAT ENGINE, AND WE

159

00:08:51,110 --> 00:08:53,379

HAVE THINGS LIKE PLATE
TECTONICS, WHICH IS RECYCLING

160

00:08:53,379 --> 00:08:58,117

THE CRUST ON SORT OF 100 MILLION
YEAR TIME SCALE.

161

00:08:58,117 --> 00:09:00,370

SO YOU CAN'T GO UP AND PICK UP A
ROCK ANYWHERE ON THE EARTH

162

00:09:00,370 --> 00:09:04,040

THAT'S MORE THAN ABOUT 3.8
BILLION YEARS OLD, AND WE'VE GOT

163

00:09:04,040 --> 00:09:07,160

ABOUT 600 MILLION YEARS OF
ACTIVITY BEFORE THAT.

164

00:09:07,160 --> 00:09:09,395

WHEN YOU GO INTO THE MANTLE AND
YOU WANT TO LOOK AT THE

165

00:09:09,395 --> 00:09:12,298

STRUCTURE OF THE MANTLE, THE
MANTLE'S ACTUALLY -- THE MANTLE

166

00:09:12,298 --> 00:09:16,319

OF THE EARTH ACTUALLY CONVECTS
FAIRLY VIGOROUSLY.

167

00:09:16,319 --> 00:09:21,007

SO, YOU HAVE HOT ROCKS RISING,
COOLER ROCKS SINKING, AND SO,

168

00:09:21,007 --> 00:09:23,459

WHATEVER STRUCTURAL EVIDENCE YOU
WOULD HAVE IN THE MANTLE FROM

169

00:09:23,459 --> 00:09:28,181

4 1/2 BILLION YEARS AGO HAS BEEN
PRETTY MUCH JUST STIRRED UP AND

170

00:09:28,181 --> 00:09:28,431

ERASED.

171

00:09:28,431 --> 00:09:32,318

SO, WE CAN FIND OUT A LOT OF
THINGS ABOUT PLANETS BY STUDYING

172

00:09:32,318 --> 00:09:38,307

THE EARTH, BUT WE CAN'T REALLY
LOOK BACK IN THOSE FIRST -- THE

173

00:09:38,307 --> 00:09:40,410

FIRST FEW MOMENTS OF PLANET
FORMATION.

174

00:09:40,410 --> 00:09:44,130

THE MOON'S ANOTHER PLACE YOU
MIGHT GO, AND WE DID GO TO THE

175

00:09:44,130 --> 00:09:44,297

MOON.

176

00:09:44,297 --> 00:09:46,265

WE DID THE SAME KINDS OF
INVESTIGATIONS ON THE MOON THAT

177

00:09:46,265 --> 00:09:48,000

WE'RE TALKING ABOUT DOING ON
MARS.

178

00:09:48,000 --> 00:09:53,272

BUT THE PROBLEM WITH THE MOON IS
IT RETAINS A LOT OF THE EARLIEST

179

00:09:53,272 --> 00:09:57,477

STRUCTURE BECAUSE IT'S BEEN
FAIRLY DEAD FOR A LONG TIME, BUT

180

00:09:57,477 --> 00:10:02,415

IT'S SO SMALL THAT THE PROCESSES
THAT WE'RE INTERESTED IN, WHICH

181

00:10:02,415 --> 00:10:06,436

ARE VERY SENSITIVE TO
TEMPERATURE AND PRESSURE NEVER

182

00:10:06,436 --> 00:10:10,223

HAPPENED ON THE MOON, BECAUSE IF
YOU GO ALL THE WAY DOWN TO THE

183

00:10:10,223 --> 00:10:13,159

CENTER OF THE MOON, YOU'RE
REALLY JUST BARELY BELOW THE

184

00:10:13,159 --> 00:10:14,377

CRUST ON THE EARTH.

185

00:10:14,377 --> 00:10:15,428

IT HAS LOW GRAVITY.

186

00:10:15,428 --> 00:10:18,314

YOU DON'T HAVE THAT MANY ROCKS
ON TOP OF YOU WHEN YOU GET DOWN

187

00:10:18,314 --> 00:10:18,481

THERE.

188

00:10:18,481 --> 00:10:22,235

AND SO, THE PRESSURE AND
TEMPERATURE CONDITIONS DON'T

189

00:10:22,235 --> 00:10:26,489
REALLY GIVE US MUCH INSIGHT INTO
WHAT GOES ON INSIDE A LARGER

190

00:10:26,489 --> 00:10:27,156
PLANET.

191

00:10:27,156 --> 00:10:31,110
SO, MARS, IT TURNS OUT, IS KIND
OF THE IDEAL PLACE TO GO.

192

00:10:31,110 --> 00:10:34,213
IT'S BIG ENOUGH TO HAVE
UNDERGONE ALL OF THE DIFFERENT

193

00:10:34,213 --> 00:10:37,200
PROCESSES THAT WE'RE INTERESTED
IN, OR MOST OF THE PROCESSES

194

00:10:37,200 --> 00:10:38,284
WE'RE INTERESTED IN.

195

00:10:38,284 --> 00:10:41,437
IT WILL TAKE US DOWN MOST OF THE
WAY THROUGH THE UPPER MANTLE AND

196

00:10:41,437 --> 00:10:46,392
A LITTLE WAY INTO THE LOWER
MANTLE IN TERMS OF PRESSURE AND

197

00:10:46,392 --> 00:10:50,396
TEMPERATURE, BUT WE HAVE
EVIDENCE FROM LOOKING AT THE

198

00:10:50,396 --> 00:10:53,466
ISOTOPE RATIOS AND MARTIAN
METEORITES THAT HAVE COME TO

199

00:10:53,466 --> 00:10:56,285

EARTH BY LOOKING AT THE DENSITY
OF CRATERS ON THE SURFACE,

200

00:10:56,285 --> 00:11:00,490

THERE'S EVIDENCE THAT MARS
REALLY HASN'T CHANGED MUCH ON A

201

00:11:00,490 --> 00:11:04,210

GROWTH SINCE ABOUT, OH,
MAYBE 100, 200 MILLION YEARS

202

00:11:04,210 --> 00:11:05,161

AFTER IT FORMED.

203

00:11:05,161 --> 00:11:07,346

AND ALL THE INTERESTING STUFF ON
A PLANET, ALL THE INTERESTING

204

00:11:07,346 --> 00:11:11,367

STUFF TO ME, AT LEAST, HAPPENED
IN ABOUT THE FIRST MAYBE 20 TO

205

00:11:11,367 --> 00:11:14,137

MAYBE 100 MILLION YEARS AFTER
ITS FORMATION.

206

00:11:14,137 --> 00:11:18,508

THAT'S WHEN YOU GO FROM BEING
NOT A PLANET TO A PLANET, MUCH

207

00:11:18,508 --> 00:11:21,060

LIKE WE SEE TODAY.

208

00:11:21,060 --> 00:11:23,062

SO, HOW DO WE MAKE A PLANET?

209

00:11:23,062 --> 00:11:24,147

WE HAVE A ROUGH IDEA.

210

00:11:24,147 --> 00:11:28,034

WE HAVE A PRETTY GOOD IDEA OF
THE BASIC WAYS THAT WE FORM A

211

00:11:28,034 --> 00:11:28,217

PLANET.

212

00:11:28,217 --> 00:11:31,487

FIRST OF ALL, YOU HAVE A SOLAR
NEBULA.

213

00:11:31,487 --> 00:11:34,357

YOU HAVE DUST THAT'S KIND OF
ORBITING AROUND THE SUN.

214

00:11:34,357 --> 00:11:42,465

IT'S MADE OUT OF METEORITIC
MATERIAL, C-1 CONDRITE IS A GOOD

215

00:11:42,465 --> 00:11:44,383

SAMPLE OF THE EARLY SOLAR
SYSTEM.

216

00:11:44,383 --> 00:11:52,091

AND SO, IT STARTS -- THESE DUST
PARTICLES START TO GLOMERATE

217

00:11:52,091 --> 00:11:53,359

TOGETHER FROM THEIR INTERACTION.

218

00:11:53,359 --> 00:11:57,213

AS IT GETS BIGGER, THE PIECES
GET BIGGER, BIGGER PIECES KIND

219

00:11:57,213 --> 00:11:59,232

OF MERGE INTO EVEN BIGGER
PIECES.

220

00:11:59,232 --> 00:12:02,335

IT GROWS AND THE INTERIOR STARTS
TO HEAT UP, AND THAT HEATS UP

221

00:12:02,335 --> 00:12:06,239

BOTH FROM JUST THE ENERGY OF
THESE THINGS BANGING TOGETHER --

222

00:12:06,239 --> 00:12:09,292

THERE'S KINETIC ENERGY THAT'S
TURNED INTO HEAT, THERE'S A

223

00:12:09,292 --> 00:12:11,043

PRESSURE INCREASES.

224

00:12:11,043 --> 00:12:14,447

YOU GET ADIOBATIC HEATING FROM
THE PRESSURE BUILDING UP, AND

225

00:12:14,447 --> 00:12:18,417

YOU ALSO GET IT STARTING TO HEAT
UP FROM THE RADIOACTIVE DECAY OF

226

00:12:18,417 --> 00:12:22,154

THE RADIOACTIVE ELEMENTS THAT
MAKE UP A SMALL PORTION OF ALL

227

00:12:22,154 --> 00:12:27,026

OUR ROCKS, SO IT STARTS TO HEAT
UP, IT GETS LARGER, THE INTERIOR

228

00:12:27,026 --> 00:12:33,216

STARTS TO MELT, STUFF HAPPENS,
AND YOU END UP WITH A PLANET.

229

00:12:33,216 --> 00:12:36,485

OKAY, SO, THAT'S WHERE INSIGHT
COMES IN.

230

00:12:36,485 --> 00:12:38,120
[LAUGHTER]
WE'RE GOING TO FIGURE OUT WHAT

231
00:12:38,120 --> 00:12:38,404
THAT STUFF IS.

232
00:12:38,404 --> 00:12:42,058
AND IF YOU THINK ABOUT IT, IT'S
ACTUALLY KIND OF AMAZING, YOU

233
00:12:42,058 --> 00:12:42,258
KNOW.

234
00:12:42,258 --> 00:12:45,511
YOU START OFF WITH THIS SOLAR
NEBULA, WHICH IS ESSENTIALLY

235
00:12:45,511 --> 00:12:47,129
PRETTY HOMOGENEOUS.

236
00:12:47,129 --> 00:12:55,238
LIKE I SAID, YOU HAVE THIS KIND
OF CARBONATIOUS CONDRIITE OF

237
00:12:55,238 --> 00:12:58,140
MATERIAL, YOU HAVE ICE FLEETING
AROUND IN IT, BUT BASICALLY,

238
00:12:58,140 --> 00:13:02,111
IT'S HOMOGENEOUS, AND YOU END UP
WITH A PLANET THAT'S GOT THESE

239
00:13:02,111 --> 00:13:06,415
THREE SORT OF BASIC DIFFERENT
ZONES, THE CRUST, MANTLE AND

240
00:13:06,415 --> 00:13:09,185
CORE, DIFFERENT COMPOSITIONS.

241

00:13:09,185 --> 00:13:11,153

AND NOWHERE ON THIS PLANET -- IF
YOU WALK AROUND THE EARTH, YOU

242

00:13:11,153 --> 00:13:14,457

PICK UP ROCKS AND YOU ANALYZE
THEM, YOU'LL NEVER FIND A ROCK

243

00:13:14,457 --> 00:13:18,411

THAT HAS THE SAME COMPOSITION AS
THESE DUST PARTICLES THAT YOU

244

00:13:18,411 --> 00:13:21,380

START OUT WITH, UNLESS YOU
HAPPEN TO PICK UP A METEORITE

245

00:13:21,380 --> 00:13:24,350

THAT JUST FELL DOWN, BUT THAT
DOESN'T COUNT.

246

00:13:24,350 --> 00:13:28,354

EVERYTHING ON THE EARTH HAS BEEN
CHANGED, YOU KNOW.

247

00:13:28,354 --> 00:13:32,208

IT'S LIKE A CATERPILLAR'S GONE
INTO THIS COCOON AND COME OUT A

248

00:13:32,208 --> 00:13:32,408

BUTTERFLY.

249

00:13:32,408 --> 00:13:35,227

THERE ARE NO CATERPILLAR ROCKS
LEFT ON THE EARTH TODAY.

250

00:13:35,227 --> 00:13:38,281

IT'S GONE THROUGH THIS PROCESS
WHICH WE CALL DIFFERENTIATION,

251

00:13:38,281 --> 00:13:44,203
AND ALL THE ROCKS HAVE BEEN
TURNED INTO OTHER ROCKS, AND

252

00:13:44,203 --> 00:13:47,440
THIS PROCESS OF DIFFERENTIATION
IS WHAT WE WANT TO STUDY.

253

00:13:47,440 --> 00:13:50,042
THE WAY DIFFERENTIATION WORKS,
WE ACTUALLY WORKED THIS OUT

254

00:13:50,042 --> 00:13:52,094
USING INFORMATION THAT WE GOT
FROM THE MOON.

255

00:13:52,094 --> 00:13:55,164
THIS IS CALLED THE LUNAR MAGMA
OCEAN MODEL.

256

00:13:55,164 --> 00:13:58,250
THE MAGMA OCEAN MEANS THAT YOU
START OFF WITH A PLANET THAT IS

257

00:13:58,250 --> 00:14:01,237
MOSTLY OR MAYBE EVEN COMPLETELY
MOLTEN FROM ALL THIS HEAT THAT

258

00:14:01,237 --> 00:14:04,390
WAS GENERATED DURING ITS
FORMATION, OKAY?

259

00:14:04,390 --> 00:14:07,209
AND AS IT COOLS, SOME DIFFERENT
THINGS HAPPEN.

260

00:14:07,209 --> 00:14:10,329
FOR ONE THING, BECAUSE OF
GRAVITY, WHEN YOU HAVE THINGS

261

00:14:10,329 --> 00:14:13,382
THAT ARE CONDENSING OUT OF THIS
MELT -- AND THE FIRST THING THAT

262
00:14:13,382 --> 00:14:17,403
CONDENSES OUT IS YOU ACTUALLY
HAVE THESE ATOMS OF IRON AND

263
00:14:17,403 --> 00:14:20,389
NICKEL AND THINGS LIKE THAT THAT
ARE FLOATING IN THIS MELT, AND

264
00:14:20,389 --> 00:14:23,225
THEY START TO CONDENSE TOGETHER
INTO DROPLETS.

265
00:14:23,225 --> 00:14:27,213
AND WHEN THEY CONDENSE, THEY
FORM THESE DROPLETS WHICH ARE

266
00:14:27,213 --> 00:14:29,382
ABOUT TWICE AS HEAVY AS THE
MATERIAL AROUND THEM.

267
00:14:29,382 --> 00:14:33,486
AND SO, THE FIRST THING THEY DO
IS THEY START TO GO DOWN TO THE

268
00:14:33,486 --> 00:14:34,153
CENTER.

269
00:14:34,153 --> 00:14:37,323
THE GRAVITY PULLS THEM DOWN TO
FORM THIS METALLIC CORE.

270
00:14:37,323 --> 00:14:43,496
AS IT GETS A LITTLE BIT COOLER,
WHAT HAPPENS IS THEN THE

271
00:14:43,496 --> 00:14:46,349

SILICATE START TO CRYSTALLIZE.

272

00:14:46,349 --> 00:14:51,520

AND THIS IS A VERY COMPLICATED
PHYSICAL-CHEMICAL PROCESS OF

273

00:14:51,520 --> 00:14:52,521

CRYSTALLIZATION.

274

00:14:52,521 --> 00:14:56,258

SO, AS THE MELT GETS COOLER, YOU
HAVE CERTAIN MINERALS WHICH

275

00:14:56,258 --> 00:14:59,378

CONDENSE AT HIGHER TEMPERATURES,
AND SO, IT STARTS TO CRYSTALLIZE

276

00:14:59,378 --> 00:15:02,198

OUT AT RELATIVELY HIGH
TEMPERATURES.

277

00:15:02,198 --> 00:15:05,117

IF THEY'RE HEAVIER, AND IT TURNS
OUT THAT THE ONES THAT

278

00:15:05,117 --> 00:15:07,319

CRYSTALLIZE AT THE HIGHEST
TEMPERATURES ARE HEAVIER,

279

00:15:07,319 --> 00:15:10,439

THEY'LL TEND TO SINK DOWN TO THE
BOTTOM AS WELL.

280

00:15:10,439 --> 00:15:15,411

BUT WHAT IF YOU HAVE THIS
MATERIAL CONVECTING?

281

00:15:15,411 --> 00:15:19,165

IF YOU HAVE A LOT OF HEAT COMING
OUT, IT'S GOING TO BE BOILING

282

00:15:19,165 --> 00:15:23,319

MORE OR LESS LIKE A CUP OF
COFFEE AS YOU PUT IT ON THE OVEN

283

00:15:23,319 --> 00:15:26,288

OR ON THE STOVE, AND IT WILL
TEND TO MIX IT UP.

284

00:15:26,288 --> 00:15:30,076

SO, IF THESE CRYSTALS ARE SORT
OF ENTRAINED IN THIS CONVECTING

285

00:15:30,076 --> 00:15:35,281

SYSTEM, WHAT HAPPENS IS AS THAT
COOLS DOWN MORE, THESE THINGS

286

00:15:35,281 --> 00:15:39,318

WILL BE REMELTED INTO THE MIX AS
THE COMPOSITION OF THE MELT

287

00:15:39,318 --> 00:15:39,502

CHANGES.

288

00:15:39,502 --> 00:15:42,488

AND SO, THE CRYSTALS THAT COME
OUT OF THE MELT WILL CHANGE AS

289

00:15:42,488 --> 00:15:44,473

YOU TAKE THINGS OUT.

290

00:15:44,473 --> 00:15:47,126

SO, WHEN THESE THINGS FIRST
START TO CRYSTALLIZE OUT AND

291

00:15:47,126 --> 00:15:51,230

FALL TO THE BOTTOM, THEN YOU'LL
ACTUALLY END UP WITH HIGHER

292

00:15:51,230 --> 00:15:53,032
CONCENTRATION OF THE STUFF
THAT'S LEFT.

293
00:15:53,032 --> 00:15:56,052
YOU'LL TAKE OUT SOME THINGS WITH
THIS, YOU'LL LEAVE SOME THINGS

294
00:15:56,052 --> 00:15:58,053
BEHIND, DIFFERENT THINGS WILL
START TO CRYSTALLIZE.

295
00:15:58,053 --> 00:16:02,374
AND SO, YOU'LL GET A PILE OF
STUFF THAT'S PILING UP HERE OF

296
00:16:02,374 --> 00:16:07,229
DIFFERENT COMPOSITIONS, AND HOW
THAT FORMS DEPENDS ON WHETHER

297
00:16:07,229 --> 00:16:09,999
THINGS ARE MOVING AROUND,
WHETHER IT'S STILL, WHETHER IT

298
00:16:09,999 --> 00:16:12,268
COOLS OFF QUICKLY, WHETHER IT
COOLS OFF SLOWLY.

299
00:16:12,268 --> 00:16:15,438
THERE'S LOTS OF THINGS THAT CAN
HAPPEN.

300
00:16:15,438 --> 00:16:18,357
AND AT THE VERY END, YOU'LL END
UP WITH GENERALLY THINGS THAT

301
00:16:18,357 --> 00:16:21,410
ARE HEAVIER AT THE BOTTOM,
LIGHTER AT THE TOP, AND SO, YOU

302

00:16:21,410 --> 00:16:23,996
HAVE YOUR CORE, MANTLE AND
CRUST.

303
00:16:23,996 --> 00:16:27,116
BUT THE DETAILS OF THIS PROCESS,
HOW YOU PUT TOGETHER THESE

304
00:16:27,116 --> 00:16:31,303
THINGS, IS VERY DEPENDENT, AS I
SAID, ON THE PHYSICS AND THE

305
00:16:31,303 --> 00:16:33,105
CHEMISTRY THAT GOES ON.

306
00:16:33,105 --> 00:16:36,442
SO, WHAT WE WOULD LIKE TO DO IS
UNDERSTAND THESE PROCESSES A

307
00:16:36,442 --> 00:16:41,046
LITTLE BETTER, AND WE CAN DO
THAT WITH SOME RELATIVELY SIMPLE

308
00:16:41,046 --> 00:16:43,349
MEASUREMENTS.

309
00:16:43,349 --> 00:16:49,405
SO, THE IDEAL THING WOULD BE TO
TAKE A ROCK SUBMARINE AND JUST

310
00:16:49,405 --> 00:16:52,374
DIVE, DIVE, DIVE DOWN, TAKE SOME
ROCKS OFF, PUT THEM IN OUR

311
00:16:52,374 --> 00:16:55,344
LABORATORY, FIGURE OUT WHAT THE
PLANET'S MADE OUT OF, AND THEN

312
00:16:55,344 --> 00:16:57,329
YOU COULD PUT IT ALL TOGETHER.

313

00:16:57,329 --> 00:17:01,116

UNFORTUNATELY, WE'RE KIND OF
STUCK UP HERE ON THE TOP AND WE

314

00:17:01,116 --> 00:17:04,220

CAN ONLY DRILL DOWN MAYBE, YOU
KNOW, 10 OR 20 KILOMETERS, WHICH

315

00:17:04,220 --> 00:17:07,122

DOESN'T EVEN GET US DOWN INTO
THE MANTLE, SO WE HAVE TO GET A

316

00:17:07,122 --> 00:17:11,060

LITTLE BIT CLEVER ABOUT HOW WE
MAKE THESE MEASUREMENTS.

317

00:17:11,060 --> 00:17:14,430

TURNS OUT THAT THE MODELS THAT
WE PUT TOGETHER USING THE

318

00:17:14,430 --> 00:17:18,284

PHYSICS AND CHEMISTRY THAT WE'VE
WORKED OUT IN THE LABORATORY

319

00:17:18,284 --> 00:17:21,403

WITH HIGH TEMPERATURE AND HIGH
PRESSURE EXPERIMENTS, WE KIND OF

320

00:17:21,403 --> 00:17:25,107

KNOW WHAT SOME OF THE REACTIONS
ARE, SOME OF THE CHEMISTRY THAT

321

00:17:25,107 --> 00:17:28,427

GOES ON, BUT WE NEED TO KNOW
WHAT THE CONDITIONS ARE IN THE

322

00:17:28,427 --> 00:17:31,463

INSIDE OF THE PLANET AND WHAT WE
ENDED UP WITH.

323

00:17:31,463 --> 00:17:34,400

AND SO, WHAT WE KNOW ARE SOME
FAIRLY SIMPLE THINGS.

324

00:17:34,400 --> 00:17:36,135

WE KNOW ABOUT THE CRUST.

325

00:17:36,135 --> 00:17:39,355

WE CAN MEASURE ITS THICKNESS,
HOW THICK THAT CRUST IS, WHICH

326

00:17:39,355 --> 00:17:43,275

TELLS US BASICALLY HOW MUCH OF
THIS STUFF IS UP ON THE TOP.

327

00:17:43,275 --> 00:17:50,032

THIS IS KIND OF A SCUM THAT'S
FLOATED UP TO THE TOP, AND THE

328

00:17:50,032 --> 00:17:52,201

AMOUNT OF SCUM THAT YOU HAVE
THERE -- SCUM OF THE EARTH, SO

329

00:17:52,201 --> 00:17:54,470

TO SPEAK -- THE AMOUNT OF SCUM
DEPENDS ON HOW MUCH OF THIS

330

00:17:54,470 --> 00:17:56,188

PLANET WAS MELTED TO BEGIN WITH.

331

00:17:56,188 --> 00:17:58,457

IF THE WHOLE THING WAS MELTED,
YOU'LL HAVE A THICKER CRUST.

332

00:17:58,457 --> 00:18:01,093

IF PART OF IT WAS MELTED, YOU'LL
HAVE A THINNER CRUST.

333

00:18:01,093 --> 00:18:06,448
AND SO, THAT GIVES YOU ONE OF
THE CONSTRAINTS RIGHT AWAY ON

334
00:18:06,448 --> 00:18:08,100
THE CONDITIONS OF THE PLANET.

335
00:18:08,100 --> 00:18:10,336
ANOTHER THING YOU'D LIKE TO KNOW
IS WHETHER THERE IS ANY

336
00:18:10,336 --> 00:18:12,121
LARGE-SCALE LAYERING IN THE
CRUST.

337
00:18:12,121 --> 00:18:14,240
IN OTHER WORDS, WHEN WE HAD
THESE DIFFERENT CRYSTALS FORMING

338
00:18:14,240 --> 00:18:16,458
AT DIFFERENT TIMES, WERE THEY
LEFT ALONE SO THEY COULD JUST

339
00:18:16,458 --> 00:18:19,328
KIND OF STACK ON TOP OF EACH
OTHER OR UNDERNEATH EACH OTHER,

340
00:18:19,328 --> 00:18:22,464
AS THE CASE MAY BE, OR DID THE
WHOLE THING GET TURNED OVER AT

341
00:18:22,464 --> 00:18:23,315
SOME POINT?

342
00:18:23,315 --> 00:18:29,104
BECAUSE WHAT HAPPENS IS
SOMETIMES YOU HAVE HEAVIER STUFF

343
00:18:29,104 --> 00:18:32,024
BEING ACCUMULATED ON THE SURFACE

FIRST, AND THEN YOU HAVE LIGHTER

344

00:18:32,024 --> 00:18:36,161

THINGS THAT CRYSTALLIZE OUT
LATER, AND THEN YOU HAVE

345

00:18:36,161 --> 00:18:38,197

INSTABILITY HERE, THOSE LIGHT
THINGS THAT LIKE TO GET UP TO

346

00:18:38,197 --> 00:18:42,051

THE TOP, SO YOU CAN ACTUALLY
HAVE THINGS THAT TURN OVER,

347

00:18:42,051 --> 00:18:43,402

REMIX AND STUFF LIKE THAT.

348

00:18:43,402 --> 00:18:47,406

SO, IF WE CAN MEASURE WHETHER
THERE ARE DIFFERENT COMPOSITIONS

349

00:18:47,406 --> 00:18:50,125

AS YOU GO DOWN THROUGH THIS
CRUST, THAT TELLS YOU SOMETHING.

350

00:18:50,125 --> 00:18:53,128

IN THE MANTLE, WE'D LIKE TO KNOW
HOW THE MANTLE'S WORKING IN

351

00:18:53,128 --> 00:18:56,081

TERMS OF ITS DYNAMICS, ITS
THERMAL PROPERTIES.

352

00:18:56,081 --> 00:18:58,083

THAT'S REALLY WHERE THE HEAT
ENGINE REALLY WORKS.

353

00:18:58,083 --> 00:19:01,153

YOU KIND OF PUSH HEAT OUT OF THE
CORE AND YOU KIND OF PULL IT OUT

354

00:19:01,153 --> 00:19:04,423

AT THE CRUST, BUT ALL THE WORK
IS REALLY DONE HERE IN THE

355

00:19:04,423 --> 00:19:09,094

MANTLE, SO WE'D LIKE TO KNOW ITS
THERMAL STRUCTURE, YOU KNOW,

356

00:19:09,094 --> 00:19:13,098

WHETHER WE HAVE A RELATIVELY
SHALLOW THERMAL GRADIENT AS YOU

357

00:19:13,098 --> 00:19:15,301

GO THROUGH HERE, WHETHER WE HAVE
CONVECTION GOING ON THAT PULLS

358

00:19:15,301 --> 00:19:18,220

HEAT OUT QUICKLY, OR WHETHER
IT'S JUST CONDUCTING HEAT OUT,

359

00:19:18,220 --> 00:19:19,221

WHICH IS A SLOWER PROCESS.

360

00:19:19,221 --> 00:19:22,408

SO, WE'D LIKE TO UNDERSTAND THE
THERMAL PROPERTIES OF THE

361

00:19:22,408 --> 00:19:25,311

MANTLE, AND TO SOME EXTENT, WE'D
LIKE TO KNOW ABOUT ITS

362

00:19:25,311 --> 00:19:27,446

STRATIFICATION IN TERMS OF
WHETHER YOU HAVE DIFFERENT

363

00:19:27,446 --> 00:19:32,201

MINERALS AT THE UPPER PARTS OR
RELATIVE TO THE ONES DEEPER

364
00:19:32,201 --> 00:19:32,351
DOWN.

365
00:19:32,351 --> 00:19:35,404
AND SO, THAT'S WHAT WE'D LIKE TO
KNOW ABOUT THE MANTLE.

366
00:19:35,404 --> 00:19:38,223
IN TERMS OF THE CORE, WHAT WE'D
REALLY LIKE TO KNOW IS THE SIZE

367
00:19:38,223 --> 00:19:42,277
OF THE CORE, HOW MUCH METAL IS
DOWN THERE, WHAT ITS COMPOSITION

368
00:19:42,277 --> 00:19:45,397
IS, WHICH WE CAN GET FROM ITS
DENSITY, AND ITS STATE, WHETHER

369
00:19:45,397 --> 00:19:47,333
IT'S LIQUID OR SOLID.

370
00:19:47,333 --> 00:19:50,269
AND THOSE THREE PARAMETERS
ACTUALLY TELL US A WHOLE LOT

371
00:19:50,269 --> 00:19:53,372
ABOUT THOSE EARLIEST PROCESSES
IN THE PLANET, BECAUSE AS THOSE

372
00:19:53,372 --> 00:19:58,494
DROPLETS ARE COMING DOWN THROUGH
THE MOLTEN PLANET, THEY'RE

373
00:19:58,494 --> 00:20:00,195
PICKING UP IMPURITIES.

374
00:20:00,195 --> 00:20:04,283
SO, WE MAY HAVE NOT JUST

METALLIC IRON, WE MIGHT HAVE

375

00:20:04,283 --> 00:20:08,287

THINGS LIKE SULFUR, WE MIGHT
HAVE SOME CARBON DOWN THERE.

376

00:20:08,287 --> 00:20:11,023

THERE'S OTHER ELEMENTS THAT
COULD GO DOWN THERE WHICH TELL

377

00:20:11,023 --> 00:20:13,459

US HOW MUCH OF THAT WAS PICKED
UP AS WE GO DOWN, WHETHER THE

378

00:20:13,459 --> 00:20:16,328

SMALL DROPLETS CAME DOWN
QUICKLY, WHETHER BIG GLOBS CAME

379

00:20:16,328 --> 00:20:18,213

DOWN SLOWLY, THINGS LIKE THAT.

380

00:20:18,213 --> 00:20:21,133

SO, IT GIVES US INFORMATION
ABOUT THE DYNAMICS.

381

00:20:21,133 --> 00:20:25,521

BUT IT TURNS OUT THAT ALSO
RELEVANT FOR ANOTHER REASON IS

382

00:20:25,521 --> 00:20:29,391

IF YOU MIX IN LIGHTER ELEMENTS
INTO THIS METALLIC CORE, THAT

383

00:20:29,391 --> 00:20:32,277

CHANGES ITS MELTING
TEMPERATURES, LIKE DISSOLVING

384

00:20:32,277 --> 00:20:33,329

SALT IN WATER.

385

00:20:33,329 --> 00:20:36,231

YOU CAN CHANGE THE FREEZING
TEMPERATURE OF WATER.

386

00:20:36,231 --> 00:20:39,485

YOU CAN MELT ICE ON A SIDEWALK
BY PUTTING SALT ON IT.

387

00:20:39,485 --> 00:20:45,107

YOU CAN ACTUALLY CAUSE THE CORE
TO STAY MOLTEN AT LOWER

388

00:20:45,107 --> 00:20:46,508

TEMPERATURES IF YOU MIX IN SOME
SULFUR.

389

00:20:46,508 --> 00:20:51,263

AND SO, THAT HAS IMPLICATIONS
FOR THINGS LIKE MAGNETIC FIELD.

390

00:20:51,263 --> 00:20:54,366

MAGNETIC FIELD, IT TURNS OUT,
HAS IMPLICATIONS FOR, YOU KNOW,

391

00:20:54,366 --> 00:20:58,554

KEEPING THE ATMOSPHERE, AS THE
MAVEN MISSION IS INVESTIGATING

392

00:20:58,554 --> 00:20:59,471

RIGHT NOW AROUND MARS.

393

00:20:59,471 --> 00:21:04,493

AND SO, ALL THESE THINGS ARE
CONNECTED NOT JUST TO THE

394

00:21:04,493 --> 00:21:08,430

ORIGINAL EVOLUTION OF THE PLANET
AND ITS FORMATION, THEY'RE ALSO

395

00:21:08,430 --> 00:21:11,200
CONNECTED TO THE EVOLUTION OF
THE PLANET'S HABITABILITY.

396
00:21:11,200 --> 00:21:16,288
AND SO, ALL THESE KIND OF TIE
TOGETHER IN THE END.

397
00:21:16,288 --> 00:21:20,476
SO, THIS IS ACTUALLY A FAIRLY
EASY BUNCH OF THINGS TO MEASURE.

398
00:21:20,476 --> 00:21:24,279
SO, WE TAKE ALL THESE THINGS, WE
PUT THEM INTO A LIST, AND THIS

399
00:21:24,279 --> 00:21:29,251
IS WHAT WE CALL OUR LEVEL ONE
REQUIREMENTS.

400
00:21:29,251 --> 00:21:31,353
THIS LIST OF MEASUREMENTS ARE
THE ONES THAT I BASICALLY SIGNED

401
00:21:31,353 --> 00:21:33,255
UP TO DO FOR NASA.

402
00:21:33,255 --> 00:21:36,258
YOU KNOW, WHEN WE PUT TOGETHER
THIS MISSION AS A PROPOSAL ABOUT

403
00:21:36,258 --> 00:21:41,096
FIVE YEARS AGO, WE WERE
COMPETING AGAINST ABOUT 25 OR 30

404
00:21:41,096 --> 00:21:43,282
OTHER MISSIONS, ONE OF THE
THINGS YOU HAVE TO DO WHEN YOU

405
00:21:43,282 --> 00:21:46,068

PUT TOGETHER THIS PROPOSAL IS
SAY THESE ARE THE THINGS I'M

406

00:21:46,068 --> 00:21:48,387
GOING TO MEASURE, THESE ARE THE
SCIENTIFIC QUESTIONS THAT THOSE

407

00:21:48,387 --> 00:21:49,455
MEASUREMENTS WILL ADDRESS.

408

00:21:49,455 --> 00:21:53,459
AND SO, THESE ARE THE THINGS
THAT I PROMISED, CROSSED MY

409

00:21:53,459 --> 00:21:56,411
HEART AS A BOY SCOUT THAT I
WOULD MEASURE, AND THEY ARE THE

410

00:21:56,411 --> 00:22:02,084
THINGS THAT I LISTED ON THAT
FIRST -- AT THAT EARLIER SLIDE,

411

00:22:02,084 --> 00:22:05,254
WHICH ARE ABOUT SEVEN DIFFERENT
MEASUREMENTS HERE, INCLUDING THE

412

00:22:05,254 --> 00:22:11,143
HEAT FLUX, WHICH TELLS US ABOUT
THE THERMAL PROPERTIES OF THE

413

00:22:11,143 --> 00:22:11,360
MANTLE.

414

00:22:11,360 --> 00:22:15,197
THE REST OF THESE ARE THE
STRUCTURE OF THE PLANET, SORT OF

415

00:22:15,197 --> 00:22:16,398
THE BASIC STRUCTURE OF THE
PLANET.

416

00:22:16,398 --> 00:22:21,203

AND THEN WE GET SOME THINGS DOWN
HERE, MORE OR LESS FOR FREE, BY

417

00:22:21,203 --> 00:22:22,504

THE WAY, WE DO THE MEASUREMENTS.

418

00:22:22,504 --> 00:22:25,457

SO, THESE ARE SORT OF A BASIC
SET OF MEASUREMENTS THAT IF WE

419

00:22:25,457 --> 00:22:30,429

CAN MAKE THESE MEASUREMENTS,
THEN THE PEOPLE WHO HAVE DONE

420

00:22:30,429 --> 00:22:34,166

THEORETICAL CALCULATIONS OF THE
HISTORY OF EARLY PLANETARY

421

00:22:34,166 --> 00:22:36,135

FORMATION CAN USE THEM TO
CONSTRAINT THEIR MODELS AND

422

00:22:36,135 --> 00:22:40,322

UNDERSTAND HOW THE PLANETS ARE
PUT TOGETHER.

423

00:22:40,322 --> 00:22:43,258

OKAY, SO, HOW ARE WE GOING TO DO
THAT?

424

00:22:43,258 --> 00:22:45,244

HOW DO YOU ACTUALLY LOOK DOWN
INTO A PLANET?

425

00:22:45,244 --> 00:22:49,248

HOW DO YOU GET INSIGHT INTO THE
DEPTHS OF A PLANET?

426

00:22:49,248 --> 00:22:52,534

YOU USE GEOPHYSICS.

427

00:22:52,534 --> 00:22:56,388

AND THE MOST EFFECTIVE TOOL WE
HAVE IN GEOPHYSICS IS

428

00:22:56,388 --> 00:22:59,057

SEISMOLOGY, SO WHAT WE HAVE IS A
SEISMOMETER, WHICH IS RIGHT

429

00:22:59,057 --> 00:22:59,241

HERE.

430

00:22:59,241 --> 00:23:02,444

ACTUALLY, WHAT YOU CAN SEE HERE
IS THE WIND AND THERMAL SHIELD

431

00:23:02,444 --> 00:23:05,280

OVER THE SEISMOMETER, BUT I'LL
SHOW YOU A SEISMOMETER IN A

432

00:23:05,280 --> 00:23:06,031

LITTLE BIT.

433

00:23:06,031 --> 00:23:08,383

WE HAVE SOMETHING TO MEASURE THE
HEAT FLOW.

434

00:23:08,383 --> 00:23:09,301

THIS IS CALLED HPQ.

435

00:23:09,301 --> 00:23:13,238

THIS STANDS FOR HEAT FLOW AND
PHYSICAL PROPERTIES PACKAGE.

436

00:23:13,238 --> 00:23:17,292

AND THAT'S GOING TO MEASURE THE
HEAT FLOW, AND IT DOES IT WITH A

437

00:23:17,292 --> 00:23:21,496

MOLE WHICH DRILLS ITSELF DOWN
INTO THE PLANET AND MEASURES ITS

438

00:23:21,496 --> 00:23:22,214

TEMPERATURE.

439

00:23:22,214 --> 00:23:26,084

AND WE DO IT WITH OUR PRECISION
TRACKING, WHICH ARE THESE TWO

440

00:23:26,084 --> 00:23:29,504

THINGS HERE, OUR MEDIUM-GAIN
ANTENNAS, WHICH COMMUNICATE WITH

441

00:23:29,504 --> 00:23:32,090

THE DEEP SPACE NETWORK DISHES
HERE ON THE EARTH.

442

00:23:32,090 --> 00:23:35,427

AND SO, OUR PAYLOAD IS BASICALLY
MADE UP OF THREE INVESTIGATIONS,

443

00:23:35,427 --> 00:23:38,497

ONLY TWO OF WHICH ARE
INSTRUMENTS, BECAUSE THE RADIO

444

00:23:38,497 --> 00:23:41,300

SYSTEM IS MORE OR LESS FOR FREE
BECAUSE WE USE THAT FOR A

445

00:23:41,300 --> 00:23:42,100

COMMUNICATION AS WELL.

446

00:23:42,100 --> 00:23:44,253

SO, WE HAVE A VERY SIMPLE
PAYLOAD.

447

00:23:44,253 --> 00:23:45,254
WE HAVE ONLY TWO INSTRUMENTS.

448
00:23:45,254 --> 00:23:47,472
THAT'S HOW I SOLD IT.

449
00:23:47,472 --> 00:23:49,491
VERY SIMPLE, EASY TO DO.

450
00:23:49,491 --> 00:23:52,511
BUT IF YOU LOOK DOWN A LITTLE
BIT MORE CAREFULLY, WE KIND OF

451
00:23:52,511 --> 00:23:55,430
CHEATED, BECAUSE WE ACTUALLY
HAVE A WHOLE BUNCH OF OTHER

452
00:23:55,430 --> 00:23:58,383
INSTRUMENTS, AND THESE ARE
INSTRUMENTS THAT WE NEED ON THE

453
00:23:58,383 --> 00:24:00,269
SPACECRAFT IN ORDER TO SUPPORT
THE SEISMOLOGY.

454
00:24:00,269 --> 00:24:01,436
NOW, I'LL SHOW YOU WHY THAT IS.

455
00:24:01,436 --> 00:24:06,391
BUT WHAT WE HAVE HERE IS WE HAVE
A FULL-UP WEATHER SYSTEM.

456
00:24:06,391 --> 00:24:08,126
WE MEASURE THE PRESSURE.

457
00:24:08,126 --> 00:24:11,063
WE HAVE PRESSURE SENSORS INSIDE
THE SPACECRAFT AND IT HAS

458

00:24:11,063 --> 00:24:14,082
AINELET UP HERE THAT IS
SPECIALLY DESIGNED TO NEGATE THE

459
00:24:14,082 --> 00:24:16,468
EFFECTS OF WIND SO WE CAN
MEASURE THE PRESSURE WITHOUT

460
00:24:16,468 --> 00:24:20,205
FLUCTUATIONS FROM THE WIND.

461
00:24:20,205 --> 00:24:24,326
WE HAVE AN ANEMOMETER -- A PAIR
OF ANEMOMETERS HERE, CALLED

462
00:24:24,326 --> 00:24:28,413
TWINS, WHICH MEASURE THE WIND
SPEED AND ITS DIRECTION AND ALSO

463
00:24:28,413 --> 00:24:31,016
THE AIR TEMPERATURE.

464
00:24:31,016 --> 00:24:34,036
WE'VE GOT A RADIOMETER, WHICH IS
SOMETHING THAT LOOKS AT THE

465
00:24:34,036 --> 00:24:35,354
THERMAL EMISSIONS FROM THE
SURFACE.

466
00:24:35,354 --> 00:24:38,206
FROM THAT, WE CAN GET THE
SURFACE TEMPERATURE, AND THAT'S

467
00:24:38,206 --> 00:24:40,509
SOMETHING THAT WE NEED AS A
BOUNDARY CONDITION FOR

468
00:24:40,509 --> 00:24:43,512
UNDERSTANDING THE AMOUNT OF HEAT

COMING OUT OF THE PLANET.

469

00:24:43,512 --> 00:24:49,034

WE HAVE A MAGNETOMETER, WHICH IS
MEASURING VARIOUS VARIATIONS IN

470

00:24:49,034 --> 00:24:50,135

THE MAGNETIC FIELD.

471

00:24:50,135 --> 00:24:52,504

THESE ARE ALL THINGS THAT AFFECT
THE SEISMOMETER, SO WE HAVE TO

472

00:24:52,504 --> 00:24:56,091

MAKE THESE KINDS OF MEASUREMENTS
IN ORDER TO GET A GOOD SEISMIC

473

00:24:56,091 --> 00:24:58,076

MEASUREMENT.

474

00:24:58,076 --> 00:25:00,445

BUT TURNS OUT THAT THEY ARE ALSO
GOOD FOR THEIR OWN SCIENCE AND

475

00:25:00,445 --> 00:25:03,048

WE'LL BE DOING SCIENCE WITH
THOSE, BUT I'M NOT GOING TO TALK

476

00:25:03,048 --> 00:25:05,350

TOO MUCH ABOUT THAT BECAUSE IT'S
NOT TOWARDS OUR MAIN MISSION

477

00:25:05,350 --> 00:25:06,018

GOALS.

478

00:25:06,018 --> 00:25:07,352

WE ALSO HAVE A COUPLE OF
CAMERAS.

479

00:25:07,352 --> 00:25:10,255
WE HAVE ONE CAMERA THAT'S UP
HERE ON THE ARM SO WE CAN USE

480
00:25:10,255 --> 00:25:13,025
THE ARM ACTUALLY TO POINT IT,
AND IT'S A MEDIUM RESOLUTION

481
00:25:13,025 --> 00:25:15,410
CAMERA.

482
00:25:15,410 --> 00:25:20,198
I WOULD SAY SIMILAR TO THE
NAVIGATION CAMERAS ON SPIRIT,

483
00:25:20,198 --> 00:25:23,035
OPPORTUNITY AND CURIOSITY,
EXCEPT IT'S NOT SIMILAR, IT'S

484
00:25:23,035 --> 00:25:24,019
ACTUALLY IDENTICAL.

485
00:25:24,019 --> 00:25:26,488
WE TOOK ONE OF THEIR SPARES OFF
THE SHELF AND THAT'S WHAT WE'RE

486
00:25:26,488 --> 00:25:30,075
FLYING, EXCEPT WE PUT A COLOR
FILTER ON IT SO IT WOULD BE

487
00:25:30,075 --> 00:25:30,425
COLOR PICTURES.

488
00:25:30,425 --> 00:25:34,029
AND WE HAVE ANOTHER WIDE-ANGLE
CAMERA DOWN HERE, WHICH IS A

489
00:25:34,029 --> 00:25:39,117
SPARE HAZARD CAMERA FROM THE
ROVERS.

490

00:25:39,117 --> 00:25:41,019

AND I THINK THAT'S PROBABLY
ABOUT IT.

491

00:25:41,019 --> 00:25:43,188

OH, AND WE HAVE THIS ROBOTIC
ARM, WHICH TURNS OUT TO BE

492

00:25:43,188 --> 00:25:45,507

REALLY KEY TO MAKING OUR
MEASUREMENTS IN THE SENSE THAT

493

00:25:45,507 --> 00:25:49,061

IT ALLOWS US TO DEPLOY OUR
INSTRUMENTS TO THE GROUND.

494

00:25:49,061 --> 00:25:52,514

SO, LET ME TALK A LITTLE BIT
ABOUT SEISMOMETER.

495

00:25:52,514 --> 00:25:58,303

A SEISMOMETER IS A PRETTY
SENSITIVE INSTRUMENT, AND

496

00:25:58,303 --> 00:26:02,190

IT'S -- BASICALLY, WHAT IT IS IS
IT'S A MASS ON A SPRING.

497

00:26:02,190 --> 00:26:04,209

SO, IF YOU HAVE THE GROUND HERE
AND YOU MOVE THE GROUND UP AND

498

00:26:04,209 --> 00:26:06,345

DOWN, YOU ACCELERATE IT UP AND
DOWN LIKE THIS.

499

00:26:06,345 --> 00:26:09,181

IF YOU HAVE A NICE, SOFT SPRING
HERE, THIS MASS WILL TEND TO

500

00:26:09,181 --> 00:26:14,136

STAY STILL, SO YOU KNOW, YOU
MOVE THE GROUND, THE MASS STAYS

501

00:26:14,136 --> 00:26:17,322

STILL, AND YOU MEASURE,
BASICALLY, THE DISPLACEMENT OF

502

00:26:17,322 --> 00:26:21,410

THIS MASS WITH RESPECT TO THE
GROUND, AND THAT'S THE BASIC OF

503

00:26:21,410 --> 00:26:23,128

A SEISMOMETER.

504

00:26:23,128 --> 00:26:28,283

AND SO, WE HAVE -- THE
SEISMOMETER DIRECTLY MEASURES

505

00:26:28,283 --> 00:26:32,020

THAT ACCELERATION, AND WE CAN
TURN THAT INTO GROUND

506

00:26:32,020 --> 00:26:32,304

DISPLACEMENT.

507

00:26:32,304 --> 00:26:35,340

SO, THE ACCELERATION OF NOISE
REQUIREMENT FOR THE

508

00:26:35,340 --> 00:26:43,231

SEISMOMETER -- THE NOISE IS WHAT
LIMITS THE PRECISION OF OUR

509

00:26:43,231 --> 00:26:48,136

MEASUREMENT, IS 10 TO THE MINUS
9 METERS PER SECOND FOR QUARTER

510

00:26:48,136 --> 00:26:48,336
HERTZ.

511
00:26:48,336 --> 00:26:52,407
SO, IF YOU'RE FRESH FROM
PHYSICS, YOU CAN GET THE

512
00:26:52,407 --> 00:26:56,261
DISPLACEMENT FROM THE
ACCELERATION FOR AN OSCILLATING

513
00:26:56,261 --> 00:26:56,428
SPRING.

514
00:26:56,428 --> 00:26:59,047
YOU CAN GO THROUGH THE
ARITHMETIC AND YOU COME OUT WITH

515
00:26:59,047 --> 00:27:03,351
A DISPLACEMENT WHICH IS $2 \frac{1}{2}$
TIMES TEN TO THE MINUS ELEVEN

516
00:27:03,351 --> 00:27:06,304
METERS, WHICH IS A PRETTY SMALL
AMOUNT, BUT THIS IS WHAT WE'RE

517
00:27:06,304 --> 00:27:07,989
ACTUALLY MEASURING.

518
00:27:07,989 --> 00:27:11,243
OKAY, THIS IS A QUANTUM
MICROGRAPH OF A HYDROGEN ATOM.

519
00:27:11,243 --> 00:27:14,179
SO, THERE'S THE RADIUS OF YOUR
HYDROGEN ATOM.

520
00:27:14,179 --> 00:27:16,314
THIS IS THE SENSITIVITY OF OUR
SEISMOMETER.

521

00:27:16,314 --> 00:27:19,184

WE'RE ACTUALLY MEASURING
DISPLACEMENTS OF THE GROUND,

522

00:27:19,184 --> 00:27:23,155

SHAKING OF THE GROUND, WHICH ARE
ON THE SAME SCALE, ACTUALLY

523

00:27:23,155 --> 00:27:27,292

SMALLER SCALE THAN AN ATOM.

524

00:27:27,292 --> 00:27:32,214

AND WE'RE DOING THAT IN THE DIRT
ON A PLANET THAT'S, YOU KNOW, 40

525

00:27:32,214 --> 00:27:37,436

MILLION KILOMETERS AWAY, AND
WE'RE DOING IT RELIABLY, AND IT

526

00:27:37,436 --> 00:27:39,354

SOUNDS LIKE MAGIC, BUT IT'S NOT.

527

00:27:39,354 --> 00:27:41,289

IT'S SCIENCE.

528

00:27:41,289 --> 00:27:44,309

WE DO THAT SORT OF ROUTINELY ON
THE EARTH, BUT THEY USUALLY DO

529

00:27:44,309 --> 00:27:47,395

IT IN A TEMPERATURE-CONTROLLED
BASEMENT IN A SCIENCE BUILDING

530

00:27:47,395 --> 00:27:48,163

AT A UNIVERSITY.

531

00:27:48,163 --> 00:27:50,465

IT'S A LITTLE BIT MORE

CHALLENGING TO DO IT IN THE DIRT

532

00:27:50,465 --> 00:27:54,436

ON MARS, AND THAT'S WHY WE HAVE
THESE OTHER INSTRUMENTS.

533

00:27:54,436 --> 00:27:58,056

JUST TO GIVE YOU ANOTHER IDEA OF
WHAT WE'RE TALK BEING IN TERMS

534

00:27:58,056 --> 00:28:01,042

OF SENSITIVITY, THESE ARE SOME
MEASUREMENTS THAT WE ACTUALLY

535

00:28:01,042 --> 00:28:04,112

MADE ON THE ASSEMBLY FLOOR AT
LOCKHEED MARTIN IN DENVER,

536

00:28:04,112 --> 00:28:09,084

COLORADO WHERE THE SPACECRAFT'S
BEING BUILT.

537

00:28:09,084 --> 00:28:11,186

THESE ARE A SUSPECT AREA OF THE
SEISMIC NOISE.

538

00:28:11,186 --> 00:28:14,973

SO, THIS IS SHAKING AT DIFFERENT
FREQUENCIES.

539

00:28:14,973 --> 00:28:19,461

SO, DOWN HERE WE HAVE VERY LOW
FREQUENCIES, AND YOU GO AT THE

540

00:28:19,461 --> 00:28:21,062

HIGHER FREQUENCIES HERE.

541

00:28:21,062 --> 00:28:23,999

SO, THIS GOES ALL THE WAY DOWN
TO, YOU KNOW, FREQUENCIES THAT

542

00:28:23,999 --> 00:28:31,072

GIVE YOU OSCILLATIONS OVER MAYBE
AN HOUR ON UP TO ALMOST A CYCLE

543

00:28:31,072 --> 00:28:31,323

PER SECOND.

544

00:28:31,323 --> 00:28:35,360

AND SO, YOU THINK OF THIS AS A
SPECTRUM.

545

00:28:35,360 --> 00:28:38,213

RED IS LOW, BLUE IS HIGH.

546

00:28:38,213 --> 00:28:42,017

SO, WE HAVE SOME SEISMIC ENERGY
THAT'S COMING THROUGH KIND OF IN

547

00:28:42,017 --> 00:28:44,085

THIS FREQUENCY BAND, AND THIS
IS TIMED.

548

00:28:44,085 --> 00:28:50,141

SO, WE JUST TAKE THESE FREQUENCY
SPECTRA EVERY FEW MINUTES FOR A

549

00:28:50,141 --> 00:28:52,344

COUPLE OF DAYS HERE.

550

00:28:52,344 --> 00:29:01,002

SO, THIS IS WHAT THE SEISMIC --
THE SEISMOGRAM LOOKS LIKE.

551

00:29:01,002 --> 00:29:02,170

THIS IS FIVE WEEKS OF DATA.

552

00:29:02,170 --> 00:29:05,957

THIS IS OVER THE WEEKEND, PEOPLE

GO TO WORK, THEY GO HOME.

553

00:29:05,957 --> 00:29:08,410

LOTS OF STUFF IS GOING ON,
PEOPLE ARE STOMPING AROUND AND

554

00:29:08,410 --> 00:29:11,980

STUFF LIKE THAT, BUT YOU HAVE
THIS KIND OF BLUE BLUR THROUGH

555

00:29:11,980 --> 00:29:13,131

HERE THAT'S THERE ALL THE TIME.

556

00:29:13,131 --> 00:29:16,234

AND WHAT THAT IS, IT'S CALLED
THE OCEAN MICROSEISMIC BAND.

557

00:29:16,234 --> 00:29:19,254

THIS IS BASICALLY THE WAVES
HITTING THE COAST IN CALIFORNIA,

558

00:29:19,254 --> 00:29:22,224

MESSING UP OUR MEASUREMENTS IN
DENVER.

559

00:29:22,224 --> 00:29:26,428

SO, THAT'S THE SENSITIVITY THAT
SEISMOLOGY IS CAPABLE OF ON THE

560

00:29:26,428 --> 00:29:27,078

EARTH.

561

00:29:27,078 --> 00:29:31,449

AND SO, THAT'S WHY WHEN THERE'S
AN EARTHQUAKE IN JAPAN, SAY, WE

562

00:29:31,449 --> 00:29:36,988

CAN ACTUALLY MEASURE IT HERE IN
CALIFORNIA, AND EVEN BETTER

563

00:29:36,988 --> 00:29:39,357

STILL, WE CAN TAKE THOSE WAVES
THAT WE'RE MEASURING WITH OUR

564

00:29:39,357 --> 00:29:44,346

SEISMOMETER AND DO SOME
MATHEMATICAL ANALYSIS ON THEM

565

00:29:44,346 --> 00:29:47,299

AND LEARN ABOUT THE ROCKS ON THE
EARTH AS THEY MOVE THROUGH THE

566

00:29:47,299 --> 00:29:49,317

EARTH TO GET TO US.

567

00:29:49,317 --> 00:29:52,387

SO, OUR SEISMOMETER'S A LITTLE
BIT MORE COMPLICATED THAN A MASS

568

00:29:52,387 --> 00:29:53,471

ON A SPRING.

569

00:29:53,471 --> 00:29:55,473

THIS IS SORT OF THE HEART OF OUR
SEISMOMETER.

570

00:29:55,473 --> 00:30:01,196

THIS IS WHAT WE CALL OUR VBB,
WHICH STANDS FOR VERY BROAD

571

00:30:01,196 --> 00:30:01,346

BAND.

572

00:30:01,346 --> 00:30:04,099

THAT MEANS THAT IT MEASURES
OSCILLATIONS FROM THINGS THAT

573

00:30:04,099 --> 00:30:07,185

TAKE ABOUT SEVEN OR EIGHT HOURS

TO COMPLETE, YOU KNOW, ONE CYCLE

574

00:30:07,185 --> 00:30:13,425

ALL THE WAY UP TO ABOUT FIVE TO
TEN CYCLES PER SECOND, A PRETTY

575

00:30:13,425 --> 00:30:14,342

LOW-FREQUENCY HUM.

576

00:30:14,342 --> 00:30:17,128

THIS IS ANOTHER SEISMOMETER THAT
WE'RE FLYING.

577

00:30:17,128 --> 00:30:19,180

THIS IS OUR SHORT-PERIOD
SEISMOMETER.

578

00:30:19,180 --> 00:30:23,084

THIS SORT OF TAKES -- OVERLAPS A
LITTLE BIT FROM ABOUT A TENTH OF

579

00:30:23,084 --> 00:30:27,055

A CYCLE PER SECOND ALL THE WAY
UP TO ABOUT 50 CYCLES PER

580

00:30:27,055 --> 00:30:29,224

SECOND, STILL NOT ANYTHING THAT
YOU COULD HEAR WITH YOUR EAR,

581

00:30:29,224 --> 00:30:30,258

BUT GETTING CLOSER.

582

00:30:30,258 --> 00:30:33,078

SO, WE TAKE THREE OF THESE
BECAUSE WE WANT TO MEASURE THE

583

00:30:33,078 --> 00:30:35,180

GROUND MOTION IN THREE DIFFERENT
DIRECTIONS SO THAT WE CAN FIGURE

584

00:30:35,180 --> 00:30:40,151

OUT EXACTLY HOW IT'S GOING, AND
WE PACK THEM INTO THIS SPHERE

585

00:30:40,151 --> 00:30:46,191

WHICH WE THEN EVACUATE BECAUSE
ANY AIR RESISTANCE TO THESE

586

00:30:46,191 --> 00:30:48,443

PENDULUMS AS THEY'RE MOVING WILL
INTERFERE WITH OUR MOTION.

587

00:30:48,443 --> 00:30:55,133

WE HAVE TO LEVEL IT SO WE HAVE
THESE THREE WHAT WE CALL LINEAR

588

00:30:55,133 --> 00:30:59,371

AXILATORS, BASICALLY FEET SO WE
DON'T HAVE GRAVITY PULLING IT

589

00:30:59,371 --> 00:31:00,372

ONE SIDE OR THE OTHER.

590

00:31:00,372 --> 00:31:04,175

THESE LEVEL IT TO A DEGREE WHERE
YOU CAN BALANCE A DIME ON ITS

591

00:31:04,175 --> 00:31:08,380

EDGE, AND AT THAT POINT, THE
SEISMOMETER ITSELF CAN KIND OF

592

00:31:08,380 --> 00:31:10,198

LEVEL ITSELF WELL ENOUGH.

593

00:31:10,198 --> 00:31:12,384

BUT THAT'S THE PRECISION TO
WHICH WE HAVE TO BE ABLE TO

594

00:31:12,384 --> 00:31:15,337

LEVEL THIS THING, AGAIN, ON THE
DIRT, ON MARS WITH THE

595

00:31:15,337 --> 00:31:21,126
TEMPERATURE GOING UP AND DOWN BY
100 DEGREES A DAY.

596

00:31:21,126 --> 00:31:25,213
OKAY, SO, MARTIAN SEISMOLOGY IS
WHAT WE'RE GOING TO USE TO PROBE

597

00:31:25,213 --> 00:31:27,148
THE CENTER OF THE PLANET.

598

00:31:27,148 --> 00:31:30,251
BUT IN ORDER TO DO SEISMOLOGY,
YOU HAVE TO HAVE SIGNALS.

599

00:31:30,251 --> 00:31:32,303
DO WE KNOW THAT THERE ARE MARS
QUAKES?

600

00:31:32,303 --> 00:31:35,323
AND THE ANSWER IS WE DON'T
ACTUALLY KNOW THAT BECAUSE WE'VE

601

00:31:35,323 --> 00:31:36,391
NEVER MEASURED IT.

602

00:31:36,391 --> 00:31:39,110
SO, WE COULD SAY, WELL, IT'S A
GOOD IDEA TO GO THERE AND

603

00:31:39,110 --> 00:31:43,148
MEASURE IT, AND NASA SAYS, WELL,
FOR \$500 MILLION, YOU HAVE TO

604

00:31:43,148 --> 00:31:45,383
GIVE IT MORE THAN A GOOD IDEA,
YOU HAVE TO BE PRETTY SURE IT'S

605

00:31:45,383 --> 00:31:46,217

GOING TO HAPPEN.

606

00:31:46,217 --> 00:31:52,140

SO, WE DID A LOT OF ANALYSIS, A
LOT OF THEORETICAL ANALYSIS.

607

00:31:52,140 --> 00:31:55,076

AND FORTUNATELY, WE CAN GO TO
MARS, WE CAN LOOK AT IT FROM

608

00:31:55,076 --> 00:31:57,429

ORBIT AND WE CAN SEE FAULTS ON
THE SURFACE.

609

00:31:57,429 --> 00:32:01,066

ALL THESE LINES THAT YOU SEE ON
THE SURFACE, THE WRINKLE RIDGES

610

00:32:01,066 --> 00:32:07,138

THAT YOU CAN SEE IN THE LAVA
PLAINS, THE GROBBEN CANYONS THAT

611

00:32:07,138 --> 00:32:10,175

YOU CAN SEE, THOSE ARE ALL
FORMED BY MOTION ALONG FAULTS,

612

00:32:10,175 --> 00:32:14,162

AND SO, WE KNOW THAT THERE'S
LOTS AND LOTS OF FAULTS ON MARS.

613

00:32:14,162 --> 00:32:17,365

UNFORTUNATELY, MOST OF THOSE ARE
3 OR 4 BILLION YEARS OLD, SO

614

00:32:17,365 --> 00:32:21,119

THAT DOESN'T HELP US MUCH TODAY,
BUT YOU CAN ACTUALLY LOOK AT THE

615

00:32:21,119 --> 00:32:24,239

AGE OF ALL OF THOSE FAULTS AND
YOU CAN SEE THAT THERE ARE FEWER

616

00:32:24,239 --> 00:32:27,459

AND FEWER FAULTS WITH TIME, BUT
YOU CAN EXTRAPOLATE THROUGH

617

00:32:27,459 --> 00:32:31,045

THOSE, AND YOU COME UP AND YOU
CAN EXTRAPOLATE TO THE PRESENT,

618

00:32:31,045 --> 00:32:37,419

AND YOU COME UP WITH A RATE OF
FAULT MOVEMENT, WHICH IS IN THIS

619

00:32:37,419 --> 00:32:40,221

BAND RIGHT HERE.

620

00:32:40,221 --> 00:32:43,508

IN THIS PLOT IS A NUMBER OF
QUAKES THAT YOU'D EXPECT PER

621

00:32:43,508 --> 00:32:47,145

YEAR AS A FUNCTION OF THE SIZE
OF THE QUAKE.

622

00:32:47,145 --> 00:32:52,183

IN THIS CASE, ITS SEISMIC MOMENT
UP HERE, WE HAVE THE MAGNITUDE.

623

00:32:52,183 --> 00:32:55,320

SO, THE BIGGER THE QUAKE IS, THE
FEWER YOU EXPECT TO SEE PER

624

00:32:55,320 --> 00:32:55,470

YEAR.

625

00:32:55,470 --> 00:32:58,056

SO, IT FOLLOWS A SLOPE LIKE
THIS.

626

00:32:58,056 --> 00:33:02,093

LOTS OF QUAKES THAT ARE VERY
SMALL, FEWER QUAKES THAT ARE

627

00:33:02,093 --> 00:33:04,012

VERY LARGE.

628

00:33:04,012 --> 00:33:09,134

AND THIS IS SORT OF THE BAND
THAT WE COME UP WITH FROM THAT

629

00:33:09,134 --> 00:33:13,221

THEORETICAL BASED ON
OBSERVATIONS BUT EXTRAPOLATED

630

00:33:13,221 --> 00:33:13,404

ESTIMATE.

631

00:33:13,404 --> 00:33:17,092

IF YOU LOOK ON THIS PLOT, THIS
LINE RIGHT HERE, THAT'S THE

632

00:33:17,092 --> 00:33:20,028

LEVEL OF ACTIVITY WE SAW ON THE
MOON.

633

00:33:20,028 --> 00:33:23,164

SO, WE SENT SEISMOMETERS TO THE
MOON BACK IN THE '70s WITH

634

00:33:23,164 --> 00:33:23,331

APOLLO.

635

00:33:23,331 --> 00:33:25,133

WE MEASURED LOTS OF MOON QUAKES.

636

00:33:25,133 --> 00:33:27,469

WE HAD A VERY SENSITIVE
SEISMOMETER.

637

00:33:27,469 --> 00:33:30,488

IT WAS THERE FOR ABOUT -- WELL,
WE HAD FOUR OF THEM THERE FOR

638

00:33:30,488 --> 00:33:34,192

ABOUT SEVEN YEARS OR SO, SO WE
GOT A PRETTY GOOD LEVEL ON THE

639

00:33:34,192 --> 00:33:34,342

MOON.

640

00:33:34,342 --> 00:33:38,313

SINCE THE MOON IS RELATIVELY
INACTIVE, IT'S DOWN HERE BELOW.

641

00:33:38,313 --> 00:33:42,133

IT'S AT LOWER NUMBERS.

642

00:33:42,133 --> 00:33:44,519

BUT WE CAN BE PRETTY SURE THAT
MARS IS GOING TO BE MORE ACTIVE

643

00:33:44,519 --> 00:33:45,403

THAN THAT.

644

00:33:45,403 --> 00:33:49,040

IT'S GOT LOTS OF VOLCANIC
ACTIVITY THAT'S EXTENDED THROUGH

645

00:33:49,040 --> 00:33:51,342

TIME MUCH, MUCH LONGER THAN ON
THE MOON.

646

00:33:51,342 --> 00:33:54,329

IN FACT, THERE'S EVIDENCE FOR
LAVA FLOWS THAT ARE MAYBE LESS

647

00:33:54,329 --> 00:33:56,231
THAN 10 MILLION YEARS OLD.

648

00:33:56,231 --> 00:33:58,516
SO, IT'S ACTIVE UP TO THE
PRESENT.

649

00:33:58,516 --> 00:34:03,238
THIS LINE UP HERE IS THE LINE OF
ACTIVITY YOU GET ON THE EARTH.

650

00:34:03,238 --> 00:34:04,289
SO, THIS IS ON THE EARTH.

651

00:34:04,289 --> 00:34:07,275
IF YOU TAKE AWAY ALL THE PLATE
BOUNDARIES, SO YOU ONLY LOOK

652

00:34:07,275 --> 00:34:12,230
AT -- YOU TAKE AWAY THE MID-OCEAN
RIDGES, TAKE AWAY THE TRENCHES,

653

00:34:12,230 --> 00:34:16,117
THE SAN ANDREAS FAULT, AND ALL
YOU'RE LEFT WITH IS, YOU KNOW,

654

00:34:16,117 --> 00:34:20,271
MISSOURI AND CANADA AND
AUSTRALIA, PLACES THAT ARE

655

00:34:20,271 --> 00:34:24,058
RELATIVELY -- YOU WOULD THINK
ARE PRETTY DEAD SEISMICALLY.

656

00:34:24,058 --> 00:34:28,296
WE DO GET EARTHQUAKES IN THE
MIDDLE OF PLATES, BUT NOT VERY

657

00:34:28,296 --> 00:34:29,013
OFTEN.

658
00:34:29,013 --> 00:34:30,398
AND SO, THAT'S THIS LINE.

659
00:34:30,398 --> 00:34:33,501
MARS WE ESTIMATE TO BE BELOW
THAT LINE, ABOVE THE MOON LINE,

660
00:34:33,501 --> 00:34:40,024
AND SO, THAT KIND OF MAKES SENSE
THAT MARS IS LESS ACTIVE THAT BE

661
00:34:40,024 --> 00:34:42,177
THAN THE EARTH, MORE THAN THE
MOON.

662
00:34:42,177 --> 00:34:44,462
SO, THIS IS WHAT WE EXPECT TO
SEE ON MARS FROM THE FAULTS WE

663
00:34:44,462 --> 00:34:45,430
CAN SEE.

664
00:34:45,430 --> 00:34:48,483
AND IF WE GET THAT ACTIVITY, WE
HAVE PLENTY OF MARS QUAKES TO

665
00:34:48,483 --> 00:34:50,068
USE TO DO OUR ANALYSIS.

666
00:34:50,068 --> 00:34:53,221
BUT IF IT TURNS OUT THAT WE'RE
UNLUCKY, WE ACTUALLY HAVE A

667
00:34:53,221 --> 00:34:56,107
COUPLE OF GUARANTEED SIGNAL
SOURCES THAT WE DON'T HAVE TO

668

00:34:56,107 --> 00:34:57,408

WORRY ABOUT.

669

00:34:57,408 --> 00:34:59,477

WE HAVE THE FOBOS TYPE.

670

00:34:59,477 --> 00:35:04,332

THIS IS THE MOON FOBOS THAT GOES
OVERHEAD ABOUT EVERY SEVEN

671

00:35:04,332 --> 00:35:04,999

HOURS.

672

00:35:04,999 --> 00:35:08,386

IT'S A SMALL MOON, BUT JUST LIKE
THE EARTH'S MOON, IT DOES RAISE

673

00:35:08,386 --> 00:35:09,053

A TIDE.

674

00:35:09,053 --> 00:35:10,455

ON THE EARTH, WE'RE FAMILIAR
WITH THE TIDE FROM THE OCEAN,

675

00:35:10,455 --> 00:35:13,291

BUT YOU MAY BE LESS FAMILIAR
WITH THE FACT THAT THE GROUND

676

00:35:13,291 --> 00:35:16,444

UNDERNEATH YOU ACTUALLY RISES BY
ALMOST A METER EVERY TIME THE

677

00:35:16,444 --> 00:35:20,014

MOON GOES OVERHEAD, AND
ACTUALLY, WHEN THE MOON'S ON THE

678

00:35:20,014 --> 00:35:22,400

OTHER SIDE OF THE PLANET, TOO,
BECAUSE IT HAPPENS TWICE A DAY.

679

00:35:22,400 --> 00:35:25,253

SO, THE GROUND'S GOING UP AND
DOWN UNDERNEATH YOU EVERY 12

680

00:35:25,253 --> 00:35:26,321

HOURS OR SO.

681

00:35:26,321 --> 00:35:29,173

WE DON'T KNOW IT BECAUSE
EVERYTHING GOES WITH IT, BUT WE

682

00:35:29,173 --> 00:35:34,212

CAN MEASURE THAT WITH SENSITIVE
INSTRUMENTS ON THE EARTH.

683

00:35:34,212 --> 00:35:38,116

FOBOS, IT TURNS OUT, IS SMALLER,
SO WE ONLY GET ABOUT A

684

00:35:38,116 --> 00:35:39,284

CENTIMETER OF DISPLACEMENT.

685

00:35:39,284 --> 00:35:42,136

BUT BY MEASURING THAT
DISPLACEMENT, WE CAN ACTUALLY

686

00:35:42,136 --> 00:35:43,504

TELL SOMETHING ABOUT THE INSIDE
OF THE PLANET, BECAUSE IF YOU

687

00:35:43,504 --> 00:35:47,342

HAVE A LIQUID CORE, IT WILL
ACTUALLY, YOU'LL GET LITTLE BIT

688

00:35:47,342 --> 00:35:49,410

MORE DISPLACEMENT THAN IF YOU
HAD A SOLID CORE.

689

00:35:49,410 --> 00:35:54,382
SO IT'S LIKE, YOU KNOW, TRYING
TO SQUEEZE A HOLLOW BALL VERSUS

690
00:35:54,382 --> 00:35:56,067
SQUEEZING A SOLID BALL.

691
00:35:56,067 --> 00:35:58,236
IF YOU HAVE IT HOLLOW, IT'S
EASIER TO SQUEEZE.

692
00:35:58,236 --> 00:36:02,323
AND SO, BY MEASURING HOW MUCH --
WHETHER YOU KNOW, ONE CENTIMETER

693
00:36:02,323 --> 00:36:08,313
OR 1.001 CENTIMETER'S THE
DIFFERENCE BETWEEN A LIQUID CORE

694
00:36:08,313 --> 00:36:10,448
AND A SOLID CORE, SO WE CAN
FIGURE OUT WHETHER THE CORE IS

695
00:36:10,448 --> 00:36:12,050
LIQUID OR SOLID VERY QUICKLY.

696
00:36:12,050 --> 00:36:14,452
THEN IF WE KEEP MEASURING THIS
DAY AFTER DAY AFTER DAY AFTER

697
00:36:14,452 --> 00:36:18,106
DAY, TURNS OUT WE CAN GET A MORE
AND MORE PRECISE MEASUREMENT OF

698
00:36:18,106 --> 00:36:19,090
THAT DISPLACEMENT.

699
00:36:19,090 --> 00:36:22,193
WE CAN ACTUALLY THEN SEE HOW BIG
THAT CORE IS.

700
00:36:22,193 --> 00:36:27,198
SO, THIS IS ONE OF OUR METHODS
OF ACTUALLY GETTING THE SIZE AND

701
00:36:27,198 --> 00:36:32,337
THE STATE OF THE CORE FOR FREE.

702
00:36:32,337 --> 00:36:33,004
RIGHT.

703
00:36:33,004 --> 00:36:35,390
ANOTHER THING WE HAVE ARE
METEORITE IMPACTS.

704
00:36:35,390 --> 00:36:40,328
ON THE LEFT HERE WE HAVE A MAP
OF METEORITES THAT HAVE BEEN

705
00:36:40,328 --> 00:36:46,134
DETECTED FROM ORBIT WITH THE
HIGH-RESOLUTION CAMERAS ON MARS'

706
00:36:46,134 --> 00:36:47,118
RECONNAISSANCE ORBITER.

707
00:36:47,118 --> 00:36:49,370
WE HAVE A BEFORE-AND-AFTER
PICTURE.

708
00:36:49,370 --> 00:36:51,389
THIS IS A PICTURE TAKEN IN JUNE
OF 2008.

709
00:36:51,389 --> 00:36:55,360
THIS IS A PICTURE THAT WAS TAKEN
ABOUT FOUR MONTHS LATER.

710
00:36:55,360 --> 00:36:57,245

AND YOU SEE THIS BLACK SPOT
HERE.

711

00:36:57,245 --> 00:37:01,432

AND IF YOU BLOW THIS UP WITH A
HIGH-RES IMAGE, YOU CAN SEE A

712

00:37:01,432 --> 00:37:05,386

WHOLE CLUSTER OF CRATERS HERE
FROM A METEORITE THAT BROKE UP

713

00:37:05,386 --> 00:37:06,404

AND HIT THE SURFACE.

714

00:37:06,404 --> 00:37:09,107

SO, THERE'S LOTS OF THESE
THINGS.

715

00:37:09,107 --> 00:37:13,428

THESE HAVE BEEN MEASURED OVER
ABOUT TEN YEARS OR SO.

716

00:37:13,428 --> 00:37:16,064

THERE'S EVEN A COUPLE IN OUR
LANDING AREA.

717

00:37:16,064 --> 00:37:19,033

SO, WE HAVE METEORITES HITTING
MARS ALL THE TIME.

718

00:37:19,033 --> 00:37:20,134

MARS HAS A THIN ATMOSPHERE.

719

00:37:20,134 --> 00:37:24,005

TURNS OUT, YOU DON'T REALLY STOP
MUCH WITH THE MARTIAN

720

00:37:24,005 --> 00:37:28,026

ATMOSPHERE, SO THESE THINGS COME
RIGHT IN AND GET BANG.

721

00:37:28,026 --> 00:37:32,063

WHEN IT BANGS ON THE SURFACE IT
CREATES SEISMIC WAVES LIKE AN

722

00:37:32,063 --> 00:37:36,384

OCEAN WOULD, SO WE CAN ACTUALLY
USE THOSE WAVES TO PROBE THE

723

00:37:36,384 --> 00:37:37,068

INTERIOR.

724

00:37:37,068 --> 00:37:39,153

SO AGAIN, THAT'S ANOTHER
GUARANTEED SIGNAL SOURCE.

725

00:37:39,153 --> 00:37:43,458

ANOTHER THING THAT'S SORT OF
ESOTERIC IS ATMOSPHERIC

726

00:37:43,458 --> 00:37:44,492

EXCITATION.

727

00:37:44,492 --> 00:37:47,311

SO, THIS IS A PICTURE OF THE
SIMULATION OF THE ATMOSPHERIC

728

00:37:47,311 --> 00:37:47,495

PRESSURE.

729

00:37:47,495 --> 00:37:50,031

THESE ARE WINDS THAT ARE COMING
ACROSS.

730

00:37:50,031 --> 00:37:52,266

WINDS ARE ALWAYS DRIVEN BY
DIFFERENCES IN THE PRESSURE.

731

00:37:52,266 --> 00:37:55,353

SO, YOU HAVE HIGH PRESSURE, THE
AIR MOVES TOWARDS LOW PRESSURE,

732

00:37:55,353 --> 00:37:58,222

AND IT EDDIES AROUND AND DOES
ALL KINDS OF STUFF LIKE THAT.

733

00:37:58,222 --> 00:38:03,378

SO, THIS IS ABOUT A 5 BY
5-KILOMETER SQUARE ON MARS.

734

00:38:03,378 --> 00:38:06,080

AND AS THESE PRESSURE WAVES GO
BY, THEY'RE PUSHING THE GROUND

735

00:38:06,080 --> 00:38:07,131

UP AND DOWN.

736

00:38:07,131 --> 00:38:10,034

AND IF YOU TAKE ANY KIND OF AN
OBJECT AND YOU START PUSHING ON

737

00:38:10,034 --> 00:38:15,022

IT, YOU PUSH ON IT EVERYWHERE,
YOU'RE BASICALLY PUSHING ENERGY

738

00:38:15,022 --> 00:38:17,108

INTO THAT OBJECT.

739

00:38:17,108 --> 00:38:23,281

AND IF IT'S A FINITE OBJECT, IT
WANTS TO VIBRATE AT CERTAIN

740

00:38:23,281 --> 00:38:24,148

RESONANT FREQUENCIES.

741

00:38:24,148 --> 00:38:25,233

SO, IT'S LIKE A BELL.

742

00:38:25,233 --> 00:38:28,436
IF YOU SIT THERE AND JUST KIND
OF JUST TAP ON A BELL AND TAP ON

743
00:38:28,436 --> 00:38:32,340
IT AND TAP ON IT, YOU'LL START
TO BUILD UP THAT RING, AND YOU

744
00:38:32,340 --> 00:38:37,411
CAN MEASURE THAT FREQUENCY IN
THE TURNS OF THE PLANET, AND

745
00:38:37,411 --> 00:38:40,098
THOSE FREQUENCIES WILL TELL YOU
SOMETHING ABOUT ITS STRUCTURE,

746
00:38:40,098 --> 00:38:42,133
ITS DENSITY AND SO FORTH.

747
00:38:42,133 --> 00:38:47,371
SO, THIS IS RIGHT ABOUT AT THE
LIMIT OF OUR SENSITIVITY, BUT WE

748
00:38:47,371 --> 00:38:50,224
THINK WE MAY BE ABLE TO USE THIS
TO PROBE THE PLANET AS WELL.

749
00:38:50,224 --> 00:38:53,327
SO, WE HAVE LOTS OF DIFFERENT
WAYS TO PROBE THE PLANET.

750
00:38:53,327 --> 00:38:55,346
AND WE'VE GOT LOTS OF
TECHNIQUES.

751
00:38:55,346 --> 00:39:00,134
I MEAN, ONE THING PEOPLE ASK ME
A LOT, BECAUSE IF THERE'S ONE

752
00:39:00,134 --> 00:39:03,354

THING PEOPLE KNOW ABOUT
SEISMOLOGY, THEY KNOW THAT YOU

753

00:39:03,354 --> 00:39:06,224

NEED THREE STATIONS TO FIGURE
OUT WHERE AN EARTHQUAKE IS,

754

00:39:06,224 --> 00:39:06,374

RIGHT?

755

00:39:06,374 --> 00:39:12,146

BECAUSE YOU NEED TO BE ABLE TO
TRIANGULATE IT.

756

00:39:12,146 --> 00:39:13,965

I THINK ESPECIALLY IN
CALIFORNIA, PEOPLE HAVE AN IDEA

757

00:39:13,965 --> 00:39:16,450

OF HOW TO DO SEISMOLOGY, BUT
WE'RE ONLY HAVING ONE STATION ON

758

00:39:16,450 --> 00:39:17,101

MARS.

759

00:39:17,101 --> 00:39:21,055

HOW CAN WE ACTUALLY USE THAT ONE
STATION TO DO THE SCIENCE IF WE

760

00:39:21,055 --> 00:39:23,207

CAN'T EVEN LOCATE WHERE OUR MARS
QUAKES ARE?

761

00:39:23,207 --> 00:39:26,360

WELL, IT TURNS OUT, THERE ARE A
LOT OF TECHNIQUES FOR GETTING

762

00:39:26,360 --> 00:39:27,094

AROUND THAT.

763

00:39:27,094 --> 00:39:32,049

I THINK THE ONE THAT'S GOING TO
BE OUR BREAD AND BUTTER USES THE

764

00:39:32,049 --> 00:39:33,985

FACT THAT MARS IS A SMALLER
PLANET.

765

00:39:33,985 --> 00:39:38,206

AND SO, WE ACTUALLY GET A LOT
MORE OF THE ENERGY FROM A MARS

766

00:39:38,206 --> 00:39:41,108

QUAKE TO GET TO US THAN YOU DO
ON THE EARTH, WHERE IT HAS TO GO

767

00:39:41,108 --> 00:39:44,095

A LONG WAYS, AND WE USE THE FACT
THAT INSTEAD OF JUST HAVING A

768

00:39:44,095 --> 00:39:48,366

"P" AND AN "S" WAVE THAT COME,
AND NORMALLY, YOU USE "P" AND

769

00:39:48,366 --> 00:39:52,320

"S" WAVES FROM THREE DIFFERENT
PLACES TO FIGURE OUT WHERE "X"

770

00:39:52,320 --> 00:39:55,356

AND "Y" AND "T," THE TIME OF THE
EVENT OCCURS, WE ACTUALLY HAVE

771

00:39:55,356 --> 00:39:58,359

MORE INFORMATION BECAUSE WE CAN
USE SURFACE WAVES THAT GO AROUND

772

00:39:58,359 --> 00:40:03,414

THE OUTSIDE OF THE PLANET, AND
THAT GIVES US ANOTHER WAVE

773

00:40:03,414 --> 00:40:05,449

ARRIVAL WITH ANOTHER VELOCITY.

774

00:40:05,449 --> 00:40:09,237

BUT ONCE THAT HITS OUR STATION,
IT KEEPS ON GOING AROUND THE

775

00:40:09,237 --> 00:40:11,422

PLANET AGAIN, AND WE CAN
ACTUALLY SEE IT COMING AROUND

776

00:40:11,422 --> 00:40:12,306

THE SECOND TIME.

777

00:40:12,306 --> 00:40:16,177

AND SO, IN THAT CASE, WE KNOW
EXACTLY HOW FAR IT'S GONE, WE

778

00:40:16,177 --> 00:40:19,130

KNOW HOW LONG IT TOOK BECAUSE WE
HAVE THE TIMING OF THOSE TWO

779

00:40:19,130 --> 00:40:19,463

ARRIVALS.

780

00:40:19,463 --> 00:40:23,117

SO, WE CAN USE THAT INFORMATION
AND START BACKING OUT THAT ALONG

781

00:40:23,117 --> 00:40:26,487

WITH THE SURFACE WAVE THAT WENT
AROUND THE LONG WAY, THESE BODY

782

00:40:26,487 --> 00:40:30,057

WAVES, THE "P" AND "S" WAVES
THAT WENT STRAIGHT THROUGH THE

783

00:40:30,057 --> 00:40:30,224

PLANET.

784

00:40:30,224 --> 00:40:32,476

AND BY USING THAT, WE NOW HAVE
FIVE PIECES OF INFORMATION THAT

785

00:40:32,476 --> 00:40:35,296

WE CAN PUT TOGETHER TO GET THE
LOCATION OF THAT EVENT.

786

00:40:35,296 --> 00:40:37,298

AND ONCE YOU HAVE THE LOCATION,
YOU HAVE THE TIMING, YOU CAN

787

00:40:37,298 --> 00:40:40,318

FIGURE OUT WHAT THE VOSS THAEY
IS, AND THE VELOCITY IS WHAT

788

00:40:40,318 --> 00:40:42,103

TELLS YOU WHAT IT'S MADE OUT OF.

789

00:40:42,103 --> 00:40:44,272

WE CAN ACTUALLY TAKE A ROCK IN A
LABORATORY, WE CAN BANG IT ON

790

00:40:44,272 --> 00:40:48,092

ONE SIDE, WE CAN FIGURE OUT HOW
FAST THE WAVES WENT THROUGH, AND

791

00:40:48,092 --> 00:40:51,529

THAT SPEED, THAT VELOCITY OF
THOSE WAVES, THOSE SOUND WAVES

792

00:40:51,529 --> 00:40:55,149

GOING THROUGH THE ROCK ARE
DIFFERENT FOR DIFFERENT

793

00:40:55,149 --> 00:41:00,054

COMPOSITIONS, AND IT TURNS OUT
THAT YOU HAVE A PLANET ACTING

794

00:41:00,054 --> 00:41:02,173

EXACTLY LIKE A LENS ACTS FOR
OPTICS.

795

00:41:02,173 --> 00:41:06,227

SO, THESE ARE WAVES, THEY GET
BENT BY GOING THROUGH DIFFERENT

796

00:41:06,227 --> 00:41:09,430

MATERIALS, THEY GET REFLECTED
OFF OF BOUNDARIES, AND WE USE

797

00:41:09,430 --> 00:41:12,433

ALL THAT INFORMATION THEN TO PUT
TOGETHER THE STRUCTURE OF THE

798

00:41:12,433 --> 00:41:13,100

PLANET.

799

00:41:13,100 --> 00:41:17,388

THESE OTHER THINGS ARE ACTUALLY
USING DIFFERENT ASPECTS OF

800

00:41:17,388 --> 00:41:20,191

RESONANCES, LIKE I WAS TALKING
ABOUT BEFORE.

801

00:41:20,191 --> 00:41:23,327

YOU HAVE A PLANET, YOU HAVE
THESE THINGS THAT THEY WANT TO

802

00:41:23,327 --> 00:41:27,415

RING AT CERTAIN FREQUENCIES
DEPENDING ON HOW BIG THINGS ARE,

803

00:41:27,415 --> 00:41:31,218

HOW DENSE THEY ARE, HOW SPRINGY
THEY ARE.

804

00:41:31,218 --> 00:41:35,273
AND BY USING THE FREQUENCIES, WE
CAN THEN PULL OUT THINGS FROM

805
00:41:35,273 --> 00:41:38,175
THE SURFACE WAVES USING THEIR
PROPERTIES, WE CAN PULL THINGS

806
00:41:38,175 --> 00:41:41,462
OUT FROM BODY WAVES IN THE
MULTIPLE BOUNCES BETWEEN THE TOP

807
00:41:41,462 --> 00:41:44,348
OF THE CRUST AND THE BOTTOM OF
THE CRUST, AND WE CAN USE THE

808
00:41:44,348 --> 00:41:48,452
RINGING OF THE WHOLE PLANET FROM
THE LARGEST QUAKES TO LOOK AT

809
00:41:48,452 --> 00:41:51,522
THESE LITTLE SPECTRAL PEAKS HERE
AT DIFFERENT FREQUENCIES.

810
00:41:51,522 --> 00:41:55,343
AND SO, WE HAVE LOTS OF
DIFFERENT METHODS IN SEISMOLOGY

811
00:41:55,343 --> 00:42:00,181
FOR TAKING A SINGLE STATION AND
PUTTING TOGETHER THE STRUCTURE

812
00:42:00,181 --> 00:42:01,215
OF THE PLANET.

813
00:42:01,215 --> 00:42:04,101
SO, A MARS QUAKE IS LIKE A
LITTLE FLASH BOLT.

814
00:42:04,101 --> 00:42:08,005

IT GOES OFF AND IT ILLUMINATES
THE INSIDE OF THE PLANET, AND WE

815

00:42:08,005 --> 00:42:11,325
HAVE ONE LITTLE CAMERA SITTING
OVER HERE ON ONE PLACE ON THE

816

00:42:11,325 --> 00:42:14,195
PLANET, SO WE HAVE TO HAVE A LOT
OF DIFFERENT FLASH BOLTS GOING

817

00:42:14,195 --> 00:42:16,397
OFF AT DIFFERENT PLACES
ILLUMINATING DIFFERENT PIECES OF

818

00:42:16,397 --> 00:42:20,351
IT TO BE ABLE TO PUT TOGETHER A
3D PICTURE, MUCH THE SAME WAY

819

00:42:20,351 --> 00:42:23,354
THAT YOU PUT -- AN MRI PUTS
TOGETHER A 3D PICTURE OF THE

820

00:42:23,354 --> 00:42:28,309
INSIDE OF YOUR BODY WHEN YOU GO
TO THE DOCTOR.

821

00:42:28,309 --> 00:42:31,512
OKAY, SO, THAT'S OUR MAIN
INSTRUMENT IS A SEISMOMETER, BUT

822

00:42:31,512 --> 00:42:34,382
IN ORDER TO GET THE THERMAL
PROPERTIES OF THE PLANET, WE'D

823

00:42:34,382 --> 00:42:36,484
LIKE TO KNOW HOW MUCH HEAT IS
COMING OUT OF THE PLANET,

824

00:42:36,484 --> 00:42:40,087

BECAUSE THAT TELLS US WHAT'S
POWERING THIS PLANETARY ENGINE.

825

00:42:40,087 --> 00:42:44,458

THE WAY WE DO THAT IS WITH OUR
HP CUTE.

826

00:42:44,458 --> 00:42:47,478

IT HAS A SELF-PENETRATING MOLD.

827

00:42:47,478 --> 00:42:51,532

THAT'S THIS LITTLE TORPEDO HERE
THAT DIGS ITSELF DOWN UP TO FIVE

828

00:42:51,532 --> 00:42:53,084

METERS INTO THE SURFACE.

829

00:42:53,084 --> 00:42:56,470

THAT'S 15 FEET.

830

00:42:56,470 --> 00:42:57,488

THAT'S ABOUT THE SIZE OF THIS
ROOM.

831

00:42:57,488 --> 00:42:59,273

SO, YOU FIGURE GOING FROM THE
CEILING TO THE FLOOR, THAT'S HOW

832

00:42:59,273 --> 00:43:00,458

DEEP WE'RE PLANNING TO GO WITH
THIS MOLE.

833

00:43:00,458 --> 00:43:03,094

SO, THAT'S OUR JOURNEY TO THE
CENTER OF THE PLANET.

834

00:43:03,094 --> 00:43:06,147

WE GO DOWN THAT FAR.

835

00:43:06,147 --> 00:43:08,299
THAT'S CLOSE ENOUGH.

836
00:43:08,299 --> 00:43:12,269
BUT A LONG CABLE TO CONNECT IT,
BECAUSE IT HAS TO BE POWERED

837
00:43:12,269 --> 00:43:12,453
SOMEHOW.

838
00:43:12,453 --> 00:43:16,340
WE HAVE THERMAL SENSORS ABOUT
EVERY 35 CENTIMETERS OR SO, AND

839
00:43:16,340 --> 00:43:19,276
SO WE CAN MEASURE THE CHANGE IN
TEMPERATURE AS YOU GO DOWN.

840
00:43:19,276 --> 00:43:22,146
I DON'T KNOW IF YOU'VE EVER BEEN
DOWN IN A MINE, BUT IT GETS

841
00:43:22,146 --> 00:43:24,482
WARMER AND WARMER THE FARTHER
YOU GO DOWN, AND THAT'S BECAUSE

842
00:43:24,482 --> 00:43:28,069
YOU'RE GETTING CLOSER AND CLOSER
TO THE HOT PART OF THE PLANET,

843
00:43:28,069 --> 00:43:32,073
AND IT'S ACTUALLY THAT THERMAL
DIFFERENCE, THE THERMAL

844
00:43:32,073 --> 00:43:33,474
GRADIENT, THAT'S PUSHING HEAT
OUT OF THE PLANET.

845
00:43:33,474 --> 00:43:39,230
AND SO, IN THE UPPER FIVE METERS

OR SO, WE CAN MEASURE THE VERY

846

00:43:39,230 --> 00:43:43,501

FRACTION OF A DEGREE INCREASE IN
TEMPERATURE, AND BY MEASURING

847

00:43:43,501 --> 00:43:47,104

THE CONDUCTIVITY OF THE ROCKS
ALONG WITH THIS TEMPERATURE

848

00:43:47,104 --> 00:43:50,224

INCREASE, WE CAN FIGURE OUT HOW
MUCH HEAT COMES OUT, WILL FLOW

849

00:43:50,224 --> 00:43:54,345

OUT -- IS FLOWING OUT OF THE
PLANET TODAY, AND THAT THEN CAN

850

00:43:54,345 --> 00:43:59,417

BE EXTRAPOLATED DOWN TO THE
DEPTHS AND HELP US TO FIGURE OUT

851

00:43:59,417 --> 00:44:04,989

WHAT IS ACTUALLY HAPPENING TO
TRANSPORT THAT HEAT OUT OF THE

852

00:44:04,989 --> 00:44:05,172

PLANET.

853

00:44:05,172 --> 00:44:08,142

SO, THIS IS A LITTLE VIDEO THAT
SHOWS HOW IT WORKS.

854

00:44:08,142 --> 00:44:09,360

OKAY, SO, WE HAVE THIS MOLE.

855

00:44:09,360 --> 00:44:12,062

WE HAVE A HAMMER WHICH PUSHES
THE MOLE FORWARD.

856

00:44:12,062 --> 00:44:15,332

NOW, IF IT'S JUST HANGING OUT IN
SPACE, IT WOULD JUST GO BACK AND

857

00:44:15,332 --> 00:44:20,471

FORTH BECAUSE YOU HAVE EQUAL AND
OPPOSITE REACTION, RIGHT?

858

00:44:20,471 --> 00:44:23,491

SO, WE HAVE THE MOISTURE THAT'S
-- MOTOR THAT'S RUNNING ON A

859

00:44:23,491 --> 00:44:24,258

LITTLE CAM UP HERE.

860

00:44:24,258 --> 00:44:27,394

IT PUSHES AGAINST THE SPRING,
THE SPRING BANGS IT DOWN QUICKLY

861

00:44:27,394 --> 00:44:31,198

AND THEN IT RECOILS AND WE HAVE
A SPRING UP HERE, SAUCER, THAT

862

00:44:31,198 --> 00:44:32,366

TAKES UP SOME OF THAT RECOIL.

863

00:44:32,366 --> 00:44:36,253

ALL THE FORCE IS STILL THERE,
BUT IT SLOWS IT DOWN AND ALLOWS

864

00:44:36,253 --> 00:44:40,291

THE FRICTION OF THE GROUND ON
THE SIDE OF THIS MOLE TO BE MORE

865

00:44:40,291 --> 00:44:40,474

EFFECTIVE.

866

00:44:40,474 --> 00:44:43,461

SO, THE FASTER YOU TRY TO PUSH

SOMETHING, THE LESS FRICTION YOU

867

00:44:43,461 --> 00:44:44,195

HAVE.

868

00:44:44,195 --> 00:44:47,114

SO, WE HAVE IT GOING VERY
QUICKLY DOWN, AND THEN THE

869

00:44:47,114 --> 00:44:51,268

RECOIL IS ACTUALLY RESISTED BY
THE FRICTION ON THE SIDES OF THE

870

00:44:51,268 --> 00:44:54,438

MOLE, AND IT BANGS ITS WAY DOWN
INTO THE GROUND.

871

00:44:54,438 --> 00:44:59,376

AGAIN, IT SOUNDS LIKE MAGIC, AND
WE HAD TO ACTUALLY PROVE TO OUR

872

00:44:59,376 --> 00:45:03,447

REVIEW PANEL THAT THIS WOULD
WORK, AND SO, WE PUT TOGETHER A

873

00:45:03,447 --> 00:45:14,391

FIVE-METER-HIGH TUBE OF SOIL IN
A LAB IN BREMEN, GERMANY, WHERE

874

00:45:14,391 --> 00:45:17,111

THEY BUILT THIS, AND BANG, IT
GOES RIGHT IN THERE, TAKES ABOUT

875

00:45:17,111 --> 00:45:19,313

AN HOUR AND A HALF TO GO FROM
THE TOP TO THE BOTTOM.

876

00:45:19,313 --> 00:45:21,048

SO, THAT'S THE HEAT FLOW.

877

00:45:21,048 --> 00:45:23,000

THE FINAL EXPERIMENT IS THE
PRECISION TRACKING EXPERIMENT,

878

00:45:23,000 --> 00:45:25,402

AND THIS IS WHERE WE REALLY
START GETTING INTO MAGIC,

879

00:45:25,402 --> 00:45:31,175

BECAUSE OVER THE LAST 50 YEARS,
THE DEEP SPACE NETWORK AND THE

880

00:45:31,175 --> 00:45:36,297

SCIENTISTS THAT WORK WITH IT
HAVE DEVELOPED TECHNIQUES THAT

881

00:45:36,297 --> 00:45:40,084

USE THE RADIO WAVES THAT ARE
SENT FROM THE SPACECRAFT AND

882

00:45:40,084 --> 00:45:44,188

BACK TO EARTH TO BE ABLE TO
LOCATE SPACECRAFT AT MARS'

883

00:45:44,188 --> 00:45:48,108

DISTANCE TO A PRECISION OF ABOUT
TEN CENTIMETERS.

884

00:45:48,108 --> 00:45:50,110

OKAY, SO THAT'S, WHAT, ABOUT
FOUR INCHES.

885

00:45:50,110 --> 00:45:54,131

SO, WE KNOW WHERE OUR SPACECRAFT
ARE IN SPACE WITH RESPECT TO

886

00:45:54,131 --> 00:45:57,451

THESE DEEP SPACE ANTENNAS TO
ACTUALLY FOUR INCHES.

887

00:45:57,451 --> 00:46:01,188

MAYBE THE ONES THAT ARE FLYING
AROUND NOT THAT GOOD, MAYBE ONLY

888

00:46:01,188 --> 00:46:04,024

20 OR 30 INCHES.

889

00:46:04,024 --> 00:46:06,193

BUT THEY'VE DEVELOPED THIS, THEY
CAN TRACK IT.

890

00:46:06,193 --> 00:46:09,396

SINCE WE'RE ON THE SURFACE OF
THE PLANET, AS YOU TRACK THE

891

00:46:09,396 --> 00:46:13,367

SPACECRAFT, YOU'RE ACTUALLY
TRACKING THE ROTATION OF THE

892

00:46:13,367 --> 00:46:14,034

PLANET.

893

00:46:14,034 --> 00:46:19,089

SO, WE TRACK IT FOR ABOUT AN
HOUR A DAY FOR FOUR OR FIVE DAYS

894

00:46:19,089 --> 00:46:24,178

DURING THE WEEK, AND WE CAN USE
THAT TO FIGURE OUT WHERE THE

895

00:46:24,178 --> 00:46:28,165

ROTATION AXIS IS, HOW FAST IT'S
ROTATING AND WHAT THE DIRECTION

896

00:46:28,165 --> 00:46:34,004

OF THAT ROTATION AXIS IS
POINTING.

897

00:46:34,004 --> 00:46:37,308

TURNS OUT THE ROTATION AXIS OF
MARS CHANGES OVER A COUPLE

898

00:46:37,308 --> 00:46:39,026

DIFFERENT TIME SCALES.

899

00:46:39,026 --> 00:46:42,346

THE FIRST TIME SCALE IS THE
SO-CALLED PROCESSIONAL TIME

900

00:46:42,346 --> 00:46:42,496

SCALE.

901

00:46:42,496 --> 00:46:44,398

THAT'S THE WOBBLE THAT YOU SEE
IN A TOP.

902

00:46:44,398 --> 00:46:47,351

SO, WHEN YOU SEE A TOP, IT SPINS
VERY QUICKLY, BUT IT WOBBLES

903

00:46:47,351 --> 00:46:50,437

AROUND A LITTLE BIT MORE SLOWLY,
AND IT WOBBLES BECAUSE GRAVITY'S

904

00:46:50,437 --> 00:46:53,023

TRYING TO MAKE IT TIP OVER.

905

00:46:53,023 --> 00:46:56,410

AND SINCE IT'S SPINNING INSTEAD
OF TIPPING OVER, IT PUSHES IT

906

00:46:56,410 --> 00:46:57,094

SIDEWAYS.

907

00:46:57,094 --> 00:46:58,362

AND SO, IT WOBBLES AROUND.

908

00:46:58,362 --> 00:47:03,233

AND THE SPEED OF THAT WOBBLE IS
DETERMINED BY HOW FAST THE TOP

909

00:47:03,233 --> 00:47:09,239

IS SPINNING, AND IT DEPENDS ON
WHAT'S CALLED A MOMENT OF

910

00:47:09,239 --> 00:47:11,358

INERTIA, WHICH IS THE
DISTRIBUTION OF MASS AWAY FROM

911

00:47:11,358 --> 00:47:13,160

THE AXIS.

912

00:47:13,160 --> 00:47:19,199

SO, IT'S LIKE A BALLERINA OR --
NO, AN ICE SKATER -- BALLERINAS

913

00:47:19,199 --> 00:47:20,234

SPIN AT ONE SPEED.

914

00:47:20,234 --> 00:47:23,420

ICE SKATERS, WHEN THEY PULL
THEIR ARMS IN, THEY ARE

915

00:47:23,420 --> 00:47:26,223

DECREASING THEIR MOMENT OF
INERTIA, BUT THEIR ENERGY STAYS

916

00:47:26,223 --> 00:47:28,075

THE SAME, SO THEY SPIN FASTER.

917

00:47:28,075 --> 00:47:31,195

SO, THE MOMENT OF INERTIA OF THE
PLANET SHOWS YOU WHERE THE MASS

918

00:47:31,195 --> 00:47:34,081

IS CONCENTRATED, WHETHER IT'S
CONCENTRATED CLOSER TO THE

919

00:47:34,081 --> 00:47:36,083

CENTER IN THE CORE OR WHETHER
IT'S MORE DISTRIBUTED.

920

00:47:36,083 --> 00:47:40,004

SO, THE BIGGER THE CORE IS, THE
LARGER THE MOMENT OF INERTIA'S

921

00:47:40,004 --> 00:47:41,055

GOING TO BE.

922

00:47:41,055 --> 00:47:44,441

SO, IF WE MEASURE THE MOMENT OF
INERTIA PRECISELY, THAT GIVES US

923

00:47:44,441 --> 00:47:48,228

A MEASURE OF THE SIZE AND
DENSITY OF THE CORE.

924

00:47:48,228 --> 00:47:52,149

SO, HERE WE GET THE MOMENT OF
INERTIA FROM THIS PROCESSION.

925

00:47:52,149 --> 00:47:58,038

IT WOBBLES ONCE AROUND THAT
CYCLE EVERY 165,000 YEARS, SO WE

926

00:47:58,038 --> 00:48:01,325

COULD JUST SIT ON THE EARTH AND
TAKE PICTURES OF IT WITH HUBBLE

927

00:48:01,325 --> 00:48:07,097

AND WAIT 165,000 YEARS AND
MEASURE THAT VERY PRECISELY, BUT

928

00:48:07,097 --> 00:48:13,170

WE'RE IMPATIENT AS SCIENTISTS,
SO WHAT WE DO IS WE MEASURE THE

929

00:48:13,170 --> 00:48:17,291
POLE AT ONE TIME, WHICH WAY IT'S
POINTING DURING VIKING, 1976, WE

930
00:48:17,291 --> 00:48:22,129
MEASURED IT AGAIN DURING
PATHFINDER, 26 YEARS LATER IN

931
00:48:22,129 --> 00:48:26,033
'96, AND WE GOT AN ESTIMATE OF
THE MOMENT OF INERTIA, BUT THOSE

932
00:48:26,033 --> 00:48:28,252
MEASUREMENTS, BECAUSE THE
TECHNOLOGY WAS, YOU KNOW, 50, 40

933
00:48:28,252 --> 00:48:31,472
YEARS OLDER, THEY'RE NOT QUITE
AS PRECISE.

934
00:48:31,472 --> 00:48:34,308
WE CAN MAKE A MUCH MORE PRECISE
MEASUREMENT NOW, USE THE VIKING

935
00:48:34,308 --> 00:48:37,378
MEASUREMENT AND THE PATHFINDER
MEASUREMENT TO INCREASE OUR

936
00:48:37,378 --> 00:48:41,482
PRECISION OF THAT MOMENT OF
INERTIA TO GET A BETTER -- OF

937
00:48:41,482 --> 00:48:44,368
THE SPEED OF THE WOBBLE -- TO
GET A BETTER ESTIMATE OF THE

938
00:48:44,368 --> 00:48:46,120
MOMENT OF INERTIA.

939
00:48:46,120 --> 00:48:50,224

IT ALSO WOBBLER ON A FASTER TIME
SCALE, WHICH ARE CALLED

940

00:48:50,224 --> 00:48:50,407
MUTATIONS.

941

00:48:50,407 --> 00:48:54,294
THESE ARE WOBBLER THAT HAPPEN
OVER THE COURSE OF A YEAR OR

942

00:48:54,294 --> 00:48:54,445
LESS.

943

00:48:54,445 --> 00:48:58,232
AND THESE ARE ACTUALLY FROM THE
INTERACTION BETWEEN THE LIQUID

944

00:48:58,232 --> 00:49:00,017
CORE, WHICH KIND OF SLOSHES
AROUND INSIDE.

945

00:49:00,017 --> 00:49:01,168
IT'S NOT QUITE COUPLED.

946

00:49:01,168 --> 00:49:04,388
IT'S NOT SOLIDLY COUPLED TO THE
REST OF THE PLANET.

947

00:49:04,388 --> 00:49:08,208
SO, AS THAT SLOSHES AROUND, IT
WOBBLER A LITTLE BIT, AND THAT'S

948

00:49:08,208 --> 00:49:09,309
A VERY SMALL WOBBLER.

949

00:49:09,309 --> 00:49:13,363
IT'S ONLY WOBBLER BY A FEW
METERS, BUT WE CAN MEASURE THAT

950

00:49:13,363 --> 00:49:16,049
WITH THIS PRECISION TRACKING.

951
00:49:16,049 --> 00:49:19,386
TWO YEARS OF TRACKING WILL BE
ABLE TO DETERMINE THE AMPLITUDE

952
00:49:19,386 --> 00:49:24,074
AND FREQUENCIES OF THESE
MUTATIONS, AND THAT WILL BE ABLE

953
00:49:24,074 --> 00:49:26,410
TO DIRECTLY GIVE US THE CORE
SIZE AND DENSITY.

954
00:49:26,410 --> 00:49:28,262
SO, THAT'S OUR OTHER PROBE OF
THE CORE.

955
00:49:28,262 --> 00:49:31,098
SO, A LITTLE SUMMARY OF THE
MISSION ITSELF.

956
00:49:31,098 --> 00:49:34,101
WE'RE FLYING A NEAR COPY OF THE
SUCCESSFUL PHOENIX LANDER.

957
00:49:34,101 --> 00:49:38,021
WE'RE USING THE SAME SPACECRAFT
DESIGN WITH JUST A FEW

958
00:49:38,021 --> 00:49:40,991
MODIFICATIONS TO MAKE IT OPERATE
BETTER AT THE EQUATOR, WHICH IS

959
00:49:40,991 --> 00:49:42,443
WHERE WE'RE GOING, INSTEAD OF
THE POLE.

960
00:49:42,443 --> 00:49:47,464

WE LAUNCH ON MARCH -- DURING THE
MONTH OF MARCH SOME TIME NEXT

961

00:49:47,464 --> 00:49:51,268
YEAR FROM VANNENBURG,
CALIFORNIA.

962

00:49:51,268 --> 00:49:54,037
WE HAVE A VERY FAST TRAJECTORY
BECAUSE WE'RE ON A VERY BIG

963

00:49:54,037 --> 00:49:59,109
ROCKET WITH A VERY SMALL SPACE
CRAFT.

964

00:49:59,109 --> 00:50:01,094
THEY DON'T MAKE THE ROCKETS THAT
PHOENIX LAUNCHED ON ANYMORE, SO

965

00:50:01,094 --> 00:50:03,113
WE CAN GET TO MARS QUICKLY.

966

00:50:03,113 --> 00:50:07,084
WE COME AROUND MARS TO EARTH AND
HIT MARS IN LESS THAN HALF AN

967

00:50:07,084 --> 00:50:09,019
ORBIT AROUND THE SUN.

968

00:50:09,019 --> 00:50:11,238
SO, WE LAND IN SEPTEMBER, WHICH
IS ABOUT SIX MONTHS AFTER OUR

969

00:50:11,238 --> 00:50:11,488
LAUNCH.

970

00:50:11,488 --> 00:50:17,277
WE SPEND TWO YEARS ON MARS,
WHICH IS ONE EARTH YEAR, SO WE

971
00:50:17,277 --> 00:50:19,296
GO THROUGH THE CYCLE.

972
00:50:19,296 --> 00:50:23,500
AND IT'S REPET PIV BECAUSE WE'RE
LISTENING FOR SEISMIC WAVES,

973
00:50:23,500 --> 00:50:24,384
SENSING THE TEMPERATURE.

974
00:50:24,384 --> 00:50:27,154
WE ACTUALLY DON'T HAVE TO DO
ANYTHING ACTIVE.

975
00:50:27,154 --> 00:50:29,406
AND OUR NOMINAL END OF MISSION
IS IN 2018.

976
00:50:29,406 --> 00:50:33,126
OF COURSE, THE COOL THING ABOUT
THIS WHOLE THING IS VANNENBURG,

977
00:50:33,126 --> 00:50:36,046
SO INSTEAD OF HAVING TO DEAL
WITH ALLIGATORS IN FLORIDA, WE

978
00:50:36,046 --> 00:50:38,415
GET TO PLAY WITH OTTERS IN
CALIFORNIA.

979
00:50:38,415 --> 00:50:43,070
AND AGAIN, THE REASON WE CAN DO
THAT IS BECAUSE WE'RE LAUNCHING

980
00:50:43,070 --> 00:50:44,071
OUR LARGE ROCKET.

981
00:50:44,071 --> 00:50:46,190
NORMALLY, YOU'RE TRYING TO

SQUEEZE EVERY BIT OF ENERGY YOU

982

00:50:46,190 --> 00:50:49,443

CAN OUT OF A LAUNCH, AND SO YOU
GET NEAR THE EQUATOR AND YOU

983

00:50:49,443 --> 00:50:52,296

LAUNCH IN THE SAME DIRECTION
THAT THE EARTH'S ROTATING, SO

984

00:50:52,296 --> 00:50:55,365

YOU GET LITTLE BIT OF A SLING
SHOT EFFECT.

985

00:50:55,365 --> 00:50:58,185

YOU LAUNCH TO THE EAST AND GET
INTO ORBIT TOWARDS MARS.

986

00:50:58,185 --> 00:51:01,054

SINCE WE HAVE A ROCKET WITH MORE
ENERGY THAN WE NEED, WE CAN

987

00:51:01,054 --> 00:51:03,340

ACTUALLY LAUNCH FROM VANNENBURG,
CALIFORNIA.

988

00:51:03,340 --> 00:51:06,443

WE LAUNCH ALMOST DUE SOUTH AND
GO KIND OF UP AND AROUND THE

989

00:51:06,443 --> 00:51:09,263

POLE AND HEAD OFF TOWARDS MARS.

990

00:51:09,263 --> 00:51:11,148

THIS SIMPLIFIES A COUPLE OF
THINGS.

991

00:51:11,148 --> 00:51:15,319

FIRST OF ALL, WE DON'T HAVE TO
TAKE A BUNCH OF PLANE FLIGHTS TO

992

00:51:15,319 --> 00:51:17,287

FLORIDA, WHICH COSTS A LOT OF
MONEY.

993

00:51:17,287 --> 00:51:21,091

BUT ALSO, IT TURNS OUT, FLORIDA
DURING THE TIME WE HAVE TO

994

00:51:21,091 --> 00:51:26,029

LAUNCH, THERE'S A LOT OF ATLAS
LAUNCHES THAT NEED TO GO OFF.

995

00:51:26,029 --> 00:51:29,416

SO, WE WERE ACTUALLY ABLE TO DO
NASA A FAVOR AND SORT OF TAKE

996

00:51:29,416 --> 00:51:35,405

SOME OF THE TRAFFIC JAM OFF OF
KENNEDY SPACE CENTER.

997

00:51:35,405 --> 00:51:37,407

THIS IS WHAT OUR SPACECRAFT
LOOKS LIKE.

998

00:51:37,407 --> 00:51:41,311

WE ACTUALLY COMPLETED THE
SPACECRAFT LAST MAY OR JUNE, AND

999

00:51:41,311 --> 00:51:44,181

SINCE THEN, WE'VE BEEN DOING A
LOT OF TESTING ON IT, SEEING

1000

00:51:44,181 --> 00:51:46,316

WHETHER THERE'S ANY PROBLEMS,
AND WE FOUND SEVERAL PROBLEMS,

1001

00:51:46,316 --> 00:51:49,102

WHICH IS NORMAL WHEN YOU'RE
PUTTING TOGETHER A VERY COMPLEX

1002

00:51:49,102 --> 00:51:50,103

SYSTEM LIKE THIS.

1003

00:51:50,103 --> 00:51:52,105

WE'VE BEEN ABLE TO FIX THEM.

1004

00:51:52,105 --> 00:51:55,192

THIS IS THE SPACECRAFT PRETTY
MUCH ALL BUTTONED UP IN ITS

1005

00:51:55,192 --> 00:51:56,143

LAUNCH CONFIGURATION.

1006

00:51:56,143 --> 00:51:59,179

HERE WE'RE PUTTING ON THE BACK
SHELL, WHICH PROTECTS IT IN

1007

00:51:59,179 --> 00:51:59,363

SPACE.

1008

00:51:59,363 --> 00:52:01,315

IF YOU PUT IT ALL TOGETHER, IT
LOOKS LIKE THIS.

1009

00:52:01,315 --> 00:52:03,183

SO, WE HAVE A HEAT SHIELD UP
HERE.

1010

00:52:03,183 --> 00:52:07,254

THESE ARE THE SOLAR PANELS IT
USES ON ITS CRUISE BETWEEN EARTH

1011

00:52:07,254 --> 00:52:08,155

AND MARS.

1012

00:52:08,155 --> 00:52:09,406

THIS WOULD BE THE ROCKET.

1013

00:52:09,406 --> 00:52:13,360

SO, WE HAVE THIS ADAPTER THAT HELPS US ATTACH TO THE ROCKET.

1014

00:52:13,360 --> 00:52:16,213

AND THIS IS THE WAY WE TRAVEL TO MARS.

1015

00:52:16,213 --> 00:52:20,233

ONCE WE GET TO MARS, WE UNFOLD IT THE WAY PHOENIX DID, AND THIS

1016

00:52:20,233 --> 00:52:23,487

IS OUR GLAMOUR SHOT.

1017

00:52:23,487 --> 00:52:25,455

WE HAD A PROFESSIONAL PHOTOGRAPHER COME IN HERE AND

1018

00:52:25,455 --> 00:52:26,340

POSE AND EVERYTHING.

1019

00:52:26,340 --> 00:52:29,142

SO, YOU CAN SEE THE SOLAR PANELS OUT HERE.

1020

00:52:29,142 --> 00:52:31,495

THIS IS THE DECK WHERE ALL OUR INSTRUMENTS ARE GOING TO LIVE

1021

00:52:31,495 --> 00:52:33,430

UNTIL WE GET TO MARS.

1022

00:52:33,430 --> 00:52:36,500

AND HERE IS A LITTLE BIT OF AN ANIMATION.

1023

00:52:36,500 --> 00:52:38,468

SO, THIS IS INSIGHT CRUISING

THROUGH SPACE.

1024

00:52:38,468 --> 00:52:43,307

WE GET TO MARS, WE EJECT THE
CRUISE STAGE WHICH HAS THE SOLAR

1025

00:52:43,307 --> 00:52:46,043

PANELS ON IT AND THEN WE START
ENTERING THE ATMOSPHERE.

1026

00:52:46,043 --> 00:52:49,079

WE BURN OFF A LOT OF THE ENERGY
USING THAT HEAT SHIELD JUST THE

1027

00:52:49,079 --> 00:52:52,115

SAME WAY APOLLO DID AND ALL MARS
LANDERS DO.

1028

00:52:52,115 --> 00:52:55,302

WE COME IN VERY, VERY QUICKLY
AND GET RID OF MOST OF THE

1029

00:52:55,302 --> 00:52:56,353

ENERGY WITH THE HEAT SHIELD.

1030

00:52:56,353 --> 00:53:00,073

WE GET DOWN ABOUT TWO TIMES THE
SPEED OF SOUND, WE POP A

1031

00:53:00,073 --> 00:53:02,359

PARACHUTE, WHICH THEN BRINGS US
DOWN CLOSER TO THE SURFACE.

1032

00:53:02,359 --> 00:53:04,311

WE EJECT OUR HEAT SHIELD.

1033

00:53:04,311 --> 00:53:07,030

WE DEPLOY OUR LEGS AND THEN WE
DROP OFF THE PARACHUTE ABOUT A

1034

00:53:07,030 --> 00:53:10,033

KILOMETER HIGH.

1035

00:53:10,033 --> 00:53:11,418

WE START UP OUR ROCKETS.

1036

00:53:11,418 --> 00:53:13,020

WE COME DOWN.

1037

00:53:13,020 --> 00:53:17,274

THERE'S NO AIRBAGS, THERE'S NO
SKY CRANE, NO CRAZY STUFF.

1038

00:53:17,274 --> 00:53:21,044

WE LAND ON ROCKETS JUST THE WAY
GOD INTENDED US TO LAND ON A

1039

00:53:21,044 --> 00:53:27,467

PLANET, RIGHT?

1040

00:53:27,467 --> 00:53:31,104

ONCE WE'RE SAFELY DOWN, WE HAVE
TO GET READY TO ACTUALLY SURVIVE

1041

00:53:31,104 --> 00:53:35,092

ON THE SURFACE, AND WE DO THAT
BY DEPLOYING OUR SOLAR PANELS.

1042

00:53:35,092 --> 00:53:38,495

THIS ALL HAPPENS DURING THE
FIRST 20 MINUTES, HALF AN HOUR

1043

00:53:38,495 --> 00:53:41,481

THAT WE'RE ON THE SURFACE OF
MARS, AND THEN WE'RE READY TO

1044

00:53:41,481 --> 00:53:44,234

GO.

1045
00:53:44,234 --> 00:53:48,105
YOU SEE THE DECK HERE IS ALL
CROWDED UP WITH STUFF, AND I'LL

1046
00:53:48,105 --> 00:53:50,340
TELL YOU A LITTLE BIT ABOUT THAT
IN A FEW MINUTES.

1047
00:53:50,340 --> 00:53:51,425
THIS IS WHERE WE'RE LANDING.

1048
00:53:51,425 --> 00:53:56,246
WE'RE LANDING IN THE WESTERN
PART OF ELYSIUM PLANITIA.

1049
00:53:56,246 --> 00:54:00,017
ODDLY ENOUGH, WE'RE ONLY ABOUT
300 KILOMETERS FROM CURIOSITY,

1050
00:54:00,017 --> 00:54:02,319
300 KILOMETERS NORTH OF
CURIOSITY.

1051
00:54:02,319 --> 00:54:04,438
THAT JUST TURNS OUT TO BE THE
BEST PLACE FOR US TO LAND FOR A

1052
00:54:04,438 --> 00:54:06,990
BUNCH OF TECHNICAL REASONS.

1053
00:54:06,990 --> 00:54:10,060
NONE OF WHICH ARE SCIENTIFIC,
BECAUSE WHEN YOU'RE STUDYING THE

1054
00:54:10,060 --> 00:54:12,996
CORE OF THE PLANET, NO MATTER
WHERE YOU LAND, THE CORE'S UNDER

1055
00:54:12,996 --> 00:54:14,164

YOUR FEET, SO THAT'S FINE.

1056

00:54:14,164 --> 00:54:17,067

BUT FOR TECHNICAL REASONS, THIS
IS THE SAFEST AND EASIEST PLACE

1057

00:54:17,067 --> 00:54:18,418

FOR US TO LAND.

1058

00:54:18,418 --> 00:54:20,470

THIS IS KIND OF A CROWDED SIDE
OF MARS.

1059

00:54:20,470 --> 00:54:23,423

WE'VE GOT SPIRIT, WE HAVE GOT
CURIOSITY.

1060

00:54:23,423 --> 00:54:25,175

VIKING 2 IS HERE.

1061

00:54:25,175 --> 00:54:29,212

EAGLE 2, REST ITS SOUL, WAS OVER
HERE.

1062

00:54:29,212 --> 00:54:36,119

BUT THIS IS WHERE WE'LL END UP,
AND THESE ARE WHERE WE'RE

1063

00:54:36,119 --> 00:54:39,256

LANDING IN AN AREA ABOUT 120
KILOMETERS LONG BY ABOUT 25

1064

00:54:39,256 --> 00:54:44,344

KILOMETERS WIDE.

1065

00:54:44,344 --> 00:54:48,281

SO, SURFACE DEPLOYMENT IS ONE OF
THE THINGS THAT WE'VE SPENT A

1066

00:54:48,281 --> 00:54:50,083
LOT OF EFFORT FIGURING OUT.

1067
00:54:50,083 --> 00:54:53,503
WE ACTUALLY SENT SEISMOMETERS TO
MARS ONCE BEFORE, BACK IN 1976

1068
00:54:53,503 --> 00:54:54,304
ON VIKING.

1069
00:54:54,304 --> 00:55:00,327
EACH OF THE VIKING SPACECRAFT
HAD A SEISMOMETER.

1070
00:55:00,327 --> 00:55:01,128
SO, THIS IS A PICTURE.

1071
00:55:01,128 --> 00:55:02,329
THIS IS ACTUALLY THE SEISMOMETER
RIGHT HERE, THE VIKING

1072
00:55:02,329 --> 00:55:03,046
SEISMOMETER.

1073
00:55:03,046 --> 00:55:04,114
THIS IS THE GROUND.

1074
00:55:04,114 --> 00:55:05,432
WHAT'S WRONG WITH THIS PICTURE,
RIGHT?

1075
00:55:05,432 --> 00:55:09,219
WE'RE SUPPOSED TO BE MEASURING,
YOU KNOW, GROUND MOTION AT, YOU

1076
00:55:09,219 --> 00:55:13,140
KNOW, ATOMIC LEVELS, AND WE'RE
SITTING UP HERE ON A SPACECRAFT

1077

00:55:13,140 --> 00:55:16,293
THAT HAS SHOCK ABSORBERS ON IT.

1078
00:55:16,293 --> 00:55:22,015
AND THE REASON FOR THIS WAS WITH
THE SEISMOMETER, IT'S LIKE THE

1079
00:55:22,015 --> 00:55:25,051
VERY LAST THING THEY ACCEPTED ON
THE PAYLOAD, LAST IN LINE FOR

1080
00:55:25,051 --> 00:55:25,485
ALL THE RESOURCES.

1081
00:55:25,485 --> 00:55:29,406
WE DIDN'T HAVE AN ARM THAT COULD
PICK IT UP, SO WE HOPED THAT WE

1082
00:55:29,406 --> 00:55:35,262
WOULD HAVE SOME FAIRLY LARGE
QUAKES THAT DIDN'T MATERIALIZE.

1083
00:55:35,262 --> 00:55:39,499
SO, MY GENIUS WAS TO FIGURE OUT
HOW TO PUT THE GROUND AND THE

1084
00:55:39,499 --> 00:55:41,201
SURFACE IN THE SAME PLACE.

1085
00:55:41,201 --> 00:55:42,369
IT'S NOT REALLY THAT HARD.

1086
00:55:42,369 --> 00:55:44,471
AND WE DO THAT WITH A ROBOTIC
ARM.

1087
00:55:44,471 --> 00:55:47,140
SO, WE PICK UP OUR SEISMOMETER.

1088

00:55:47,140 --> 00:55:51,278
IT'S CONNECTED TO THE DECK WITH
A BUNCH OF EXPLOSIVE BOLTS THAT

1089
00:55:51,278 --> 00:55:51,461
UNLATCH.

1090
00:55:51,461 --> 00:55:53,113
WE TAKE IT OUT.

1091
00:55:53,113 --> 00:55:57,117
WE'VE ALREADY MAPPED OUT THIS
GROUND WITH OUR CAMERA AND DONE

1092
00:55:57,117 --> 00:56:01,054
SOME 3D ANALYSIS TO FIGURE OUT
WHAT A GOOD, SAFE PLACE TO PUT

1093
00:56:01,054 --> 00:56:03,073
THE SEISMOMETER DOWN.

1094
00:56:03,073 --> 00:56:07,444
ONCE WE'VE TAKEN SOME PICTURES
WITH OUR CAMERA, WE'VE DONE SOME

1095
00:56:07,444 --> 00:56:10,180
ANALYSIS OF OUR NOISE LEVEL AND
WE'RE SATISFIED WITH WHERE WE

1096
00:56:10,180 --> 00:56:13,416
ARE, WE GO BACK AND PICK THIS
THING UP.

1097
00:56:13,416 --> 00:56:16,203
THIS IS OUR WYNDHAM THERMAL
SHIELD.

1098
00:56:16,203 --> 00:56:19,105
IT'S AN ALUMINUM DOME ALMOST
ABOUT A METER ACROSS.

1099

00:56:19,105 --> 00:56:22,008

YOU PICK IT UP, AND OOH, THERE'S
SOMETHING COOL, IT'S GOT A

1100

00:56:22,008 --> 00:56:24,161

SKIRT, OKAY?

1101

00:56:24,161 --> 00:56:27,414

NICE PLEATED SKIRT LIKE YOU'D
WEAR TO A SQUARE DANCE OR

1102

00:56:27,414 --> 00:56:31,067

SOMETHING LIKE THAT, AND IT'S UP
ON LEGS.

1103

00:56:31,067 --> 00:56:34,437

IF YOU PUT THIS DOWN, THIS IS A
THERMAL PROTECTION HERE, A

1104

00:56:34,437 --> 00:56:36,339

THERMAL BLANKET.

1105

00:56:36,339 --> 00:56:42,095

AND UNDER HERE, IT HAS A CHAIN
MAIL AND DOESN'T LET THE WIND

1106

00:56:42,095 --> 00:56:45,465

IN, MAKES A SNUG LITTLE COCOON
FOR OUR SEISMOMETER TO SIT IN

1107

00:56:45,465 --> 00:56:47,317

AND BE RELATIVELY SHIELDED FROM
THE ENVIRONMENT.

1108

00:56:47,317 --> 00:56:50,253

AND ONCE WE FINISH WITH THAT, WE
GO BACK AND DO OUR LAST

1109

00:56:50,253 --> 00:56:53,190
DEPLOYMENT, BECAUSE IF WE
ACTUALLY STARTED THEM ALL HERE,

1110
00:56:53,190 --> 00:56:55,158
IT WOULD GO RIGHT DOWN THROUGH
OUR COMPUTER, AND THAT WOULDN'T

1111
00:56:55,158 --> 00:56:56,126
BE GOOD.

1112
00:56:56,126 --> 00:56:58,144
SO, WE WANT TO PUT IT ON THE
GROUND AS WELL.

1113
00:56:58,144 --> 00:57:06,219
EACH OF THESE THINGS IS, OF
COURSE, CONNECTED BACK TO THE

1114
00:57:06,219 --> 00:57:09,039
SPACECRAFT BY A CABLE THAT
ALLOWS US TO POWER AND GET THE

1115
00:57:09,039 --> 00:57:11,057
SIGNALS BACK.

1116
00:57:11,057 --> 00:57:13,126
WE PUT THE STRUCTURE FOR THE
MOLE ON HERE.

1117
00:57:13,126 --> 00:57:14,461
THE MOLE LIVES IN THIS CHIMNEY
HERE.

1118
00:57:14,461 --> 00:57:17,447
ONCE WE PUT IT ON THE GROUND, WE
LET GO OF IT WITH OUR ARM AND

1119
00:57:17,447 --> 00:57:21,268
THEN WE CAN RELEASE THE MOLE AND

IT STARTS DIGGING ITS WAY DOWN

1120

00:57:21,268 --> 00:57:28,091

TO ITS 15-METER DEPTH.

1121

00:57:28,091 --> 00:57:30,210

SO, WE'D LIKE TO LEAVE YOU WITH
THIS PICTURE.

1122

00:57:30,210 --> 00:57:34,431

THIS IS A PICTURE THAT SPIRIT
TOOK BACK IN 2004, I THINK.

1123

00:57:34,431 --> 00:57:39,102

IT'S AN IMAGE FROM GUSEV CRATER.

1124

00:57:39,102 --> 00:57:41,121

THIS IS THE RIM OF GUSEV CRATER.

1125

00:57:41,121 --> 00:57:42,372

THIS DOT UP HERE IS THE EARTH.

1126

00:57:42,372 --> 00:57:46,176

SO, I THINK THIS PICTURE'S VERY
EMBLEMATIC OF SORT OF OUR

1127

00:57:46,176 --> 00:57:49,279

MISSION GOAL, WHICH IS TO GET
INSIGHT INTO THE EARTH BY

1128

00:57:49,279 --> 00:57:50,030

EXPLORING MARS.

1129

00:57:50,030 --> 00:57:52,482

AND WITH THAT, I'LL TAKE SOME
QUESTIONS.

1130

00:57:52,482 --> 00:58:02,225

[APPLAUSE]

AND IF YOU WANT TO ASK A

1131

00:58:02,225 --> 00:58:03,043
QUESTION, COULD YOU GET.

1132

00:58:03,043 --> 00:58:06,963
AND GO TO THE MICROPHONE,
BECAUSE THAT WAY, PEOPLE WILL BE

1133

00:58:06,963 --> 00:58:12,052
ABLE TO HEAR YOU.

1134

00:58:12,052 --> 00:58:16,022
>> HOW DO YOU MEASURE THE
THERMAL CONDUCTIVITY AT ABOUT

1135

00:58:16,022 --> 00:58:16,990
FIVE-METER DEPTH?

1136

00:58:16,990 --> 00:58:19,092
OTHERWISE, IF YOU DON'T, IT'S
JUST A THERMAL GRADIENT.

1137

00:58:19,092 --> 00:58:19,376
>> RIGHT.

1138

00:58:19,376 --> 00:58:22,095
WE ACTUALLY MEASURE THE
THERMAL -- WE HAVE HEATERS ON

1139

00:58:22,095 --> 00:58:23,046
THE MOLE.

1140

00:58:23,046 --> 00:58:27,150
WE STOP ABOUT EVERY HALF METER
AND WE PUT A HEAT PULSE IN.

1141

00:58:27,150 --> 00:58:31,037
THEN WE TURN OFF THE HEATER, WE

LOOK AT THE DECREASE IN

1142

00:58:31,037 --> 00:58:34,124

TEMPERATURE, AND BY LOOKING AT
HOW QUICKLY THE TEMPERATURE GOES

1143

00:58:34,124 --> 00:58:40,330

AWAY, YOU CAN GET THE THERMAL
DIFFUSIVITY OUT OF THAT.

1144

00:58:40,330 --> 00:58:42,198

[INAUDIBLE]

YEAH, AND THAT DECAYS AWAY.

1145

00:58:42,198 --> 00:58:44,384

AND AFTER A FEW WEEKS, THAT'S NO
LONGER CONTAMINATING OUR

1146

00:58:44,384 --> 00:58:47,103

TEMPERATURE MEASUREMENT.

1147

00:58:47,103 --> 00:58:50,090

[INAUDIBLE]

YEAH.

1148

00:58:50,090 --> 00:59:00,016

>> IN REGARD TO THE METEORITE,
AOH-84001, THERE ANY CURRENT

1149

00:59:00,016 --> 00:59:05,372

METEORITES THAT HAVE BEEN
DISCOVERED THAT ARE LIKE THAT?

1150

00:59:05,372 --> 00:59:11,044

>> WELL, ALLEN HILL'S 84001 IS
ONE OF A WHOLE COLLECTION OF

1151

00:59:11,044 --> 00:59:13,263

METEORITES THAT WE'VE GOTTEN
THAT HAVE COME FROM MARS.

1152

00:59:13,263 --> 00:59:17,967

THAT ONE'S FAMOUS OF THE VARIOUS
DIFFERENT STRUCTURES THAT THEY

1153

00:59:17,967 --> 00:59:21,037

FOUND IN IT THAT HAVE BEEN
INTERPRETED IN TERMS OF THE

1154

00:59:21,037 --> 00:59:24,457

RESULT OF BIOLOGICAL ACRE.

1155

00:59:24,457 --> 00:59:28,044

AND THERE'S A LOT OF CONTROVERSY
OVER WHETHER IT'S ACTUALLY

1156

00:59:28,044 --> 00:59:32,048

BIOLOGICAL OR NOT, BUT WE DO
HAVE LOTS, YOU KNOW, DOZENS OF

1157

00:59:32,048 --> 00:59:35,135

METEORITES THAT WE CAN IDENTIFY
AS HAVING COME FROM MARS, JUST

1158

00:59:35,135 --> 00:59:39,155

THEY WERE BLASTED OFF BY A BIG
IMPACT ON MARS AND THEY FLEW

1159

00:59:39,155 --> 00:59:42,058

THROUGH SPACE FOR A WHILE AND
EVENTUALLY RAN INTO THE EARTH.

1160

00:59:42,058 --> 00:59:46,429

AND WE CAN USE THOSE FOR LOTS OF
THINGS.

1161

00:59:46,429 --> 00:59:50,266

THE MOST RELEVANT TO US IS THEY
CAN ACTUALLY LOOK AT THE AMOUNT

1162

00:59:50,266 --> 00:59:54,404

OF RADIOACTIVE MATERIAL IN IT
AND DO SOME AGE DATING OF THESE

1163

00:59:54,404 --> 00:59:55,071

THINGS.

1164

00:59:55,071 --> 01:00:02,095

THEY CAN LOOK AT THE DETAILED
MINEROLGY OF THE METEORITES AND

1165

01:00:02,095 --> 01:00:04,314

DETERMINE THAT THEY CAME FROM
THE MANTLE OF MARS, SO WE KNOW

1166

01:00:04,314 --> 01:00:07,117

SOMETHING ABOUT THE COMPOSITION
OF THE UPPER MANTLE OF MARS, AT

1167

01:00:07,117 --> 01:00:09,469

LEAST, THAT WE CAN USE TO
CONSTRAIN OUR MODELS.

1168

01:00:09,469 --> 01:00:12,155

SO, THOSE ARE VERY USEFUL THAT
WAY.

1169

01:00:12,155 --> 01:00:12,372

>> THANK YOU.

1170

01:00:12,372 --> 01:00:17,060

>> SURE.

1171

01:00:17,060 --> 01:00:19,345

>> GOOD EVENING.

1172

01:00:19,345 --> 01:00:24,417

ASSUMING THAT THE MOLE
ENCOUNTERS ARE REALLY HARD

1173

01:00:24,417 --> 01:00:27,437

BOLDER, MAYBE ONE METER DOWN
INSTEAD OF FIVE, HOW WILL THAT

1174

01:00:27,437 --> 01:00:28,254

AFFECT YOUR SCIENCE?

1175

01:00:28,254 --> 01:00:31,424

>> OKAY, YEAH, WE ACTUALLY
THOUGHT ABOUT THAT A LITTLE BIT,

1176

01:00:31,424 --> 01:00:35,211

BECAUSE OBVIOUSLY, ONE THING YOU
DON'T WANT IS FOR THE MOLE TO GO

1177

01:00:35,211 --> 01:00:37,213

DOWN AND GO BUNK AGAINST A BIG
ROCK.

1178

01:00:37,213 --> 01:00:42,051

AND THERE'S A COUPLE OF THINGS
THAT WE'VE DONE.

1179

01:00:42,051 --> 01:00:47,073

FIRST OF ALL, WE'VE PICKED OUR
LANDING SITE PRETTY CAREFULLY.

1180

01:00:47,073 --> 01:00:53,480

IT'S ESPERIAN AGE, WHICH MEANS
IT'S ABOUT A 3 BILLION-YEAR-OLD

1181

01:00:53,480 --> 01:00:57,383

SURFACE, WHICH MEANS IT'S BEEN
PULVERIZED BY METEORITES FOR A

1182

01:00:57,383 --> 01:01:01,070

LONG TIME AND THERE ARE LARGE
CRATERS AROUND THE LANDING LIP

1183

01:01:01,070 --> 01:01:04,124

WHERE YOU CAN LOOK AT THE CROSS
SECTION OF THE MATERIAL

1184

01:01:04,124 --> 01:01:11,448

UNDERNEATH, AND WE CAN ACTUALLY
SHOW THAT THE DENSITY OF ROCKS

1185

01:01:11,448 --> 01:01:17,153

IS -- IF YOU CONVERT IT INTO A
SURFACE COVERAGE, IT'S ABOUT 4%

1186

01:01:17,153 --> 01:01:18,054

OR 5%.

1187

01:01:18,054 --> 01:01:19,439

AND YOU CAN DO THE STATISTICS.

1188

01:01:19,439 --> 01:01:25,328

AND STATISTICALLY, WE'VE GOT
SOMEWHERE BETWEEN 92% AND 98%

1189

01:01:25,328 --> 01:01:29,165

PROBABILITY OF GETTING DOWN TO
FIVE METERS WITHOUT ENCOUNTERING

1190

01:01:29,165 --> 01:01:30,183

A ROCK.

1191

01:01:30,183 --> 01:01:34,420

SO, BUT IF YOU'RE NOT LUCKY,
THERE'S A COUPLE OTHER THINGS IN

1192

01:01:34,420 --> 01:01:35,121

OUR FAVOR.

1193

01:01:35,121 --> 01:01:38,124

FIRST OF ALL, SMALL ROCKS,
ANYTHING UP TO A COUPLE INCHES,

1194

01:01:38,124 --> 01:01:41,227

IT WILL ACTUALLY JUST PUSH OUT
OF THE WAY.

1195

01:01:41,227 --> 01:01:42,262

IT'S PRETTY STRONG.

1196

01:01:42,262 --> 01:01:46,149

AND IF IT HITS A BIGGER ROCK --
IF IT HITS IT FLAT ON, THEN YOU

1197

01:01:46,149 --> 01:01:49,085

KNOW, THAT'S IT, THAT'S AS FAR
AS WE GO.

1198

01:01:49,085 --> 01:01:52,088

IF IT HITS IT AT AN ANGLE,
YOU'RE ON THE EDGE OF A ROCK AT

1199

01:01:52,088 --> 01:01:55,158

ABOUT, YOU KNOW, ROUGHLY 45
DEGREES, IT WILL ACTUALLY, YOU

1200

01:01:55,158 --> 01:01:58,394

KNOW, DIG A LITTLE GOUGE, TURN
AROUND AND ACTUALLY KEEP ON

1201

01:01:58,394 --> 01:02:00,413

GOING AT AN ANGLE.

1202

01:02:00,413 --> 01:02:05,034

AND WE HAVE TILT METERS INSIDE
THE MOLE THAT ACTUALLY MEASURE

1203

01:02:05,034 --> 01:02:06,269

THE ANGLE THAT THE MOLE IS
GOING.

1204

01:02:06,269 --> 01:02:10,490
SO, IF IT DOESN'T GO STRAIGHT
DOWN, IF IT GOES DOWN AT AN

1205
01:02:10,490 --> 01:02:14,427
ANGLE, WE CAN THEN STILL FIGURE
OUT THE DEPTH THAT IT GETS TO

1206
01:02:14,427 --> 01:02:18,381
AND FIGURE OUT THE DEPTH OF THE
SENSORS FOR THE VERTICAL

1207
01:02:18,381 --> 01:02:19,215
GRADIENT.

1208
01:02:19,215 --> 01:02:22,235
SO, IT WILL GO AROUND SOME ROCKS
IF IT HITS ENOUGH OF THE EDGE,

1209
01:02:22,235 --> 01:02:26,072
AND IF WE ONLY GET DOWN TO -- WE
HAVE TO GET THE TIP OF THE MOLE

1210
01:02:26,072 --> 01:02:29,158
DOWN TO ABOUT TWO METERS IN
ORDER TO BE ABLE TO MAKE OUR

1211
01:02:29,158 --> 01:02:29,375
MEASUREMENT.

1212
01:02:29,375 --> 01:02:33,263
IF WE GET IT DOWN TO TWO METERS
AND WE LAST FOR A YEAR, WE CAN

1213
01:02:33,263 --> 01:02:37,300
PULL OUT OUR MEASUREMENT AT THE
PRECISION THAT WE NEED.

1214
01:02:37,300 --> 01:02:41,170
SO, TWO METERS IS KIND OF LIKE

WHERE WE'LL BE KEEPING OUR

1215

01:02:41,170 --> 01:02:43,256

FINGERS CROSSED UNTIL WE GET TO
TWO METERS.

1216

01:02:43,256 --> 01:02:46,526

THEN IT'S KIND OF LIKE
EVERYTHING AFTER THAT'S GRAVY.

1217

01:02:46,526 --> 01:02:48,077

>> THANK YOU.

1218

01:02:48,077 --> 01:02:48,394

>> SURE.

1219

01:02:48,394 --> 01:02:52,198

>> MY QUESTION IS KIND OF THE
OPPOSITE OF THE LAST ONE.

1220

01:02:52,198 --> 01:02:55,368

THE SEISMOMETER, SINCE YOU'RE
PUTTING IT JUST ON TOP OF THE

1221

01:02:55,368 --> 01:02:58,171

GROUND, WHAT ARE THE EFFECTS OF
IT SITTING ON LOOSE DIRT RATHER

1222

01:02:58,171 --> 01:03:01,324

THAN BEING ANCHORED TO, LIKE,
BEDROCK?

1223

01:03:01,324 --> 01:03:04,344

>> IT'S ACTUALLY A PRETTY
EFFECTIVE COUPLING.

1224

01:03:04,344 --> 01:03:07,447

YOU DO WORRY ABOUT THE COUPLING
BETWEEN, YOU KNOW, YOUR SURFACE

1225

01:03:07,447 --> 01:03:10,116

AND THE SEISMOMETER.

1226

01:03:10,116 --> 01:03:15,421

NORMALLY, WHAT WE DO ON THE
EARTH IS THEY PUT THEM ON CEMENT

1227

01:03:15,421 --> 01:03:18,224

PIERS, AND THEY JUST HAVE LITTLE
POINTY FEET.

1228

01:03:18,224 --> 01:03:21,027

THEY DON'T BOLT THEM ON TO THE
CEMENT, THEY ACTUALLY JUST SET

1229

01:03:21,027 --> 01:03:24,063

THEM ON THERE, BECAUSE IF YOU
BOLT THEM DOWN, JUST THE

1230

01:03:24,063 --> 01:03:26,266

STRESSES IN THERE, THEY KEEP
MOVING AROUND THE LEVELS THAT

1231

01:03:26,266 --> 01:03:27,417

WE'RE TALKING ABOUT.

1232

01:03:27,417 --> 01:03:32,505

SO, THEY JUST HAVE POINTS
SITTING ON THE CEMENT, BUT YOU

1233

01:03:32,505 --> 01:03:34,307

CAN MEASURE ON THE GROUND.

1234

01:03:34,307 --> 01:03:39,095

THERE'S SOME MICROPHYSICS WITH
THE WAY THE GREENS KIND OF

1235

01:03:39,095 --> 01:03:40,129

REARRANGE THEMSELVES.

1236

01:03:40,129 --> 01:03:43,499

ON THE EARTH, THEY DO SEISMOLOGY
IN THE FIELD, AND THERE ARE WAYS

1237

01:03:43,499 --> 01:03:44,434

OF DEALING WITH THAT.

1238

01:03:44,434 --> 01:03:49,038

YOU KNOW, WE'VE DESIGNED THE
FEET WITH A CONE WITH A FLANGE

1239

01:03:49,038 --> 01:03:51,240

THAT ACTUALLY GIVES US PRETTY
GOOD COUPLING.

1240

01:03:51,240 --> 01:03:54,427

AND THE SEISMIC WAVES, IT'S NOT
LIKE, YOU KNOW, WE'RE VIBRATING

1241

01:03:54,427 --> 01:03:59,115

SO FAST THAT YOU CAN'T FOLLOW
THE GROUND.

1242

01:03:59,115 --> 01:04:04,003

THE FASTEST OSCILLATIONS THAT
WE'RE LOOKING AT ARE RELATIVELY

1243

01:04:04,003 --> 01:04:07,223

SLOW, AND OUR BREAD AND BUTTER
IS KIND OF THE ONE CYCLE PER

1244

01:04:07,223 --> 01:04:09,125

SECOND AND SLOWER REGIME.

1245

01:04:09,125 --> 01:04:13,062

AND SO, IT'S NOT LIKE -- LIKE I
SAY, YOU'RE NOT GOING TO BE LIKE

1246

01:04:13,062 --> 01:04:16,432
SCOOTING AROUND ON THE GROUND AT
THOSE LEVELS.

1247
01:04:16,432 --> 01:04:21,104
THE MORE DIFFICULT PROBLEM IS
ACTUALLY IF YOU HAVE DIRT, YOU

1248
01:04:21,104 --> 01:04:25,241
TEND TO GET NOISE THAT GETS
TRAPPED IN THIS -- DIRT HAS A

1249
01:04:25,241 --> 01:04:28,211
LOW VELOCITY AND YOU TRAP IT
BETWEEN THE BEDROCK BELOW AND

1250
01:04:28,211 --> 01:04:28,478
THE SURFACE.

1251
01:04:28,478 --> 01:04:32,398
AND SO, THAT KIND OF INCREASES
THE AMOUNT OF NOISE THAT YOU

1252
01:04:32,398 --> 01:04:33,366
TEND TO GET.

1253
01:04:33,366 --> 01:04:37,353
BUT WE'VE DONE, YOU KNOW,
CALCULATIONS OF THE LEVEL OF

1254
01:04:37,353 --> 01:04:40,323
SORT OF EXTRA NOISE THAT WE GET
FROM THAT, AND WE'RE OKAY WITH

1255
01:04:40,323 --> 01:04:40,473
THAT.

1256
01:04:40,473 --> 01:04:41,224
>> THANKS.

1257

01:04:41,224 --> 01:04:46,029

AND JUST QUICKLY, DO YOU EXPECT
FOR AN INITIAL PERIOD OF TIME IT

1258

01:04:46,029 --> 01:04:47,180

WILL SETTLE IN?

1259

01:04:47,180 --> 01:04:50,383

>> YEAH, FOR THE FIRST MONTH OR
SO, WE'LL PROBABLY HAVE SOME

1260

01:04:50,383 --> 01:04:51,384

ISSUES WITH SETTLING.

1261

01:04:51,384 --> 01:04:54,303

>> THANKS.

>> SURE.

1262

01:04:54,303 --> 01:04:55,338

>> HELLO, BRUCE.

1263

01:04:55,338 --> 01:04:58,508

I REALLY ENJOYED THE
PRESENTATION.

1264

01:04:58,508 --> 01:04:59,192

THANK YOU.

1265

01:04:59,192 --> 01:05:05,048

SOMETHING THAT WAS MISSING WAS
THERE WAS NO TALK ABOUT HOW THE

1266

01:05:05,048 --> 01:05:08,251

ATMOSPHERE -- THE SITUATION OF
THE ATMOSPHERE OF MARS AFFECTS

1267

01:05:08,251 --> 01:05:09,235

THESE DATA.

1268

01:05:09,235 --> 01:05:12,155

IS IT TRULY NOT AFFECTED BY WHAT
THE CONDITIONS OF THE ATMOSPHERE

1269

01:05:12,155 --> 01:05:12,288

IS?

1270

01:05:12,288 --> 01:05:14,440

>> OH, IT'S VERY MUCH AFFECTED.

1271

01:05:14,440 --> 01:05:16,175

THAT'S WHY WE HAVE THAT SHIELD
OVER IT.

1272

01:05:16,175 --> 01:05:19,345

AND THAT SHIELD -- I MEAN, IT
LOOKS LIKE WE JUST BOUGHT A ROCK

1273

01:05:19,345 --> 01:05:22,398

AND TURNED IT OVER AND -- BUT
THERE'S A LITTLE BIT MORE TO IT.

1274

01:05:22,398 --> 01:05:27,153

WE ACTUALLY DID A LOT OF
HYDRODYNAMICAL CALCULATIONS.

1275

01:05:27,153 --> 01:05:32,325

AND THAT DOME IS ACTUALLY
AERODYNAMICALLY FORMED SO IT HAS

1276

01:05:32,325 --> 01:05:33,126

NEGATIVE LIFT.

1277

01:05:33,126 --> 01:05:36,279

SO, WHEN THE WIND BLOWS, INSTEAD
OF JUST FLIPPING UP AND ROLLING

1278

01:05:36,279 --> 01:05:40,249

AWAY LIKE A TUMBLEWEED, IT

ACTUALLY PRESSES DOWN AND STAYS

1279

01:05:40,249 --> 01:05:40,483

IN PLACE.

1280

01:05:40,483 --> 01:05:44,420

AND LIKE I SAY, WE DESIGNED THAT
SKIRT TO KIND OF SEAL AROUND THE

1281

01:05:44,420 --> 01:05:49,358

BOTTOM SO THAT WE DON'T HAVE THE
WIND GOING DIRECTLY AGAINST THE

1282

01:05:49,358 --> 01:05:51,394

SEISMOMETER.

1283

01:05:51,394 --> 01:05:55,064

BUT IT STILL HAS FRICTION ON THE
GROUND, IS BLOWING THE

1284

01:05:55,064 --> 01:05:55,264

SPACECRAFT.

1285

01:05:55,264 --> 01:05:58,034

IT BLOWS OUR SOLAR PANELS.

1286

01:05:58,034 --> 01:06:03,206

BUT WE PUT ON OUR ANEMOMETERS,
THOSE TWO WIND SENSORS, SO THAT

1287

01:06:03,206 --> 01:06:05,241

WE CAN MEASURE THE WIND.

1288

01:06:05,241 --> 01:06:08,444

AND WHAT WE DO IS WHEN IT'S VERY
WINDY, WE JUST KIND OF THROW

1289

01:06:08,444 --> 01:06:11,214

THAT DATA AWAY BECAUSE IT GETS

TOO NOISY.

1290

01:06:11,214 --> 01:06:15,051

BUT WE NEED TO KNOW WHEN THE
WIND'S BLOWING AND WHEN IT'S NOT

1291

01:06:15,051 --> 01:06:15,218

BLOWING.

1292

01:06:15,218 --> 01:06:19,405

ONE OF THE PROBLEMS WITH VIKING
IS THAT IT HAD AN ANEMOMETER AS

1293

01:06:19,405 --> 01:06:22,191

WELL, BUT SINCE THEY WERE
LIMITED IN THE AMOUNT OF DATA,

1294

01:06:22,191 --> 01:06:25,311

USUALLY THEY TURNED ON THE
ANEMOMETER AND TURNED OFF THE

1295

01:06:25,311 --> 01:06:29,465

SEISMOMETER AND VISA VERSA, SO
WHEN YOU DID GET A SIGNAL ON THE

1296

01:06:29,465 --> 01:06:33,202

SEISMOMETER, YOU'RE GOING, OH, I
THINK THAT IS ACTUALLY PROBABLY

1297

01:06:33,202 --> 01:06:35,054

WIND, BUT YOU DIDN'T KNOW FOR
SURE.

1298

01:06:35,054 --> 01:06:41,377

SO, AGAIN, WE'RE RUNNING THEM AT
THE SAME TIME.

1299

01:06:41,377 --> 01:06:44,163

SO, THE WIND IS ONE THING.

1300

01:06:44,163 --> 01:06:46,249

THE BIGGER PROBLEM IS ACTUALLY
PRESSURE VARIATIONS.

1301

01:06:46,249 --> 01:06:49,035

AND IT'S NOT BECAUSE THE
PRESSURE PUSHES ON THE

1302

01:06:49,035 --> 01:06:49,235

SEISMOMETER.

1303

01:06:49,235 --> 01:06:52,155

IT'S BECAUSE IT ACTUALLY -- YOU
KNOW, IF YOU GET A LITTLE BREEZE

1304

01:06:52,155 --> 01:06:56,359

GOING BY, YOU KNOW, JUST KIND OF
THREE OR FOUR MILES AN HOUR,

1305

01:06:56,359 --> 01:07:03,032

VERY, VERY MILD IT CHANGES THE
PRESSURE BY A FRACTION OF

1306

01:07:03,032 --> 01:07:07,436

1,000th OF AN ATMOSPHERE, AND IT
PUSHES DOWN ON THE GROUND JUST A

1307

01:07:07,436 --> 01:07:10,256

LITTLE BIT HARDER OR A LITTLE
BIT LESS, AND IT TILTS IT.

1308

01:07:10,256 --> 01:07:14,460

AND THE SEISMOMETER GO, WHOA,
THIS IS A BIG -- SO, WE ACTUALLY

1309

01:07:14,460 --> 01:07:18,064

HAVE A VERY, VERY SENSITIVE
MEASURE OF THE PRESSURE, NOT

1310

01:07:18,064 --> 01:07:23,186
JUST THE STATIC PRESSURE, BUT
THE PRESSURE VARIATIONS IN OUR

1311
01:07:23,186 --> 01:07:23,436
FREQUENCY RANGE.

1312
01:07:23,436 --> 01:07:27,323
AND SO, BY DOING THAT, WE CAN
ACTUALLY, YOU KNOW, MEASURE THE

1313
01:07:27,323 --> 01:07:32,128
PRESSURE, WE CAN LOOK AT THE
SIGNALS ON THE SEISMIC RECORD,

1314
01:07:32,128 --> 01:07:39,285
AND MATHEMATICALLY, WE CAN JUST
ELIMINATE THOSE SIGNALS OUT TO

1315
01:07:39,285 --> 01:07:43,022
GET OUR DATA BACK.
>> SO, WHEN YOU SHOWED ME THE --

1316
01:07:43,022 --> 01:07:47,026
WHEN YOU SHOWED US THE PRESSURE
THAT CAN APPLY FROM THE

1317
01:07:47,026 --> 01:07:51,147
ATMOSPHERE OF MARS AND YOU CAN
POTENTIALLY LOOK AT IT WITH YOUR

1318
01:07:51,147 --> 01:07:55,234
SEISMOMETER, I'M NOT GOING TO
GET TOO EXCITED IN HERE, BUT

1319
01:07:55,234 --> 01:07:59,405
WITH ALL THIS MARS, YOU KNOW,
CAN WE POTENTIALLY FIND OUT WHAT

1320
01:07:59,405 --> 01:08:03,175

THE MIXING RATIOS ARE IN THE
GAS, IN THE ATMOSPHERES OF MARS?

1321

01:08:03,175 --> 01:08:04,126

>> NOT FROM OUR MEASUREMENTS.

1322

01:08:04,126 --> 01:08:07,163

WE DON'T HAVE ANY COMPOSITIONAL
MEASUREMENTS AT ALL.

1323

01:08:07,163 --> 01:08:11,317

>> BUT WE CAN SEE HOW THE MIXING
AND PRESSURE IS NEAR THE GROUND?

1324

01:08:11,317 --> 01:08:17,290

>> WE CAN LOOK AT PRESSURE
VARIATIONS, WE CAN LOOK AT THE

1325

01:08:17,290 --> 01:08:20,126

WIND SPEEDS.

1326

01:08:20,126 --> 01:08:24,096

ON AN EARLIER PROPOSAL, WE
ACTUALLY HAD MEASUREMENTS OF THE

1327

01:08:24,096 --> 01:08:27,099

WIND AT THREE DIFFERENT
ELEVATIONS SO WE COULD LOOK AT,

1328

01:08:27,099 --> 01:08:32,104

YOU KNOW, BOUNDARY LAYER
PROCESSES AND REALLY DO SOME

1329

01:08:32,104 --> 01:08:33,306

REALLY INTERESTING METEOROLOGY.

1330

01:08:33,306 --> 01:08:36,425

BUT IN ORDER TO GET -- YOU KNOW,
WE HAD A COST CAP THAT WE HAD TO

1331

01:08:36,425 --> 01:08:37,310

STAY UNDERNEATH.

1332

01:08:37,310 --> 01:08:43,082

AND SO, I HAD TO KIND OF CHOP
OFF ALL OF THE OTHER INSTRUMENTS

1333

01:08:43,082 --> 01:08:47,136

WE WERE GOING TO HAVE TO FLY IN
ORDER TO DO THAT.

1334

01:08:47,136 --> 01:08:48,271

BUT OTHER MISSIONS ARE PLANNED
TO LOOK AT THAT.

1335

01:08:48,271 --> 01:08:48,487

>> THANK YOU.

1336

01:08:48,487 --> 01:08:52,074

>> SURE.

1337

01:08:52,074 --> 01:08:55,478

>> SO, MY QUESTION ISN'T REALLY
ABOUT INSIGHT, MORE ABOUT MARS

1338

01:08:55,478 --> 01:08:58,364

IN GENERAL.

1339

01:08:58,364 --> 01:09:02,969

OBVIOUSLY, ELON MUSK HAS BEEN
GENERATING A LOT OF CONTROVERSY,

1340

01:09:02,969 --> 01:09:05,171

I GUESS, OR A LOT OF DEBATE
BETWEEN HIS --

1341

01:09:05,171 --> 01:09:09,041

>> I LIKE TO CALL IT INTEREST.
>> YEAH, HIS INTEREST IN MARS.

1342

01:09:09,041 --> 01:09:13,229

AND THE MOST RECENT ONE I THINK
WAS, LIKE, REPORTED IN

1343

01:09:13,229 --> 01:09:14,063

SEPTEMBER.

1344

01:09:14,063 --> 01:09:16,098

HE WANTS TO "NUKE" MARS.

1345

01:09:16,098 --> 01:09:19,201

I JUST WANTED TO KNOW WHAT YOUR
OPINION ON THAT WAS.

1346

01:09:19,201 --> 01:09:22,438

>> YEAH, I DON'T REMEMBER
READING THAT ONE, BUT THAT WOULD

1347

01:09:22,438 --> 01:09:28,277

BE GREAT FOR US, BECAUSE --
[LAUGHTER]

1348

01:09:28,277 --> 01:09:33,299

ONE OF THE OTHER THINGS THAT
WE'VE LOOKED AT IN VARIOUS OTHER

1349

01:09:33,299 --> 01:09:38,054

MISSION CONCEPTS IS ACTUALLY
TAKING OUR OWN SEISMIC ENERGY TO

1350

01:09:38,054 --> 01:09:43,092

MARS IN THE FORM OF, BASICALLY
CANNON BALLS.

1351

01:09:43,092 --> 01:09:49,131

SO, WE PUT OUR SEISMOMETER DOWN
AND THEN YOU COME IN FROM SPACE

1352

01:09:49,131 --> 01:09:53,085
AND HAVE YOUR OWN METEORITE AND
HAVE IT HIT, YOU KNOW, NOT ON

1353
01:09:53,085 --> 01:09:56,422
THE SPACECRAFT, BUT MAYBE 10 OR
20 KILOMETERS AWAY, AND THAT

1354
01:09:56,422 --> 01:09:59,342
WILL GENERATE ENOUGH SEISMIC
ENERGY THAT IT WILL GO DOWN,

1355
01:09:59,342 --> 01:10:02,278
BOUNCE OFF THE BOTTOM OF THE
CRUST AND COME BACK UP AGAIN.

1356
01:10:02,278 --> 01:10:09,051
ASSOCIATION YOU CAN ACTUALLY
TAKE FIVE KILOGRAMS OF TUNGSTEN,

1357
01:10:09,051 --> 01:10:11,387
AND IF IT COMES FROM THE SPEED
THAT YOU COME FROM THE EARTH,

1358
01:10:11,387 --> 01:10:16,092
YOU CAN ACTUALLY PROBE THE CRUST
WITH THESE THINGS AND GET SOME

1359
01:10:16,092 --> 01:10:17,143
PRETTY GOOD DATA.

1360
01:10:17,143 --> 01:10:24,050
IF YOU GET SOMETHING BIGGER, YOU
KNOW, 100 KILOGRAMS OR

1361
01:10:24,050 --> 01:10:25,484
SOMETHING, YOU CAN GET IT
FURTHER AWAY AND GET MORE

1362
01:10:25,484 --> 01:10:26,202

PENETRATION.

1363

01:10:26,202 --> 01:10:29,305

SO, A NUKE, THAT WOULD BE A
GREAT SEISMIC SOURCE.

1364

01:10:29,305 --> 01:10:33,492

>> AND IF HE DOESN'T GO WITH
THAT PLAN OF NUKING MARS, DO YOU

1365

01:10:33,492 --> 01:10:40,316

THINK HE CAN POSSIBLY MAYBE EVEN
WORK WITH NASA TO GET

1366

01:10:40,316 --> 01:10:45,154

CIVILIZATION OR HIMSELF ON TO
MARS?

1367

01:10:45,154 --> 01:10:48,107

>> I WOULDN'T PUT IT OUT OF THE
REALM OF POSSIBILITY.

1368

01:10:48,107 --> 01:10:52,378

I MEAN, ONE OF THE THINGS THAT
NASA'S ALWAYS BEING PUSHED TO DO

1369

01:10:52,378 --> 01:10:57,316

BY CONGRESS, AND YOU KNOW, WHO
ARE FUNDED BY TAXPAYERS, IS TO,

1370

01:10:57,316 --> 01:11:02,455

YOU KNOW, COLLABORATE WITH
PRIVATE INDUSTRY TO BOTH BRING

1371

01:11:02,455 --> 01:11:06,409

DOWN THE COST OF SPACE
EXPLORATION AND TO BRING IN MORE

1372

01:11:06,409 --> 01:11:07,126

EXPERTISE.

1373

01:11:07,126 --> 01:11:09,495

AND SO, I WOULD SAY THAT THAT'S
CERTAINLY A POSSIBILITY.

1374

01:11:09,495 --> 01:11:13,215

YOU KNOW, THE THINGS THAT ARE
HAPPENING IN TERMS OF SENDING

1375

01:11:13,215 --> 01:11:19,238

HUMANS TO MARS, YOU KNOW, NASA
HAS A BIG PROGRAM THAT'S AIMING

1376

01:11:19,238 --> 01:11:23,125

AT SENDING HUMANS TO MARS IN
MAYBE 20 YEARS OR SOMETHING LIKE

1377

01:11:23,125 --> 01:11:25,461

THAT, AND THAT'S ALL VERY
INTERESTING, BUT I'M NOT REALLY

1378

01:11:25,461 --> 01:11:27,296

AN EXPERT IN THAT, SO.
>> THANK YOU.

1379

01:11:27,296 --> 01:11:29,432

>> SURE.

1380

01:11:29,432 --> 01:11:33,069

>> YOU MENTIONED THAT MARS MIGHT
HAVE QUAKES LIKE THE ONES WE

1381

01:11:33,069 --> 01:11:36,405

HAVE IN MISSOURI ON THE NEW
MADRID FAULT.

1382

01:11:36,405 --> 01:11:41,093

AT THIS POINT IN TIME, DO WE
HAVE ANY IDEA HOW STRONG MARS

1383

01:11:41,093 --> 01:11:45,181

QUACKS MIGHT BE USING THE KINDS
OF MEASUREMENTS WE USE TO

1384

01:11:45,181 --> 01:11:46,265

MEASURE EARTHQUAKES HERE?

1385

01:11:46,265 --> 01:11:49,301

>> AGAIN, WE'VE MEASURED --
WE'VE MADE SOME CALCULATIONS.

1386

01:11:49,301 --> 01:11:55,157

WE CAN ONLY GUESS, AND THEY'RE
ALL PRETTY MUCH JUST STATISTICS.

1387

01:11:55,157 --> 01:11:59,245

YOU KNOW, EARTHQUAKES ARE A
CASTIC PROCESS.

1388

01:11:59,245 --> 01:12:03,082

YOU GET A LOT OF SMALL ONES, YOU
GET BIG ONES, AND YOU KNOW KIND

1389

01:12:03,082 --> 01:12:05,167

OF AN AVERAGE TIME BETWEEN THEM,
BUT IT'S RANDOM.

1390

01:12:05,167 --> 01:12:08,154

YOU KNOW, YOU CAN GET TWO BIG
ONES REALLY CLOSE TOGETHER OR

1391

01:12:08,154 --> 01:12:10,322

YOU CAN HAVE A LONG TIME IN
BETWEEN.

1392

01:12:10,322 --> 01:12:15,277

SO, WE HAVE A CALCULATION OF
KIND OF THE LARGEST MARS QUAKE

1393

01:12:15,277 --> 01:12:18,063
THAT IT LOOKS LIKE IT'S
REASONABLE TO SUPPORT ON THE

1394
01:12:18,063 --> 01:12:20,132
KINDS OF FAULTS THAT WE SEE.

1395
01:12:20,132 --> 01:12:24,019
THERE'S ACTUALLY AN INTERESTING
PAPER ABOUT TWO YEARS AGO WHERE

1396
01:12:24,019 --> 01:12:29,041
A PHOTOGEOLOGIST LOOKED AT
BOULDER TRACKS WHERE BOULDERS

1397
01:12:29,041 --> 01:12:34,346
HAD ROLLED DOWN A VERY LONG
RIDGE, AND ALL THESE BOULDER

1398
01:12:34,346 --> 01:12:36,132
TRACKS WERE VERY RECENT, YOU
KNOW.

1399
01:12:36,132 --> 01:12:39,051
THEY WERE TRACKS IN THE DUST AT
THE SURFACE AND THEY WOULD

1400
01:12:39,051 --> 01:12:42,371
DISAPPEAR IN, YOU KNOW, MAYBE A
FEW THOUSAND YEARS JUST FROM THE

1401
01:12:42,371 --> 01:12:43,439
WIND ACTION.

1402
01:12:43,439 --> 01:12:49,261
AND HE FOUND AN INTERESTING
PATTERN WHERE THERE WAS A LOT OF

1403
01:12:49,261 --> 01:12:51,247
BOULDERS THAT HAD COME DOWN IN

THIS ONE AREA AND THEN IT DIED

1404

01:12:51,247 --> 01:12:54,133
OFF AS YOU WENT EACH DIRECTION
DOWN THE RIDGE, AND HE MATCHED

1405

01:12:54,133 --> 01:12:57,369
IT WITH A SIMILAR PATTERN THAT'S
BEEN SEEN -- THAT WAS SEEN IN

1406

01:12:57,369 --> 01:12:59,238
ITALY WITH AN EARTHQUAKE.

1407

01:12:59,238 --> 01:13:02,208
AND YOU KNOW, IT JUST SHAKES
BOULDERS LOOSE AND THEN THEY

1408

01:13:02,208 --> 01:13:07,179
ROLL DOWN THE HILL AND LEAVE
THESE TRACKS.

1409

01:13:07,179 --> 01:13:13,035
BY LOOKING AT THE LENGTH OF THIS
AREA THAT HAD BOULDERS COMING

1410

01:13:13,035 --> 01:13:16,055
DOWN, HE CALCULATED THE SIZE OF
THE MARS QUAKE THAT WOULD HAVE

1411

01:13:16,055 --> 01:13:19,091
BEEN NECESSARY NEAR THE CENTER
OF THIS THING TO MAKE THAT

1412

01:13:19,091 --> 01:13:19,258
HAPPEN.

1413

01:13:19,258 --> 01:13:22,044
AND HE CAME UP WITH SOMETHING
THAT WAS LIKE A MAGNITUDE

1414

01:13:22,044 --> 01:13:22,211

7-PLUS.

1415

01:13:22,211 --> 01:13:25,097

SO, A PRETTY GOOD-SIZED MARS
QUAKE.

1416

01:13:25,097 --> 01:13:29,418

WE'VE BEEN SORT OF
CONSERVATIVELY SAYING THAT A

1417

01:13:29,418 --> 01:13:33,222

MAGNITUDE 6ISH IS THE LARGEST
THAT WE WOULD EXPECT TO SEE, AND

1418

01:13:33,222 --> 01:13:38,194

EVEN THAT, WE'D PROBABLY ONLY
SEE ONE OR TWO OF THOSE EVERY

1419

01:13:38,194 --> 01:13:39,461

COUPLE OF YEARS.

1420

01:13:39,461 --> 01:13:42,498

WHICH MEANS WE MIGHT SEE ONE AND
WE MIGHT NOT IN OUR ONE YEAR.

1421

01:13:42,498 --> 01:13:45,517

OF COURSE, THE LENGTH OF TIME
THAT WE'RE PLANNING TO STAY

1422

01:13:45,517 --> 01:13:49,338

THERE ON MARS IS NOT AN
ACCIDENT, BECAUSE IT TURNS OUT

1423

01:13:49,338 --> 01:13:53,142

THAT IF YOU DESIGN A SPACECRAFT
TO SURVIVE A MARTIAN SUMMER AND

1424

01:13:53,142 --> 01:13:56,478

A MARTIAN WINTER, THERE'S NO
REAL GOOD REASON WHY IT CAN'T

1425

01:13:56,478 --> 01:14:00,032

SURVIVE ANOTHER MARTIAN SUMMER
AND ANOTHER MARTIAN WINTER.

1426

01:14:00,032 --> 01:14:04,169

SO, YOU KNOW, I HAVE A HOPE THAT
WE CAN ACTUALLY LAST FOR MUCH

1427

01:14:04,169 --> 01:14:08,324

MORE THAN OUR PRIME MISSION OF
TWO YEARS ON MARS, THAT WE'D BE

1428

01:14:08,324 --> 01:14:13,012

ABLE TO SORT OF BUILD UP OUR
STATISTICS ON THE MARS

1429

01:14:13,012 --> 01:14:15,331

SEISMOLOGY OVER SEVERAL YEARS,
AND THE LONGER THAT YOU STAY

1430

01:14:15,331 --> 01:14:20,352

THERE, THE MORE LIKELY YOU ARE
TO SEE ONE OF THE LARGER QUAKES

1431

01:14:20,352 --> 01:14:22,221

THAT ARE GOING TO BE MORE RARE.
>> THANK YOU.

1432

01:14:22,221 --> 01:14:22,454

>> SURE.

1433

01:14:22,454 --> 01:14:26,425

>> OKAY, YOU TOOK MOST OF MY
QUESTION BECAUSE I WANTED TO

1434

01:14:26,425 --> 01:14:30,145

KNOW HOW LONG YOU THOUGHT YOU

MIGHT LAST THERE.

1435

01:14:30,145 --> 01:14:37,069

BUT IF YOU DID LAST LONGER,
SEVERAL YEARS, CAN YOU EXPLAIN

1436

01:14:37,069 --> 01:14:41,190

HOW YOU CAN DO SO MUCH WITH ONLY
ONE SEISMOMETER.

1437

01:14:41,190 --> 01:14:43,425

BUT I WOULD IMAGINE IF YOU HAD
MORE THAN ONE SEISMOMETER, THAT

1438

01:14:43,425 --> 01:14:44,493

WOULD BE NICE.

>> YEAH.

1439

01:14:44,493 --> 01:14:49,198

>> AND WOULDN'T IT BE FAIRLY
EASY TO ADD A SEISMOMETER TO

1440

01:14:49,198 --> 01:14:51,350

ANOTHER MISSION THAT WASN'T
JUST -- YOU KNOW, THAT WAS

1441

01:14:51,350 --> 01:14:55,187

LANDING ANYWAY, JUST DROP THIS
OFF.

1442

01:14:55,187 --> 01:14:58,257

>> THAT'S EXACTLY WHAT I TELL
NASA.

1443

01:14:58,257 --> 01:15:02,394

JUST PUT IT ON THERE AND DROP IT
OFF.

1444

01:15:02,394 --> 01:15:05,381

BUT IT'S -- IT'S A LITTLE BIT

MORE COMPLICATED THAN THAT.

1445

01:15:05,381 --> 01:15:12,037

WE DEFINITELY HAVE AD VEHICLED
THAT -- I'VE BEEN ADVOCATING FOR

1446

01:15:12,037 --> 01:15:16,041

A SEISMOMETER ON MARS FOR MORE
THAN 25 YEARS.

1447

01:15:16,041 --> 01:15:19,128

AND SINCE THIS IS THE FIRST ONE
THAT'S GONE SINCE VIKING, YOU

1448

01:15:19,128 --> 01:15:21,347

CAN SEE HOW SUCCESSFUL I'VE
BEEN.

1449

01:15:21,347 --> 01:15:24,183

BUT THERE HAVE BEEN SEVERAL
TIMES WHERE WE CAME CLOSE, AND

1450

01:15:24,183 --> 01:15:29,438

WE HAVE ADVOCATED, ME AND MY
FRIENDS, WE HAVE ADVOCATED THAT,

1451

01:15:29,438 --> 01:15:32,274

YOU KNOW, YOU SHOULD GO WITH
US -- EVERY TIME YOU GO TO THE

1452

01:15:32,274 --> 01:15:37,146

SURFACE, YOU SHOULD TAKE DOWN A
CERTAIN SORT OF STANDARD

1453

01:15:37,146 --> 01:15:37,346

INSTRUMENT.

1454

01:15:37,346 --> 01:15:41,233

YOU SHOULD TAKE A WEATHER
STATION, YOU SHOULD TAKE A

1455

01:15:41,233 --> 01:15:44,303

SEISMOMETER ANY TIME YOU GO
DOWN, BUT YOU HAVE TO BE ABLE TO

1456

01:15:44,303 --> 01:15:45,137

SUPPORT IT.

1457

01:15:45,137 --> 01:15:48,273

THE BIG PROBLEM WITH THE BIG
SEISMOMETER, IT DOESN'T TAKE

1458

01:15:48,273 --> 01:15:49,174

MUCH POWER.

1459

01:15:49,174 --> 01:15:50,042

IT'S NOT HEAVY.

1460

01:15:50,042 --> 01:15:51,410

IT DOESN'T HAVE TO BE HEAVY.

1461

01:15:51,410 --> 01:15:55,297

THE BIG PROBLEM IS IT GENERATES
A LOT OF DATA.

1462

01:15:55,297 --> 01:15:59,084

WE'RE TAKING ABOUT SEVERAL
HUNDRED MEASUREMENTS A SECOND

1463

01:15:59,084 --> 01:16:02,321

CONTINUOUSLY, AND THAT ADDS UP
TO A LOT OF DATA.

1464

01:16:02,321 --> 01:16:11,213

IN FACT, ONE OF THE -- WE ONLY
BRING BACK ABOUT MAYBE 3% OR 4%,

1465

01:16:11,213 --> 01:16:15,267

MAYBE 5% OF THE DATA THAT WE

COLLECT WITH OUR LINK TO EARTH,

1466

01:16:15,267 --> 01:16:18,037

AND WE HAVE SOME FAIRLY
SOPHISTICATED WAY OF FIGURING

1467

01:16:18,037 --> 01:16:19,188

OUT WHICH DATA IS IMPORTANT.

1468

01:16:19,188 --> 01:16:22,358

YOU KNOW, MOST OF THE TIME WE'RE
JUST MEASURING WIND AND NOISE

1469

01:16:22,358 --> 01:16:26,261

AND STUFF, AND WE HAVE A WAY
THAT WE CAN ACTUALLY JUST BRING

1470

01:16:26,261 --> 01:16:29,398

DOWN THE PIECES THAT ARE
INTERESTED TO US.

1471

01:16:29,398 --> 01:16:32,317

BUT -- SO, WHENEVER YOU PUT A
SEISMOMETER DOWN, YOU HAVE TO

1472

01:16:32,317 --> 01:16:36,188

HAVE A RADIO ON IT THAT CAN GET
ALL THAT DATA BACK, AND RADIOS

1473

01:16:36,188 --> 01:16:41,477

TAKE POWER AND THEY HAVE TO BE
KEPT COOL, AND PRETTY SOON, YOU

1474

01:16:41,477 --> 01:16:44,213

END UP HAVING A LITTLE BIT MORE
THAN YOU'D LIKE, WHICH HAS

1475

01:16:44,213 --> 01:16:46,098

ALWAYS BEEN THE PROBLEM IN THE
PAST.

1476

01:16:46,098 --> 01:16:51,236

BUT I AGREE, YOU KNOW, WE'RE
ACTUALLY -- WE HAVE PEOPLE

1477

01:16:51,236 --> 01:16:54,239

WHISPERING INTO THE EAR OF THE
PROJECT MANAGER ON MARS 2020.

1478

01:16:54,239 --> 01:16:57,276

YOU KNOW, JUST DROP OFF A
SEISMOMETER.

1479

01:16:57,276 --> 01:17:01,013

PROBABLY NOT GOING IT HAPPEN,
BUT WE'LL KEEP ON WORKING ON IT.

1480

01:17:01,013 --> 01:17:04,166

AND THE EUROPEANS HAVE SOME
IDEAS ON THAT AS WELL.

1481

01:17:04,166 --> 01:17:08,320

SO, WE COULD ACTUALLY GET A
CHAMPIONON SEISMOMETER TO KEEP

1482

01:17:08,320 --> 01:17:11,106

US COMPANY ON MARS SOME TIME IN
THE NEAR FUTURE.

1483

01:17:11,106 --> 01:17:13,459

>> THANK YOU.

>> SURE.

1484

01:17:13,459 --> 01:17:20,132

>> IF YOU DON'T DISPLAY YOUR
MOLE TOO QUICKLY AFTER YOU

1485

01:17:20,132 --> 01:17:23,435

DEPLOY THE SEISMOMETER, COULDN'T
YOU USE THE VIBRATIONS FROM THE

1486

01:17:23,435 --> 01:17:26,338

MOLE TO HELP CALIBRATE THE
SEISMOMETER?

1487

01:17:26,338 --> 01:17:30,142

>> WE CAN USE THE VIBRATIONS
FROM THE MOLE NOT TO CALIBRATE

1488

01:17:30,142 --> 01:17:35,114

THE SEISMOMETER, BECAUSE IT HAS
ITS OWN INTERNAL CALIBRATION,

1489

01:17:35,114 --> 01:17:39,284

WHICH IS MORE PRECISE, BUT WHAT
WE CAN USE IT FOR IS ACTUALLY,

1490

01:17:39,284 --> 01:17:41,487

WE CAN DO SEISMOLOGY ON A SMALL
SCALE.

1491

01:17:41,487 --> 01:17:45,157

SO, WE HAVE THIS MOLE THAT'S
GOING BANG, PUTTING WAVES

1492

01:17:45,157 --> 01:17:45,441

THROUGH THE GROUND.

1493

01:17:45,441 --> 01:17:51,213

IN PARTICULAR, AS IT GOES DOWN
AND HITS BEDROCK, THE WAVES WILL

1494

01:17:51,213 --> 01:17:52,414

HIT OFF AGAIN.

1495

01:17:52,414 --> 01:17:55,200

YOU HAVE WAVES THAT GO STRAIGHT
TO YOU, YOU HAVE WAVES THAT CAN

1496

01:17:55,200 --> 01:17:59,505
BOUNCE OFF OF LAYERS, AND IT'S
NOT OFTEN SET UP TO DO THAT

1497
01:17:59,505 --> 01:18:01,957
BECAUSE MOST OF THE FREQUENCIES
COMING FROM THE MOLE ARE GOING

1498
01:18:01,957 --> 01:18:07,346
TO BE HIGH FREQUENCIES, AND WE
ONLY GO UP TO ABOUT 50 CYCLES

1499
01:18:07,346 --> 01:18:08,230
PER SECOND.

1500
01:18:08,230 --> 01:18:12,000
BUT THIS IS ACTUALLY SO FUN THAT
MOST OF THE PEOPLE ON OUR TEAM

1501
01:18:12,000 --> 01:18:15,270
ARE ACTUALLY, YOU KNOW, KIND OF
IN THEIR SPARE TIME TRYING TO

1502
01:18:15,270 --> 01:18:18,006
FIGURE OUT HOW TO USE THIS MOLE
INFORMATION.

1503
01:18:18,006 --> 01:18:24,413
THEY FIGURED OUT HOW TO
INTERPOLATE AND BASICALLY GET

1504
01:18:24,413 --> 01:18:27,032
DOUBLE THE FREQUENCY AND GET
THAT RESOLUTION.

1505
01:18:27,032 --> 01:18:31,436
AND SO, I THINK THAT ONE OF THE
FIRST PAPERS THAT MIGHT COME OUT

1506
01:18:31,436 --> 01:18:36,058

OF THIS SIZE MOMTERS IS ACTUALLY
ANALYZING THE MOLE, THE MOLE

1507

01:18:36,058 --> 01:18:39,027
PENETRATION DATA TO GET THE
SHALLOW STRUCTURE, YOU KNOW, THE

1508

01:18:39,027 --> 01:18:43,115
UPPER TENS OF METERS OF
STRUCTURE UNDERNEATH OUR

1509

01:18:43,115 --> 01:18:46,034
SPACECRAFT, WHICH ISN'T PART OF
OUR MAIN GOAL, BUT THAT DOESN'T

1510

01:18:46,034 --> 01:18:47,486
STOP IT FROM BEING COOL SCIENCE.

1511

01:18:47,486 --> 01:18:48,203
>> THANK YOU.

1512

01:18:48,203 --> 01:18:50,422
>> SURE.

1513

01:18:50,422 --> 01:18:54,293
NOW, DID WE GET ANY -- I THINK
WE HAVE A CHAT GOING ON, AND

1514

01:18:54,293 --> 01:19:02,384
WE'RE GETTING SOME QUESTIONS
FROM THE INTERNET.

1515

01:19:02,384 --> 01:19:07,039
SO, THIS ONE SAYS, "WHAT WERE
THE CHALLENGES IN DEVELOPING

1516

01:19:07,039 --> 01:19:16,248
THESE INSTRUMENTS VERSUS EARTH,
I.E., DEVELOPMENTAL CONDITIONS.

1517

01:19:16,248 --> 01:19:19,351

SO, THE BIGGEST THINGS ABOUT
GETTING INSTRUMENTS TO MARS IS

1518

01:19:19,351 --> 01:19:21,303

GETTING THEM TO WORK IN THE MARS
ENVIRONMENT.

1519

01:19:21,303 --> 01:19:26,208

SO, ON MARS, DURING THE DAY, THE
TEMPERATURE GOES UP AND DOWN BY

1520

01:19:26,208 --> 01:19:32,047

40 OR 60 DEGREES SENT GRADE, AND
YOU ALMOST DOUBLE THAT TO GET TO

1521

01:19:32,047 --> 01:19:32,214

ANOTHER.

1522

01:19:32,214 --> 01:19:36,201

THEN YOU HAVE ANOTHER 40 TO 50
DEGREES FROM WINTER TO SUMMER.

1523

01:19:36,201 --> 01:19:39,238

SO, BEING ABLE TO OPERATE OVER
THAT HUGE TEMPERATURE RANGE

1524

01:19:39,238 --> 01:19:42,174

THAT'S LIKE GOING FROM DEATH
VALLEY IN THE SUMMER TO

1525

01:19:42,174 --> 01:19:46,161

ANTARCTICA IN THE WINTER, AND
YOU HAVE TO HAVE THE SAME

1526

01:19:46,161 --> 01:19:48,130

INSTRUMENT OPERATE OVER ALL
THOSE TEMPERATURES.

1527

01:19:48,130 --> 01:19:51,149
THAT'S PROBABLY ONE OF THE
BIGGEST CHALLENGES.

1528
01:19:51,149 --> 01:19:54,419
PLUS, YOU PUT IT ON TOP OF A
ROCKET AND THROW IT DOWN AND

1529
01:19:54,419 --> 01:19:56,488
THEN GO DOWN TO MARS AND BANG IT
ON THE SURFACE.

1530
01:19:56,488 --> 01:20:00,008
AND ALL THAT HAS TO BE VERY,
VERY LIGHT BECAUSE IT CAN'T TAKE

1531
01:20:00,008 --> 01:20:02,227
THAT MUCH MASS.

1532
01:20:02,227 --> 01:20:03,278
SO, THOSE ARE THE BIGGEST
CHALLENGES.

1533
01:20:03,278 --> 01:20:09,268
IT'S EASY TO MEASURE, YOU KNOW,
LESS THAN THAT IN A LABORATORY,

1534
01:20:09,268 --> 01:20:14,072
BUT DOING IT IN THE DIRT ON MARS
AFTER YOU'VE SHAKEN IT AND PUT

1535
01:20:14,072 --> 01:20:16,208
IT DOWN, THAT'S THE TOUGH THING.

1536
01:20:16,208 --> 01:20:24,182
AND THEN GARY PN1 ASKS, WILL
SIZE BE TURNED ON WHEN IT STARTS

1537
01:20:24,182 --> 01:20:26,218
HAMMERING, AND IF SO, DO YOU

EXPECT TO SEE ANYTHING?

1538

01:20:26,218 --> 01:20:29,071

SEE MY ANSWER FIVE MINUTES AGO.

1539

01:20:29,071 --> 01:20:33,358

AND S.T. ASKS, COULD YOU EXPAND
ON THE UNDERLYING MECHANISM

1540

01:20:33,358 --> 01:20:35,444

BEHIND THE FAULTS OBSERVED ON
MARS?

1541

01:20:35,444 --> 01:20:39,381

YEAH, THAT'S ACTUALLY KIND OF
INTERESTING, BECAUSE AGAIN, ALL

1542

01:20:39,381 --> 01:20:43,201

OF THOSE FAULTS ARE BEING DRIVEN
BY THE HEAT ENGINE.

1543

01:20:43,201 --> 01:20:46,254

SO, HOW DOES THE HEAT ENGINE DRY
THESE THINGS.

1544

01:20:46,254 --> 01:20:50,158

SN WELL, IF YOU HAVE A PLANET
THAT STARTS OFF HOT AND IT GETS

1545

01:20:50,158 --> 01:20:52,344

COLDER AND COLDER, IT SHRINKS,
RIGHT?

1546

01:20:52,344 --> 01:20:57,499

AS YOU GET SOMETHING COLDER, IT
CONTRACTS THERMALLY.

1547

01:20:57,499 --> 01:21:01,036

AS IT CONTRACTS, DIFFERENT
MATERIALS CONTRACT BY DIFFERENT

1548

01:21:01,036 --> 01:21:03,005

AMOUNTS, AND THE SURFACE
CONTRACTS AT A DIFFERENT RATE

1549

01:21:03,005 --> 01:21:05,123

THAN THE INTERIOR.

1550

01:21:05,123 --> 01:21:10,379

AND SO, YOU PUT THE CRUST INTO
EITHER COMPRESSION OR

1551

01:21:10,379 --> 01:21:13,398

CONTRACTION, DEPENDING ON THE
DETAILS OF HOW THINGS ARE BUILT.

1552

01:21:13,398 --> 01:21:18,086

AND SO, YOU CAN GET IT TO BE
BUCKLING AS IT GETS KIND OF

1553

01:21:18,086 --> 01:21:20,472

TRYING TO SQUEEZE ON TO A
SMALLER AND SMALLER BALL

1554

01:21:20,472 --> 01:21:29,214

UNDERNEATH, OR YOU CAN GET IT TO
ACTUALLY BE PULLING APART AND

1555

01:21:29,214 --> 01:21:32,284

CRACKING IF IT'S CONTRACTING
FASTER THAN THE INTERIOR.

1556

01:21:32,284 --> 01:21:35,504

SO, IT'S REALLY THIS KIND OF
CONTRACTION OF THE PLANET THAT

1557

01:21:35,504 --> 01:21:40,092

WE THINK IS MOSTLY BEHIND THE
FALSE THAT WE SEE ON MARS.

1558

01:21:40,092 --> 01:21:42,144

THERE ARE OTHER THINGS THAT
CAUSE THE FAULTS.

1559

01:21:42,144 --> 01:21:46,431

WHEN YOU MAKE A BIG VOLCANIC
PLATEAU LIKE THE THARSIS PLATEAU

1560

01:21:46,431 --> 01:21:52,304

ON MARS, WHICH HAS VOLCANOS THAT
RISE UP 25 OR 28 KILOMETERS

1561

01:21:52,304 --> 01:21:57,476

ABOVE THE AVERAGE ELEVATION,
THOSE CREATE BIG PRESSES.

1562

01:21:57,476 --> 01:22:00,228

AND AS THEY TRY TO RELAX, THEY
CAUSE CRACKING AS WELL.

1563

01:22:00,228 --> 01:22:03,365

SO, THOSE ARE SOME OF THE THINGS
THAT CAN CAUSE THAT, MARS

1564

01:22:03,365 --> 01:22:04,032

QUAKES.

1565

01:22:04,032 --> 01:22:05,183

I HAVE A QUESTION FROM INSIDE
HERE?

1566

01:22:05,183 --> 01:22:07,119

>> YEAH, HI.

>> HI.

1567

01:22:07,119 --> 01:22:11,373

>> A FOLLOW-UP TO THE NEW CMARS
QUESTION.

1568

01:22:11,373 --> 01:22:18,430
ARE THERE ANY STEPS BEING TAKEN
TO MAP ANY POTENTIAL METEOR

1569
01:22:18,430 --> 01:22:23,452
IMPACTS ON MARS SO THAT, YOU
KNOW, LIKE A MASS CAN BE IMAGED

1570
01:22:23,452 --> 01:22:27,105
BEFOREHAND TO HELP YOU GATHER
RELEVANT DATA IF SOMETHING BIG

1571
01:22:27,105 --> 01:22:29,307
ACTUALLY HITS THERE AND
RESONATES, YOU KNOW?

1572
01:22:29,307 --> 01:22:31,510
>> YEAH, I MEAN --
>> SIMILAR TO WHAT YOU WERE

1573
01:22:31,510 --> 01:22:36,081
TALKING ABOUT, LIKE ACTUALLY
LAUNCHING SOMETHING TO HIT IT,

1574
01:22:36,081 --> 01:22:38,450
LIKE --
>> SO, YOU'RE ASKING ARE WE

1575
01:22:38,450 --> 01:22:41,236
ACTUALLY PUTTING TOGETHER A
DATABASE SO WE CAN LOOK INTO THE

1576
01:22:41,236 --> 01:22:43,155
FUTURE --
>> YEAH, SO IF SOMETHING'S GOING

1577
01:22:43,155 --> 01:22:46,291
TO IMPACT, YOU CAN TRY TO
MEASURE THE MASS OF THAT OBJECT

1578

01:22:46,291 --> 01:22:50,429
AND THEN GET THE DATA FROM IT.
>> THAT IS GOING ON NOW, AGAIN,

1579
01:22:50,429 --> 01:22:54,232
WITH MARS RECONNAISSANCE
ORBITER.

1580
01:22:54,232 --> 01:22:58,270
TWO DIFFERENT CAMERAS HAVE, ONE
IS A MEDIUM RESOLUTION, WHICH

1581
01:22:58,270 --> 01:23:03,091
USED TO BE A HIGH RESOLUTION,
BUT IT'S KIND OF TENS OF METER

1582
01:23:03,091 --> 01:23:03,308
RESOLUTION.

1583
01:23:03,308 --> 01:23:08,313
AND IT CAN SEE THE BLACK
BLOTCHES.

1584
01:23:08,313 --> 01:23:11,066
WHEN A METEORITE HITS MARS IT
BLOWS THE DUST OFF AND THAT

1585
01:23:11,066 --> 01:23:12,217
MAKES THE CONTRAST.

1586
01:23:12,217 --> 01:23:17,439
AND WHEN THEY SEE ONE OF THOSE,
THEY GO BACK WITH THEIR

1587
01:23:17,439 --> 01:23:20,058
HIGH-RESOLUTION CAMERA AND LOOK
AT IT TO BE ABLE TO SEE THE

1588
01:23:20,058 --> 01:23:21,359
IMPACTS.

1589

01:23:21,359 --> 01:23:27,182

SO, CTX HAS ALREADY COVERED THE ENTIRE PLANET ONCE WITH THAT

1590

01:23:27,182 --> 01:23:28,183

MEDIUM REDS LUCIAN.

1591

01:23:28,183 --> 01:23:36,274

SO, WE ALREADY HAVE KIND OF A BASE DATA SET TO USE.

1592

01:23:36,274 --> 01:23:39,110

AND AS LONG AS WE HAVE AN ORBITER IN PLACE TO TAKE FURTHER

1593

01:23:39,110 --> 01:23:44,282

IMAGES, YOU KNOW, WE'LL BE FINDING MORE AND MORE OF THESE

1594

01:23:44,282 --> 01:23:44,483

METEORITES.

1595

01:23:44,483 --> 01:23:49,488

ONE OF THE THINGS WE HOPED TO DO WITH INSIGHT WAS TO CONSTRAIN

1596

01:23:49,488 --> 01:23:50,372

THE IMPACTS BETTER.

1597

01:23:50,372 --> 01:23:56,428

WITH THE CAMERAS, IT ALWAYS SEES IT, IT'S RELATIVELY FEATURELESS,

1598

01:23:56,428 --> 01:23:57,529

IT HAS DUST.

1599

01:23:57,529 --> 01:24:02,200

THE MAP I PUT UP THERE, THERE

ARE SOME PLACES WITH LARGE

1600

01:24:02,200 --> 01:24:03,335

IMPACTS AND OTHERS WITHOUT ANY.

1601

01:24:03,335 --> 01:24:05,370

AND THAT'S NOT BECAUSE THEY
DIDN'T HIT THERE, BUT BECAUSE

1602

01:24:05,370 --> 01:24:07,088

IT'S HARD TO SEE THEM.

1603

01:24:07,088 --> 01:24:11,009

WITH A SEISMOMETER, WE'LL BE
ABLE TO SEE ANYTHING OVER A

1604

01:24:11,009 --> 01:24:12,244

CERTAIN SIZE AT A GIVEN
DISTANCE.

1605

01:24:12,244 --> 01:24:15,363

SO, WE SHOULD BE ABLE TO PUT A
BETTER CONSTRAINT ON THE RATE OF

1606

01:24:15,363 --> 01:24:17,432

METEORITE IMPACTS ON MARS TODAY.

1607

01:24:17,432 --> 01:24:20,468

>> THANKS.

>> SURE.

1608

01:24:20,468 --> 01:24:25,056

SO, IF THERE'S NO MORE
QUESTIONS, I GUESS I'LL JUST SAY

1609

01:24:25,056 --> 01:24:25,257

GOODNIGHT.

1610

01:24:25,257 --> 01:24:29,077

AND IF YOU WANT TO COME TALK TO
ME FOR A LITTLE WHILE, I'LL HANG