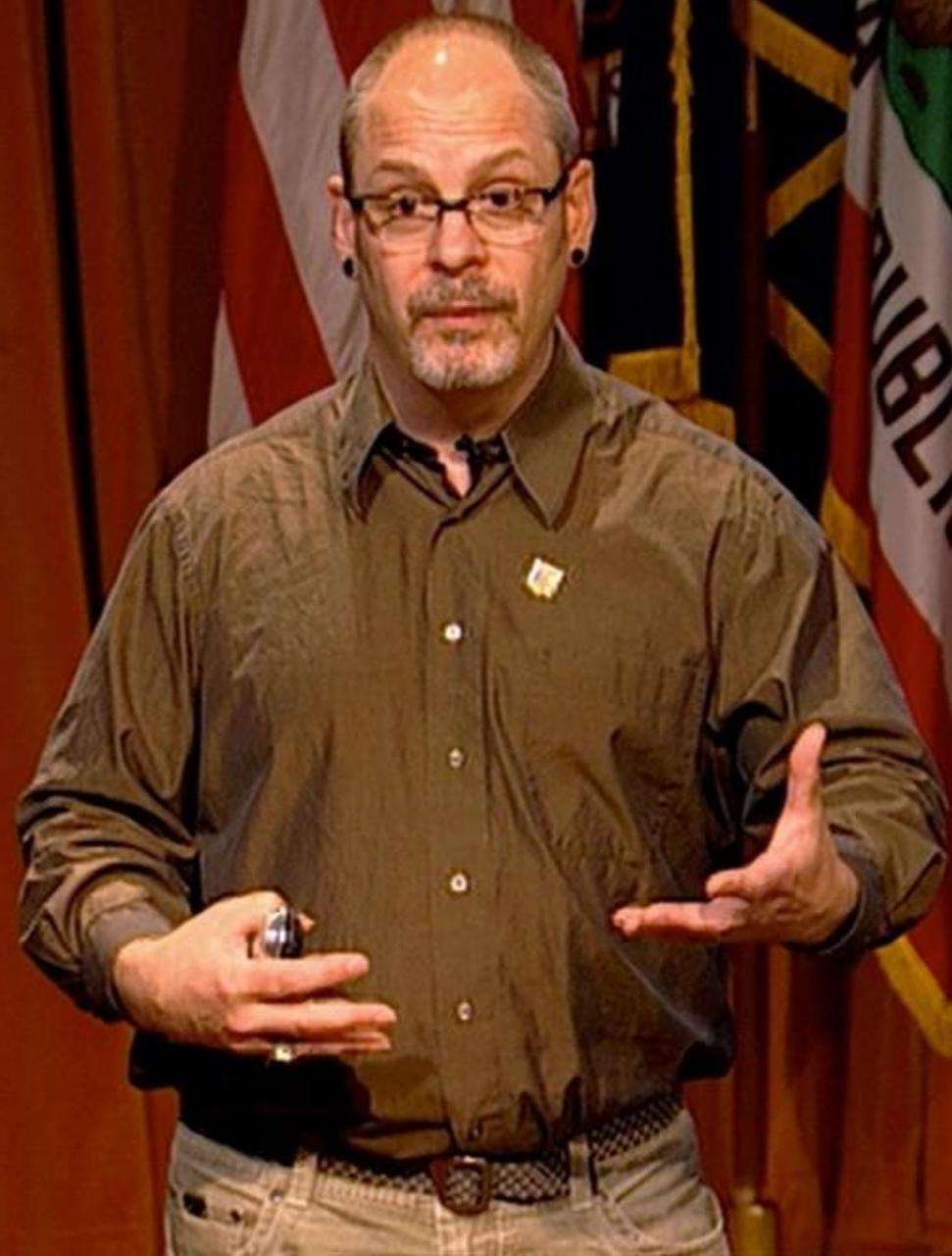


Research Center



DISCOVERY
7
YEAR

NASA

1
00:00:01,000 --> 00:00:07,000
[music playing]

2
00:00:16,933 --> 00:00:17,966
- WELCOME, EVERYBODY,

3
00:00:17,966 --> 00:00:20,366
TO THE 75th ANNIVERSARY
CELEBRATIONS

4
00:00:20,366 --> 00:00:22,033
HERE AT NASA AMES RESEARCH
CENTER.

5
00:00:22,033 --> 00:00:24,766
THIS IS THE LAST TALK
OF 18 TALKS

6
00:00:24,766 --> 00:00:26,766
PRESENTED BY THE OFFICE
OF THE CHIEF SCIENTIST.

7
00:00:26,766 --> 00:00:30,766
SO NASA AMES RESEARCH CENTER
HAS BEEN PURSUING

8
00:00:30,766 --> 00:00:33,066
SOME OF HUMANITY'S
GRANDEST QUESTIONS,

9
00:00:33,066 --> 00:00:35,500
BOTH PHILOSOPHICALLY
AND SCIENTIFICALLY,

10
00:00:35,500 --> 00:00:37,633
AND THOROUGHLY THROUGH
A MULTIDISCIPLINARY

11
00:00:37,633 --> 00:00:40,900

AND INTERNATIONAL PERSPECTIVE.

12

00:00:40,900 --> 00:00:44,300

ASTROBIOLOGY IS SEEN AS KIND
OF A CROSS-CUTTING DISCIPLINE

13

00:00:44,300 --> 00:00:46,133

ACROSS MOST OF WHAT SCIENCE--

14

00:00:46,133 --> 00:00:49,033

NASA SCIENCE MISSIONS
HAVE DONE,

15

00:00:49,033 --> 00:00:52,233

AND KIND OF IN THE SPIRIT
OF ASTROBIOLOGY,

16

00:00:52,233 --> 00:00:54,500

THERE ARE
THREE FUNDAMENTAL QUESTIONS

17

00:00:54,500 --> 00:00:56,100

THAT GENERALLY ARE ADDRESSED,

18

00:00:56,100 --> 00:00:58,266

AND IT'S,
WHERE DID WE COME FROM?

19

00:00:58,266 --> 00:01:00,266

WHAT'S THE EVOLUTION OF LIFE?

20

00:01:00,266 --> 00:01:02,766

WHERE IS IT EVOLVING TO?

21

00:01:02,766 --> 00:01:05,500

IF WE ARE ALONE, THE SEARCH
FOR LIFE IN THE UNIVERSE.

22

00:01:05,500 --> 00:01:08,566

AND, ULTIMATELY, ESTABLISHING
WHERE WE'RE GOING NEXT

23

00:01:08,566 --> 00:01:11,566
AS AN INTERPLANETARY SPECIES.

24

00:01:11,566 --> 00:01:13,733
THE KEPLER MISSION
WAS LAUNCHED IN 2009

25

00:01:13,733 --> 00:01:16,666
AND HAS RADICALLY ALTERED
OUR VIEW

26

00:01:16,666 --> 00:01:19,500
OF PLANETS, PLANETARY SYSTEMS,
AND OURSELVES REALLY.

27

00:01:19,500 --> 00:01:23,633
AND APPROXIMATELY, I THINK,
1 1/2 THOUSAND PLANETS

28

00:01:23,633 --> 00:01:24,900
HAVE BEEN DISCOVERED,

29

00:01:24,900 --> 00:01:26,233
AND WHAT'S INTERESTING
ABOUT THIS

30

00:01:26,233 --> 00:01:28,133
IS IT REALLY ADDRESSES
THE SECOND QUESTION OF

31

00:01:28,133 --> 00:01:30,000
"IS THERE LIFE IN THE UNIVERSE?"

32

00:01:30,000 --> 00:01:31,333
ARE THERE HABITABLE PLANETS?

33

00:01:31,333 --> 00:01:33,366
IS THERE INTELLIGENT LIFE
IN THE UNIVERSE?

34
00:01:33,366 --> 00:01:36,666
DR. JON M. JENKINS
RECEIVED HIS BACHELOR'S DEGREE

35
00:01:36,666 --> 00:01:38,666
IN ELECTRICAL ENGINEERING
AND APPLIED MATH

36
00:01:38,666 --> 00:01:41,233
AT GEORGIA TECH
INSTITUTE OF TECHNOLOGY,

37
00:01:41,233 --> 00:01:44,100
BOTH HIS MASTER'S AND Ph.D.
IN ELECTRICAL ENGINEERING

38
00:01:44,100 --> 00:01:45,766
FROM GEORGIA TECH.

39
00:01:45,766 --> 00:01:47,466
HE CURRENTLY SERVES
AS CO-INVESTIGATOR

40
00:01:47,466 --> 00:01:49,800
FOR DATA PROCESSING
FOR BOTH THE KEPLER MISSION

41
00:01:49,800 --> 00:01:53,100
AND THE UPCOMING TRANSITING
EXOPLANET SURVEY SATELLITE,

42
00:01:53,100 --> 00:01:54,733
KNOWN AS TESS.

43
00:01:54,733 --> 00:01:56,500
TODAY'S TALK IS ENTITLED

44
00:01:56,500 --> 00:01:57,833
"CHASING SHADOW WORLDS:

45
00:01:57,833 --> 00:01:59,666
EXOPLANETS FROM KEPLER
AND BEYOND."

46
00:01:59,666 --> 00:02:02,466
PLEASE JOIN ME IN WELCOMING
DR. JON JENKINS.

47
00:02:02,466 --> 00:02:05,166
[applause]

48
00:02:10,666 --> 00:02:12,033
- WELL, GOOD AFTERNOON.

49
00:02:12,033 --> 00:02:15,700
THANK YOU FOR COMING TO SPEND
THE AFTERNOON WITH ME.

50
00:02:15,700 --> 00:02:18,433
YOU MIGHT HAVE THOUGHT
THAT EXOPLANETS GOT THEIR START

51
00:02:18,433 --> 00:02:19,800
IN 2009 WHEN KEPLER LAUNCHED,

52
00:02:19,800 --> 00:02:21,566
AND I WOULDN'T BLAME YOU
IF YOU THOUGHT THAT,

53
00:02:21,566 --> 00:02:25,333
BUT, ACTUALLY,
IT STARTED MUCH EARLIER.

54
00:02:25,333 --> 00:02:28,100
BUT CAN ANY OF YOU REMEMBER WHAT

LIFE WAS LIKE BEFORE EXOPLANETS?

55

00:02:28,100 --> 00:02:29,666

AND THIS IS ACTUALLY
A PICTURE OF MYSELF

56

00:02:29,666 --> 00:02:31,500

TWO YEARS INTO MY TENURE

57

00:02:31,500 --> 00:02:33,266

WITH THE SETI INSTITUTE
HERE AT AMES,

58

00:02:33,266 --> 00:02:34,766

WHEN I WAS THINKING
OF ALIEN WORLDS,

59

00:02:34,766 --> 00:02:36,266

BUT I WAS THINKING
MAINLY OF VENUS.

60

00:02:36,266 --> 00:02:38,266

I HAD COME HERE TO CONTINUE
MY RESEARCH

61

00:02:38,266 --> 00:02:41,000

INTO REMOTE SENSING
OF PLANETARY ATMOSPHERES.

62

00:02:41,000 --> 00:02:43,833

AT THE TIME, I WAS
WORKING ON PIONEER VENUS DATA,

63

00:02:43,833 --> 00:02:45,166

AND MAGELLAN WAS IN ORBIT,

64

00:02:45,166 --> 00:02:46,700

AND I WAS WORKING
ON MAGELLAN DATA.

65

00:02:46,700 --> 00:02:49,800

IT WAS A FASCINATING,
EXCITING TIME TO BE HERE,

66

00:02:49,800 --> 00:02:51,566

BECAUSE I'D GONE
TO GEORGIA TECH.

67

00:02:51,566 --> 00:02:53,433

MY ADVISOR WAS
THE ONLY PROFESSOR

68

00:02:53,433 --> 00:02:55,900

DOING SPACE RESEARCH
ON THE CAMPUS,

69

00:02:55,900 --> 00:02:57,166

AND, SUDDENLY, I WAS HERE

70

00:02:57,166 --> 00:02:59,066

AND SURROUNDED BY
LOTS OF PLANETARY SCIENTISTS,

71

00:02:59,066 --> 00:03:00,566

ASTRONOMERS, GEOPHYSICISTS.

72

00:03:00,566 --> 00:03:02,800

IT WAS AN EXCITING TIME.

73

00:03:02,800 --> 00:03:05,033

BUT IN OCTOBER OF 1994,

74

00:03:05,033 --> 00:03:06,566

BOTH PIONEER VENUS
AND MAGELLAN

75

00:03:06,566 --> 00:03:07,933

CRASHED INTO THE ATMOSPHERE
OF VENUS,

76

00:03:07,933 --> 00:03:09,400
ENDING THEIR SOJOURN,

77

00:03:09,400 --> 00:03:14,200
AND SO I WAS HIGH AND DRY
WITHOUT A DATA SOURCE.

78

00:03:14,200 --> 00:03:16,200
I DID INDEED FALL
INTO BAD COMPANY

79

00:03:16,200 --> 00:03:19,200
BACK CIRCA 1988, 1989,

80

00:03:19,200 --> 00:03:22,133
WHEN I WAS STARTING TO WORK
ON THE PIONEER VENUS DATA,

81

00:03:22,133 --> 00:03:23,400
AND I MET BILL BORUCKI,

82

00:03:23,400 --> 00:03:26,566
WHO BECAME THE P.I.
FOR KEPLER, OF COURSE,

83

00:03:26,566 --> 00:03:27,700
BUT HE WAS A CO-INVESTIGATOR

84

00:03:27,700 --> 00:03:29,633
ON PIONEER VENUS
STUDYING LIGHTNING,

85

00:03:29,633 --> 00:03:33,000
SO HE AND I GO WAY BACK.

86

00:03:33,000 --> 00:03:35,533
IN 1994, IT WAS ALSO
A WATERSHED MOMENT FOR MYSELF,

87

00:03:35,533 --> 00:03:37,266
BECAUSE ANOTHER PERSON,
LAURANCE DOYLE,

88

00:03:37,266 --> 00:03:40,066
WHOM I MET MY FIRST DAY
ON CAMPUS HERE,

89

00:03:40,066 --> 00:03:41,566
ALSO WORKED
FOR SETI INSTITUTE,

90

00:03:41,566 --> 00:03:44,500
BECAME INVOLVED
WITH AN INTERNATIONAL COALITION

91

00:03:44,500 --> 00:03:46,466
OF ASTRONOMERS
WHO WERE INTERESTED IN FINDING

92

00:03:46,466 --> 00:03:49,300
TRANSITING PLANETS
AROUND BINARY STARS,

93

00:03:49,300 --> 00:03:50,666
AND THEY HAD PICKED
THE SMALLEST KNOWN

94

00:03:50,666 --> 00:03:53,600
ECLIPSING BINARY AT THE TIME,
CM DRAC, TO OBSERVE,

95

00:03:53,600 --> 00:03:56,166
AND THEY NEEDED SOMEBODY TO COME
UP WITH A DETECTION ALGORITHM.

96

00:03:56,166 --> 00:03:57,666
I'D GO TO LUNCH
WITH THESE GUYS,

97

00:03:57,666 --> 00:03:59,833
AND THEY WOULD COMPLAIN
ABOUT HOW HARD IT WAS

98

00:03:59,833 --> 00:04:01,466
TO COME UP
WITH A DETECTION ALGORITHM,

99

00:04:01,466 --> 00:04:03,800
AND I GOT INTERESTED,
AND IT WAS A REAL PUZZLE.

100

00:04:03,800 --> 00:04:05,566
BUT WE NEVER GOT FUNDING.

101

00:04:05,566 --> 00:04:07,066
WE OBSERVED FOR SIX YEARS.

102

00:04:07,066 --> 00:04:08,500
I DID WRITE
DETECTION ALGORITHMS.

103

00:04:08,500 --> 00:04:10,433
THEY WORKED.
WE PUT GOOD UPPER LIMITS

104

00:04:10,433 --> 00:04:12,133
ON ANY PLANETS
THAT WERE THERE.

105

00:04:12,133 --> 00:04:13,466
BUT THAT WORK BROUGHT ME
TO THE ATTENTION

106

00:04:13,466 --> 00:04:14,600
OF BILL BORUCKI LATER,

107

00:04:14,600 --> 00:04:17,700

WHO THEN ASKED ME TO JOIN
HIS TEAM.

108
00:04:17,700 --> 00:04:20,933
NOW, IN 1994,
HERE IS A PICTURE

109
00:04:20,933 --> 00:04:22,433
OF ALL THE KNOWN PLANETS
IN THE UNIVERSE.

110
00:04:22,433 --> 00:04:25,366
OF COURSE, THERE IS ONE EXTRA
THAT WE GOT RID OF LATER,

111
00:04:25,366 --> 00:04:26,766
BUT, YOU KNOW,
DWARVES ARE PEOPLE,

112
00:04:26,766 --> 00:04:28,700
SO DWARF PLANETS
ARE PLANETS, TOO.

113
00:04:28,700 --> 00:04:33,233
AT ANY RATE, WE THOUGHT
THAT ALL THE GAS GIANTS

114
00:04:33,233 --> 00:04:35,400
WOULD BE FOUND IN THE OUTER PART
OF A SOLAR SYSTEM

115
00:04:35,400 --> 00:04:38,366
WHEN WE WERE FINDING PLANETS,
BECAUSE THEY HAVE TO FORM THERE.

116
00:04:38,366 --> 00:04:40,600
IT'S TOO HOT INTERIOR
TO ABOUT 5 A.U.

117
00:04:40,600 --> 00:04:42,300

FOR WATER TO EXIST

118

00:04:42,300 --> 00:04:43,800

AND FOR YOU TO GET
WATER AND ICE,

119

00:04:43,800 --> 00:04:45,000

THAT KIND OF THING.

120

00:04:45,000 --> 00:04:46,800

SO WE KNEW THAT GIANT PLANETS

121

00:04:46,800 --> 00:04:48,800

HAD TO EXIST IN THE OUTER PART
OF THE SOLAR SYSTEM

122

00:04:48,800 --> 00:04:51,233

AND THAT THE ROCKY PLANETS,
ONES THAT WE CAN STAND ON,

123

00:04:51,233 --> 00:04:53,566

HAD TO BE CLOSER TO THEIR STAR.

124

00:04:53,566 --> 00:04:55,600

AND ALL THE MODELS
THAT WE'D COME UP WITH

125

00:04:55,600 --> 00:04:57,166

PREDICTED THAT
THAT WOULD BE THE CASE.

126

00:04:57,166 --> 00:04:58,466

SO ONE OF THE THEMES--

127

00:04:58,466 --> 00:05:00,300

I'LL TRY TO REMEMBER TO SAY IT
MORE THAN ONCE--

128

00:05:00,300 --> 00:05:02,700

IS THAT IT'S VERY DIFFICULT
TO EXTRAPOLATE

129

00:05:02,700 --> 00:05:04,900
FROM A SAMPLE OF ONE,

130

00:05:04,900 --> 00:05:06,166
AND YOU OFTEN GET IT WRONG.

131

00:05:06,166 --> 00:05:08,200
EXPERTS BECOME FOOLS
QUITE QUICKLY

132

00:05:08,200 --> 00:05:10,900
ONCE THEY START TO EXTRAPOLATE.

133

00:05:10,900 --> 00:05:12,566
NOW, HERE'S THE PICTURE
WE HAVE TODAY,

134

00:05:12,566 --> 00:05:14,200
OR AT LEAST
AS OF ABOUT TWO YEARS AGO.

135

00:05:14,200 --> 00:05:16,166
THIS IS AN "xkcd" CARTOON,

136

00:05:16,166 --> 00:05:19,366
AND IT SHOWS ALL 768
KNOWN PLANETS AT THAT TIME

137

00:05:19,366 --> 00:05:21,400
DRAWN TO SCALE,
AND IF YOU LOOK CLOSELY,

138

00:05:21,400 --> 00:05:22,766
YOU CAN FIND THE SOLAR SYSTEM.

139

00:05:22,766 --> 00:05:24,433

YOU CAN SEE
THAT MOST PLANETS DETECTED

140
00:05:24,433 --> 00:05:25,900
UP TO THIS POINT IN TIME

141
00:05:25,900 --> 00:05:28,333
LOOK NOTHING LIKE THE PLANETS
IN OUR OWN SOLAR SYSTEM.

142
00:05:28,333 --> 00:05:30,033
HERE'S SOME HELP FOR YOU.

143
00:05:30,033 --> 00:05:31,766
HERE'S OUR SOLAR SYSTEM
RIGHT HERE,

144
00:05:31,766 --> 00:05:34,433
AND YOU CAN SEE JUPITER IS NOT
THE BIGGEST BULLY ON THE BLOCK.

145
00:05:34,433 --> 00:05:37,266
THERE ARE A LOT OF PLANETS THAT
ARE MUCH BIGGER THAN JUPITER.

146
00:05:37,266 --> 00:05:38,866
INDEED,
THE FIRST PLANETS WE FOUND

147
00:05:38,866 --> 00:05:40,000
WERE MUCH BIGGER THAN JUPITER

148
00:05:40,000 --> 00:05:41,533
AND MUCH CLOSER
TO THEIR STAR

149
00:05:41,533 --> 00:05:44,600
THAN JUPITER IS TO OURS.

150

00:05:44,600 --> 00:05:46,866
AND THERE ARE
A FEW SMALL SPECKS HERE

151
00:05:46,866 --> 00:05:50,500
THAT ARE COMPARABLE
IN SIZE TO EARTH OR THEREABOUTS

152
00:05:50,500 --> 00:05:51,700
WITHIN A FACTOR OF TWO.

153
00:05:51,700 --> 00:05:53,700
THOSE WERE KEPLER DISCOVERIES,
OF COURSE.

154
00:05:53,700 --> 00:05:55,700
WELL, HOW DOES KEPLER WORK?

155
00:05:55,700 --> 00:05:56,733
IT'S VERY SIMPLE.

156
00:05:56,733 --> 00:05:58,633
WE LOOK TO WATCH
FOR OCCASIONS

157
00:05:58,633 --> 00:06:00,633
WHEN A STAR BLINKS AT US

158
00:06:00,633 --> 00:06:03,500
AS A PLANET CROSSES
THE FACE OF THE STAR.

159
00:06:03,500 --> 00:06:05,866
WE DON'T IMAGE THE STAR
OR RESOLVE IT.

160
00:06:05,866 --> 00:06:07,566
WE MEASURE THE BRIGHTNESS
AS A FUNCTION OF TIME,

161
00:06:07,566 --> 00:06:09,700
LOOKING FOR THESE DIPS
IN BRIGHTNESS

162
00:06:09,700 --> 00:06:12,100
CORRESPONDING TO THOSE TIMES.

163
00:06:12,100 --> 00:06:14,866
THE DEPTH OF THE TRANSIT
IS THE RELATIVE AREA

164
00:06:14,866 --> 00:06:16,633
OF THE PLANET TO THE STAR.

165
00:06:16,633 --> 00:06:18,133
IF THEY BLOCK 1%
OF THE LIGHT,

166
00:06:18,133 --> 00:06:21,766
THEN THE PLANET'S AREA IS 1%
OF THAT OF THE DISK OF THE STAR.

167
00:06:21,766 --> 00:06:23,566
IT WILL REPEAT ONCE PER ORBIT,

168
00:06:23,566 --> 00:06:26,166
AND SO THE INTERVAL OF TIME
BETWEEN THE TWO TRANSITS

169
00:06:26,166 --> 00:06:27,533
TELLS YOU THE YEAR.

170
00:06:27,533 --> 00:06:29,233
IF YOU KNOW THE MASS
OF THE STAR,

171
00:06:29,233 --> 00:06:31,700
THEN THAT PERIOD,
TOGETHER WITH KEPLER'S LAWS,

172

00:06:31,700 --> 00:06:32,800
GIVES YOU THE DISTANCE,

173

00:06:32,800 --> 00:06:34,066
THE MEAN DISTANCE
TO THE PLANET.

174

00:06:34,066 --> 00:06:35,366
THAT, TOGETHER WITH THE SIZE

175

00:06:35,366 --> 00:06:37,066
AND THE EFFECTIVE TEMPERATURE
OF THE STAR,

176

00:06:37,066 --> 00:06:39,500
ALLOW YOU TO ESTIMATE
THAT EQUILIBRIUM TEMPERATURE

177

00:06:39,500 --> 00:06:42,033
THAT THE PLANET IS EXPERIENCING,
SO THAT WE CAN ESTIMATE

178

00:06:42,033 --> 00:06:43,833
THE RANGE OF DISTANCES
FROM A STAR

179

00:06:43,833 --> 00:06:45,100
FOR WHICH LIQUID WATER

180

00:06:45,100 --> 00:06:47,033
WOULD POOL ON THE SURFACE
OF THAT PLANET.

181

00:06:47,033 --> 00:06:49,200
AND THAT'S KNOWN
AS THE HABITABLE ZONE.

182

00:06:54,733 --> 00:06:57,533

SO I MENTIONED THAT I'D WORKED
FOR ABOUT SIX YEARS

183
00:06:57,533 --> 00:07:00,500
WITH LAURANCE DOYLE,
TRYING TO GET FUNDING

184
00:07:00,500 --> 00:07:03,700
TO PROVIDE A SOURCE OF REVENUE
FOR OURSELVES,

185
00:07:03,700 --> 00:07:07,266
BUT ALSO FOR A SMALL TELESCOPE
UP AT LICK OBSERVATORY

186
00:07:07,266 --> 00:07:09,233
AT THE CROSSLEY DOME,
TO LOOK FOR PLANETS

187
00:07:09,233 --> 00:07:10,900
AROUND A SMALL ECLIPSING BINARY,

188
00:07:10,900 --> 00:07:12,533
AND WE GOT REJECTED
EVERY TIME.

189
00:07:12,533 --> 00:07:13,766
SOME OF THE REJECTIONS WERE,

190
00:07:13,766 --> 00:07:15,466
"BINARY STARS
DON'T HAVE PLANETS."

191
00:07:15,466 --> 00:07:19,100
SOME OF THE REJECTIONS WERE,
"M' STARS DON'T HAVE PLANETS,"

192
00:07:19,100 --> 00:07:22,333
AND SO EVEN THE EXPERTS
WHO WERE READING OUR...

193

00:07:22,333 --> 00:07:26,466

OUR PROPOSALS REALLY DIDN'T KNOW
WHAT WAS WHAT.

194

00:07:26,466 --> 00:07:28,633

AND, IN FACT, MOST
OF WHAT WE THOUGHT WE UNDERSTOOD

195

00:07:28,633 --> 00:07:31,233

ABOUT PLANETS,
LIKE MUCH OF PHYSICS AND SPACE,

196

00:07:31,233 --> 00:07:34,133

IT MAY BE PARTIALLY RIGHT,
BUT IT'S OFTEN WRONG.

197

00:07:34,133 --> 00:07:36,900

BUT KEPLER-16b,
AKA "TATOOINE,"

198

00:07:36,900 --> 00:07:40,033

WAS THE FIRST CONFIRMED
TRANSITING CIRCUMBINARY PLANET

199

00:07:40,033 --> 00:07:41,266

ORBITING TWO STARS.

200

00:07:41,266 --> 00:07:43,100

ONE OF THEM IS A SMALL "M" STAR.

201

00:07:43,100 --> 00:07:45,466

AND LAURANCE
IS REALLY A VISIONARY.

202

00:07:45,466 --> 00:07:47,166

HE'S A FASCINATING MAN.

203

00:07:47,166 --> 00:07:49,600

HE WAS THE FIRST I HEARD
IN A PUBLIC FORUM TO PREDICT

204

00:07:49,600 --> 00:07:52,633
THAT WE WOULD ACTUALLY LEARN
ABOUT PLANETARY ATMOSPHERES

205

00:07:52,633 --> 00:07:54,366
OF ALIEN WORLDS

206

00:07:54,366 --> 00:07:58,100
THROUGH TRANSIT TRANSMISSION
SPECTROSCOPY.

207

00:07:58,100 --> 00:08:00,400
AND I'LL TALK
A LITTLE BIT ABOUT THAT LATER.

208

00:08:00,400 --> 00:08:02,500
BUT AT THE TIME,
A VERY RENOWNED SCIENTIST

209

00:08:02,500 --> 00:08:04,866
GOT UP AND SAID,
"IT'LL NEVER WORK."

210

00:08:04,866 --> 00:08:06,533
OF COURSE, IT HAS.

211

00:08:06,533 --> 00:08:09,200
AND, INDEED,
WITHIN THE FIRST SIX

212

00:08:09,200 --> 00:08:11,166
CIRCUMBINARY PLANETARY SYSTEMS
THAT WE'D FOUND--

213

00:08:11,166 --> 00:08:12,766
CASES WHERE YOU FIND A PLANET

214
00:08:12,766 --> 00:08:15,833
ORBITING OUTSIDE OF TWO STARS
IN A VERY TIGHT ORBIT--

215
00:08:15,833 --> 00:08:21,000
KEPLER-47c WAS DISCOVERED
ORBITING IN THE HABITABLE ZONE

216
00:08:21,000 --> 00:08:22,866
OF ITS STAR.

217
00:08:22,866 --> 00:08:24,700
AND THAT'S FASCINATING,
BECAUSE WE FOUND

218
00:08:24,700 --> 00:08:27,800
MANY, MANY, MANY PLANETS
ORBITING SINGLE STARS

219
00:08:27,800 --> 00:08:29,000
BEFORE WE FOUND
THE FIRST ONE

220
00:08:29,000 --> 00:08:30,633
THAT WAS IN THE HABITABLE ZONE
OF ITS STAR,

221
00:08:30,633 --> 00:08:32,500
WHEREAS IT ONLY TOOK
ABOUT SIX TRIES

222
00:08:32,500 --> 00:08:35,500
FOR A CIRCUMBINARY SYSTEM
TO BE FOUND

223
00:08:35,500 --> 00:08:37,333
WHERE A PLANET
WAS IN THE HABITABLE ZONE.

224

00:08:37,333 --> 00:08:40,266
NOW, KEPLER-47c
IS NOT A HABITABLE PLANET,

225
00:08:40,266 --> 00:08:43,233
BUT IT MIGHT HAVE A MOON
THAT COULD BE HABITABLE.

226
00:08:43,233 --> 00:08:44,633
AND IF YOU THINK ABOUT IT,

227
00:08:44,633 --> 00:08:47,933
THREE OUT OF EVERY TWO STARS
YOU LOOK UP AT THE SKY AT

228
00:08:47,933 --> 00:08:49,166
ARE BINARY STARS.

229
00:08:51,900 --> 00:08:57,700
WELL, 1995 WAS THE YEAR THAT
THE FIRST EXTRASOLAR PLANET

230
00:08:57,700 --> 00:09:00,066
WAS DISCOVERED ORBITING
A MAIN SEQUENCE STAR

231
00:09:00,066 --> 00:09:01,833
THAT WAS RECOGNIZED AS SUCH,

232
00:09:01,833 --> 00:09:03,333
BUT IT WAS ALSO THE YEAR--
EARLIER THAT YEAR,

233
00:09:03,333 --> 00:09:05,566
WE HAD THE ExNPS REPORT
AND WE HAD THE ExNPS WORKSHOP.

234
00:09:05,566 --> 00:09:08,666
THIS WAS "EXPLORATION OF
NEIGHBORING PLANETARY SYSTEMS."

235

00:09:08,666 --> 00:09:10,933

AND THEY WORKED OUT A ROAD MAP
OF TECHNOLOGY

236

00:09:10,933 --> 00:09:13,566

THAT WOULD TAKE US
FROM DETECTING PLANETS,

237

00:09:13,566 --> 00:09:14,866

LEARNING ABOUT THEIR ORBITS,

238

00:09:14,866 --> 00:09:16,466

TO DIRECT IMAGING
TO SPECTROSCOPY

239

00:09:16,466 --> 00:09:19,066

TO LEARNING
WHAT'S IN THEIR ATMOSPHERES.

240

00:09:19,066 --> 00:09:21,233

A LOT OF PEOPLE WORKED ON THIS.

241

00:09:21,233 --> 00:09:24,700

THEY HAD A ROAD MAP HERE
OF TECHNOLOGIES.

242

00:09:24,700 --> 00:09:26,900

SEE? THEY'RE DOING
RADIO VELOCITY, ASTROMETRY,

243

00:09:26,900 --> 00:09:30,800

DISKS, DIRECT IMAGING
OF JUPITERS,

244

00:09:30,800 --> 00:09:34,000

MORE SPECTROSCOPY,
DETAILED IMAGING.

245

00:09:34,000 --> 00:09:35,100
BUT WHERE ARE TRANSITS?

246
00:09:35,100 --> 00:09:36,333
TRANSITS ARE NOWHERE.

247
00:09:36,333 --> 00:09:39,500
AT THAT TIME, TRANSIT PHOTOMETRY
WAS CONTROVERSIAL.

248
00:09:39,500 --> 00:09:41,266
A LOT OF PEOPLE
IN THE FIELD,

249
00:09:41,266 --> 00:09:44,366
VERY BRIGHT TECHNICAL PEOPLE,
THOUGHT IT COULD NOT BE DONE.

250
00:09:44,366 --> 00:09:47,900
THEY DIDN'T THINK THAT CCDs
LIKE THIS ONE...

251
00:09:47,900 --> 00:09:50,533
THIS IS ONE OF THE CCDs
THAT WE USED IN THE LABORATORY

252
00:09:50,533 --> 00:09:53,066
TO DEMONSTRATE
THAT CCD PHOTOMETRY

253
00:09:53,066 --> 00:09:55,033
CAN ACHIEVE THE PRECISION
NECESSARY

254
00:09:55,033 --> 00:09:57,333
TO DETECT
SMALL EARTH-SIZE PLANETS.

255
00:09:57,333 --> 00:10:01,266
YOU NEED TO ACHIEVE A PRECISION

OF ABOUT TEN PARTS PER MILLION

256

00:10:01,266 --> 00:10:02,833

FROM THE INSTRUMENT NOISE
PERSPECTIVE

257

00:10:02,833 --> 00:10:04,166

TO BE ABLE TO DO THAT.

258

00:10:06,633 --> 00:10:10,033

WELL, SO, I HAD MORE HAIR
BEFORE PLANETS--EXOPLANETS.

259

00:10:10,033 --> 00:10:11,100

I HAVE LESS HAIR HERE.

260

00:10:11,100 --> 00:10:12,400

I LOOK A LITTLE BIT
MORE SERIOUS.

261

00:10:12,400 --> 00:10:14,466

THAT'S PROBABLY BECAUSE
BILL IS A REAL WORKHORSE,

262

00:10:14,466 --> 00:10:16,966

AND I'M WORKING FOR BILL NOW.

263

00:10:16,966 --> 00:10:18,666

SO I WAS THINKING
A LOT ABOUT PLANETS,

264

00:10:18,666 --> 00:10:21,133

AND, INDEED, I WAS
A SKEPTIC AT FIRST, TOO.

265

00:10:21,133 --> 00:10:24,033

PEOPLE SAID,
"WHAT ABOUT STAR SPOTS?"

266

00:10:24,033 --> 00:10:26,000
PEOPLE HAD ALL KINDS OF...

267

00:10:26,000 --> 00:10:27,866
ALL KINDS OF QUESTIONS,
TECHNICAL QUESTIONS,

268

00:10:27,866 --> 00:10:30,033
ABOUT WHAT COULD POSSIBLY
BE THE STRAW

269

00:10:30,033 --> 00:10:31,366
THAT BREAKS THE CAMEL'S BACK.

270

00:10:31,366 --> 00:10:33,066
AND ONE BY ONE,
WE SET UP THOSE DOMINOS

271

00:10:33,066 --> 00:10:34,366
AND KNOCKED THEM DOWN,

272

00:10:34,366 --> 00:10:35,533
AND AFTER ABOUT A YEAR,

273

00:10:35,533 --> 00:10:37,200
I WAS CONVINCED
THAT WE COULD DO THIS.

274

00:10:37,200 --> 00:10:41,166
SOMEWHAT LATER--WE TOOK
A LITTLE BIT MORE EFFORT

275

00:10:41,166 --> 00:10:43,266
TO CONVINCING OUR COLLEAGUES
AND CONVINCING NASA

276

00:10:43,266 --> 00:10:44,966
THAT WE WERE WORTHY OF FUNDING,

277

00:10:44,966 --> 00:10:48,033
SO DAVID KOCH TOOK
THE CONSOLATION PRIZE.

278
00:10:48,033 --> 00:10:50,333
IN THE '96 DISCOVERY
PROPOSAL CYCLE,

279
00:10:50,333 --> 00:10:51,766
WE WERE NOT SELECTED,

280
00:10:51,766 --> 00:10:54,766
BUT WE DID GET \$500,000
TO USE TO DO

281
00:10:54,766 --> 00:10:56,900
A HARDWARE-BASED LABORATORY
DEMONSTRATION.

282
00:10:56,900 --> 00:11:00,300
SO THIS IS THE LABORATORY SETUP
THAT DAVID KOCH DESIGNED,

283
00:11:00,300 --> 00:11:01,733
AND THAT WE BUILT
AND THEN OPERATED,

284
00:11:01,733 --> 00:11:02,966
AND HE LED THE WHOLE EFFORT.

285
00:11:02,966 --> 00:11:04,500
THERE'S A TELESCOPE,

286
00:11:04,500 --> 00:11:07,333
THERE'S AN INTEGRATING SPHERE
TO ILLUMINATE A STAR PLATE HERE

287
00:11:07,333 --> 00:11:08,633
WITH HOLES FOR THE STARS.

288

00:11:08,633 --> 00:11:10,900

THEY GET IMAGED
ONTO A CCD LIKE THIS ONE.

289

00:11:10,900 --> 00:11:13,766

ACTUALLY, IT WAS A MARCONI,
A LITTLE BIT LATER DEVICE,

290

00:11:13,766 --> 00:11:17,133

AND THEN DAVE CAME UP
WITH THIS INGENIOUS WAY

291

00:11:17,133 --> 00:11:19,166

TO CREATE TRANSITS,
AND AS FAR AS I KNOW,

292

00:11:19,166 --> 00:11:22,433

IT'S THE ONLY WAY YOU CAN
CREATE EARTH-SIZE TRANSITS

293

00:11:22,433 --> 00:11:25,100

IN THE LABORATORY
IN A ROBUST, REPEATABLE WAY.

294

00:11:25,100 --> 00:11:28,300

BUT YOU PUT A RIBBON WIRE
ACROSS A LASER-MILLED HOLE,

295

00:11:28,300 --> 00:11:30,133

AND YOU PUT A COUPLE
OF MILLIAMPS THROUGH THAT.

296

00:11:30,133 --> 00:11:32,366

IT EXPANDS BY ONE ATOM,
AND THAT'S ENOUGH TO BLOCK

297

00:11:32,366 --> 00:11:35,733

1 PART IN 10,000 OF THE LIGHT
THAT'S COMING THROUGH THAT HOLE.

298

00:11:35,733 --> 00:11:37,566

AND SO DOWN HERE
ARE SOME OF THE LIGHT CURVES

299

00:11:37,566 --> 00:11:39,833

THAT WE WERE ABLE TO OBTAIN
IN THE LABORATORY

300

00:11:39,833 --> 00:11:41,266

WITH THIS DEVICE,

301

00:11:41,266 --> 00:11:43,466

DEMONSTRATING THE SIGNAL-
TO-NOISE THAT WE COULD ACHIEVE

302

00:11:43,466 --> 00:11:45,833

AGAINST THE INSTRUMENTAL NOISE

303

00:11:45,833 --> 00:11:49,966

FOR STARS ON THE STAR PLATE
IN THAT SETUP.

304

00:11:49,966 --> 00:11:54,100

THAT, TOGETHER
WITH THE DISCOVERY OF 51 PEG,

305

00:11:54,100 --> 00:11:56,400

AND THEN LATER, IN 2000,
OF COURSE,

306

00:11:56,400 --> 00:11:59,333

WE DISCOVERED THE FIRST
TRANSITING EXTRASOLAR PLANET,

307

00:11:59,333 --> 00:12:01,566

HD 209458b.

308

00:12:01,566 --> 00:12:03,833

THAT WAS VERY IMPORTANT,

BECAUSE AT THE TIME,

309

00:12:03,833 --> 00:12:05,166

THERE WERE STILL
A LOT OF SKEPTICS

310

00:12:05,166 --> 00:12:07,466

WITH RESPECT TO WHETHER
THESE EXTRASOLAR PLANETS

311

00:12:07,466 --> 00:12:08,700

WERE ACTUALLY PLANETS.

312

00:12:08,700 --> 00:12:10,866

PERHAPS, YES,
THEY'RE SUBSTELLAR MASS,

313

00:12:10,866 --> 00:12:14,166

BUT PERHAPS THEY FORM
MUCH MORE LIKE BINARY STARS FORM

314

00:12:14,166 --> 00:12:16,266

THAN LIKE PLANETS FORM.

315

00:12:16,266 --> 00:12:18,233

AND IT TOOK A WHILE
FOR THEORY TO CATCH UP

316

00:12:18,233 --> 00:12:21,100

AND FOR US TO HAVE GOOD WAYS
TO PREDICT AND MODEL

317

00:12:21,100 --> 00:12:24,766

THE VOYAGE OF GIANT PLANETS
AS THEY TRANSIT--

318

00:12:24,766 --> 00:12:26,566

AS THEY TRANSITION
AND MIGRATE

319

00:12:26,566 --> 00:12:28,933
FROM THE OUTER SOLAR SYSTEM
TO THE INNER SOLAR SYSTEM.

320

00:12:28,933 --> 00:12:30,366
A LOT OF THEM TEND
TO BRAKE AND STOP

321

00:12:30,366 --> 00:12:32,266
IN A THREE-DAY PERIOD ORBIT.

322

00:12:32,266 --> 00:12:33,933
SO I WANT TO SHARE SOME
OF THE KEY SCIENCE RESULTS

323

00:12:33,933 --> 00:12:35,566
FROM KEPLER WITH YOU.

324

00:12:35,566 --> 00:12:37,400
I'M NOT GONNA BE ABLE TO PLAY
ALL THE GREATEST HITS,

325

00:12:37,400 --> 00:12:39,766
BUT I'M GOING TO TRY
TO HIT SOME OF THEM.

326

00:12:39,766 --> 00:12:42,800
SO THIS SPEAKS MORE
TO THE IMPACT

327

00:12:42,800 --> 00:12:45,500
THAT KEPLER HAS HAD ON THE FIELD
OF EXTRASOLAR PLANETS.

328

00:12:45,500 --> 00:12:47,566
THIS IS
THE FIRST EXTRASOLAR PLANET.

329

00:12:47,566 --> 00:12:49,600

1989 WAS THE YEAR
THIS WAS DISCOVERED,

330
00:12:49,600 --> 00:12:51,000
BUT IT WASN'T RECOGNIZED
FOR SOME TIME

331
00:12:51,000 --> 00:12:52,033
TO ACTUALLY BE A PLANET.

332
00:12:52,033 --> 00:12:53,066
THERE WAS A QUESTION
AS TO WHETHER

333
00:12:53,066 --> 00:12:54,800
IT WAS A BROWN DWARF
OR WHAT.

334
00:12:54,800 --> 00:12:55,933
BUT, INDEED, LATER ON,

335
00:12:55,933 --> 00:12:57,433
THAT PROVED TO BE, INDEED,
THE CASE,

336
00:12:57,433 --> 00:12:59,966
AND THAT'S DUE TO DAVE LATHAM.

337
00:12:59,966 --> 00:13:01,900
BUT IF WE LOOK
AT ALL THE PLANETS

338
00:13:01,900 --> 00:13:04,733
THAT WERE DISCOVERED
OUTSIDE OUR SOLAR SYSTEM

339
00:13:04,733 --> 00:13:07,700
NOT FROM KEPLER
THROUGH 2012,

340
00:13:07,700 --> 00:13:09,033
THEN WE HAVE A WHOLE BUNCH

341
00:13:09,033 --> 00:13:11,500
DETECTED
BY RADIO VELOCITY TECHNIQUES

342
00:13:11,500 --> 00:13:13,533
WHERE YOU LOOK
FOR THE REFLEX VELOCITY,

343
00:13:13,533 --> 00:13:15,100
KIND OF LIKE A SPEED GUN,

344
00:13:15,100 --> 00:13:17,433
TO LOOK FOR A VARIATION
IN THE VELOCITY OF THE STAR

345
00:13:17,433 --> 00:13:19,633
AS IT ORBITS
THE COMMON BARYCENTER.

346
00:13:19,633 --> 00:13:22,666
AND THAT BY FAR WAS
THE MOST SUCCESSFUL METHOD

347
00:13:22,666 --> 00:13:24,433
IN TERMS OF THE BULK NUMBERS

348
00:13:24,433 --> 00:13:27,866
AND ALSO REACHING DOWN
RELIABLY TO SMALL MASSES.

349
00:13:27,866 --> 00:13:30,500
THESE ARE THE TRANSITING PLANETS
THAT WERE DISCOVERED

350
00:13:30,500 --> 00:13:31,733
LARGELY FROM THE GROUND.

351

00:13:31,733 --> 00:13:33,933

IT'S HARD TO DETECT
AN EARTH-SIZE PLANET

352

00:13:33,933 --> 00:13:36,066

BY TRANSIT OR ANY OTHER METHOD.

353

00:13:36,066 --> 00:13:38,266

EARTH COVERS
1 PART IN 10,000,

354

00:13:38,266 --> 00:13:40,766

A PERCENT OF A PERCENT,
OF THE AREA OF THE SUN.

355

00:13:40,766 --> 00:13:42,433

JUPITER COVERS 1%.

356

00:13:42,433 --> 00:13:43,900

YOU CAN ACHIEVE THAT EASILY

357

00:13:43,900 --> 00:13:47,900

USING A CCD IN YOUR BACKYARD
WITH AMATEUR EQUIPMENT TODAY.

358

00:13:47,900 --> 00:13:50,200

SO THERE ARE--THERE WERE

359

00:13:50,200 --> 00:13:52,033

APPROXIMATELY
70 TRANSITING PLANETS

360

00:13:52,033 --> 00:13:54,500

THAT WERE DISCOVERED
BEFORE KEPLER FLEW,

361

00:13:54,500 --> 00:13:57,133

BUT YOU SEE THEY'RE STILL

MORE OR LESS MORIBUND

362

00:13:57,133 --> 00:14:00,200

UP HERE NEAR JUPITER
IN TERMS OF THEIR SIZE

363

00:14:00,200 --> 00:14:03,833

AND LIMITED TO A FEW DAYS
OR SO AN ORBITAL PERIOD.

364

00:14:03,833 --> 00:14:06,500

THIS ONE POINT HERE
IS COROT-7b,

365

00:14:06,500 --> 00:14:09,366

AND THAT WAS ACTUALLY OBTAINED
FROM THE COROT SPACECRAFT,

366

00:14:09,366 --> 00:14:11,700

WHICH LAUNCHED IN 2007--

367

00:14:11,700 --> 00:14:14,066

OR AT THE END OF 2006.

368

00:14:14,066 --> 00:14:17,066

AND THEN THERE ARE
SOME MICROLENSING PLANETS.

369

00:14:17,066 --> 00:14:18,900

THEY HAVE LONG PERIODS
BECAUSE THEY'RE DETECTED

370

00:14:18,900 --> 00:14:20,833

TYPICALLY VERY FAR
FROM THEIR STAR--

371

00:14:20,833 --> 00:14:22,133

TWO A.U. OR FURTHER--

372

00:14:22,133 --> 00:14:24,366
AND WE'RE STARTING TO SEE
SOME DIRECT IMAGING.

373
00:14:24,366 --> 00:14:25,533
AND WE SAW
THAT DIRECT IMAGING

374
00:14:25,533 --> 00:14:27,566
WAS CALLED OUT ON THE ROAD MAP
BY ExNPS,

375
00:14:27,566 --> 00:14:29,233
AND SO ExNPS GOT
A LOT OF IT RIGHT,

376
00:14:29,233 --> 00:14:30,633
BUT THEY GOT SOME
OF THE DETAILS WRONG,

377
00:14:30,633 --> 00:14:32,666
LIKE WE ALL DO
WHEN WE PROGNOSTICATE.

378
00:14:32,666 --> 00:14:34,933
THIS IS WHAT KEPLER
HAS DONE TO THE FIELD.

379
00:14:34,933 --> 00:14:36,833
SO NOW WE HAVE--
I THINK IN THIS CASE,

380
00:14:36,833 --> 00:14:38,200
THIS IS ABOUT 3,400,

381
00:14:38,200 --> 00:14:41,333
BUT TODAY, WE HAVE
OVER 4,000 CANDIDATES,

382
00:14:41,333 --> 00:14:44,233

950 OR SO CONFIRMED
OR VALIDATED PLANETS,

383

00:14:44,233 --> 00:14:45,966
AND YOU SEE WE'VE REALLY
PUSHED THE ENVELOPE DOWN

384

00:14:45,966 --> 00:14:48,533
SO THAT THE BULK OF OUR PLANETS
THAT WE'RE DISCOVERING

385

00:14:48,533 --> 00:14:49,900
ARE SMALLER THAN NEPTUNE.

386

00:14:49,900 --> 00:14:52,633
IN FACT, MOST OF THEM
ARE TWO EARTH RADII

387

00:14:52,633 --> 00:14:54,133
OR SMALLER, THEREABOUTS.

388

00:14:54,133 --> 00:14:56,700
AND WE DON'T HAVE
TWO EARTH RADIUS PLANETS

389

00:14:56,700 --> 00:14:57,900
IN OUR SOLAR SYSTEM,

390

00:14:57,900 --> 00:14:59,566
SO THESE ARE
COMPLETELY DIFFERENT BEASTS

391

00:14:59,566 --> 00:15:02,566
FROM THOSE THAT
PLANETARY SCIENTISTS LIKE MYSELF

392

00:15:02,566 --> 00:15:04,366
GREW TO KNOW AND LOVE

393

00:15:04,366 --> 00:15:06,300
THROUGH OUR VOYAGES
THROUGH THE SOLAR SYSTEM

394
00:15:06,300 --> 00:15:10,333
ON THE PLANETARY PROBES
THAT NASA'S LAUNCHED AND ESA.

395
00:15:10,333 --> 00:15:12,066
AND AS WE'VE
ACCUMULATED DATA,

396
00:15:12,066 --> 00:15:14,700
WE'VE PUSHED OUT
THE ORBITAL PERIOD

397
00:15:14,700 --> 00:15:17,300
FOR WHICH WE CAN FIND
SUCH PLANETS AS SMALL AS EARTH,

398
00:15:17,300 --> 00:15:18,733
SO WE'RE REACHING OUT
AT THIS POINT

399
00:15:18,733 --> 00:15:21,400
TO A COUPLE OF HUNDRED DAYS
FOR THE ORBITAL PERIOD.

400
00:15:21,400 --> 00:15:22,900
NOW, THAT'S NOT
QUITE THE HOLY GRAIL,

401
00:15:22,900 --> 00:15:25,166
BUT WE'RE ON OUR WAY THERE,
WE BELIEVE.

402
00:15:25,166 --> 00:15:27,600
ONE OF THE BIGGEST,
EXCITING NEWS THIS YEAR,

403

00:15:27,600 --> 00:15:29,000
WAS THE FACT
THAT WE WERE ABLE TO USE

404
00:15:29,000 --> 00:15:30,566
A STATISTICAL
VALIDATION TECHNIQUE

405
00:15:30,566 --> 00:15:34,666
ON ALL OF THE MULTIPLE
PLANET SYSTEMS WE'VE DISCOVERED.

406
00:15:34,666 --> 00:15:37,533
TWO ACTUALLY DOMINATE THE FIELD,

407
00:15:37,533 --> 00:15:40,133
SO NOW WE'VE DETECTED
AND CONFIRMED OR VALIDATED

408
00:15:40,133 --> 00:15:41,800
MORE PLANETS
THAN ANYBODY ELSE,

409
00:15:41,800 --> 00:15:43,500
AND MOST OF OURS
WERE VERY SMALL.

410
00:15:43,500 --> 00:15:45,666
MOREOVER, THEY'RE
IN MULTIPLE PLANET SYSTEMS.

411
00:15:45,666 --> 00:15:46,833
THESE ARE VERY INTERESTING.

412
00:15:46,833 --> 00:15:48,800
YOU WANT TO KNOW
ABOUT THE SYSTEM,

413
00:15:48,800 --> 00:15:50,866
NOT JUST ABOUT A SINGLE PLANET

AROUND A SINGLE STAR.

414

00:15:50,866 --> 00:15:52,966

WE WANT TO KNOW IF
OUR OWN SOLAR SYSTEM IS NORMAL

415

00:15:52,966 --> 00:15:54,366

OR WHETHER IT'S WEIRD.

416

00:15:54,366 --> 00:15:56,333

IN FACT, IT'S A LOT LESS WEIRD
THAN IT USED TO BE

417

00:15:56,333 --> 00:15:58,533

AGAINST THE BACKDROP
OF EXOPLANETS,

418

00:15:58,533 --> 00:16:00,200

BUT IT'S NOT NORMAL, EITHER,

419

00:16:00,200 --> 00:16:02,033

SO THERE'S A LOT MORE TO LEARN.

420

00:16:02,033 --> 00:16:04,700

SO THIS WAS
A PHENOMENAL STEP FORWARD

421

00:16:04,700 --> 00:16:06,533

FOR THE FIELD
AND FOR KEPLER.

422

00:16:06,533 --> 00:16:10,866

WE HAVE MADE PROGRESS
IN FINDING SMALL,

423

00:16:10,866 --> 00:16:14,566

MOST LIKELY ROCKY--
POSSIBLY ROCKY PLANETS.

424

00:16:14,566 --> 00:16:16,233
THIS IS 62e AND f,

425
00:16:16,233 --> 00:16:21,733
ABOUT 1.5 OR SO,
1.6 EARTH RADII.

426
00:16:21,733 --> 00:16:23,233
THEY COULD BE ROCKY,

427
00:16:23,233 --> 00:16:24,566
AND THEY'RE BOTH EITHER--

428
00:16:24,566 --> 00:16:27,733
62e IS ON THE INNER EDGE
OF THE HABITABLE ZONE,

429
00:16:27,733 --> 00:16:29,433
AND 62f IS SMACK DAB
IN THE MIDDLE

430
00:16:29,433 --> 00:16:30,933
OF ITS HABITABLE ZONE.

431
00:16:30,933 --> 00:16:32,166
NOW, THIS STAR
IS A LITTLE BIT SMALLER

432
00:16:32,166 --> 00:16:33,600
AND COOLER THAN THE SUN,

433
00:16:33,600 --> 00:16:35,300
SO THE HABITABLE ZONE,
THAT GREEN LANE,

434
00:16:35,300 --> 00:16:40,000
IS CLOSER TO ITS STAR
THAN OUR HABITABLE ZONE IS.

435

00:16:40,000 --> 00:16:41,066

BUT AT THAT DISTANCE,

436

00:16:41,066 --> 00:16:43,133

IT RECEIVES

ABOUT THE SAME RADIATION

437

00:16:43,133 --> 00:16:45,566

THAT WE DO FROM THE SUN.

438

00:16:45,566 --> 00:16:48,300

NOW, I PROMISED TO TALK

ACOUSTIC OSCILLATIONS IN STARS,

439

00:16:48,300 --> 00:16:51,933

BECAUSE THIS IS THE UNSUNG STORY

OF KEPLER.

440

00:16:51,933 --> 00:16:53,466

"WHY DO STARS SING?"

441

00:16:53,466 --> 00:16:55,733

WELL, PAY ATTENTION

TO THIS GRAPH DOWN HERE.

442

00:16:55,733 --> 00:16:58,633

SO IF YOU HAVE A STARQUAKE,

STARS ARE BIG BALLS OF FLUID,

443

00:16:58,633 --> 00:17:00,866

AND THEY RESONATE

KIND OF LIKE BOWLS OF JELL-O,

444

00:17:00,866 --> 00:17:03,600

AND IF YOU HAVE STARQUAKE,

YOU CAN EXCITE AN ACOUSTIC WAVE

445

00:17:03,600 --> 00:17:05,966

THAT WILL TRAVEL DOWN

TOWARDS THE CENTER OF THE STAR,

446

00:17:05,966 --> 00:17:06,966
BUT IT WILL REFRACT BACK,

447

00:17:06,966 --> 00:17:08,800
BECAUSE OF
THE SOUND SPEED CHANGE.

448

00:17:08,800 --> 00:17:10,366
THEN IT WILL BOUNCE AROUND,

449

00:17:10,366 --> 00:17:12,266
AND IF IT COMES BACK
TO THE SAME POINT IT STARTED AT,

450

00:17:12,266 --> 00:17:13,533
IT KEEPS ON GOING AROUND.

451

00:17:13,533 --> 00:17:16,300
SO YOU SET UP THESE
QUASI-HARMONIC OSCILLATIONS,

452

00:17:16,300 --> 00:17:18,000
AND JUST AS WITH BELLS,

453

00:17:18,000 --> 00:17:21,166
THE BIGGER THE STAR IS,
THE DEEPER THE TONE, RIGHT?

454

00:17:21,166 --> 00:17:22,433
THE LOWER THE FREQUENCY

455

00:17:22,433 --> 00:17:24,866
OR THE LOWER THE PITCH
THAT IT SINGS.

456

00:17:24,866 --> 00:17:27,333
SO ASTRONOMERS,
ASTEROSEISMOLOGISTS

457

00:17:27,333 --> 00:17:28,600
CAN STUDY THE INTERVALS

458

00:17:28,600 --> 00:17:30,800
OF THE SPACING
OF THE DIFFERENT MODES

459

00:17:30,800 --> 00:17:32,466
AND THE CENTER FREQUENCY

460

00:17:32,466 --> 00:17:35,433
AND LEARN ABOUT THE MASS,
THE AGE, AND THE SIZE.

461

00:17:35,433 --> 00:17:38,300
IN FACT, FOR THESE STARS,
YOU CAN MEASURE THE AGE--

462

00:17:38,300 --> 00:17:41,100
EXCUSE ME, THE MASS AND THE SIZE
TO A COUPLE PERCENT,

463

00:17:41,100 --> 00:17:43,400
WHICH IS PHENOMENAL, BECAUSE
THEY'RE JUST POINT SOURCES.

464

00:17:43,400 --> 00:17:46,366
WE CAN'T SEE THEM.

465

00:17:46,366 --> 00:17:48,900
THIS IS HOW WE'VE CHANGED
THE FIELD IN ASTEROSEISMOLOGY

466

00:17:48,900 --> 00:17:50,666
JUST WITH THE FIRST COUPLE
OF YEARS OF DATA.

467

00:17:50,666 --> 00:17:52,333

THIS WAS PUBLISHED IN 2011,

468

00:17:52,333 --> 00:17:53,666

BUT THERE ARE OVER 500 STARS

469

00:17:53,666 --> 00:17:55,966

FOR WHICH WE'VE OBSERVED
THESE P MODE OSCILLATIONS,

470

00:17:55,966 --> 00:17:57,500

OR PRESSURE MODE OSCILLATIONS,

471

00:17:57,500 --> 00:18:00,700

ALL UP AND DOWN THE HR DIAGRAM.

472

00:18:00,700 --> 00:18:03,100

BEFORE KEPLER, THERE WERE
MAYBE A COUPLE OF DOZEN STARS

473

00:18:03,100 --> 00:18:04,233

FOR WHICH WE COULD DO THIS

474

00:18:04,233 --> 00:18:07,533

VIA DOPPLER TECHNIQUES
FROM THE GROUND.

475

00:18:07,533 --> 00:18:08,966

[oscillation warbling]

476

00:18:08,966 --> 00:18:10,933

AND THIS IS THE SOUND
THAT THE STARS ARE MAKING.

477

00:18:10,933 --> 00:18:12,966

NOW, IT'S SPED UP SO THAT
WE CAN ACTUALLY PERCEIVE IT,

478

00:18:12,966 --> 00:18:15,200

BECAUSE YOU DON'T WANT TO BE

HERE FOR FOUR YEARS, DO YOU?

479

00:18:15,200 --> 00:18:16,833

I DON'T.

480

00:18:16,833 --> 00:18:19,200

[oscillation stops]

481

00:18:19,200 --> 00:18:21,466

NOW I WANT TO HIGHLIGHT
ONE OF THE WEIRDEST DISCOVERIES,

482

00:18:21,466 --> 00:18:23,266

PERHAPS THE MOST BIZARRE
DISCOVERY KEPLER HAS MADE,

483

00:18:23,266 --> 00:18:25,933

AND THAT IS THAT WE SAW
THIS LIGHT CURVE EARLY ON

484

00:18:25,933 --> 00:18:27,233

WHERE YOU SEE THIS HAIR.

485

00:18:27,233 --> 00:18:28,566

THESE ARE TRANSIT-LIKE FEATURES

486

00:18:28,566 --> 00:18:30,600

OCCURRING
EVERY 16 HOURS OR SO--

487

00:18:30,600 --> 00:18:33,333

PRECISELY EVERY
16-POINT-SOME HOURS--

488

00:18:33,333 --> 00:18:36,200

BUT THEY CHANGE DEPTH,
AND PLANETS DON'T DO THAT.

489

00:18:36,200 --> 00:18:38,566

SO THIS WAS RELIABLY DETECTED
BY OUR PIPELINE

490

00:18:38,566 --> 00:18:40,533
EACH AND EVERY TIME WE RAN IT,
BUT IT WAS IGNORED,

491

00:18:40,533 --> 00:18:42,566
BECAUSE PEOPLE WERE
INTERESTED IN PLANETS.

492

00:18:42,566 --> 00:18:44,633
THIS LOOKED LIKE
SOME KIND OF STRANGE ARTIFACT.

493

00:18:44,633 --> 00:18:47,000
BUT SAUL RAPPAPORT SAW THIS
AND SAID,

494

00:18:47,000 --> 00:18:48,600
"THIS MUST BE
SOMETHING INTERESTING.

495

00:18:48,600 --> 00:18:49,966
WHAT COULD POSSIBLY
BE GOING ON HERE?"

496

00:18:49,966 --> 00:18:51,400
AND IT TURNS OUT
THAT THIS PLANET

497

00:18:51,400 --> 00:18:53,933
IS SO CLOSE TO ITS STAR
IN THIS 16-HOUR ORBIT

498

00:18:53,933 --> 00:18:55,666
THAT IT'S EVAPORATING,

499

00:18:55,666 --> 00:18:59,266
AND SO IT'S ABOUT 2,300 KELVIN

ON THE SURFACE,

500

00:18:59,266 --> 00:19:01,000

AND IT'S EVAPORATING MATERIAL
OFF THE SURFACE.

501

00:19:01,000 --> 00:19:02,433

IT'S BLOWING OFF.

502

00:19:02,433 --> 00:19:04,633

IT'S THEN COOLING AND CONDENSING
INTO A COMET-LIKE TAIL,

503

00:19:04,633 --> 00:19:06,633

SO WHAT WE'RE SEEING
IS THE COMET TAIL

504

00:19:06,633 --> 00:19:08,700

OCCLUDING OR BLOCKING
THE LIGHT FROM THE STAR,

505

00:19:08,700 --> 00:19:10,300

AND BECAUSE
THE ACTIVITY CHANGES

506

00:19:10,300 --> 00:19:12,100

AS A FUNCTION
OF THE RADIATION OF THE STAR,

507

00:19:12,100 --> 00:19:13,466

AND THE STAR HAS SPOTS,

508

00:19:13,466 --> 00:19:16,266

SO YOU GET THESE OUTBURSTS,
AND IT CHANGES OVER TIME,

509

00:19:16,266 --> 00:19:18,900

THEN YOU GET A CHANGING DEPTH
OF THE TRANSIT-LIKE FEATURE

510
00:19:18,900 --> 00:19:21,500
BECAUSE THE TAIL IS CHANGING.

511
00:19:21,500 --> 00:19:23,266
NOW, WE ONLY HAVE
ONE OTHER CANDIDATE

512
00:19:23,266 --> 00:19:25,200
IN ALL OF OUR
200,000 LIGHT CURVES

513
00:19:25,200 --> 00:19:26,733
THAT LOOKS LIKE
IT MIGHT BE ONE OF THESE.

514
00:19:26,733 --> 00:19:28,333
BUT THESE
ARE VERY SHORT-LIVED OBJECTS.

515
00:19:28,333 --> 00:19:31,333
THIS, WE BELIEVE, WILL EVAPORATE
WITHIN 200 MILLION YEARS,

516
00:19:31,333 --> 00:19:33,000
WHICH IS KIND OF THE BLINK
OF AN EYE

517
00:19:33,000 --> 00:19:36,600
IN TERMS OF THE AGE
OF THE UNIVERSE.

518
00:19:36,600 --> 00:19:39,333
WELL, I WANT TO TELL YOU
WHERE PLANETS COME FROM.

519
00:19:42,166 --> 00:19:43,800
THEY START OUT
WITH RAW DATA.

520

00:19:43,800 --> 00:19:45,300
SO WE HAVE THE POSTAGE STAMPS

521
00:19:45,300 --> 00:19:47,366
COMING DOWN
FROM THE SPACECRAFT,

522
00:19:47,366 --> 00:19:48,833
AND THIS ESSENTIALLY
IS MY BABY,

523
00:19:48,833 --> 00:19:50,533
AND THERE ARE A LOT OF PEOPLE
HERE WHO'VE HELPED ME

524
00:19:50,533 --> 00:19:52,066
OVER MANY YEARS
TO BUILD THIS THING.

525
00:19:52,066 --> 00:19:54,066
WE HAVE TO DO THE STANDARD
KINDS OF CORRECTIONS

526
00:19:54,066 --> 00:19:57,366
THAT PHOTOMETRISTS DO
WHEN THEY COLLECT DATA

527
00:19:57,366 --> 00:19:58,500
FROM CCDs ON THE GROUND.

528
00:19:58,500 --> 00:19:59,966
WE HAVE TO CALIBRATE
THE PIXELS,

529
00:19:59,966 --> 00:20:01,800
REMOVE ON-CHIP ARTIFACTS.

530
00:20:01,800 --> 00:20:03,800
WE HAVE TO THEN SUM UP
ALL THE PIXELS

531

00:20:03,800 --> 00:20:05,633

UNDERNEATH THE IMAGE
OF EACH STAR

532

00:20:05,633 --> 00:20:07,200

TO COUNT THE COUNTS,

533

00:20:07,200 --> 00:20:08,900

AND THAT GIVES US THE BRIGHTNESS
AS A FUNCTION OF TIME.

534

00:20:08,900 --> 00:20:10,533

YOU CAN SEE AN EXAMPLE HERE.

535

00:20:10,533 --> 00:20:12,000

YOU ALSO SEE
SOME OTHER THINGS GOING ON

536

00:20:12,000 --> 00:20:13,266

THAT ARE SYSTEMATIC

537

00:20:13,266 --> 00:20:16,700

DUE TO HOW THE INSTRUMENT
IS DRIFTING OVER TIME.

538

00:20:16,700 --> 00:20:19,366

SO WE HAVE TO IDENTIFY THOSE
IN THIS MODULE AND REMOVE THEM

539

00:20:19,366 --> 00:20:20,833

SO THAT THE DATA
ARE CLEAN ENOUGH

540

00:20:20,833 --> 00:20:22,833

TO PRESENT
TO OUR DETECTION ALGORITHM,

541

00:20:22,833 --> 00:20:24,100

WHICH THEN COMBS
THROUGH THE DATA

542

00:20:24,100 --> 00:20:26,066

LOOKING FOR
TRANSIT-LIKE FEATURES,

543

00:20:26,066 --> 00:20:27,233

AND IT DOES A REALLY GOOD JOB

544

00:20:27,233 --> 00:20:28,633

AT FINDING
TRANSIT-LIKE FEATURES,

545

00:20:28,633 --> 00:20:30,400

AND IT TURNS OUT--
I'LL TELL YOU LATER--

546

00:20:30,400 --> 00:20:31,566

THAT A LOT OF OTHER THINGS

547

00:20:31,566 --> 00:20:33,066

CAN LOOK LIKE
TRANSIT-LIKE FEATURES, TOO,

548

00:20:33,066 --> 00:20:34,500

SO IT'S VERY CHALLENGING.

549

00:20:34,500 --> 00:20:36,200

BUT THEN WE HAND IT OVER
TO DATA VALIDATION,

550

00:20:36,200 --> 00:20:39,333

WHICH THEN CREATES A SUITE
OF DIAGNOSTIC TESTS

551

00:20:39,333 --> 00:20:40,633

THAT HELP THE SCIENTISTS

552

00:20:40,633 --> 00:20:42,200
AND ASTRONOMERS
AND ASTROPHYSICISTS

553
00:20:42,200 --> 00:20:44,066
DECIDE WHETHER THIS
IS A PLANET OR NOT.

554
00:20:44,066 --> 00:20:46,900
IT CAN HELP MAKE OR BREAK
THAT HYPOTHESIS.

555
00:20:46,900 --> 00:20:48,933
AND THEN WE LEAVE IT

556
00:20:48,933 --> 00:20:50,700
TO THE THRESHOLD
CROSSING EVENT REVIEW TEAM,

557
00:20:50,700 --> 00:20:52,100
A GROUP OF PEOPLE--

558
00:20:52,100 --> 00:20:54,500
SCIENTISTS IN THE SCIENCE OFFICE
AND ON THE SCIENCE TEAM--

559
00:20:54,500 --> 00:20:56,533
TO ACTUALLY DECIDE
WHAT'S WHAT,

560
00:20:56,533 --> 00:20:58,733
PLANET OR DUD?

561
00:20:58,733 --> 00:21:01,033
THIS IS AN EXAMPLE
OF ONE OF THE END PRODUCTS

562
00:21:01,033 --> 00:21:02,700
FROM THE KEPLER PIPELINE.

563

00:21:02,700 --> 00:21:04,466
THIS IS A DATA VALIDATION
SUMMARY REPORT

564

00:21:04,466 --> 00:21:06,833
WHERE WE SUMMARIZE
THE MOST IMPORTANT INFORMATION

565

00:21:06,833 --> 00:21:08,200
ON ONE PAGE.

566

00:21:08,200 --> 00:21:10,100
THIS IS A REALLY
GOOD-LOOKING SIGNATURE

567

00:21:10,100 --> 00:21:11,633
OF A PLANET TRANSITING HERE.

568

00:21:11,633 --> 00:21:13,533
IT'S FOLDED AT THE PERIOD
OF THE PLANET.

569

00:21:13,533 --> 00:21:15,533
YOU CAN SEE
THE INDIVIDUAL TRANSITS MARKED.

570

00:21:15,533 --> 00:21:17,233
YOU CAN
SEE THE FULL LIGHT CURVE.

571

00:21:17,233 --> 00:21:19,433
YOU CAN SEE THE ODD AND EVEN,

572

00:21:19,433 --> 00:21:21,333
AND EVERYTHING'S BLACK HERE.

573

00:21:21,333 --> 00:21:22,466
IF ANYTHING WERE RED,

574

00:21:22,466 --> 00:21:24,633
IT WOULD BE CALLED
POSSIBLY INTO QUESTION,

575

00:21:24,633 --> 00:21:25,766
BUT EVERYTHING IS BLACK.

576

00:21:25,766 --> 00:21:28,733
THIS WAS CREATED
ON 30th OF OCTOBER, 2012.

577

00:21:28,733 --> 00:21:30,833
THIS WAS THE SUBJECT
OF A VERY IMPORTANT DISCOVERY

578

00:21:30,833 --> 00:21:33,000
ANNOUNCED EARLIER THIS YEAR,
KEPLER-186f.

579

00:21:33,000 --> 00:21:34,433
THIS IS THE DISCOVERY SHOT.

580

00:21:34,433 --> 00:21:37,733
THIS WAS WHAT GAVE ASTRONOMERS
THE INFORMATION THEY NEEDED

581

00:21:37,733 --> 00:21:39,533
TO SAY THIS IS
A VERY INTERESTING OBJECT

582

00:21:39,533 --> 00:21:40,966
AND MOST LIKELY A PLANET,

583

00:21:40,966 --> 00:21:43,366
BARRING
ANY UNFORESEEN CIRCUMSTANCES

584

00:21:43,366 --> 00:21:46,333
THAT GET TURNED UP LATER

BY THE FOLLOW-UP OBSERVATIONS.

585

00:21:46,333 --> 00:21:47,766

BUT THIS IS WHAT EVERYBODY
WANTS TO SEE

586

00:21:47,766 --> 00:21:49,700

WHEN THEY'RE
LOOKING AT THESE REPORTS.

587

00:21:49,700 --> 00:21:51,966

NOW, UNFORTUNATELY,
WE'VE HAD A PLAGUE

588

00:21:51,966 --> 00:21:53,233

OF PLANET-LIKE SIGNATURES,

589

00:21:53,233 --> 00:21:54,800

AND AS WE'VE ACCUMULATED
MORE DATA,

590

00:21:54,800 --> 00:21:56,733

IT'S KIND OF LIKE BALES
OF HAY FALLING ON YOUR HEAD,

591

00:21:56,733 --> 00:21:58,433

AND YOU'RE LOOKING
FOR GOLDEN NEEDLES.

592

00:21:58,433 --> 00:22:01,833

SO THE SYSTEM WAS SPEEDING UP
AS WE WERE ACCUMULATING DATA,

593

00:22:01,833 --> 00:22:03,766

AND IT WAS RUNNING
FASTER AND FASTER,

594

00:22:03,766 --> 00:22:05,366

AND SO IT WAS DIFFICULT
TO DEAL WITH.

595

00:22:05,366 --> 00:22:06,733

IN FACT,
IT WAS SO DIFFICULT,

596

00:22:06,733 --> 00:22:08,933

WE HAD TO CHANGE OUR
ARCHITECTURE FOR OUR HARDWARE.

597

00:22:08,933 --> 00:22:11,033

SO THIS WAS...
THESE WERE OUR LOCAL CLUSTERS

598

00:22:11,033 --> 00:22:14,166

OR LOCAL COMPUTERS WE USED
FOR THE FIRST THREE OR SO YEARS,

599

00:22:14,166 --> 00:22:15,400

AND THEN IT BECAME APPARENT

600

00:22:15,400 --> 00:22:17,000

THAT WE COULDN'T KEEP UP
WITH THE DATA.

601

00:22:17,000 --> 00:22:18,266

WELL, WE COULD KEEP UP
WITH THE DATA,

602

00:22:18,266 --> 00:22:19,700

BUT WE COULDN'T GO BACK
AND REPROCESS IT

603

00:22:19,700 --> 00:22:21,500

TO TAKE ADVANTAGE
OF ALL THOSE IMPROVEMENTS

604

00:22:21,500 --> 00:22:23,133

THAT WE'D MADE
TO THE SOFTWARE,

605

00:22:23,133 --> 00:22:24,733
HAVING LEARNED SO MUCH
ABOUT THE INSTRUMENT

606

00:22:24,733 --> 00:22:26,400
AND ABOUT THE SKY
IN THE MEANTIME.

607

00:22:26,400 --> 00:22:30,833
SO WE MOVED OUR OPERATIONS
TO THE SUPERCOMPUTER.

608

00:22:30,833 --> 00:22:33,133
KEPLER IS A STORY
OF MANY THREADS

609

00:22:33,133 --> 00:22:35,933
HAVING TO COME TOGETHER
TO ENABLE IT TO FLY

610

00:22:35,933 --> 00:22:37,533
WHEN IT FLEW
AND TO BE SUCCESSFUL.

611

00:22:37,533 --> 00:22:38,633
WE NEEDED TECHNOLOGY.

612

00:22:38,633 --> 00:22:41,000
WE NEEDED
BACK-ILLUMINATED CCDs.

613

00:22:41,000 --> 00:22:42,900
WE NEEDED COMPUTERS
ON BOARD FAST ENOUGH

614

00:22:42,900 --> 00:22:44,333
TO COLLECT THE DATA
AND DEAL WITH IT.

615

00:22:44,333 --> 00:22:46,433
WE NEEDED THE POLITICAL WILL

616
00:22:46,433 --> 00:22:48,400
OF THE ASTRONOMERS
AND THE COMMUNITY

617
00:22:48,400 --> 00:22:51,000
TO GET BEHIND THIS PROJECT
AND BELIEVE THAT IT COULD WORK,

618
00:22:51,000 --> 00:22:52,633
BECAUSE IT WAS NOT CHEAP.

619
00:22:52,633 --> 00:22:55,833
AND WE NEEDED OUTSTANDING
COMPUTATIONAL RESOURCES

620
00:22:55,833 --> 00:22:59,500
AVAILABLE HERE AT NASA AMES
TO DO THIS JOB.

621
00:22:59,500 --> 00:23:01,733
IF YOU TOOK ALL
OF THE DATA VALIDATION REPORTS

622
00:23:01,733 --> 00:23:04,800
FROM A TYPICAL RUN ACROSS
FOUR YEARS OF KEPLER DATA,

623
00:23:04,800 --> 00:23:09,500
YOU WOULD CREATE A STACK
OF PAPER 150 STORIES HIGH.

624
00:23:09,500 --> 00:23:11,400
THIS IS THE CHICAGO SPIRE.

625
00:23:11,400 --> 00:23:13,633
I THINK THAT'S ONLY PROPOSED.
IT HASN'T BEEN BUILT,

626

00:23:13,633 --> 00:23:15,266

BUT THAT MIGHT BE
A LITTLE BIT TALLER

627

00:23:15,266 --> 00:23:17,233

THAN THIS STACK OF PAPER.

628

00:23:17,233 --> 00:23:19,466

BUT I DON'T KNOW ANYBODY
THAT WOULD WANT TO CRAWL THROUGH

629

00:23:19,466 --> 00:23:21,533

150 STORIES OF PAPER

630

00:23:21,533 --> 00:23:23,766

IN ORDER TO DECIDE WHETHER
SOMETHING'S A PLANET OR NOT.

631

00:23:23,766 --> 00:23:25,366

IT'S REALLY
AN OVERWHELMING JOB.

632

00:23:25,366 --> 00:23:29,033

WE'LL COME BACK TO THIS POINT
A LITTLE BIT LATER.

633

00:23:29,033 --> 00:23:32,100

SO IN THE END, HAVING ANALYZED
ALL THE DATA FROM THE PIPELINE

634

00:23:32,100 --> 00:23:34,133

AND GONE OUT AND GOTTEN
ADDITIONAL INFORMATION,

635

00:23:34,133 --> 00:23:35,400

ADDITIONAL OBSERVATIONS,

636

00:23:35,400 --> 00:23:37,300

AND DONE ADDITIONAL
VALIDATION ANALYSES,

637

00:23:37,300 --> 00:23:38,866
WE HAVE KEPLER-186f,

638

00:23:38,866 --> 00:23:41,833
WHICH IS OUR FIRST EXAMPLE
OF AN EARTH-SIZE PLANET

639

00:23:41,833 --> 00:23:43,866
IN THE HABITABLE ZONE
OF A MAIN SEQUENCE STAR

640

00:23:43,866 --> 00:23:45,433
BURNING HYDROGEN
IN ITS CORE.

641

00:23:45,433 --> 00:23:46,866
THE KEPLER-186 SYSTEM.

642

00:23:46,866 --> 00:23:49,266
SO IT'S ORBITING AN "M" STAR
ABOUT HALF THE MASS

643

00:23:49,266 --> 00:23:51,400
AND HALF THE SIZE
OF OUR OWN SUN,

644

00:23:51,400 --> 00:23:53,600
SO THE HABITABLE ZONE
IS MUCH CLOSER,

645

00:23:53,600 --> 00:23:56,633
BUT IT'S A LITTLE BIT BIGGER
THAN EARTH,

646

00:23:56,633 --> 00:23:58,000
BUT NOT TOO MUCH.

647

00:23:58,000 --> 00:24:00,800

IT RECEIVES A LITTLE BIT LESS
RADIATION THAN WE DO,

648

00:24:00,800 --> 00:24:02,400

BUT IN PRINCIPLE,
THAT'S NOT A PROBLEM.

649

00:24:02,400 --> 00:24:04,466

NOW, PEOPLE HAVE OTHER ISSUES
WITH "M" STARS,

650

00:24:04,466 --> 00:24:05,733

BECAUSE THEY FLARE.

651

00:24:05,733 --> 00:24:07,333

THE HABITABLE ZONE
IS SO TIGHT

652

00:24:07,333 --> 00:24:09,366

THAT MOST OF THE PLANETS
WOULD BE LOCKED,

653

00:24:09,366 --> 00:24:12,333

LIKE THE MOON IS LOCKED
IN ITS ORBIT ABOUT THE EARTH.

654

00:24:12,333 --> 00:24:14,166

I PERSONALLY DON'T THINK
THAT'S A PROBLEM.

655

00:24:14,166 --> 00:24:15,633

HAVING STUDIED VENUS,

656

00:24:15,633 --> 00:24:16,900

IF YOU WANT TO
KNOW WHAT THE TEMPERATURE

657

00:24:16,900 --> 00:24:19,266

OF A PARTICULAR PLACE IS
IN THE VENUS ATMOSPHERE,

658

00:24:19,266 --> 00:24:21,833

IT'S A FUNCTION

NOT OF THE ANGLE TO THE SUN.

659

00:24:21,833 --> 00:24:24,633

IT'S A FUNCTION OF YOUR ALTITUDE

AND YOUR LATITUDE ONLY.

660

00:24:24,633 --> 00:24:28,200

THAT'S BECAUSE THE WIND ON VENUS

IN THE THICK ATMOSPHERE

661

00:24:28,200 --> 00:24:30,633

CIRCULATES THE HEAT

SO EFFECTIVELY

662

00:24:30,633 --> 00:24:33,200

FROM THE SUN SIDE

TO THE ANTI-SUN SIDE,

663

00:24:33,200 --> 00:24:35,966

THAT IT DOESN'T MATTER

WHETHER IT'S LIGHT OR DARK.

664

00:24:35,966 --> 00:24:37,866

SO YOU JUST NEED

A THICK ATMOSPHERE.

665

00:24:37,866 --> 00:24:39,466

HOPEFULLY NOT TOO THICK.

666

00:24:39,466 --> 00:24:41,433

NOW, WE HAVE COLLECTED

A NUMBER

667

00:24:41,433 --> 00:24:42,900

OF SMALL HABITABLE ZONE

CANDIDATES,

668

00:24:42,900 --> 00:24:44,100

AND THIS IS

THE LATEST AND GREATEST

669

00:24:44,100 --> 00:24:46,700

THAT I GOT FROM NATALIE.

THANK YOU.

670

00:24:46,700 --> 00:24:48,133

AND WE HAVE

A LOT MORE CANDIDATES,

671

00:24:48,133 --> 00:24:50,366

AND SOME OF THESE HAVE BEEN

CONFIRMED OR VALIDATED.

672

00:24:50,366 --> 00:24:52,433

AND THESE GREEN LANES INDICATE

673

00:24:52,433 --> 00:24:53,966

WHERE WE BELIEVE

THE HABITABLE ZONE IS.

674

00:24:53,966 --> 00:24:55,266

NOW,

THERE ARE TWO MARKED HERE,

675

00:24:55,266 --> 00:24:57,800

BECAUSE WE'RE NOT QUITE CERTAIN

AS SCIENTISTS

676

00:24:57,800 --> 00:25:00,500

WHAT WE SHOULD DEFINE TO BE

THE HABITABLE ZONE.

677

00:25:00,500 --> 00:25:02,900

THERE'S SOME CONTROVERSY,

AND I'LL SAY

678

00:25:02,900 --> 00:25:05,333

THERE'S AN ACTIVE DISCUSSION
AND DIALOGUE GOING ON.

679

00:25:05,333 --> 00:25:07,300

BUT THIS ON THE "X" AXIS

680

00:25:07,300 --> 00:25:08,966

IS THE FLUX RECEIVED
BY THE PLANET

681

00:25:08,966 --> 00:25:11,166

RELATIVE TO WHAT WE RECEIVE
HERE ON EARTH,

682

00:25:11,166 --> 00:25:13,066

SO ONE IS WHERE THE EARTH IS
WAY UP HERE.

683

00:25:13,066 --> 00:25:15,333

THIS IS THE TEMPERATURE
OF THE STAR,

684

00:25:15,333 --> 00:25:16,866

SO THIS ALLOWS US
TO CONVENIENTLY PLOT

685

00:25:16,866 --> 00:25:18,066

ALL THESE POINTS
ON ONE GRAPH

686

00:25:18,066 --> 00:25:20,200

AND SEE WHERE THEY LIE.

687

00:25:20,200 --> 00:25:21,600

THIS IS VERY EXCITING.

688

00:25:21,600 --> 00:25:25,000

THIS WHAT WE HOPED TO SEE
WHEN WE LAUNCHED KEPLER.

689

00:25:25,000 --> 00:25:27,300
ARE WE THERE YET?

690

00:25:27,300 --> 00:25:29,100
WELL, THE ANSWER IS NO.

691

00:25:29,100 --> 00:25:32,033
WE NEED TO UNDERSTAND WHAT
THE DISCOVERIES WE'VE MADE MEAN.

692

00:25:32,033 --> 00:25:34,633
IT'S NO TIME TO FALL ASLEEP.

693

00:25:34,633 --> 00:25:35,933
WE NEED TO KEEP PRESSING ON,

694

00:25:35,933 --> 00:25:38,000
AND, FORTUNATELY,
HEADQUARTERS HAS ALLOWED US

695

00:25:38,000 --> 00:25:39,433
TO GO ON
FOR AN EXTENDED MISSION,

696

00:25:39,433 --> 00:25:40,800
A CLOSE-OUT MISSION NOW,

697

00:25:40,800 --> 00:25:42,700
TO FINISH THE JOB
THAT WE STARTED,

698

00:25:42,700 --> 00:25:45,666
NAMELY TO FIND
AND DETERMINE THE FREQUENCY

699

00:25:45,666 --> 00:25:47,866

OF EARTH-SIZE PLANETS
IN THE HABITABLE ZONE

700
00:25:47,866 --> 00:25:50,333
OF SUN-LIKE STARS
IN OUR TARGET SAMPLE,

701
00:25:50,333 --> 00:25:53,300
WHICH THEN INFORMS US
ABOUT THE GALAXY.

702
00:25:53,300 --> 00:25:56,100
IN FACT, NATALIE
IS THE CHIEF SCIENTIST,

703
00:25:56,100 --> 00:25:57,233
OUR MISSION SCIENTIST,

704
00:25:57,233 --> 00:25:58,566
WHO'S BEEN THINKING
ABOUT THIS,

705
00:25:58,566 --> 00:26:00,066
AND SHE'S BEEN PUTTING TOGETHER
THE RECIPE

706
00:26:00,066 --> 00:26:02,433
FOR HOW WE'RE GONNA
BAKE THIS CAKE.

707
00:26:02,433 --> 00:26:04,900
SO WE NEED TO HAVE
THE BEST PLANET CANDIDATES

708
00:26:04,900 --> 00:26:07,533
AND SET OF CONFIRMED AND
VALIDATED PLANETS THAT WE CAN,

709
00:26:07,533 --> 00:26:08,866
AND THAT'S WHERE THE SOC

COMES IN.

710

00:26:08,866 --> 00:26:11,133
THAT'S OUR JOB IS TO FIND

711

00:26:11,133 --> 00:26:12,666
THE PLANET SIGNATURES
IN THE DATA.

712

00:26:12,666 --> 00:26:15,200
WE ALSO NEED TO CHARACTERIZE
THE COMPLETENESS

713

00:26:15,200 --> 00:26:16,733
OF THE KEPLER PLANET
DISCOVERY SYSTEM.

714

00:26:16,733 --> 00:26:18,333
IT'S NOT ENOUGH TO KNOW
THAT YOU HAVE A BUNCH

715

00:26:18,333 --> 00:26:19,500
OF PRETTY, SHINY MARBLES.

716

00:26:19,500 --> 00:26:21,433
YOU WANT TO KNOW
HOW MANY YOU MISSED.

717

00:26:21,433 --> 00:26:22,866
YOU WANT TO KNOW
HOW MANY ARE IN THE BAG

718

00:26:22,866 --> 00:26:24,066
THAT YOU STILL HAVE

719

00:26:24,066 --> 00:26:25,766
BUT YOU CAN'T LOOK
IN DIRECTLY, RIGHT?

720

00:26:25,766 --> 00:26:27,700
YOU ALSO WANT TO KNOW
HOW MANY OF THOSE MARBLES

721
00:26:27,700 --> 00:26:29,100
ARE FALSE-POSITIVES,

722
00:26:29,100 --> 00:26:31,966
SO YOU NEED TO UNDERSTAND
THE RELIABILITY OF YOUR SAMPLE

723
00:26:31,966 --> 00:26:34,933
IN ORDER TO DRAW THE CONCLUSIONS
YOU WANT TO DRAW.

724
00:26:34,933 --> 00:26:36,666
YOU NEED TO KNOW
ABOUT THE STARS.

725
00:26:36,666 --> 00:26:38,433
IN FACT, WE COULD NOT AFFORD
TO KNOW AS MUCH

726
00:26:38,433 --> 00:26:40,666
ABOUT THE STARS
WHEN WE LAUNCHED

727
00:26:40,666 --> 00:26:42,800
AS WE REALLY NEEDED TO
IN ORDER TO DO THIS JOB.

728
00:26:42,800 --> 00:26:44,566
SO WE'RE PLAYING CATCH UP
AFTER THE FACT,

729
00:26:44,566 --> 00:26:47,733
BECAUSE WE COULD SIMPLY
NOT AFFORD TO DO THIS

730
00:26:47,733 --> 00:26:50,066

FOR, WHAT WAS IT, NATALIE,

731

00:26:50,066 --> 00:26:53,833
5 MILLION STARS IN OUR CATALOG,
SOMETHING LIKE THAT?

732

00:26:53,833 --> 00:26:55,633
THANK YOU, BILL.
15 MILLION STARS.

733

00:26:55,633 --> 00:26:57,000
THAT WOULD HAVE TAKEN
A LONG TIME,

734

00:26:57,000 --> 00:26:58,466
AT LEAST WITH ASSETS THEN,

735

00:26:58,466 --> 00:27:00,066
AND PROBABLY STILL TODAY.

736

00:27:00,066 --> 00:27:01,433
WE ALSO NEED TO KNOW

737

00:27:01,433 --> 00:27:03,866
ABOUT THE BACKGROUND ECLIPSING
BINARY DISTRIBUTION,

738

00:27:03,866 --> 00:27:05,966
BECAUSE THAT...
ECLIPSING BINARIES,

739

00:27:05,966 --> 00:27:07,766
AS I'VE SAID MANY TIMES BEFORE
FOR EXOPLANETS,

740

00:27:07,766 --> 00:27:09,533
ARE THE SCOURGE
OF THE UNIVERSE.

741

00:27:09,533 --> 00:27:11,533
THEY MIMIC PLANETARY TRANSITS,

742

00:27:11,533 --> 00:27:13,466
AND THEY'RE GREAT WHEN
YOU HAVE CIRCUMBINARY SYSTEMS,

743

00:27:13,466 --> 00:27:15,766
BUT OTHERWISE, WHO CARES?

744

00:27:15,766 --> 00:27:17,933
ACTUALLY, WE HAVE PEOPLE ON THE
SCIENCE TEAM THAT CARE A LOT,

745

00:27:17,933 --> 00:27:20,133
AND IT'S REALLY COOL SCIENCE
THEY'RE DOING.

746

00:27:20,133 --> 00:27:22,033
FURTHERMORE,
WE NEED TO UNDERSTAND

747

00:27:22,033 --> 00:27:23,333
WHAT KINDS OF PLANET--

748

00:27:23,333 --> 00:27:25,133
WHAT KINDS OF STARS WE CHOSE
TO BE OUR TARGETS.

749

00:27:25,133 --> 00:27:28,000
WE WERE VERY SELECTIVE,
SO THERE ARE SELECTION BIASES

750

00:27:28,000 --> 00:27:31,800
IN THE POOL
OF PLANETARY TARGETS, OF STARS,

751

00:27:31,800 --> 00:27:33,100
THAT WE CHOSE TO OBSERVE.

752

00:27:33,100 --> 00:27:35,600

WE NEED TO KNOW HOW
THE PROPERTIES OF THE STARS

753

00:27:35,600 --> 00:27:37,100

WE CHOSE TO OBSERVE
RELATE TO THE PROPERTIES

754

00:27:37,100 --> 00:27:39,866

OF THE GENERAL STAR THAT WE FIND
IN THE SOLAR NEIGHBORHOOD.

755

00:27:39,866 --> 00:27:41,266

NOW WE CAN TIE IT
ALL TOGETHER

756

00:27:41,266 --> 00:27:42,700

AND UNDERSTAND
WHAT'S GOING ON.

757

00:27:42,700 --> 00:27:44,733

WELL, WE'VE MADE
SOME INITIAL ATTEMPTS.

758

00:27:44,733 --> 00:27:47,100

IN FACT, THE COMMUNITY HAS MADE
INITIAL ATTEMPTS

759

00:27:47,100 --> 00:27:49,466

TO IDENTIFY WHAT
THE OCCURRENCE RATES ARE

760

00:27:49,466 --> 00:27:50,600

FOR SMALL PLANETS,

761

00:27:50,600 --> 00:27:52,433

AND YOU SEE TWO PUBLISHED
RESULTS HERE.

762

00:27:52,433 --> 00:27:54,566
THIS IS
A RECENT PRELIMINARY RESULT

763
00:27:54,566 --> 00:27:56,766
WITHIN THE KEPLER TEAM
ITSELF,

764
00:27:56,766 --> 00:27:58,966
BY CHRIS BURKE,
WHO WORKS IN THE SCIENCE OFFICE,

765
00:27:58,966 --> 00:28:00,800
AND HE ESTIMATES,
BASED ON OUR UNDERSTANDING

766
00:28:00,800 --> 00:28:02,900
OF OUR PIPELINE COMPLETENESS
AND RELIABILITY,

767
00:28:02,900 --> 00:28:04,800
THAT ABOUT
A THIRD OF THE STARS

768
00:28:04,800 --> 00:28:07,233
THAT ARE MAIN SEQUENCE STARS
IN OUR SAMPLE

769
00:28:07,233 --> 00:28:09,333
HAVE PLANETS BETWEEN
ONE AND TWO EARTH RADII

770
00:28:09,333 --> 00:28:11,800
WITH ORBITAL PERIODS
BETWEEN 50 AND 200 DAYS.

771
00:28:11,800 --> 00:28:15,333
THAT'S A VERY EXCITING PIECE
OF REAL ESTATE.

772

00:28:15,333 --> 00:28:16,633
WE WANT TO IMPROVE THAT.

773

00:28:16,633 --> 00:28:19,166
HOWEVER, IT DEPENDS
ON WHAT ASSUMPTIONS YOU MAKE

774

00:28:19,166 --> 00:28:22,666
ABOUT YOUR SYSTEM, AND SO CHRIS
HAS DONE DUE DILIGENCE

775

00:28:22,666 --> 00:28:25,333
AND FOUND THAT, DEPENDING
ON WHAT ASSUMPTIONS HE MAKES

776

00:28:25,333 --> 00:28:28,900
ABOUT OUR STARS
AND ABOUT WHAT WE'RE DOING,

777

00:28:28,900 --> 00:28:32,333
HE CAN GET ANSWER ANYWHERE
BETWEEN ABOUT 0.2 AND 0.6,

778

00:28:32,333 --> 00:28:34,800
AND WITH TAILS THAT GO
UP TO 0.9 OR SO,

779

00:28:34,800 --> 00:28:37,233
AND, OF COURSE, TAILS THAT GO
DOWN TO ABOUT 0.1.

780

00:28:37,233 --> 00:28:39,700
I DON'T KNOW ABOUT YOU,
BUT AT THIS POINT,

781

00:28:39,700 --> 00:28:41,133
I DON'T THINK
THAT WE HAVE A RESULT

782

00:28:41,133 --> 00:28:43,333

THAT WE CAN BE PROUD OF THAT
CAN ACTUALLY CARRY US FORWARD

783

00:28:43,333 --> 00:28:44,800

TO UNDERSTAND
WHAT WE NEED TO KNOW

784

00:28:44,800 --> 00:28:48,366

IN ORDER TO SUPPORT
FOLLOW-ON MISSIONS.

785

00:28:48,366 --> 00:28:49,666

SO HOW DO WE CHARACTERIZE

786

00:28:49,666 --> 00:28:52,033

THE KEPLER PLANET
DISCOVERY SYSTEM?

787

00:28:52,033 --> 00:28:53,700

WELL, IT'S
A REAL SAUSAGE MAKER.

788

00:28:53,700 --> 00:28:56,600

FIRST WE TAKE
THE TARGET STAR PIXELS,

789

00:28:56,600 --> 00:28:58,900

THESE POSTAGE STAMPS, WE GRIND
THEM THROUGH THE PIPELINE

790

00:28:58,900 --> 00:29:00,966

TO MAKE LIGHT CURVES,

791

00:29:00,966 --> 00:29:04,066

IDENTIFY TRANSITING
THRESHOLD CROSSING EVENTS.

792

00:29:04,066 --> 00:29:05,666

THESE ARE
TRANSIT-LIKE FEATURES,

793

00:29:05,666 --> 00:29:07,900

AND THOSE
IN THE DV DIAGNOSTICS

794

00:29:07,900 --> 00:29:09,833

GO TO THE THRESHOLD
CROSSING EVENT REVIEW TEAM,

795

00:29:09,833 --> 00:29:10,900

A GROUP OF PEOPLE--

796

00:29:10,900 --> 00:29:12,133

SO WE HAVE A PEOPLE PIPELINE--

797

00:29:12,133 --> 00:29:16,233

THAT THEN PUMP OUT
THE PLANETS.

798

00:29:16,233 --> 00:29:18,100

BUT WE NEED TO UNDERSTAND
AND CHARACTERIZE

799

00:29:18,100 --> 00:29:19,533

THE COMPLETENESS
AND RELIABILITY,

800

00:29:19,533 --> 00:29:20,700

SO WE'VE CLOSED THE LOOP

801

00:29:20,700 --> 00:29:23,266

BY ADDING THE CAPABILITY
WITHIN THE SOC

802

00:29:23,266 --> 00:29:25,466

AND THE SCIENCE OFFICE
TO INJECT ARTIFICIAL TRANSITS

803

00:29:25,466 --> 00:29:27,766

AND BACKGROUND ECLIPSING
BINARIES INTO THE DATA.

804

00:29:27,766 --> 00:29:30,500
THAT PROVIDES THE GROUND TRUTH
SO THAT WE CAN PUT THOSE IN

805

00:29:30,500 --> 00:29:31,933
AND SEE HOW THEY ALL FALL OUT.

806

00:29:31,933 --> 00:29:34,733
DO WE DETECT THE THINGS
WE KNOW WE SHOULD BE DETECTING?

807

00:29:34,733 --> 00:29:36,400
DO WE MAKE THE RIGHT DECISION?

808

00:29:36,400 --> 00:29:38,700
IS THIS AN ECLIPSING BINARY,
OR IS THIS A PLANET?

809

00:29:38,700 --> 00:29:40,166
SO WE CAN TEST OUR SYSTEM.

810

00:29:40,166 --> 00:29:42,233
WE CAN TEST THE PEOPLE, TOO.

811

00:29:46,000 --> 00:29:47,533
NOW, IN THE END,
I THINK IT'S TOO HARD

812

00:29:47,533 --> 00:29:48,966
FOR PEOPLE TO DO ALL THAT,

813

00:29:48,966 --> 00:29:51,533
AT LEAST IN A COMPLETE,
RELIABLE, AND CONSISTENT MANNER,

814

00:29:51,533 --> 00:29:54,100

SO I'VE BEEN WORKING
WITH SOME COLLEAGUES

815
00:29:54,100 --> 00:29:56,200
IN THE SOC AND SCIENCE OFFICE.

816
00:29:56,200 --> 00:29:58,200
SEAN McCAULIFF IS HERE?

817
00:29:58,200 --> 00:29:59,966
YES, THERE HE IS, OKAY.

818
00:29:59,966 --> 00:30:01,966
AND JOE CATANZARITE
AND CHRIS BURKE

819
00:30:01,966 --> 00:30:06,100
AND JEFF COUGHLIN TO BUILD
AN AUTO-VETTING MACHINE

820
00:30:06,100 --> 00:30:08,200
BASED ON USING
MACHINE LEARNING APPROACHES

821
00:30:08,200 --> 00:30:12,233
TO TRY TO DECIDE
WHETHER SOMETHING SHOULD BE...

822
00:30:12,233 --> 00:30:14,066
SHOULD WARRANT ADDITIONAL
ATTENTION OR NOT.

823
00:30:14,066 --> 00:30:17,766
AND WE'VE BEEN USING
A RANDOM FOREST APPROACH.

824
00:30:17,766 --> 00:30:19,500
THIS IS BECAUSE WE GET

825

00:30:19,500 --> 00:30:21,900
ABOUT 20,000
THRESHOLD CROSSING EVENTS

826
00:30:21,900 --> 00:30:23,100
OUT OF A TYPICAL RUN.

827
00:30:23,100 --> 00:30:24,500
ALMOST ALL OF THOSE ARE DUDS.

828
00:30:24,500 --> 00:30:27,500
WHY ASK A HUMAN BEING
TO SORT THROUGH ALL THAT JUNK?

829
00:30:27,500 --> 00:30:29,766
WHAT WE WANT TO DO
IS TRAIN A MACHINE,

830
00:30:29,766 --> 00:30:32,333
BASED ON WHAT THE HUMANS
HAVE DONE IN THE PAST,

831
00:30:32,333 --> 00:30:34,533
TO DO THIS JOB
AT LEAST AS WELL AS HUMANS,

832
00:30:34,533 --> 00:30:35,700
AND PERHAPS EVEN BETTER,

833
00:30:35,700 --> 00:30:39,066
BECAUSE HUMANS
ARE FICKLE PEOPLE.

834
00:30:39,066 --> 00:30:40,866
YOUR DECISION DEPENDS

835
00:30:40,866 --> 00:30:42,100
ON WHETHER YOU JUST HAD
A CUP OF COFFEE.

836

00:30:42,100 --> 00:30:44,000

DID YOU HAVE A FIGHT
WITH YOUR SPOUSE?

837

00:30:44,000 --> 00:30:46,466

HOW MUCH SLEEP DID YOU GET
LAST NIGHT?

838

00:30:46,466 --> 00:30:47,866

IS THIS THE TENTH

839

00:30:47,866 --> 00:30:49,800

OR THE HUNDREDTH ONE
THAT YOU'RE LOOKING AT TODAY?

840

00:30:49,800 --> 00:30:52,900

A MACHINE DOESN'T
FALL INTO THOSE FOIBLES.

841

00:30:52,900 --> 00:30:54,933

HUMAN JUDGMENT
IS A WONDERFUL THING,

842

00:30:54,933 --> 00:30:56,466

BUT IT IS BY ITS NATURE

843

00:30:56,466 --> 00:30:59,200

FLEXIBLE AND CHANGEABLE
OVER TIME.

844

00:30:59,200 --> 00:31:01,100

SO I DON'T HAVE TIME TO GO
INTO DETAILS,

845

00:31:01,100 --> 00:31:04,200

BUT WHAT WE'VE DONE RECENTLY
IS BEEN ABLE TO TAKE

846

00:31:04,200 --> 00:31:06,866

THIS RANDOM FOREST, WHICH IS
A COLLECTION OF DECISION TREES,

847

00:31:06,866 --> 00:31:07,966
SAY A THOUSAND,

848

00:31:07,966 --> 00:31:09,800
EACH DECISION TREE
THEN CASTS A VOTE

849

00:31:09,800 --> 00:31:10,900
AS TO WHETHER IT THINKS

850

00:31:10,900 --> 00:31:12,466
AN OBJECT
BASED ON THE ATTRIBUTES--

851

00:31:12,466 --> 00:31:14,300
THE DIAGNOSTICS
FROM THE DV REPORT--

852

00:31:14,300 --> 00:31:16,166
WHETHER IT SHOULD BE
A PLANET,

853

00:31:16,166 --> 00:31:17,900
AN ASTROPHYSICAL
FALSE-POSITIVE

854

00:31:17,900 --> 00:31:19,200
LIKE A BACKGROUND
ECLIPSING BINARY,

855

00:31:19,200 --> 00:31:21,100
OR WHETHER IT'S JUST
AN ARTIFACT OF SOME SORT.

856

00:31:21,100 --> 00:31:24,600
AND IF YOU THEN TAKE
THE VOTE FRACTION

857

00:31:24,600 --> 00:31:27,033
FOR THE VOTE FOR "DUD"

858

00:31:27,033 --> 00:31:29,000
AND THE VOTE FRACTION
FOR THE VOTE FOR "PLANET,"

859

00:31:29,000 --> 00:31:31,166
AND EACH CANDIDATE SIGNATURE

860

00:31:31,166 --> 00:31:33,266
THEN IS A POINT ON THIS GRAPH,
RIGHT?

861

00:31:33,266 --> 00:31:34,933
'CAUSE EVERYTHING SUMS TO ONE.

862

00:31:34,933 --> 00:31:37,266
IF YOU'RE DOWN HERE,
YOU'RE A DUD ON THE LEFT.

863

00:31:37,266 --> 00:31:38,500
IF YOU'RE OVER HERE,

864

00:31:38,500 --> 00:31:41,100
YOU'RE A ASTROPHYSICAL
FALSE-POSITIVE.

865

00:31:41,100 --> 00:31:43,233
WHAT I'M SHOWING HERE,
THOUGH, IS THAT

866

00:31:43,233 --> 00:31:44,433
WE CAN NOW COLOR EACH POINT

867

00:31:44,433 --> 00:31:47,066
AND ATTRIBUTE
A POSTERIOR PROBABILITY

868

00:31:47,066 --> 00:31:48,533

THAT IT IS A PLANET,

869

00:31:48,533 --> 00:31:50,900

THAT IT IS

A ASTROPHYSICAL FALSE-POSITIVE,

870

00:31:50,900 --> 00:31:52,700

OR THAT IT'S A DUD,

871

00:31:52,700 --> 00:31:55,833

SO NOW WE DON'T JUST HAVE

A THUMBS UP OR A THUMBS DOWN.

872

00:31:55,833 --> 00:31:57,500

WE HAVE A RELIABILITY ESTIMATE.

873

00:31:57,500 --> 00:32:02,333

IS THIS 80% SIGNIFICANT

IN TERMS OF

874

00:32:02,333 --> 00:32:04,766

SHOULD WE COUNT THIS

AS 80% OF A PLANET

875

00:32:04,766 --> 00:32:08,166

OR .01% OF A PLANET?

876

00:32:08,166 --> 00:32:10,466

SO THIS WILL HELP US

WITH THE STATISTICS

877

00:32:10,466 --> 00:32:12,766

THAT WE NEED IN ORDER

TO FINISH THE JOB.

878

00:32:12,766 --> 00:32:15,066

SO AT THIS POINT,

I'M GONNA TURN TO

879

00:32:15,066 --> 00:32:17,733

THE BRIDGE BETWEEN KEPLER
AND TESS, AND THAT IS...

880

00:32:17,733 --> 00:32:19,333

EVERYBODY KNOWS--
TAKE OFF YOUR HATS--

881

00:32:19,333 --> 00:32:21,900

THAT KEPLER DIED
IN MAY OF 2012

882

00:32:21,900 --> 00:32:23,700

WHEN WE LOST
OUR SECOND REACTION WHEEL,

883

00:32:23,700 --> 00:32:25,266

AND THERE WAS A LOT OF MOANING
OVER THAT.

884

00:32:25,266 --> 00:32:26,466

WE WERE ALL CRUSHED.

885

00:32:26,466 --> 00:32:28,000

IT HAD BEEN
A LONG, GOOD RIDE,

886

00:32:28,000 --> 00:32:31,233

BUT WE WERE HOPING
FOR ANOTHER TWO TO FOUR YEARS,

887

00:32:31,233 --> 00:32:32,533

BUT, YEA VERILY,

888

00:32:32,533 --> 00:32:34,700

THE BALL AEROSPACE TECHNICAL
SERVICE CORPORATION

889

00:32:34,700 --> 00:32:37,033

CAME UP WITH A GREAT IDEA
FOR HOW TO RESURRECT KEPLER,

890

00:32:37,033 --> 00:32:39,333

AND THE COMMUNITY CAME UP
WITH A GREAT IDEA

891

00:32:39,333 --> 00:32:40,900

AS TO WHAT WE SHOULD DO
WITH THIS MISSION.

892

00:32:40,900 --> 00:32:42,033

WE'RE DUBBING IT K2,

893

00:32:42,033 --> 00:32:43,266

AND IT WAS APPROVED
BY THE SENIOR REVIEW

894

00:32:43,266 --> 00:32:46,000

EARLIER THIS YEAR.

895

00:32:46,000 --> 00:32:48,266

KEPLER'S GONE THROUGH
SOME CHANGES OVER THE YEARS.

896

00:32:48,266 --> 00:32:50,066

SO AT FIRST WHEN WE LAUNCHED,
IT HAD FOUR REACTION WHEELS,

897

00:32:50,066 --> 00:32:51,900

AND IT THOUGHT ITSELF
TO BE A GO-CART.

898

00:32:51,900 --> 00:32:55,033

THEN IN JUNE OF 2012, WE LOST
ONE OF OUR REACTION WHEELS,

899

00:32:55,033 --> 00:32:56,766

AND IT BECAME A TRICYCLE,

900

00:32:56,766 --> 00:32:58,766

AND TRICYCLES ARE A LITTLE MORE
STABLE THAN BICYCLES--

901

00:32:58,766 --> 00:33:00,466

THAN GO-CARTS,

902

00:33:00,466 --> 00:33:03,100

AND, IN FACT,
OUR POINTING BEHAVIOR

903

00:33:03,100 --> 00:33:04,300

WAS A LITTLE BIT BETTER
WITH THREE WHEELS

904

00:33:04,300 --> 00:33:05,733

THAN IT WAS WITH FOUR.

905

00:33:05,733 --> 00:33:07,066

WE LAUNCHED WITH FOUR WHEELS.

906

00:33:07,066 --> 00:33:09,400

TWO OF THEM TURNED OUT
TO NOT BE SO GOOD.

907

00:33:09,400 --> 00:33:11,533

THEY STARTED MISBEHAVING
SHORTLY AFTER LAUNCH.

908

00:33:11,533 --> 00:33:13,600

WE DIDN'T RECOGNIZE THAT
UNTIL THE FIRST ONE FAILED,

909

00:33:13,600 --> 00:33:16,033

AND WE WENT BACK AND DUG
INTO THE ENGINEERING DATA,

910

00:33:16,033 --> 00:33:19,433
BUT THEN LAST MAY,
WE LOST THE SECOND FICKLE WHEEL,

911
00:33:19,433 --> 00:33:21,033
AND WE'RE A BICYCLE NOW.

912
00:33:21,033 --> 00:33:23,366
BUT BICYCLES ARE GREAT.

913
00:33:23,366 --> 00:33:27,500
SO WE'RE ACTUALLY CONDUCTING
OBSERVATIONS NOW WITH K2.

914
00:33:27,500 --> 00:33:29,700
THIS IS OUR FIRST LIGHT IMAGE
IN THE ECLIPTIC,

915
00:33:29,700 --> 00:33:31,566
AND WE'VE CHOSEN FIELDS
AROUND THE ECLIPTIC

916
00:33:31,566 --> 00:33:32,733
OR THE ORBITAL PLANE

917
00:33:32,733 --> 00:33:34,000
IN ORDER TO CARRY OUT
THIS MISSION.

918
00:33:34,000 --> 00:33:35,600
THE WAY IT WORKS IS THAT

919
00:33:35,600 --> 00:33:37,033
WITH THE KEPLER SPACECRAFT...

920
00:33:40,366 --> 00:33:41,766
WE CAN USE THE REACTION WHEELS

921
00:33:41,766 --> 00:33:43,266

TO POINT ANYWHERE
ON THE SKY WE WANT.

922

00:33:43,266 --> 00:33:44,733

WHAT WE CAN'T DO
IS USE THE REACTION WHEELS

923

00:33:44,733 --> 00:33:45,933

TO CONTROL THE ROLL,

924

00:33:45,933 --> 00:33:48,300

BUT IF THAT'S THE SUN,
AS LONG--

925

00:33:48,300 --> 00:33:49,866

AND THIS IS THE ORBIT--

926

00:33:49,866 --> 00:33:51,533

AS LONG AS I'VE GOT THE SUN

927

00:33:51,533 --> 00:33:53,500

ON THE MIDLINE
OF THE SOLAR ARRAYS,

928

00:33:53,500 --> 00:33:56,033

IT'S ROUGHLY SYMMETRICAL,
AND IT WANTS TO STAY THERE.

929

00:33:56,033 --> 00:33:57,366

AND SO WE ONLY HAVE TO ACTUATE

930

00:33:57,366 --> 00:33:58,866

THE THRUSTERS
ONCE IN A WHILE

931

00:33:58,866 --> 00:34:00,466

TO BRING IT BACK TO POINT,

932

00:34:00,466 --> 00:34:02,533

KIND OF LIKE A ROWBOAT
IN A STREAM

933

00:34:02,533 --> 00:34:03,933
TIED TO A TETHER, RIGHT?

934

00:34:03,933 --> 00:34:06,600
IT WANTS TO LINE UP
WITH THE STREAM.

935

00:34:06,600 --> 00:34:08,266
SO IF WE POINT IT THIS WAY,

936

00:34:08,266 --> 00:34:10,366
AS IT'S ORBITING
AROUND THE SUN,

937

00:34:10,366 --> 00:34:11,766
THE SUN STAYS ON MIDLINE,

938

00:34:11,766 --> 00:34:13,833
WE CAN STAY POINTED
AT THAT EMERGENCY EXIT,

939

00:34:13,833 --> 00:34:15,833
WHICH IS VERY IMPORTANT FOR
EVERYBODY TO KNOW WHERE IT IS,

940

00:34:15,833 --> 00:34:17,266
FOR AS LONG AS 80 DAYS

941

00:34:17,266 --> 00:34:20,000
BEFORE WE HAVE TO FIND
ANOTHER EMERGENCY EXIT.

942

00:34:20,000 --> 00:34:21,433
SO WE--[laughs]

943

00:34:21,433 --> 00:34:23,566

WE DO THAT FOUR TIMES A YEAR,

944

00:34:23,566 --> 00:34:26,000

AND WE BELIEVE THAT WE HAVE
ENOUGH FUEL ON BOARD

945

00:34:26,000 --> 00:34:28,100

TO CONTINUE THIS MISSION...

946

00:34:33,200 --> 00:34:35,633

FOR ANOTHER 2 1/2 YEARS
OR SO.

947

00:34:35,633 --> 00:34:37,333

SO THAT'S
A VERY EXCITING MISSION.

948

00:34:37,333 --> 00:34:40,600

IT'S ALSO GONNA PAVE THE WAY
TO TESS, WHICH IS THE NEXT ONE,

949

00:34:40,600 --> 00:34:43,466

BECAUSE IT'S GONNA BE LOOKING
IN FIELDS,

950

00:34:43,466 --> 00:34:44,866

LOOKING FOR PLANETS
THAT ARE SIMILAR TO THOSE

951

00:34:44,866 --> 00:34:46,400

THAT TESS IS GONNA BE
LOOKING FOR.

952

00:34:46,400 --> 00:34:48,633

SO WE WERE VERY ELATED
A YEAR AGO OR SO

953

00:34:48,633 --> 00:34:50,566

WHEN WE HEARD THAT NASA
HAD SELECTED

954

00:34:50,566 --> 00:34:53,700

TESS FOR AN EXPLORER PROGRAM
TO LAUNCH IN 2017

955

00:34:53,700 --> 00:34:56,100

TO LOOK FOR THE NEAREST
AND BEST EXOPLANETS

956

00:34:56,100 --> 00:34:58,866

TO FOLLOW UP AND CHARACTERIZE
FOR THE NEXT 50 YEARS OR SO.

957

00:34:58,866 --> 00:35:00,466

WELL, IT DOES THIS

958

00:35:00,466 --> 00:35:02,533

FOLLOWING ON THE SUCCESS
OF KEPLER.

959

00:35:02,533 --> 00:35:03,800

KEPLER LOOKS
AT A FIELD OF VIEW

960

00:35:03,800 --> 00:35:05,066

ABOUT THE SIZE
OF THE PALM OF YOUR HAND

961

00:35:05,066 --> 00:35:06,400

HELD AT ARM'S LENGTH.

962

00:35:06,400 --> 00:35:09,066

IT'S A LIGHT CONE
ABOUT 3,000 LIGHT-YEARS DEEP

963

00:35:09,066 --> 00:35:10,466

AND THAT WIDE,

964

00:35:10,466 --> 00:35:12,200

BUT THERE ARE 400 FIELDS
AROUND THE SKY

965
00:35:12,200 --> 00:35:13,500
THAT YOU COULD POINT
KEPLER AT

966
00:35:13,500 --> 00:35:16,233
WHEN IT HAD THREE
OR MORE REACTION WHEELS.

967
00:35:16,233 --> 00:35:20,833
BUT TESS FOCUSES ITS ATTENTION
ON THE NEAREST 200 LIGHT-YEARS,

968
00:35:20,833 --> 00:35:22,833
AND IT'S AN ALL-SKY SURVEY.

969
00:35:22,833 --> 00:35:24,700
AND THE WAY THAT WORKS,

970
00:35:24,700 --> 00:35:26,500
BECAUSE WE CAN'T OBSERVE
ALL THE SKY AT ONCE,

971
00:35:26,500 --> 00:35:28,666
IS THAT IT OBSERVES IT
IN 26 DIFFERENT CHUNKS.

972
00:35:28,666 --> 00:35:30,433
SO IT'S FOUR TELESCOPES,

973
00:35:30,433 --> 00:35:32,733
EACH OF WHICH HAS
24 BY 24 DEGREE FIELD OF VIEW

974
00:35:32,733 --> 00:35:33,933
STACKED ONE ON TOP
OF THE OTHER,

975

00:35:33,933 --> 00:35:36,900

SO IT'S

24 BY 96 DEGREES HIGH,

976

00:35:36,900 --> 00:35:39,700

AND YOU GO FROM THE EQUATOR

A LITTLE BIT OVER THE POLE,

977

00:35:39,700 --> 00:35:42,900

AND SO YOU COVER

ONE OF THESE SWATHS--

978

00:35:42,900 --> 00:35:45,033

IF YOU CAN

JUST BARELY SEE THEM--

979

00:35:45,033 --> 00:35:46,433

LIKE THAT,

980

00:35:46,433 --> 00:35:49,166

AND, OF COURSE, WE'RE ALWAYS

COVERING THIS SPOT HERE

981

00:35:49,166 --> 00:35:51,066

WHILE WE'RE OPERATING

IN THE NORTHERN HEMISPHERE.

982

00:35:51,066 --> 00:35:54,200

WE GET A CONTINUOUS YEAR OF

COVERAGE ON 500 SQUARE DEGREES,

983

00:35:54,200 --> 00:35:57,200

WHICH IS FIVE TIMES THE SIZE

OF THE KEPLER FIELD OF VIEW.

984

00:35:57,200 --> 00:36:00,300

MOST STARS ARE GONNA BE OBSERVED

ONLY FOR ONE MONTH--27 DAYS--

985

00:36:00,300 --> 00:36:02,066
SO WE'RE LOOKING
FOR SHORT PERIOD PLANETS,

986
00:36:02,066 --> 00:36:04,200
BUT WE'RE LOOKING
FOR SUPER-EARTHS AND EARTHS,

987
00:36:04,200 --> 00:36:06,133
AND THOSE ARE
ACTUALLY VERY EXCITING,

988
00:36:06,133 --> 00:36:07,666
BECAUSE THOSE ARE
THE KINDS OF PLANETS

989
00:36:07,666 --> 00:36:10,000
THAT JAMES WEBB AND OTHER ASSETS
IN THE NEAR FUTURE

990
00:36:10,000 --> 00:36:11,333
WILL BE ABLE TO FOLLOW UP
AND CHARACTERIZE,

991
00:36:11,333 --> 00:36:13,400
SO THAT WE CAN LEARN MORE
ABOUT THEIR ATMOSPHERES

992
00:36:13,400 --> 00:36:16,200
AND WHAT MAKES THEM TICK.

993
00:36:16,200 --> 00:36:20,033
TESS IS A SMALL SPACECRAFT
AND AN INSTRUMENT

994
00:36:20,033 --> 00:36:21,533
WITH A VERY LARGE APPETITE.

995
00:36:21,533 --> 00:36:23,500
THIS IS

A VERY HAPPY PROPOSAL MANAGER

996

00:36:23,500 --> 00:36:26,400
WITH ONE OF OUR CAMERAS,
RIGHT?

997

00:36:26,400 --> 00:36:27,733
NOW, THIS MAN
AND THIS INSTRUMENT

998

00:36:27,733 --> 00:36:28,866
COULD FIT IN THE BARREL

999

00:36:28,866 --> 00:36:31,433
OF THE TELESCOPE OF KEPLER
QUITE EASILY,

1000

00:36:31,433 --> 00:36:34,400
JUST TO GIVE YOU
SOME SIZE REFERENCE THERE.

1001

00:36:34,400 --> 00:36:35,733
AND THIS IS A MOCK-UP,

1002

00:36:35,733 --> 00:36:38,700
A FULL-SCALE REPLICA
OF THE TESS CONCEPT SPACECRAFT

1003

00:36:38,700 --> 00:36:40,000
AND INSTRUMENT,

1004

00:36:40,000 --> 00:36:41,933
ALTHOUGH YOU CAN'T SEE
THE CAMERAS IN THERE.

1005

00:36:41,933 --> 00:36:43,433
WITH GEORGE RICKER,
SARA SEAGER--

1006

00:36:43,433 --> 00:36:44,933
PROFESSOR SARA SEAGER,
JOSH WINN,

1007
00:36:44,933 --> 00:36:46,833
AND ROLAND VANDERSPEK,

1008
00:36:46,833 --> 00:36:49,233
OUR DEPUTY PRINCIPAL
INVESTIGATOR,

1009
00:36:49,233 --> 00:36:50,966
AND GEORGE IS
OUR PRINCIPAL INVESTIGATOR.

1010
00:36:50,966 --> 00:36:53,833
THEY'RE ALL AT M.I.T.

1011
00:36:53,833 --> 00:36:56,400
IF YOU LOOK AT THE SCIENCE TEAM
FOR KEPLER AND FOR TESS,

1012
00:36:56,400 --> 00:36:58,833
YOU'LL FIND THAT THERE'S
A STRONG OVERLAP.

1013
00:36:58,833 --> 00:37:01,400
THERE'S A HUGE INTEREST
IN TESS.

1014
00:37:01,400 --> 00:37:03,166
THERE'S A HUGE INTEREST IN K2,

1015
00:37:03,166 --> 00:37:04,433
AND ALL OF IT HAS COME ABOUT

1016
00:37:04,433 --> 00:37:08,666
BECAUSE OF THE SUCCESS
OF KEPLER.

1017

00:37:08,666 --> 00:37:12,133

TESS WILL IDENTIFY THE BEST
AND SMALLEST EXOPLANET TARGETS,

1018

00:37:12,133 --> 00:37:15,800

BECAUSE IT'S LOOKING AT STARS
THAT ARE 100 TIMES BRIGHTER,

1019

00:37:15,800 --> 00:37:17,933

SO YOU HAVE 100 TIMES
AS MANY PHOTONS TO WORK WITH

1020

00:37:17,933 --> 00:37:21,133

TO GET SPECTRA AS YOU DO
WITH THE TYPICAL KEPLER TARGET.

1021

00:37:21,133 --> 00:37:23,300

WE'LL BE ABLE TO GET MASSES
BECAUSE ALMOST ALL OF THEM

1022

00:37:23,300 --> 00:37:25,900

WILL BE SUBJECTED
TO RADIAL VELOCITY.

1023

00:37:25,900 --> 00:37:27,833

WE CAN REACH THEM
WITH RADIAL VELOCITY.

1024

00:37:27,833 --> 00:37:29,300

WITH KEPLER,
WE CAN ONLY GET MASSES

1025

00:37:29,300 --> 00:37:31,400

FOR A SMALL FRACTION
OF THE PLANETS.

1026

00:37:31,400 --> 00:37:33,366

THOSE ARE
THE MOST EXCITING FINDS WE HAVE,

1027

00:37:33,366 --> 00:37:34,700

BECAUSE ONCE YOU HAVE THE MASS
AND THE SIZE,

1028

00:37:34,700 --> 00:37:35,966

YOU CAN ESTIMATE THE DENSITY

1029

00:37:35,966 --> 00:37:39,200

AND THEN START ARGUING
OVER WHAT IT'S MADE OF.

1030

00:37:39,200 --> 00:37:41,366

AND WE'LL BE IDENTIFYING
THESE PLANETS

1031

00:37:41,366 --> 00:37:43,666

AND FOLLOWING THEM UP WITH
JAMES WEBB SPACE TELESCOPE--

1032

00:37:43,666 --> 00:37:45,966

EXTREMELY LARGE TELESCOPES,

1033

00:37:45,966 --> 00:37:48,633

PROBES,
AND OTHER LARGE MISSIONS.

1034

00:37:48,633 --> 00:37:50,266

AND EVENTUALLY
WHAT WE HOPE TO DO

1035

00:37:50,266 --> 00:37:52,533

IS TO DO
TRANSMISSION SPECTROSCOPY

1036

00:37:52,533 --> 00:37:55,366

IN TRANSIT BY TAKING
A SPECTRUM OUT OF TRANSIT

1037

00:37:55,366 --> 00:37:56,800

AND TAKING ONE IN

1038

00:37:56,800 --> 00:37:59,433

AND NOTING THAT A SMALL FRACTION
OF THE PHOTONS FROM THE STAR

1039

00:37:59,433 --> 00:38:01,766

PASS THROUGH THE ATMOSPHERE
ON THEIR WAY TO THE TELESCOPE,

1040

00:38:01,766 --> 00:38:04,000

SO THAT WE CAN ACTUALLY ANALYZE
THE SPECTRUM

1041

00:38:04,000 --> 00:38:07,133

AND LOOK FOR SPECIES ASSOCIATED
WITH LIFE.

1042

00:38:07,133 --> 00:38:09,833

WE WANT TO LOOK FOR OZONE
AND OXYGEN, WATER VAPOR,

1043

00:38:09,833 --> 00:38:11,866

METHANE, CO₂.

1044

00:38:11,866 --> 00:38:13,466

PLANTS LOVE CARBON DIOXIDE.

1045

00:38:13,466 --> 00:38:18,200

IF YOU HAVE CARBON DIOXIDE
AND WATER,

1046

00:38:18,200 --> 00:38:21,566

AND THEN YOU MIGHT HAVE PLANTS,

1047

00:38:21,566 --> 00:38:22,966

AND AS BILL BORUCKI
SAID THIS MORNING,

1048

00:38:22,966 --> 00:38:24,433

IF YOU HAVE PLANTS
AND YOU HAVE WATER,

1049

00:38:24,433 --> 00:38:25,866

YOU MIGHT HAVE FLYING FISH,

1050

00:38:25,866 --> 00:38:30,433

BECAUSE YOU NOW HAVE OXYGEN
FOR THE FLYING FISH TO BREATHE.

1051

00:38:30,433 --> 00:38:33,166

SO THIS IS SOMETHING
THAT I HOPE I SEE

1052

00:38:33,166 --> 00:38:34,600

IN MY OWN LIFETIME.

1053

00:38:34,600 --> 00:38:38,100

I HAD NO IDEA 20 YEARS AGO
WHEN I STARTED WORKING ON THIS

1054

00:38:38,100 --> 00:38:40,133

THAT WE WOULD BE
SO SUCCESSFUL,

1055

00:38:40,133 --> 00:38:41,566

OR THAT I'D
BE STANDING HERE TODAY

1056

00:38:41,566 --> 00:38:44,100

TALKING ABOUT THE PHENOMENAL
SUCCESSSES OF KEPLER,

1057

00:38:44,100 --> 00:38:46,666

AND IT'S THE PRODUCT
OF MANY YEARS OF EFFORT

1058

00:38:46,666 --> 00:38:48,833

ON THOUSANDS

OF INDIVIDUALS' PART,

1059

00:38:48,833 --> 00:38:51,500

AND A LOT

OF IT HAS TAKEN PLACE HERE

1060

00:38:51,500 --> 00:38:54,066

IN A VERY MAGICAL PLACE,

NASA AMES RESEARCH CENTER.

1061

00:38:54,066 --> 00:38:56,866

IT'S JUST A HOTBED

OF ENTHUSIASM, INNOVATION,

1062

00:38:56,866 --> 00:39:00,966

AND IN ALL ASPECTS

FOR SPACE SCIENCE.

1063

00:39:02,900 --> 00:39:04,533

SO HERE'S MY SUMMARY.

1064

00:39:04,533 --> 00:39:06,433

KEPLER HAS RETURNED

A BONANZA OF PLANETS,

1065

00:39:06,433 --> 00:39:08,133

FAR MORE THAN ANY OTHER MISSION

OR PROJECT,

1066

00:39:08,133 --> 00:39:10,433

BUT FAR MORE IMPORTANTLY,

THEY'RE MUCH MORE INTERESTING

1067

00:39:10,433 --> 00:39:12,100

IN TERMS OF LEADING US

DOWN THE ROAD

1068

00:39:12,100 --> 00:39:14,000

TO FIND EVIDENCE FOR LIFE.

1069

00:39:14,000 --> 00:39:17,266

THE FIRST STEP IS TO DEFINE
THE FREQUENCY OF PLANETS

1070

00:39:17,266 --> 00:39:20,066

AND WHERE YOU FIND THEM.

1071

00:39:20,066 --> 00:39:22,033

WE DO HAVE
ABOUT 3 1/2 YEARS TO GO

1072

00:39:22,033 --> 00:39:24,233

WHERE WE NEED TO CHARACTERIZE
THE COMPLETENESS AND RELIABILITY

1073

00:39:24,233 --> 00:39:26,700

OF THE KEPLER MISSION.

1074

00:39:26,700 --> 00:39:29,166

MACHINE LEARNING I THINK
IS GONNA REALLY TAKE OVER,

1075

00:39:29,166 --> 00:39:31,866

BECAUSE IT REALLY
IS THE ONLY THING PRACTICAL

1076

00:39:31,866 --> 00:39:34,200

TO DO THE JOB IN A CONSISTENT
AND THOROUGH FASHION,

1077

00:39:34,200 --> 00:39:36,700

AND IT'S TESTABLE.
HUMANS ARE NOT TESTABLE,

1078

00:39:36,700 --> 00:39:38,333

NOT IN THIS KIND OF CONTEXT.

1079

00:39:38,333 --> 00:39:40,666

AND OTHER MISSIONS

LIKE TESS AND PLATO,

1080

00:39:40,666 --> 00:39:43,166

A EUROPEAN MISSION
THAT MIGHT FLY IN 2024

1081

00:39:43,166 --> 00:39:45,666

THAT WAS JUST SELECTED
FOR LAUNCH LAST YEAR,

1082

00:39:45,666 --> 00:39:48,466

OR EARLIER THIS YEAR--
EXCUSE ME--

1083

00:39:48,466 --> 00:39:51,233

ARE GONNA LOOK AT A MUCH LARGER
REAL ESTATE ON THE SKY,

1084

00:39:51,233 --> 00:39:53,133

AND THEY'LL NEED
MACHINE LEARNING TECHNIQUES.

1085

00:39:53,133 --> 00:39:55,566

ASTRONOMERS ARE BEING DRAGGED
KICKING AND SCREAMING

1086

00:39:55,566 --> 00:39:57,000

TO THE BIG DATA ERA,

1087

00:39:57,000 --> 00:39:59,000

WHERE INSTEAD OF FOCUSING
OUR OWN EYES

1088

00:39:59,000 --> 00:40:00,833

AND OUR OWN HANDS
ON A PIECE OF DATA,

1089

00:40:00,833 --> 00:40:04,600

WE NEED TO TRAIN MACHINES
TO HELP US DO THAT JOB.

1090

00:40:04,600 --> 00:40:05,833

K2 IS VERY EXCITING.

1091

00:40:05,833 --> 00:40:07,200

IT'S GOTTEN UNDERWAY,

1092

00:40:07,200 --> 00:40:09,500

AND IT SHOULD BRIDGE THE GAP
BETWEEN KEPLER AND TESS

1093

00:40:09,500 --> 00:40:11,266

AND TRAIN A LOT OF THE PEOPLE

1094

00:40:11,266 --> 00:40:13,533

WHO ARE GONNA BE DOING
FOLLOW-UP OBSERVATIONS FOR TESS

1095

00:40:13,533 --> 00:40:14,900

ON VERY SIMILAR OBJECTS.

1096

00:40:14,900 --> 00:40:17,133

WITH TESS, EVERY MONTH,
YOU GET A SLUG OF DATA,

1097

00:40:17,133 --> 00:40:18,866

AND YOU GET A SLEW
OF PLANETS TO FOLLOW UP,

1098

00:40:18,866 --> 00:40:22,000

SO THEY'RE GONNA
HAVE TO KEEP PACE.

1099

00:40:22,000 --> 00:40:23,733

AND WE HOPE--
CROSSING OUR FINGERS--

1100

00:40:23,733 --> 00:40:27,100

THAT TESS WILL FLY

IN AUGUST OF 2017

1101

00:40:27,100 --> 00:40:30,500

AND START MAPPING THE EARTH-
AND SUPER-EARTH-SIZE PLANETS

1102

00:40:30,500 --> 00:40:33,800

ACROSS THE SKY.

1103

00:40:33,800 --> 00:40:36,200

SO...HOW AM I DOING ON TIME?

1104

00:40:36,200 --> 00:40:37,500

- THREE MINUTES.

1105

00:40:37,500 --> 00:40:39,300

- ALL RIGHT, I'M GONNA
COME BACK TO THIS.

1106

00:40:39,300 --> 00:40:42,533

SO FOR THOSE
OF YOU SONOPHILES,

1107

00:40:42,533 --> 00:40:44,400

THIS IS ONE
OF MY FAVORITE OBJECTS.

1108

00:40:44,400 --> 00:40:45,700

IT'S AN ECLIPSING BINARY.

1109

00:40:45,700 --> 00:40:47,566

THIS IS TIME IN DAYS.

1110

00:40:47,566 --> 00:40:49,200

THE IS THE CHANGE IN INTENSITY,

1111

00:40:49,200 --> 00:40:50,966

AND THIS IS
AN ECLIPSING BINARY.

1112
00:40:50,966 --> 00:40:52,966
BUT YOU SEE
THAT THERE'S SOMETHING WRONG

1113
00:40:52,966 --> 00:40:54,166
WITH THE PRINTER HERE,

1114
00:40:54,166 --> 00:40:55,766
BECAUSE THERE ARE
ALL THESE SMEARS HERE,

1115
00:40:55,766 --> 00:40:57,000
AND IF YOU FOCUS IN,

1116
00:40:57,000 --> 00:40:58,933
YOU SEE THEY'RE
HIGH-FREQUENCY OSCILLATIONS.

1117
00:40:58,933 --> 00:41:00,166
SO THIS IS A PAIR OF STARS,

1118
00:41:00,166 --> 00:41:01,433
AT LEAST ONE OF WHICH

1119
00:41:01,433 --> 00:41:03,066
HAS HIGH-FREQUENCY PULSATIONS
GOING ON.

1120
00:41:03,066 --> 00:41:04,900
I DON'T KNOW WHAT
THE PHYSICAL MECHANISM IS.

1121
00:41:04,900 --> 00:41:08,300
THAT'S WHAT OUR
ASTEROSEISMOLOGISTS ARE FOR.

1122
00:41:08,300 --> 00:41:10,466
AND THIS IS

THE FOURIER DOMAIN,

1123

00:41:10,466 --> 00:41:12,000
SO THIS IS A PERIODOGRAM.

1124

00:41:12,000 --> 00:41:14,733
BUT IT SOUNDS REALLY COOL,
SO I'M GONNA PLAY IT FOR YOU.

1125

00:41:23,233 --> 00:41:24,700
OH, LET'S SEE.

1126

00:41:24,700 --> 00:41:26,633
LET'S TRY THIS ONE.

1127

00:41:29,566 --> 00:41:31,200
LET'S TRY THIS.

1128

00:41:35,066 --> 00:41:40,133
[high-pitched tone oscillating
over intermittent thumping]

1129

00:41:40,133 --> 00:41:42,333
SO THE BASS THUMPING
IS REALLY THE ECLIPSE,

1130

00:41:42,333 --> 00:41:44,833
SO THAT'S
NOT THERMOMECHANICAL ENERGY,

1131

00:41:44,833 --> 00:41:46,333
BUT THE WHISTLING IS STUFF

1132

00:41:46,333 --> 00:41:48,400
GOING INSIDE THE ENVELOPE
OF THE STAR.

1133

00:41:50,366 --> 00:41:52,266
AND THIS IS

A VERY INTERESTING STAR,

1134

00:41:52,266 --> 00:41:55,233
BECAUSE WE THOUGHT
FOR HALF A SECOND

1135

00:41:55,233 --> 00:41:56,600
THIS MIGHT BE A BLACK HOLE,

1136

00:41:56,600 --> 00:41:59,466
AND IF SO, IT WOULD HAVE BEEN
A PHENOMENAL DISCOVERY.

1137

00:41:59,466 --> 00:42:02,233
BUT REASON TOOK OVER
AFTER HALF A SECOND.

1138

00:42:02,233 --> 00:42:03,866
[rapid thumping]

1139

00:42:03,866 --> 00:42:07,833
AND THIS IS WHAT WE DUBBED
AS A HEARTBEAT STAR.

1140

00:42:07,833 --> 00:42:09,700
[thumping]

1141

00:42:14,666 --> 00:42:16,433
AND I'LL EXPLAIN
WHAT'S GOING HERE.

1142

00:42:16,433 --> 00:42:17,466
SO HERE'S THE LIGHT CURVE.

1143

00:42:17,466 --> 00:42:20,533
THIS IS TIME IN DAYS,

1144

00:42:20,533 --> 00:42:24,166
AND IT'S 42 DAYS

IN BETWEEN EACH OF THESE SPIKES,

1145

00:42:24,166 --> 00:42:26,333

AND WHAT'S HAPPENING IS WE HAVE
TWO "A" STARS

1146

00:42:26,333 --> 00:42:27,900

THAT ARE NEARLY IDENTICAL,

1147

00:42:27,900 --> 00:42:29,400

AND THEY'RE
IN A HIGHLY ELLIPTIC ORBIT,

1148

00:42:29,400 --> 00:42:31,100

AND THEY'RE BROADSIDE.
THEY ACTUALLY DON'T TRAN--

1149

00:42:31,100 --> 00:42:34,400

THEY DON'T ECLIPSE EACH OTHER,

1150

00:42:34,400 --> 00:42:35,966

BUT WHEN
THEY GET CLOSE TOGETHER,

1151

00:42:35,966 --> 00:42:37,800

THEY PERTURB EACH OTHER
GRAVITATIONALLY,

1152

00:42:37,800 --> 00:42:39,433

AND THEY RADIATE ENERGY
OFF EACH OTHER,

1153

00:42:39,433 --> 00:42:40,766

AND THEY CHANGE THEIR SHAPES,

1154

00:42:40,766 --> 00:42:43,233

SO YOU GET A BIG SPIKE
EVERY 42 DAYS,

1155

00:42:43,233 --> 00:42:44,866
AND YOU HAVE
ALL THESE OVERTONES

1156
00:42:44,866 --> 00:42:46,300
THAT ARE BEING EXCITED.

1157
00:42:46,300 --> 00:42:48,833
I THINK THE 91st OVERTONE
IS THE ONE THAT'S DOMINANT

1158
00:42:48,833 --> 00:42:50,400
IF YOU LOOK
IN THE FOURIER DOMAIN.

1159
00:42:50,400 --> 00:42:54,100
AND SO YOU END UP WITH
THIS HIGHLY PERIODIC STRUCTURE

1160
00:42:54,100 --> 00:42:56,333
ON TOP OF A FUNDAMENTAL
AT 42 DAYS.

1161
00:42:56,333 --> 00:42:59,433
AND THIS IS A NEW CLASS
OF BINARIES

1162
00:42:59,433 --> 00:43:02,766
THAT HAS BEEN ELUCIDATED
BY KEPLER,

1163
00:43:02,766 --> 00:43:05,666
AND THEY
ALSO SOUND REALLY COOL.

1164
00:43:05,666 --> 00:43:08,466
SO WITH THAT, I'D LIKE TO OPEN
THE FLOOR FOR QUESTIONS

1165
00:43:08,466 --> 00:43:10,000

IF ANYBODY HAS ANY.

1166

00:43:10,000 --> 00:43:13,066

[applause]

1167

00:43:24,933 --> 00:43:26,300

- GOOD AFTERNOON.

1168

00:43:30,000 --> 00:43:31,766

[amplified] CAN YOU HEAR ME?

AH, GOOD.

1169

00:43:31,766 --> 00:43:33,600

IS THIS THING ON?

1170

00:43:33,600 --> 00:43:39,800

SO IF I GO BACK TO YOUR PLOT
OF ETA EARTH DISTRIBUTIONS...

1171

00:43:45,833 --> 00:43:47,833

YEAH, THAT'S THE ONE.

1172

00:43:47,833 --> 00:43:51,333

ARE YOU COMFORTABLE,
CONFIDENT SAYING

1173

00:43:51,333 --> 00:43:54,800

THAT THE VALUES NEAR ZERO
ARE RULED OUT?

1174

00:43:57,300 --> 00:43:59,433

'CAUSE NONE OF THOSE PLOTS
GOES DOWN TO ZERO,

1175

00:43:59,433 --> 00:44:01,833

AND I THINK
IF IT'S TRUE THAT...

1176

00:44:01,833 --> 00:44:04,866

THAT ZERO IS...

1177

00:44:04,866 --> 00:44:07,133
OR EFFECTIVELY ZERO
IS RULED OUT,

1178

00:44:07,133 --> 00:44:09,000
THAT'S
A VERY EXCITING RESULT.

1179

00:44:09,000 --> 00:44:11,266
- I PERSONALLY DO THINK
IT'S RULED OUT.

1180

00:44:11,266 --> 00:44:16,366
THESE OTHER ANALYSES
ARE EITHER MAKING REASONABLE,

1181

00:44:16,366 --> 00:44:18,566
BUT SOMEWHAT
AD HOC AND WRONG ASSUMPTIONS

1182

00:44:18,566 --> 00:44:21,333
ABOUT THE COMPLETENESS
AND RELIABILITY OF THE SAMPLE,

1183

00:44:21,333 --> 00:44:24,433
AND ONE IS BASICALLY
A PIPELINE

1184

00:44:24,433 --> 00:44:27,233
THAT WAS BUILT
BY A GRADUATE STUDENT

1185

00:44:27,233 --> 00:44:30,466
THAT'S JUST NOT QUITE
AS SENSITIVE AS OURS IS,

1186

00:44:30,466 --> 00:44:35,300
AND HE EVEN ACKNOWLEDGES

IT'S A VERY PRELIMINARY RESULT.

1187

00:44:35,300 --> 00:44:36,566
NATALIE WOULD REMIND YOU,

1188

00:44:36,566 --> 00:44:38,233
AND BILL BORUCKI REMINDED
FOLKS THIS MORNING,

1189

00:44:38,233 --> 00:44:39,766
THAT WE HAVE YET TO DISCOVER

1190

00:44:39,766 --> 00:44:41,500
AN EARTH-SIZE PLANET
IN THE HABITABLE ZONE

1191

00:44:41,500 --> 00:44:43,866
OF A SUN ANALOG STAR.

1192

00:44:43,866 --> 00:44:45,066
THAT'S STILL THE HOLY GRAIL

1193

00:44:45,066 --> 00:44:46,600
THAT WE'RE STILL PURSUING
IN THE DATA.

1194

00:44:46,600 --> 00:44:49,366
AND SO, IN SOME SENSE,

1195

00:44:49,366 --> 00:44:51,033
THESE RESULTS
ARE EXTRAPOLATIONS,

1196

00:44:51,033 --> 00:44:53,333
BUT WE'VE GOT A LARGER SAMPLE
OURSELVES NOW,

1197

00:44:53,333 --> 00:44:54,900
AND WHAT WE'RE DOING

IS TRYING TO UNDERSTAND

1198

00:44:54,900 --> 00:44:58,600

THE SENSITIVITY
OF THE OUTCOME OF THE ANALYSIS,

1199

00:44:58,600 --> 00:45:02,366

BASED ON THE EXTREMES
OF OUR KNOWLEDGE

1200

00:45:02,366 --> 00:45:03,966

OF WHAT'S GOING
INTO THE CALCULATIONS

1201

00:45:03,966 --> 00:45:06,366

AND WHAT'S HAPPENING ON
THE SKY AND IN OUR INSTRUMENT.

1202

00:45:06,366 --> 00:45:10,033

BUT I'M COMFORTABLE WITH...

1203

00:45:10,033 --> 00:45:12,133

WITH RIGHT NOW A THIRD
OF THE STARS THAT YOU LOOK AT

1204

00:45:12,133 --> 00:45:13,266

THAT ARE BURNING HYDROGEN

1205

00:45:13,266 --> 00:45:14,933

HAVE A ONE-
TO TWO-EARTH-RADIUS PLANET.

1206

00:45:14,933 --> 00:45:16,466

I THINK THAT'S
THE BEST BET WE HAVE.

1207

00:45:16,466 --> 00:45:20,100

AND IN THE END, I THINK WE'RE
GONNA HAVE A VERY GOOD RESULT.

1208

00:45:24,300 --> 00:45:25,533

- HI.

1209

00:45:25,533 --> 00:45:28,000

BASED ON

WHAT YOU'VE SEEN SO FAR,

1210

00:45:28,000 --> 00:45:31,800

WHAT WOULD YOU SAY IS A TYPICAL
STELLAR PLANETARY SYSTEM,

1211

00:45:31,800 --> 00:45:33,800

AND HOW WOULD IT
BE DIFFERENT FROM OURS?

1212

00:45:35,166 --> 00:45:37,000

- WELL, IT'S KIND OF LIKE
GOING TO THE ZOO.

1213

00:45:37,000 --> 00:45:39,333

SO WHAT'S THE TYPICAL ANIMAL
AT THE ZOO LOOK LIKE?

1214

00:45:39,333 --> 00:45:41,100

I'M NOT SURE IF I CAN POINT
TO JUST ONE ANIMAL AND SAY,

1215

00:45:41,100 --> 00:45:44,100

"THAT'S WHAT YOU SEE
WHEN YOU GO TO THE ZOO."

1216

00:45:44,100 --> 00:45:47,100

HOWEVER, WE HAVE
AN ENORMOUS NUMBER

1217

00:45:47,100 --> 00:45:50,200

OF THESE VERY COMPACT
MULTIPLANET SYSTEMS,

1218

00:45:50,200 --> 00:45:51,600
AND THOSE SEEM TO BE
IN SOME SENSE,

1219
00:45:51,600 --> 00:45:52,933
BECAUSE WE SEE
SO MANY OF THEM,

1220
00:45:52,933 --> 00:45:57,800
THAT SEEMS TO BE
A VERY PREDOMINANT HIERARCHY

1221
00:45:57,800 --> 00:46:01,066
OR TYPOLOGY FOR US TO FIND
THESE PLANETARY SYSTEMS IN.

1222
00:46:01,066 --> 00:46:04,033
SO KEEP IN MIND KEPLER-11,
WHICH WAS THE POSTER CHILD

1223
00:46:04,033 --> 00:46:05,500
FOR MULTIPLE PLANET SYSTEMS,

1224
00:46:05,500 --> 00:46:08,033
DISCOVERED FAIRLY EARLY
IN KEPLER'S MISSION,

1225
00:46:08,033 --> 00:46:09,866
HAD SIX PLANETS,
THE FIVE INNERMOST OF WHICH

1226
00:46:09,866 --> 00:46:11,400
ARE WITHIN THE ORBIT
OF MERCURY

1227
00:46:11,400 --> 00:46:13,166
IN TERMS OF THEIR DISTANCE
FROM THEIR STAR,

1228
00:46:13,166 --> 00:46:18,000

THE OUTER OF WHICH
IS WITHIN THE ORBIT OF VENUS.

1229

00:46:18,000 --> 00:46:21,933
SO NATURE SEEMS TO HAVE
A PREDISPOSITION

1230

00:46:21,933 --> 00:46:25,200
TO FORMING PLANETARY SYSTEMS
THAT ARE HIGHLY COPLANAR

1231

00:46:25,200 --> 00:46:27,533
AND THAT ARE
MUCH MORE DYNAMICALLY PACKED

1232

00:46:27,533 --> 00:46:28,633
THAN OUR OWN SYSTEM,

1233

00:46:28,633 --> 00:46:30,066
AND SO WE BELIEVE
THAT THESE SYSTEMS

1234

00:46:30,066 --> 00:46:31,466
ACTUALLY DIDN'T START
OUT THAT WAY.

1235

00:46:31,466 --> 00:46:32,766
WE BELIEVE THEY EVOLVED.

1236

00:46:32,766 --> 00:46:34,633
BUT, YOU KNOW, WE LOOK
AT OUR OWN SOLAR SYSTEM,

1237

00:46:34,633 --> 00:46:36,766
WE THINK, OH, IT'S BEEN
LIKE THIS FOR A LONG TIME.

1238

00:46:36,766 --> 00:46:38,666
OUR OWN SOLAR SYSTEM
HAS EVOLVED, TOO,

1239

00:46:38,666 --> 00:46:43,833

BUT THE DEGREE TO WHICH
THESE SYSTEMS HAVE EVOLVED

1240

00:46:43,833 --> 00:46:45,300

IS VERY MARKED.

1241

00:46:45,300 --> 00:46:47,766

INDEED, THE FIRST PLANETS WE
FOUND WERE THESE HOT JUPITERS,

1242

00:46:47,766 --> 00:46:50,333

WHICH MUST HAVE MIGRATED
IN FROM THE OUTSIDE

1243

00:46:50,333 --> 00:46:51,766

AND COULD NOT HAVE FORMED

1244

00:46:51,766 --> 00:46:54,933

YOU KNOW, AT .04 A.U.
FROM THEIR STAR, RIGHT?

1245

00:46:54,933 --> 00:46:57,366

SO CHANGE
SEEMS TO BE THE RULE,

1246

00:46:57,366 --> 00:46:59,900

AND WE'RE TRYING TO ASSEMBLE
ENOUGH EXAMPLES

1247

00:46:59,900 --> 00:47:01,966

SO THAT WE CAN START TEASING
OUT THE RULES

1248

00:47:01,966 --> 00:47:04,633

LYING UNDERNEATH
WHAT WE SEE IN NATURE.

1249

00:47:07,533 --> 00:47:11,033
- SO PLEASE JOIN ME IN THANKING
DR. JON JENKINS.

1250
00:47:11,033 --> 00:47:13,600
[applause]

1251
00:47:22,166 --> 00:47:24,100
I SEE THAT WE DO HAVE
ONE MORE QUESTION,

1252
00:47:24,100 --> 00:47:25,733
SO LET'S GO AHEAD
AND PUT THAT IN THERE.

1253
00:47:31,466 --> 00:47:33,333
- I'M JUST CURIOUS TO KNOW

1254
00:47:33,333 --> 00:47:36,200
WHAT IS THE LEGAL IMPLICATIONS
OF ALL THESE DISCOVERIES.

1255
00:47:36,200 --> 00:47:39,400
CAN THE U.S. CLAIM THE LAND
OF ALL THESE PLANETS?

1256
00:47:39,400 --> 00:47:40,900
- [chuckles]

1257
00:47:40,900 --> 00:47:43,333
- I'LL HAVE TO TURN THAT OVER
TO ONE OF OUR BOSSES,

1258
00:47:43,333 --> 00:47:44,633
MICHAEL BICAY HERE.

1259
00:47:44,633 --> 00:47:46,033
PERHAPS HE COULD
ANSWER THAT QUESTION.

1260
00:47:46,033 --> 00:47:47,733
[laughs]

1261
00:47:47,733 --> 00:47:49,900
WELL, I'M NO EXPERT,

1262
00:47:49,900 --> 00:47:51,400
BUT I BELIEVE
THE SPACE ACT TREATY

1263
00:47:51,400 --> 00:47:54,500
PROHIBITS US FROM CLAIMING
LAND AS OUR OWN,

1264
00:47:54,500 --> 00:47:56,333
AT LEAST ON OTHER PLANETS
IN OUR SOLAR SYSTEM.

1265
00:47:56,333 --> 00:47:58,000
I WOULD SEE NO REASON
WHY THAT WOULD

1266
00:47:58,000 --> 00:48:00,066
NOT PERTAIN TO OTHER PLANETS,
BUT, OF COURSE,

1267
00:48:00,066 --> 00:48:01,933
BY THE INTERNATIONAL
ASTRONOMICAL UNION'S

1268
00:48:01,933 --> 00:48:03,000
DEFINITION OF A PLANET,

1269
00:48:03,000 --> 00:48:04,500
NONE OF THESE ARE PLANETS
ANYWAY.

1270
00:48:08,900 --> 00:48:11,600
- OKAY, ON THAT NOTE,

THANK YOU AGAIN.

1271

00:48:11,600 --> 00:48:14,500

[applause]