



1
00:00:02,969 --> 00:00:05,672
>> Narrator: NASA's Jet
Propulsion Laboratory presents

2
00:00:06,539 --> 00:00:08,141
the von Kármán Lecture,

3
00:00:08,174 --> 00:00:10,943
a series of talks by
scientists and engineers,

4
00:00:10,976 --> 00:00:14,480
who are exploring our
planet, our solar system,

5
00:00:14,513 --> 00:00:16,849
and all that lies beyond.

6
00:00:16,882 --> 00:00:19,719
[uplifting music]

7
00:00:28,928 --> 00:00:30,696
>> Hey, good evening,
ladies and gentlemen.

8
00:00:30,729 --> 00:00:32,365
How's everyone tonight?

9
00:00:32,398 --> 00:00:34,133
Good, thanks for coming
out to join us on

10
00:00:34,166 --> 00:00:35,568
this really toasty evening.

11
00:00:36,802 --> 00:00:38,571
So, the Spitzer Space Telescope

12

00:00:38,604 --> 00:00:40,506
is one of NASA's
great observatories,

13
00:00:40,539 --> 00:00:43,476
and was designed to observe
the universe in infrared light.

14
00:00:44,877 --> 00:00:48,047
Launched in 2003, with an
expected lifetime of five years,

15
00:00:48,080 --> 00:00:50,550
the scope is still making
amazing discoveries

16
00:00:50,583 --> 00:00:53,052
in its 15th year of operations.

17
00:00:53,085 --> 00:00:54,520
Tonight, our guest will discuss

18
00:00:54,553 --> 00:00:56,222
some of the novel
engineering feats

19
00:00:56,255 --> 00:00:58,958
that have been made to extend
the operation of Spitzer,

20
00:00:58,991 --> 00:01:01,327
as well as some of the
technical challenges

21
00:01:01,360 --> 00:01:02,829
that the team is now facing.

22
00:01:02,862 --> 00:01:04,931
We'll also see some
recent science highlights,

23

00:01:04,964 --> 00:01:08,901
including science that Spitzer
was never designed to do.

24

00:01:08,934 --> 00:01:11,304
Tonight's guest received
his PhD in astronomy

25

00:01:11,337 --> 00:01:14,407
from Rensselaer Polytechnic
Institute in 1995.

26

00:01:15,574 --> 00:01:17,643
Prior to arriving
at Caltech in 2002,

27

00:01:17,676 --> 00:01:19,011
he worked at Boston College,

28

00:01:19,044 --> 00:01:21,247
and the Air Force
Research Laboratory,

29

00:01:21,280 --> 00:01:23,149
helping to produce
an infrared survey

30

00:01:23,182 --> 00:01:26,819
of the galactic plane
with the MSX satellite.

31

00:01:26,852 --> 00:01:29,889
At Caltech, he has worked
at IPAC in various roles

32

00:01:29,922 --> 00:01:31,691
at the Spitzer Science Center,

33

00:01:31,724 --> 00:01:33,793
including leading the
instrument support team

34
00:01:33,826 --> 00:01:36,429
for the infrared array
camera on Spitzer,

35
00:01:36,462 --> 00:01:41,234
before becoming the manager of
the science center, in 2016.

36
00:01:41,267 --> 00:01:44,704
He has diverse research
interests, from exoplanets,

37
00:01:44,737 --> 00:01:47,773
to massive star formation,
to mere Earth asteroids.

38
00:01:47,806 --> 00:01:49,075
He enjoys the challenges of

39
00:01:49,108 --> 00:01:50,977
calibrating infrared
instruments,

40
00:01:51,010 --> 00:01:53,012
and he likes to give data
away to the community

41
00:01:53,045 --> 00:01:56,215
in the form of large surveys
of the plane of our galaxy.

42
00:01:56,248 --> 00:01:57,783
Ladies and gentlemen,
please help me welcome

43
00:01:57,816 --> 00:02:00,153

tonight's guest,
Dr. Shawn Carey.

44

00:02:00,186 --> 00:02:03,089
[audience applauds]

45

00:02:03,989 --> 00:02:06,025
>> Thank you, thank you.

46

00:02:06,058 --> 00:02:07,060
Thank you, everyone.

47

00:02:08,260 --> 00:02:10,096
It's my privilege to
talk to you tonight,

48

00:02:10,129 --> 00:02:12,031
about the Spitzer
Space Telescope,

49

00:02:12,064 --> 00:02:13,699
which is an amazing instrument,

50

00:02:13,732 --> 00:02:15,668
which many of you
may never heard of.

51

00:02:15,701 --> 00:02:17,503
I hope all of you
have heard about the

52

00:02:17,536 --> 00:02:19,305
Hubble Space Telescope,
may I see a raise of hands,

53

00:02:19,338 --> 00:02:21,040
how many people have
heard of Hubble?

54

00:02:21,073 --> 00:02:22,508
Okay, pretty good.

55
00:02:22,541 --> 00:02:24,710
How about Spitzer, how many
of you heard of Spitzer?

56
00:02:24,743 --> 00:02:27,313
Oh, that's awesome,
actually, that's fantastic,

57
00:02:27,346 --> 00:02:29,115
so talking to my people here.

58
00:02:31,250 --> 00:02:32,451
It's a little bit humbling,

59
00:02:32,484 --> 00:02:34,253
because Spitzer's been
operating for 15 years,

60
00:02:34,286 --> 00:02:37,957
and there's an amazing breadth
and depth to the discoveries.

61
00:02:37,990 --> 00:02:40,126
So I'm not gonna be
able to cover all that,

62
00:02:40,159 --> 00:02:42,461
nor am I gonna be
able to cover all the

63
00:02:42,494 --> 00:02:45,665
excellent engineering that
went into building Spitzer,

64
00:02:45,698 --> 00:02:47,934
getting it launched, and then
continuing to operate it,

65

00:02:47,967 --> 00:02:49,235
for as long as we can.

66

00:02:49,268 --> 00:02:51,170
So, I'm gonna kind
of pick the things

67

00:02:51,203 --> 00:02:53,606
that I think are
interesting, pretty much.

68

00:02:53,639 --> 00:02:55,408
So, as you know in these days,

69

00:02:55,441 --> 00:02:59,312
you have to understand where
your information's coming from.

70

00:02:59,345 --> 00:03:00,746
What the source of
the information is,

71

00:03:00,779 --> 00:03:02,248
and what their biases are.

72

00:03:02,281 --> 00:03:04,551
So I'm gonna try to tell
you about my biases, okay?

73

00:03:05,985 --> 00:03:08,054
First thing is, since we've
been in operation so long,

74

00:03:08,087 --> 00:03:10,356
I've kind of forgotten
what happened

75

00:03:10,389 --> 00:03:12,358

before the cryogen ran out.

76

00:03:12,391 --> 00:03:14,594

So most of the stuff
I'm gonna tell you about

77

00:03:14,627 --> 00:03:16,062

is the new stuff.

78

00:03:16,095 --> 00:03:18,097

What we did in the post
cryogenic role for Spitzer,

79

00:03:18,130 --> 00:03:20,299

when all the helium
ran out of the tank.

80

00:03:20,332 --> 00:03:22,568

And I'll explain why
that's important.

81

00:03:22,601 --> 00:03:26,138

Part of that, too, is
because all of that data,

82

00:03:26,171 --> 00:03:28,474

is focused on the
instrument that I worked on,

83

00:03:28,507 --> 00:03:30,209

which was the
infrared ray camera,

84

00:03:30,242 --> 00:03:32,211

which half of that
is still operating,

85

00:03:32,244 --> 00:03:35,281

and we'll talk a little
bit more about that.

86

00:03:35,314 --> 00:03:37,383

And then as far
as research goes,

87

00:03:37,416 --> 00:03:40,219

I don't know very much
about black holes,

88

00:03:40,252 --> 00:03:43,322

the high redshift universe,
galaxies in general,

89

00:03:43,355 --> 00:03:45,224

so you're not gonna hear
a whole lot about that,

90

00:03:45,257 --> 00:03:47,793

so if you're interested
in that, I'm sorry.

91

00:03:47,826 --> 00:03:49,328

I know there's some
other good talks

92

00:03:49,361 --> 00:03:52,064

in the von Kármán Lecture
series that discuss those,

93

00:03:52,097 --> 00:03:54,133

and if there's any of my
colleagues in the audience,

94

00:03:54,166 --> 00:03:56,402

whom that's the
research interest,

95

00:03:56,435 --> 00:03:58,204

you can bother
me later.

96

00:03:58,237 --> 00:04:01,507

I'm sorry, but I don't feel comfortable talking about that.

97

00:04:01,540 --> 00:04:04,110

What I am comfortable talking about, is images like this.

98

00:04:04,143 --> 00:04:07,346

So this is an image of the plane of our galaxy,

99

00:04:07,379 --> 00:04:10,416

so this is a little bit of the Milky Way.

100

00:04:10,449 --> 00:04:12,285

And it's seen in the infrared,

101

00:04:12,318 --> 00:04:16,188

and in the images I show, the way we're gonna map it,

102

00:04:16,221 --> 00:04:18,524

is we usually have three different

103

00:04:18,557 --> 00:04:20,359

colors, or wavelengths.

104

00:04:20,392 --> 00:04:23,129

And the blue is, the shortest wavelength will be blue,

105

00:04:23,162 --> 00:04:24,764

the middle one will be green,

106

00:04:24,797 --> 00:04:26,465

and then the longest
wavelength will be red.

107

00:04:26,498 --> 00:04:28,067

So you can see, there's
things that are blue in here,

108

00:04:28,100 --> 00:04:31,237

and those are the
objects that emitted

109

00:04:31,270 --> 00:04:32,505

the shortest wavelength,
those are stars.

110

00:04:32,538 --> 00:04:35,574

And then you see a lot
of stuff that's green,

111

00:04:35,607 --> 00:04:37,109

which is gas and dust.

112

00:04:37,142 --> 00:04:39,879

That's a pretty common theme
of what's done with Spitzer.

113

00:04:39,912 --> 00:04:42,748

And then there's some red spots
too, which are gas and dust

114

00:04:42,781 --> 00:04:44,750

and some other
things of interest.

115

00:04:44,783 --> 00:04:46,552

Okay, and this
image actually has

116

00:04:46,585 --> 00:04:48,421

my favorite object ever in it,

117

00:04:48,454 --> 00:04:51,324
something I've been
studying for a long time,

118

00:04:51,357 --> 00:04:53,893
since 1998, which is this...

119

00:04:53,926 --> 00:04:56,562
Here, let's see, I
can point it out...

120

00:04:56,595 --> 00:04:58,898
This snake like shape
that's very dark,

121

00:04:58,931 --> 00:05:00,466
and it's very dark
in the infrared,

122

00:05:00,499 --> 00:05:02,968
and we called it The Snake
when we first discovered it,

123

00:05:03,001 --> 00:05:06,739
in my previous existence,
working with the MSX satellite.

124

00:05:06,772 --> 00:05:07,940
Which did a survey.

125

00:05:07,973 --> 00:05:10,009
Oh, see, running
out of battery here.

126

00:05:10,876 --> 00:05:11,744
Okay, anyways.

127

00:05:12,978 --> 00:05:14,147

You can see the snake.

128

00:05:15,247 --> 00:05:17,950

That object there, is blocking

129

00:05:17,983 --> 00:05:20,319

not just visible light,
but infrared light,

130

00:05:20,352 --> 00:05:23,222

and that tells us
it's very dense,

131

00:05:23,255 --> 00:05:24,457

and there's a lot
of material there,

132

00:05:24,490 --> 00:05:25,991

'cause that's the only
way you're blocking

133

00:05:26,024 --> 00:05:27,593

the background infrared light.

134

00:05:28,961 --> 00:05:30,463

And because of that,
there's a lot of material,

135

00:05:30,496 --> 00:05:32,498

it's cold material,
if it wasn't cold,

136

00:05:32,531 --> 00:05:34,500

it would be emitting
in the infrared.

137

00:05:34,533 --> 00:05:37,136

This is something where,
place where stars are forming,

138

00:05:37,169 --> 00:05:39,105

and we knew about that
but with the MSX stuff,

139

00:05:39,138 --> 00:05:40,973

we didn't have the
beautiful resolution,

140

00:05:41,006 --> 00:05:42,608

the very clear
picture from Spitzer,

141

00:05:42,641 --> 00:05:44,210

and we didn't see
the little red dots,

142

00:05:44,243 --> 00:05:47,480

can everybody see the little
red dots in the dark plane?

143

00:05:47,513 --> 00:05:51,751

Those are objects that are
formed, they're becoming stars.

144

00:05:51,784 --> 00:05:54,320

Those are what we call
protostars, or baby stars.

145

00:05:54,353 --> 00:05:55,521

So they haven't
gotten to the point

146

00:05:55,554 --> 00:05:57,022

where they have nuclear fusion,

147

00:05:57,055 --> 00:05:59,425

and have lit up and are
glowing and are very hot,

148

00:05:59,458 --> 00:06:00,559
but they're on their way,

149
00:06:00,592 --> 00:06:02,428
they're gravitationally
collapsing,

150
00:06:02,461 --> 00:06:04,830
and so they're sort
of hottish, warmish,

151
00:06:04,863 --> 00:06:06,966
and they're emitting
in the infrared.

152
00:06:06,999 --> 00:06:10,002
Anyways, this is one of
my favorite pictures.

153
00:06:10,035 --> 00:06:11,837
The other reason it's one
of my favorite pictures,

154
00:06:11,870 --> 00:06:13,472
is it shows the whole life cycle

155
00:06:13,505 --> 00:06:15,574
of star formation,
from the dark stuff,

156
00:06:15,607 --> 00:06:19,044
which is material stars could
potentially form out of.

157
00:06:19,077 --> 00:06:22,248
So the red little dots,
which are parts of

158
00:06:22,281 --> 00:06:24,316
that stuff that are

gravitationally collapsing,

159

00:06:24,349 --> 00:06:26,118

and are on their way
to forming stars,

160

00:06:26,151 --> 00:06:28,654

to all the blue dots, okay,
all the little blue specs,

161

00:06:28,687 --> 00:06:29,889

those are stars.

162

00:06:29,922 --> 00:06:32,024

Okay, there's a lot of
stars in this image.

163

00:06:32,057 --> 00:06:35,528

To this bright, red object ...

164

00:06:35,561 --> 00:06:36,429

Good, I got it back.

165

00:06:36,462 --> 00:06:37,696

Just have to press hard.

166

00:06:37,729 --> 00:06:40,766

Down here, that blob
there, actually,

167

00:06:40,799 --> 00:06:42,968

is the remains of what happens

168

00:06:43,001 --> 00:06:45,971

when a massive star explodes,
this is a supernova remnant,

169

00:06:46,004 --> 00:06:49,875

and what you're seeing is

the hot gas that's left over,

170

00:06:49,908 --> 00:06:51,811

after the star
exploded and heated up

171

00:06:51,844 --> 00:06:53,312

the material around it.

172

00:06:53,345 --> 00:06:56,248

So we go all the way from
possibly forming stars,

173

00:06:56,281 --> 00:06:58,417

to forming stars,
to actual stars,

174

00:06:58,450 --> 00:07:00,953

to the death of a
star, all in one image.

175

00:07:03,689 --> 00:07:05,090

Okay.

176

00:07:05,123 --> 00:07:07,359

But, before we get
more into the science,

177

00:07:07,392 --> 00:07:08,961

why do you care
about the infrared?

178

00:07:08,994 --> 00:07:11,764

I mean, why not just build
more Hubble Space Telescopes?

179

00:07:11,797 --> 00:07:14,066

Well, the reason is,
the infrared gives us

180

00:07:14,099 --> 00:07:17,970

an entirely different
picture of the universe,

181

00:07:18,003 --> 00:07:19,638

than what we can see
in visible light.

182

00:07:19,671 --> 00:07:21,874

Here's a friend of mine,
and a former colleague,

183

00:07:21,907 --> 00:07:23,943

Jim Keller, and you can see
him in the visible light.

184

00:07:23,976 --> 00:07:25,177

Looking quite dapper.

185

00:07:25,210 --> 00:07:27,446

And then this is Jim
in the infrared light.

186

00:07:27,479 --> 00:07:30,449

Taken with a camera that you
could put on your iPhone now,

187

00:07:30,482 --> 00:07:33,252

or one of the floor cameras
that the firefighters use.

188

00:07:33,285 --> 00:07:35,254

And you can see
quite a difference,

189

00:07:35,287 --> 00:07:37,823

in what you can see
and not see, right?

190

00:07:37,856 --> 00:07:39,959

Jim's hands, he's
wearing a trash bag here,

191

00:07:39,992 --> 00:07:41,227

he doesn't usually do that,

192

00:07:41,260 --> 00:07:42,728

but he's doing it
for this purpose,

193

00:07:42,761 --> 00:07:45,297

because in visible light,
you can't see his hands,

194

00:07:45,330 --> 00:07:47,800

but the trash bag, the plastic,

195

00:07:47,833 --> 00:07:49,268

is transparent in
the infrared light.

196

00:07:49,301 --> 00:07:52,304

So the infrared light
will pass through objects

197

00:07:52,337 --> 00:07:54,406

that are absorbing
visible light,

198

00:07:54,439 --> 00:07:55,741

and that's kind
of a common theme,

199

00:07:55,774 --> 00:07:57,977

you should go to longer
and longer wavelengths.

200

00:07:58,010 --> 00:08:01,213

The material in our galaxy,

all the material between stars,

201

00:08:01,246 --> 00:08:04,450
the interstellar medium, will
absorb shorter wavelengths,

202

00:08:04,483 --> 00:08:08,988
like visible light first, and
the infrared light, less so.

203

00:08:09,021 --> 00:08:11,190
So it's longer the
wavelength it goes,

204

00:08:11,223 --> 00:08:13,292
the more you can see
through things in general,

205

00:08:13,325 --> 00:08:14,693
but not quite, right?

206

00:08:14,726 --> 00:08:16,495
Because his glasses...
you can't see in the infrared,

207

00:08:16,528 --> 00:08:19,064
the glass actually blocks
the infrared light.

208

00:08:19,097 --> 00:08:20,266
And the other thing you notice,

209

00:08:20,299 --> 00:08:22,368
is that, in the visible light,

210

00:08:22,401 --> 00:08:24,003
what we're seeing is
the light reflected

211

00:08:24,036 --> 00:08:26,038
off of Jim from an
external source.

212
00:08:26,071 --> 00:08:29,708
In the infrared, you can
actually see the glow from him,

213
00:08:29,741 --> 00:08:33,112
it's his body heat that's
emitting the infrared radiation.

214
00:08:33,145 --> 00:08:35,781
So, the infrared light
allows us to see things

215
00:08:35,814 --> 00:08:37,817
that are cooler than
emit visible light.

216
00:08:39,351 --> 00:08:40,786
So, that's what I
was saying here,

217
00:08:40,819 --> 00:08:42,988
objects colder than stars
that give off infrared light.

218
00:08:43,021 --> 00:08:45,024
So here's an object,

219
00:08:45,057 --> 00:08:47,059
this is another thing,
called a Bok globule.

220
00:08:47,092 --> 00:08:48,727
It's kind of like those
infrared dark clouds

221
00:08:48,760 --> 00:08:50,996

that I talked about, in
this you see invisible light

222

00:08:51,029 --> 00:08:52,031
and you can't really
see through it,

223

00:08:52,064 --> 00:08:53,699
there's a couple
little red dots,

224

00:08:53,732 --> 00:08:56,068
which are stars on the edge.

225

00:08:56,101 --> 00:08:58,571
Where the material's
not as thick,

226

00:08:58,604 --> 00:09:00,506
that you can see sort
of poking through.

227

00:09:00,539 --> 00:09:01,840
Then if you look at
the infrared light,

228

00:09:01,873 --> 00:09:03,309
you get an entirely
different picture.

229

00:09:03,342 --> 00:09:05,578
So I'm just gonna flip back
and forth for a second,

230

00:09:05,611 --> 00:09:07,012
so you can see that.

231

00:09:07,045 --> 00:09:08,847
And one of the things you'll
notice is there's this

232

00:09:08,880 --> 00:09:12,151

bright blob, bright thing
there, that's a star.

233

00:09:12,184 --> 00:09:15,921

That's a cool object, it's
not a star, it's a protostar,

234

00:09:15,954 --> 00:09:17,756

it's something on the
way to forming a star,

235

00:09:17,789 --> 00:09:19,825

so you wouldn't see it
in the visible light,

236

00:09:19,858 --> 00:09:22,895

even if it was
right on the surface

237

00:09:22,928 --> 00:09:24,597

of the globule that
it's forming out of.

238

00:09:24,630 --> 00:09:27,499

The only thing you see
there is a little blob,

239

00:09:27,532 --> 00:09:29,234

which is a protostellar jet.

240

00:09:29,267 --> 00:09:34,273

So this material here, coming
either way from the star,

241

00:09:35,407 --> 00:09:36,875

is what we call a
protostellar outflow.

242

00:09:36,908 --> 00:09:39,945

Basically, what happens
when something's collapsing

243

00:09:39,978 --> 00:09:43,816

to form a star, it collapses
and forms a disc, a pancake,

244

00:09:43,849 --> 00:09:45,417

and the material
from the pancake

245

00:09:45,450 --> 00:09:47,286

infall to a central object.

246

00:09:47,319 --> 00:09:49,588

And then when the
material infalls,

247

00:09:49,621 --> 00:09:51,957

some of it gets pushed
out, in an outflow,

248

00:09:51,990 --> 00:09:53,359

and that's what
you're seeing there,

249

00:09:53,392 --> 00:09:57,630

along the line, is
that's gas being ejected.

250

00:09:57,663 --> 00:09:59,565

Part of, some of the
inflowing material

251

00:09:59,598 --> 00:10:02,668

being back ejected out from
the star that's forming.

252

00:10:04,036 --> 00:10:07,206

So, things that give off
infrared light that are colder

253

00:10:07,239 --> 00:10:09,775

than things we see in the
visible light, are protostars.

254

00:10:09,808 --> 00:10:11,276

Planets also, if
they're warm enough,

255

00:10:11,309 --> 00:10:13,612

will emit in the infrared,
and we can actually see

256

00:10:13,645 --> 00:10:15,614

the emission of the
planets in the infrared.

257

00:10:15,647 --> 00:10:17,716

And then, in our solar
system we can see

258

00:10:17,749 --> 00:10:21,920

asteroids and comets in
the reflected sunlight,

259

00:10:21,953 --> 00:10:24,890

but we can also see
them much more easily

260

00:10:24,923 --> 00:10:26,625

in their own infrared radiation,

261

00:10:26,658 --> 00:10:28,193

provided that
they're hot enough,

262

00:10:28,226 --> 00:10:31,163

so as comets come
in and heat up,

263

00:10:31,196 --> 00:10:33,899

you'll pick them up very
easily in the infrared.

264

00:10:37,602 --> 00:10:39,605

The other thing, which we talked
a little bit about already,

265

00:10:39,638 --> 00:10:41,674

I just want to give another
example is it's easier

266

00:10:41,707 --> 00:10:44,410

to see through the dust
that's between the stars,

267

00:10:44,443 --> 00:10:45,644

and when I talk about dust here,

268

00:10:45,677 --> 00:10:48,947

it's not like dirt sized dust,

269

00:10:48,980 --> 00:10:50,783

this is more like cosmic soot,

270

00:10:50,816 --> 00:10:52,551

so it's not like the dust
bunnies under your bed,

271

00:10:52,584 --> 00:10:54,520

it's more like auto
exhaust, actually.

272

00:10:54,553 --> 00:10:56,622

Or smog, is a good example.

273

00:10:56,655 --> 00:10:58,323

And that actually blocks
out visible light,

274

00:10:58,356 --> 00:11:00,592

as you could tell
looking at the mountains

275

00:11:00,625 --> 00:11:04,597

on your way here, right, if
you were coming from the south.

276

00:11:06,064 --> 00:11:08,333

In the infrared, that light
passes more readily through,

277

00:11:08,366 --> 00:11:11,036

because it's a longer wavelength
and you can see that here,

278

00:11:11,069 --> 00:11:13,338

in an image of the
North American Nebula,

279

00:11:13,371 --> 00:11:15,207

where there's this dark
dust lane, in between,

280

00:11:15,240 --> 00:11:16,375

you can see sort of the shape

281

00:11:16,408 --> 00:11:18,844

of the North
America here, right.

282

00:11:18,877 --> 00:11:22,848

There's the outline, there's
Mexico, maybe Florida there.

283

00:11:22,881 --> 00:11:25,884

It takes a little imagination
to come up with these names

284

00:11:25,917 --> 00:11:28,220

but then, there's this
dark lane here, right,

285

00:11:28,253 --> 00:11:32,157

and that dark lane, with some
foreground stars, is lit up,

286

00:11:32,190 --> 00:11:35,461

in the infrared light, what
you're seeing there is the gap,

287

00:11:35,494 --> 00:11:38,630

the dust and gas
that is obscuring,

288

00:11:38,663 --> 00:11:42,234

the invisible light from behind,
is glowing in the infrared.

289

00:11:42,267 --> 00:11:46,505

so we get to understand about
the material in between stars,

290

00:11:46,538 --> 00:11:48,140

by looking at infrared light.

291

00:11:49,641 --> 00:11:51,610

And then the other thing
that's really interesting,

292

00:11:51,643 --> 00:11:54,179

is it allows us to see objects

293

00:11:54,212 --> 00:11:56,215

more easily that are in
the early universe, okay,

294

00:11:56,248 --> 00:11:58,784

and this takes a little
bit of effort, because...

295

00:11:58,817 --> 00:12:00,085

What's happening here...

296

00:12:00,118 --> 00:12:02,187

So, the foreground
stuff, all the things

297

00:12:02,220 --> 00:12:05,090

that are greenish-blue
are stars.

298

00:12:05,123 --> 00:12:07,693

The little red dots
are background galaxies

299

00:12:07,726 --> 00:12:10,062

that are fairly
far away from us,

300

00:12:10,095 --> 00:12:12,397

and so we're seeing
light that was emitted

301

00:12:12,430 --> 00:12:16,235

from some time in
the past, right,

302

00:12:16,268 --> 00:12:18,437

because the light takes
time to travel to us,

303

00:12:18,470 --> 00:12:19,838

the farther away something is,

304

00:12:19,871 --> 00:12:21,907
the longer the light
takes to travel to us,

305
00:12:21,940 --> 00:12:24,076
and since the
universe is expanding,

306
00:12:24,109 --> 00:12:26,378
as the light's traveling to us,

307
00:12:26,411 --> 00:12:29,314
the distance that it
travels gets larger.

308
00:12:29,347 --> 00:12:33,252
So as space is expanding,
and when it does that,

309
00:12:33,285 --> 00:12:34,853
it has the property
of making the light

310
00:12:34,886 --> 00:12:36,722
as it travels through
and we see it,

311
00:12:36,755 --> 00:12:39,057
go to longer and longer
wavelengths, meaning basically,

312
00:12:39,090 --> 00:12:41,093
the material it's
travelling through,

313
00:12:41,126 --> 00:12:44,129
is stretched out, so the
light gets stretched out.

314
00:12:44,162 --> 00:12:48,100

So, as you look further
and further back in time,

315
00:12:48,133 --> 00:12:51,303
something emits invisible
light will look progressively

316
00:12:51,336 --> 00:12:53,172
redder and redder.

317
00:12:53,205 --> 00:12:55,274
That's, when you heard
the term redshift,

318
00:12:55,307 --> 00:12:56,608
that's actually, that's
what we mean by that,

319
00:12:56,641 --> 00:12:59,178
is that the light is
actually getting redder,

320
00:12:59,211 --> 00:13:01,981
the further you look
back in the universe.

321
00:13:03,281 --> 00:13:04,883
Which is just what
I was saying there.

322
00:13:04,916 --> 00:13:06,218
Okay.
So that's very important.

323
00:13:06,251 --> 00:13:08,720
If you're interested in studying

324
00:13:08,753 --> 00:13:10,422
the early universe,
which I have to admit,

325

00:13:10,455 --> 00:13:13,525

I'm not super interested in,
but I think it's pretty cool,

326

00:13:13,558 --> 00:13:15,060

then you want to use the
infrared light

327

00:13:15,093 --> 00:13:16,529

to do that as well.

328

00:13:17,629 --> 00:13:19,231

Okay, so that brings
us to Spitzer.

329

00:13:19,264 --> 00:13:23,435

Okay, Spitzer is an
infrared observatory,

330

00:13:23,468 --> 00:13:26,572

that is used by astronomers
all over the world,

331

00:13:26,605 --> 00:13:28,540

anybody in the
world can propose,

332

00:13:28,573 --> 00:13:31,243

if you wanted to write a
proposal to use Spitzer time,

333

00:13:31,276 --> 00:13:34,580

you could do that,
anybody, any country,

334

00:13:34,613 --> 00:13:35,814

you don't have to have a degree,

335

00:13:35,847 --> 00:13:37,349

you just have to
have a good idea,

336

00:13:37,382 --> 00:13:40,118

and get it past the people who
review the ideas to make sure

337

00:13:40,151 --> 00:13:42,921

one, it's a really good science
idea, so it should be done,

338

00:13:42,954 --> 00:13:45,757

and two, we can actually
take the data that you need

339

00:13:45,790 --> 00:13:47,559

to get your science idea done.

340

00:13:47,592 --> 00:13:50,829

So, Spitzer launched
August 25th, 2003,

341

00:13:50,862 --> 00:13:53,031

which seems like a
lifetime ago to me now,

342

00:13:53,064 --> 00:13:54,166

but it wasn't that long ago.

343

00:13:54,199 --> 00:13:55,601

It was very exciting.

344

00:13:55,634 --> 00:13:57,603

Here's Spitzer on
the Delta Heavy

345

00:13:57,636 --> 00:14:00,138

that it was launched
from at Cape Canaveral.

346

00:14:00,171 --> 00:14:02,107

We had a few launch
delays before that,

347

00:14:02,140 --> 00:14:04,142

so everybody that was
working on the project was

348

00:14:04,175 --> 00:14:07,746

really anxious for it to get
launched and us to get going.

349

00:14:07,779 --> 00:14:10,883

It was the last of NASA's
Great Observatory program.

350

00:14:12,317 --> 00:14:16,822

Which included the Compton
Gamma Ray Satellite,

351

00:14:16,855 --> 00:14:18,857

the Hubble Space Telescope,
which you've all heard of,

352

00:14:18,890 --> 00:14:20,692

and the Chandra X-ray Telescope.

353

00:14:20,725 --> 00:14:22,828

So three of those four
great observatories

354

00:14:22,861 --> 00:14:25,430

are still operating,
giving us wonderful data,

355

00:14:25,463 --> 00:14:28,033

which spans a whole
range of wavelengths

356

00:14:28,066 --> 00:14:30,168

that astronomers are
really interested in,

357

00:14:30,201 --> 00:14:34,172

and the synergy between those
three observatories is huge.

358

00:14:34,205 --> 00:14:36,642

A lot of times, we
will take Spitzer data

359

00:14:36,675 --> 00:14:38,310

because Hubble has
discovered something.

360

00:14:38,343 --> 00:14:40,145

Or somebody will see
something in Spitzer data,

361

00:14:40,178 --> 00:14:42,915

and do a follow up with
the Chandra X-ray Telescope

362

00:14:42,948 --> 00:14:44,316

to get more information.

363

00:14:45,884 --> 00:14:49,321

Spitzer's expected lifetime
was five years, and ...

364

00:14:49,354 --> 00:14:51,723

[phone ringtone]

365

00:14:51,756 --> 00:14:53,559

I'll just wait for
somebody to mute.

366

00:14:54,726 --> 00:14:56,462

It's okay, I do that
all the time, too.

367
00:14:57,562 --> 00:14:59,298
Its expected lifetime
was five years,

368
00:14:59,331 --> 00:15:03,101
that's how much helium
we had in the tank,

369
00:15:03,134 --> 00:15:04,636
or what we thought it was.

370
00:15:04,669 --> 00:15:07,506
And the lifetime, if it only
lasted two and a half years,

371
00:15:07,539 --> 00:15:08,941
we would've met
our mission goal,

372
00:15:08,974 --> 00:15:10,208
so we would've been happy
with two and a half.

373
00:15:10,241 --> 00:15:12,244
We were ecstatic with five.

374
00:15:12,277 --> 00:15:13,879
It ended up the
cryogenic mission,

375
00:15:13,912 --> 00:15:16,448
so when we ran out of the
coolant that we needed,

376
00:15:16,481 --> 00:15:19,051
ended 15 May, 2009,
so we even got more

377

00:15:19,084 --> 00:15:20,485
than the five years' we planned,

378

00:15:20,518 --> 00:15:23,588
because people were really
smart in how we use the helium,

379

00:15:23,621 --> 00:15:25,357
because we actually had
some control over that,

380

00:15:25,390 --> 00:15:27,025
which I'll talk
about in a second.

381

00:15:27,058 --> 00:15:30,362
And then after we ran
out of the cryogen,

382

00:15:30,395 --> 00:15:34,599
we started the warm mission
science in July, 2009,

383

00:15:34,632 --> 00:15:37,569
and we're still going,
which is fantastic.

384

00:15:37,602 --> 00:15:38,904
It's fantastic for
a lot of reasons,

385

00:15:38,937 --> 00:15:40,305
one, the spacecraft
still working.

386

00:15:40,338 --> 00:15:41,506
[knocking]

387

00:15:41,539 --> 00:15:43,008

Knock on wood every
time I say that,

388

00:15:43,041 --> 00:15:46,411

because my phone may go off
and that would be a bad thing,

389

00:15:46,444 --> 00:15:47,879

because that would tell
us there's an anomaly,

390

00:15:47,912 --> 00:15:49,114

and if there's a bunch of people

391

00:15:49,147 --> 00:15:50,816

in the audience, that
I know, got up too,

392

00:15:50,849 --> 00:15:53,919

we would know it's a really
big deal, but so far, so good.

393

00:15:53,952 --> 00:15:55,187

So I haven't jinxed us.

394

00:15:56,955 --> 00:15:59,124

And the science still
is excellent, in fact,

395

00:15:59,157 --> 00:16:01,493

the science now, I would
argue in some ways,

396

00:16:01,526 --> 00:16:03,462

is better, because
people's ideas are better,

397

00:16:03,495 --> 00:16:06,431

because we're learning

more every year,

398

00:16:06,464 --> 00:16:08,000
about the universe.

399

00:16:10,301 --> 00:16:11,870
Let's see, what did
I not do right here?

400

00:16:11,903 --> 00:16:13,939
Okay, so ...

401

00:16:13,972 --> 00:16:15,874
The Spitzer Space
Telescope was named after

402

00:16:15,907 --> 00:16:18,377
a very prominent astronomer
named Lyman Spitzer,

403

00:16:18,410 --> 00:16:19,878
here's a picture
of Lyman Spitzer,

404

00:16:19,911 --> 00:16:22,581
he was also an avid mountain
climber, and this is him,

405

00:16:22,614 --> 00:16:25,350
Lyman, on his way to
climbing the Matterhorn.

406

00:16:25,383 --> 00:16:28,587
And this is... and the
way Spitzer was named,

407

00:16:28,620 --> 00:16:30,922
is we had a contest, actually,

408

00:16:30,955 --> 00:16:33,625
and people wrote in
whom they thought,

409
00:16:33,658 --> 00:16:36,261
what the name for the
telescope should be,

410
00:16:36,294 --> 00:16:39,197
because the idea usually,
or back in the past was,

411
00:16:39,230 --> 00:16:41,733
you didn't name an
observatory that was launched

412
00:16:41,766 --> 00:16:44,169
into space until it was
actually operational.

413
00:16:44,202 --> 00:16:47,272
Before Spitzer was operational,
it was called SIRTf,

414
00:16:47,305 --> 00:16:49,841
which was an acronym for
a popular NASA thing,

415
00:16:49,874 --> 00:16:54,480
which stood for Space
Infrared Telescope Facility,

416
00:16:55,380 --> 00:16:56,515
really exciting, right?

417
00:16:57,916 --> 00:17:00,052
Before it was the Space
Infrared Telescope Facility,

418
00:17:00,085 --> 00:17:01,586

and a form incarnation,

419

00:17:01,619 --> 00:17:03,789

it was actually the Shuttle
Infrared Telescope Facility,

420

00:17:03,822 --> 00:17:05,424

the idea was that
was gonna be launched

421

00:17:05,457 --> 00:17:07,159

on the shuttle like Hubble.

422

00:17:07,192 --> 00:17:09,928

It ended up by the time that
it was getting developed,

423

00:17:09,961 --> 00:17:12,330

in the 90s, that got
really expensive to do,

424

00:17:12,363 --> 00:17:14,132

and people had a much
better way of doing it,

425

00:17:14,165 --> 00:17:15,734

so instead of putting
it on the shuttle

426

00:17:15,767 --> 00:17:18,970

and lifting it up,
like Hubble was done,

427

00:17:19,003 --> 00:17:21,339

and then the idea then was
you were gonna periodically

428

00:17:21,372 --> 00:17:24,142

send up the shuttle and top
off the tank of cryogen,

429

00:17:24,175 --> 00:17:26,645

so you would have
a continuing tank.

430

00:17:26,678 --> 00:17:28,180

There was a much
cheaper, actually,

431

00:17:28,213 --> 00:17:30,582

way of doing it, which
provided better science,

432

00:17:30,615 --> 00:17:33,051

even though it made
a smaller telescope,

433

00:17:33,084 --> 00:17:35,654

and I'm gonna talk about
that in a little bit.

434

00:17:35,687 --> 00:17:38,523

But, Lyman Spitzer was an expert
in the interstellar medium,

435

00:17:38,556 --> 00:17:40,792

so having an infrared telescope

436

00:17:40,825 --> 00:17:42,427

named after him is
entirely appropriate,

437

00:17:42,460 --> 00:17:44,429

because the infrared,
as we've just learned,

438

00:17:44,462 --> 00:17:46,131

is really great
for understanding

439

00:17:46,164 --> 00:17:47,732

all the stuff between the stars,

440

00:17:47,765 --> 00:17:50,735

all that gas and dust which
you can't see in the visible,

441

00:17:50,768 --> 00:17:52,337

you can see in the infrared.

442

00:17:52,370 --> 00:17:55,574

And Lyman would be really
excited about that.

443

00:17:55,607 --> 00:17:56,741

Unfortunately, he passed away

444

00:17:56,774 --> 00:18:01,046

before the telescope
was launched.

445

00:18:01,079 --> 00:18:03,115

And the other thing, this
is the really cool part,

446

00:18:03,148 --> 00:18:05,250

is he was the first
person to think of putting

447

00:18:05,283 --> 00:18:07,152

a telescope in space.

448

00:18:07,185 --> 00:18:08,887

He did this in 1946.

449

00:18:08,920 --> 00:18:11,022

And his idea led to the
Hubble Space Telescope.

450

00:18:11,055 --> 00:18:13,425

He was a huge proponent for
the Hubble Space Telescope,

451

00:18:13,458 --> 00:18:15,026

and he's one of the
driving influences

452

00:18:15,059 --> 00:18:16,595

in getting that launched.

453

00:18:16,628 --> 00:18:19,731

And the reason you wanna
put telescopes in space,

454

00:18:19,764 --> 00:18:22,634

not just infrared telescopes,
but telescopes in space,

455

00:18:22,667 --> 00:18:23,935

they get you above
the atmosphere,

456

00:18:23,968 --> 00:18:26,204

which is really
annoying to astronomers,

457

00:18:26,237 --> 00:18:27,873

because the atmosphere,
what it does,

458

00:18:27,906 --> 00:18:30,976

is it blurs your vision, so
with an optical telescope,

459

00:18:31,009 --> 00:18:34,012

you can't see the fine
resolution you want as well.

460

00:18:34,045 --> 00:18:36,715

And in the infrared
light, actually,

461

00:18:36,748 --> 00:18:38,216

the atmosphere
blocks a lot of the

462

00:18:38,249 --> 00:18:39,818

infrared wavelengths
we're interested in.

463

00:18:39,851 --> 00:18:42,354

You can sort of see
some of the wavelengths

464

00:18:42,387 --> 00:18:45,357

Spitzer looks at from the
ground, but not really well,

465

00:18:45,390 --> 00:18:47,359

so instead of blowing a
hole through the atmosphere,

466

00:18:47,392 --> 00:18:50,228

you have to put your telescope
above the atmosphere.

467

00:18:50,261 --> 00:18:53,165

There's another very good
telescope called Sofia,

468

00:18:53,198 --> 00:18:55,066

I don't remember, it's
like stratospheric,

469

00:18:55,099 --> 00:18:56,334

because it's on an airplane.

470

00:18:56,367 --> 00:18:58,937

So it's an infrared
telescope on a 747,

471
00:18:58,970 --> 00:19:01,306
and that flies up to
about 40 thousand feet,

472
00:19:01,339 --> 00:19:03,074
so it's above most of the
water in the atmosphere,

473
00:19:03,107 --> 00:19:04,576
which is the big problem.

474
00:19:04,609 --> 00:19:07,345
especially if you're looking
for water somewhere else,

475
00:19:07,378 --> 00:19:10,048
you don't wanna see the
water in the atmosphere.

476
00:19:10,081 --> 00:19:11,449
So anyways, it's
a good idea to get

477
00:19:11,482 --> 00:19:14,419
your telescope away
from the atmosphere,

478
00:19:14,452 --> 00:19:16,522
because that makes it
hard to see things.

479
00:19:17,689 --> 00:19:20,258
Even though it's really
good for us otherwise.

480
00:19:20,291 --> 00:19:21,726
Okay, so the Spitzer

Space Telescope,

481

00:19:21,759 --> 00:19:23,395

let's give some stats to it now.

482

00:19:23,428 --> 00:19:25,830

It's an 85 centimeter,
infrared telescope.

483

00:19:25,863 --> 00:19:27,999

Now, 85 centimeters is
smaller than a mirror.

484

00:19:28,032 --> 00:19:29,834

It's... and there it is.

485

00:19:29,867 --> 00:19:31,303

That's the telescope, actually

486

00:19:31,336 --> 00:19:34,639

before it was encased in a tube,
and had all its instruments

487

00:19:34,672 --> 00:19:36,875

and the cryogenic tank put
underneath it and stuff,

488

00:19:36,908 --> 00:19:38,276

and you can kind of
get the scale for it,

489

00:19:38,309 --> 00:19:41,012

because there's two
normal sized people,

490

00:19:41,045 --> 00:19:43,081

I think this was at JPL.

491

00:19:45,550 --> 00:19:46,851

And it's very shiny,
because you want

492
00:19:46,884 --> 00:19:48,620
your mirror to be reflective.

493
00:19:48,653 --> 00:19:51,223
There's a secondary mirror
under that column there,

494
00:19:51,256 --> 00:19:53,925
and the telescope was made
entirely of beryllium.

495
00:19:53,958 --> 00:19:56,027
The mirror's solid beryllium,
and the reason why,

496
00:19:56,060 --> 00:19:58,563
is that when you cool it
down to the temperatures,

497
00:19:58,596 --> 00:20:01,566
you wanna cool infrared
telescopes down to,

498
00:20:01,599 --> 00:20:04,570
you don't want the
mirror to shrink.

499
00:20:05,337 --> 00:20:07,939
So it has to be
thermally stable,

500
00:20:07,972 --> 00:20:09,874
at very low temperatures,

501
00:20:09,907 --> 00:20:12,811
and the low temperatures
in this case are

502

00:20:12,844 --> 00:20:17,048
between five and 12 degrees
above absolute zero.

503

00:20:17,081 --> 00:20:19,084
The reason you want
the mirror that cold,

504

00:20:19,117 --> 00:20:21,386
is if the mirror
isn't that cold,

505

00:20:21,419 --> 00:20:25,257
then you see the infrared
radiation from the mirror,

506

00:20:25,290 --> 00:20:27,025
and then that takes
away the signals

507

00:20:27,058 --> 00:20:28,360
that you're interested in.

508

00:20:30,728 --> 00:20:31,896
Okay.

509

00:20:31,929 --> 00:20:33,531
And there are three
instruments on Spitzer.

510

00:20:33,564 --> 00:20:37,302
One was, had a very
useful acronym, IRAC,

511

00:20:37,335 --> 00:20:40,138
with the infrared array camera,
and so set of four cameras,

512

00:20:40,171 --> 00:20:43,408
that operate from
three to nine microns.

513
00:20:43,441 --> 00:20:45,243
I was trying to think of
a... what a good analogy...

514
00:20:45,276 --> 00:20:48,780
so a micron is a
millionth of a meter,

515
00:20:48,813 --> 00:20:52,217
and 70 microns is about
the width of a human hair,

516
00:20:52,250 --> 00:20:54,620
so it's a pretty tiny...

517
00:20:56,487 --> 00:20:58,023
size for the wavelength.

518
00:20:58,056 --> 00:21:01,293
But the longest wavelength
we can see with our eyes,

519
00:21:01,326 --> 00:21:03,795
is about .8 microns, that's
about as red as you can go,

520
00:21:03,828 --> 00:21:05,430
I think bees and dogs can see

521
00:21:05,463 --> 00:21:08,033
slightly farther
into our infrared,

522
00:21:08,066 --> 00:21:11,703
but, so this is between
what's, .8, so you know,

523

00:21:11,736 --> 00:21:14,839

it's like four or
five times the size,

524

00:21:14,872 --> 00:21:17,175

of visible light
going out further,

525

00:21:17,208 --> 00:21:20,178

the spectrographs,
disperse the light...

526

00:21:21,679 --> 00:21:24,249

From five to 38 microns,
and that instrument

527

00:21:24,282 --> 00:21:28,019

was called the IRS
Infrared Spectrograph.

528

00:21:28,052 --> 00:21:29,287

And then there was a
set of cameras with

529

00:21:29,320 --> 00:21:32,991

much longer wavelengths,
24, 70 and 160 microns,

530

00:21:33,024 --> 00:21:34,526

and that had the acronym, MIPS,

531

00:21:34,559 --> 00:21:39,364

so it was the Multi-imaging
Band Photometer for Spitzer.

532

00:21:41,065 --> 00:21:43,435

And all these three
instruments give us different

533

00:21:43,468 --> 00:21:46,871
wavelength ranges, and
view on the universe, and,

534

00:21:46,904 --> 00:21:48,506
no, no, that's not the ...

535

00:21:48,539 --> 00:21:50,942
Come on ...
Laser pointer.

536

00:21:50,975 --> 00:21:51,810
Alright, anyways.

537

00:21:53,044 --> 00:21:56,047
IRAC and MIPS show
us that protostar

538

00:21:56,080 --> 00:21:58,049
we showed you earlier, okay.

539

00:21:58,082 --> 00:22:01,286
And the reddest
colors are for MIPS,

540

00:22:01,319 --> 00:22:04,055
and the bluish and green
are from IRAC in that image.

541

00:22:04,088 --> 00:22:07,959
And then, what we're seeing
in the diagram there,

542

00:22:07,992 --> 00:22:10,862
is a plot of brightness, is
a function of wavelength,

543

00:22:10,895 --> 00:22:13,064
and that's from IRS,

and what you can see,

544

00:22:13,097 --> 00:22:16,434

is that it's rising in
general, the protostar,

545

00:22:16,467 --> 00:22:18,136

as you get to longer
and longer wavelengths,

546

00:22:18,169 --> 00:22:19,437

because it's a sort
of cool object,

547

00:22:19,470 --> 00:22:21,539

so it's brighter at
longer wavelengths,

548

00:22:21,572 --> 00:22:24,442

and then you see all these
dips in the spectrum,

549

00:22:24,475 --> 00:22:26,344

those troughs and
stuff, and those are due

550

00:22:26,377 --> 00:22:30,982

to different materials
absorbing some of the light,

551

00:22:31,015 --> 00:22:33,952

the gas and dust in
front of the star,

552

00:22:33,985 --> 00:22:36,755

the protostar, actually,
so you can see water, ice,

553

00:22:36,788 --> 00:22:38,223

there's a line to

methyl alcohol,

554

00:22:38,256 --> 00:22:40,058

so it tells you about the
chemical constituents,

555

00:22:40,091 --> 00:22:42,026

so spectroscopy
is really powerful

556

00:22:42,059 --> 00:22:44,662

if you wanna understand what
something is made out of,

557

00:22:44,695 --> 00:22:47,165

not just where it
is, or how hot it is.

558

00:22:49,167 --> 00:22:50,268

Okay.

559

00:22:50,301 --> 00:22:51,903

So Spitzer had a
few innovations,

560

00:22:51,936 --> 00:22:54,372

which are fantastic
and other observatories

561

00:22:54,405 --> 00:22:56,941

are copying them now, because
we've learned from Spitzer.

562

00:22:56,974 --> 00:22:58,877

The first thing,
and this was another

563

00:22:58,910 --> 00:23:00,445

good thing for an
infrared telescope,

564

00:23:00,478 --> 00:23:03,148

is you have to get it
away from a really bright

565

00:23:03,181 --> 00:23:04,883

infrared source,
which is the Earth.

566

00:23:04,916 --> 00:23:07,218

The Earth gives out a lot
of infrared radiation.

567

00:23:07,251 --> 00:23:08,720

So Spitzer was designed to be an

568

00:23:08,753 --> 00:23:10,922

Earth trailing orbit
around the sun.

569

00:23:12,423 --> 00:23:13,258

Thank you.

570

00:23:14,826 --> 00:23:16,728

I'll give it back, okay.

571

00:23:16,761 --> 00:23:18,263

Oh, that's so much better.

572

00:23:19,397 --> 00:23:20,465

I'm gonna go crazy
with the pointer now.

573

00:23:20,498 --> 00:23:21,333

No, I won't.

574

00:23:23,334 --> 00:23:26,538

So, getting Spitzer
away from the Earth

575

00:23:26,571 --> 00:23:29,407
meant that you're getting it
away from this huge heat bath,

576

00:23:29,440 --> 00:23:31,443
which also allowed you
to do something called

577

00:23:31,476 --> 00:23:33,645
passive cooling, because
you're away from the heat bath,

578

00:23:33,678 --> 00:23:35,680
and this is a really
neat, and also,

579

00:23:35,713 --> 00:23:37,182
it sounds really simple concept,

580

00:23:37,215 --> 00:23:39,350
but it's really hard when you
actually do the engineering.

581

00:23:39,383 --> 00:23:40,785
Except now, people
know how to do it,

582

00:23:40,818 --> 00:23:43,254
so they made it look, they
made the hard look really easy.

583

00:23:43,287 --> 00:23:46,791
And basically, the idea is
that the telescope here,

584

00:23:46,824 --> 00:23:48,059
so remember, I showed
you the mirror,

585

00:23:48,092 --> 00:23:50,528

it's inside this tube,
there's a shiny side,

586

00:23:50,561 --> 00:23:52,697

which is always pointing
towards the sun, which is good,

587

00:23:52,730 --> 00:23:54,833

because those are solar
rays, which power Spitzer,

588

00:23:54,866 --> 00:23:56,301

so you need power to power it,

589

00:23:56,334 --> 00:23:59,037

and the side in the
back is painted black,

590

00:23:59,070 --> 00:24:01,372

and that radiates to cold space.

591

00:24:01,405 --> 00:24:04,742

Because Spitzer is always in
the shadow of the solar rays,

592

00:24:04,775 --> 00:24:07,779

so it's, the tube
itself gets very cold,

593

00:24:07,812 --> 00:24:09,380

just by the fact that you keep

594

00:24:09,413 --> 00:24:11,549

starlight away from it,
sunlight away from it,

595

00:24:11,582 --> 00:24:13,685

and that's the only

heat source going on.

596

00:24:13,718 --> 00:24:14,853

Then down at the
bottom, actually,

597

00:24:14,886 --> 00:24:16,354

is all the warm electronics,

598

00:24:16,387 --> 00:24:18,423

so those are actually warm
because they're powered

599

00:24:18,456 --> 00:24:20,758

and there's things like
heaters and computers

600

00:24:20,791 --> 00:24:22,293

and stuff that
keep it pretty hot.

601

00:24:22,326 --> 00:24:24,162

In the back, there
are two star trackers,

602

00:24:24,195 --> 00:24:27,131

which help Spitzer tell
itself where it's pointed,

603

00:24:27,164 --> 00:24:28,633

'cause that's very important.

604

00:24:28,666 --> 00:24:30,635

If you wanna look at
something you wanna make sure

605

00:24:30,668 --> 00:24:32,971

you can actually point
the telescope to it.

606
00:24:33,004 --> 00:24:35,807
So this passive
cooling is the thing

607
00:24:35,840 --> 00:24:37,876
that allowed Spitzer
to keep going,

608
00:24:37,909 --> 00:24:41,079
'cause even after we ran
out of the tank of helium,

609
00:24:41,946 --> 00:24:43,515
it's still very cold.

610
00:24:44,549 --> 00:24:45,984
Before, what it also did,

611
00:24:46,017 --> 00:24:48,319
is allowed us to keep
that tank of helium small,

612
00:24:48,352 --> 00:24:50,588
because we didn't have to
cool the whole telescope

613
00:24:50,621 --> 00:24:52,991
as much as you would if it
wasn't passively cooled,

614
00:24:53,024 --> 00:24:56,194
and it also allowed us to
adaptively cool the telescope.

615
00:24:56,227 --> 00:24:58,062
So we had a tank of helium,

616
00:24:58,095 --> 00:24:59,864
and then we'd had

a little heater.

617

00:24:59,897 --> 00:25:01,399

So it's kind of
counter intuitive.

618

00:25:01,432 --> 00:25:04,035

You heat the helium, you allow
it to pass through a tube,

619

00:25:04,068 --> 00:25:06,037

and then that tube,
the helium goes up

620

00:25:06,070 --> 00:25:10,542

and it cools the mirror, so
the more you heat the tank,

621

00:25:10,575 --> 00:25:11,943

the more helium flows through,

622

00:25:11,976 --> 00:25:13,244

so when we're doing the longest

623

00:25:13,277 --> 00:25:15,179

wavelength
observations with MIPS,

624

00:25:15,212 --> 00:25:18,116

we cool the mirror more, because
the longer the wavelength,

625

00:25:18,149 --> 00:25:19,885

the colder you want
your telescope.

626

00:25:22,219 --> 00:25:23,421

Okay.

627

00:25:23,454 --> 00:25:26,324

The one downside to this
Earth trailing orbit,

628

00:25:26,357 --> 00:25:29,227

is that Spitzer is getting
farther away from the Earth

629

00:25:29,260 --> 00:25:31,563

every year, and that's
complicating things now,

630

00:25:31,596 --> 00:25:34,365

because we're way
beyond how far away

631

00:25:34,398 --> 00:25:36,200

we thought we would
be from the Earth.

632

00:25:36,233 --> 00:25:37,936

So the Earth's down
here, and every year,

633

00:25:37,969 --> 00:25:39,537

Spitzer will recede
further and further,

634

00:25:39,570 --> 00:25:42,674

so in April, 2006, which
was, that was our goal,

635

00:25:42,707 --> 00:25:43,942

if we got that, we were happy.

636

00:25:43,975 --> 00:25:46,210

Spitzer was gonna
be that far away.

637

00:25:46,243 --> 00:25:49,213

When we ran out of coolant
and started the warm mission,

638

00:25:49,246 --> 00:25:50,982

it was this far away,
and here are now,

639

00:25:51,015 --> 00:25:52,450

almost toward the
15th anniversary,

640

00:25:52,483 --> 00:25:56,921

it's 1.6 astronomical
units away from the Earth,

641

00:25:56,954 --> 00:25:58,923

so it's further
away from the Earth

642

00:25:58,956 --> 00:26:01,559

than either Spitzer or the Earth

643

00:26:01,592 --> 00:26:03,227

is away from the sun.

644

00:26:03,260 --> 00:26:06,731

And running to a problem
now, because of geometry,

645

00:26:06,764 --> 00:26:10,034

because we keep the solar rays
pointed at the sun to power,

646

00:26:10,067 --> 00:26:13,204

but we have to point, let
me just go back a second...

647

00:26:13,237 --> 00:26:15,139

I can go back a second?

Yes.

648

00:26:15,172 --> 00:26:17,575

At the bottom here,
that's the antennae that

649

00:26:17,608 --> 00:26:19,644

we have to point back to
Earth to get the data down,

650

00:26:19,677 --> 00:26:21,546

so you can take all
the data you want,

651

00:26:21,579 --> 00:26:24,148

but if you don't get it
down to the astronomers,

652

00:26:24,181 --> 00:26:26,217

then you got a lot
of grumpy astronomers

653

00:26:26,250 --> 00:26:27,285

and no good science.

654

00:26:28,386 --> 00:26:29,821

So now, every time we do this,

655

00:26:29,854 --> 00:26:31,923

I'm gonna put this stuff down
for a second, so I can...

656

00:26:31,956 --> 00:26:35,360

So, we gotta keep the solar
rays pointed to the sun,

657

00:26:35,393 --> 00:26:37,028

and then the Earth's
off to the side,

658

00:26:37,061 --> 00:26:38,730
so we point the antennae...

659
00:26:39,563 --> 00:26:40,598
Which is my elbow here,

660
00:26:40,631 --> 00:26:42,734
to the Earth, but as we do that,

661
00:26:42,767 --> 00:26:45,136
as we get further and
further away from the Earth,

662
00:26:45,169 --> 00:26:46,371
and you'll just kinda...

663
00:26:46,404 --> 00:26:48,406
you guys can puzzle
this out as you...

664
00:26:48,439 --> 00:26:52,010
We have to point the
telescope further away

665
00:26:52,043 --> 00:26:54,245
from pointing the
solar rays so that

666
00:26:54,278 --> 00:26:57,015
the sunlight hits it
at a 90 degree angle.

667
00:26:57,048 --> 00:26:59,751
And when we do that, the
solar rays get less efficient,

668
00:26:59,784 --> 00:27:01,552
just like the solar
rays on your roof

669

00:27:01,585 --> 00:27:02,887

would get less
efficient, you know,

670

00:27:02,920 --> 00:27:04,822

depending upon the
angle of incidence

671

00:27:04,855 --> 00:27:08,560

of the light of the sun as
it, you know, rises and sets.

672

00:27:09,593 --> 00:27:11,029

And that's a
problem, because now,

673

00:27:11,062 --> 00:27:13,398

when we're downlinking data,
we're at the point now,

674

00:27:13,431 --> 00:27:17,969

we've reached the point
actually, in 2013, where,

675

00:27:18,002 --> 00:27:19,404

no actually, no, it was a
little bit further, I'm sorry,

676

00:27:19,437 --> 00:27:23,474

when we get towards 2016,
we're no longer power positive.

677

00:27:23,507 --> 00:27:26,344

We don't get enough
light from the sun,

678

00:27:26,377 --> 00:27:30,648

when we're downlinking
data, to power Spitzer,

679

00:27:30,681 --> 00:27:32,717

but fortunately,
Spitzer has a battery,

680

00:27:32,750 --> 00:27:35,219

which gets charged, usually,
when the sunlight's hitting it,

681

00:27:35,252 --> 00:27:37,255

but now we're draining the
battery during downlinks,

682

00:27:37,288 --> 00:27:39,557

and that means we can
only spend so much time

683

00:27:39,590 --> 00:27:42,627

during downlink because we
can't drain the battery fully,

684

00:27:42,660 --> 00:27:44,095

because then, Spitzer dies.

685

00:27:44,128 --> 00:27:45,863

So there's a finite
amount of time

686

00:27:45,896 --> 00:27:47,532

that we can spend
downlinking data,

687

00:27:47,565 --> 00:27:50,234

and that's getting less
and less each year.

688

00:27:50,267 --> 00:27:52,003

Upshot of that, means
that we can take

689

00:27:52,036 --> 00:27:54,472

less and less science
data each year,

690

00:27:54,505 --> 00:27:57,642

each time between downlinks,
because it's getting

691

00:27:57,675 --> 00:27:59,577

harder and harder
to communicate.

692

00:27:59,610 --> 00:28:01,946

There's also some things
with things like sun sensors,

693

00:28:01,979 --> 00:28:03,614

which tell us how close
to the sun we are,

694

00:28:03,647 --> 00:28:06,050

and during downlinks, we
have to turn those off now.

695

00:28:06,083 --> 00:28:08,653

Which engineers don't
like to turn off

696

00:28:08,686 --> 00:28:10,354

things that help keep you safe

697

00:28:10,387 --> 00:28:11,723

and keep you from
pointing to the sun,

698

00:28:11,756 --> 00:28:14,426

but they weren't useful anymore.

699

00:28:15,626 --> 00:28:17,228

Okay, so now, here's a

little bit of science.

700

00:28:17,261 --> 00:28:20,932

This is science of the
plane of our galaxy,

701

00:28:20,965 --> 00:28:24,836

and what you're gonna see
here, is a map with IRAC,

702

00:28:24,869 --> 00:28:27,004

of pretty much the entire
plane of our galaxy,

703

00:28:27,037 --> 00:28:28,806

and I'm not going
to show it all.

704

00:28:28,839 --> 00:28:32,276

And what you're seeing is,
so, as it's going through,

705

00:28:32,309 --> 00:28:34,712

we're seeing the plane, because
remember, The Milky, okay.

706

00:28:34,745 --> 00:28:37,048

First, we're seeing the
galactic center in the infrared,

707

00:28:37,081 --> 00:28:38,516

which you can see the
center of the galaxy,

708

00:28:38,549 --> 00:28:41,219

where in the visible light,
it's entirely opaque,

709

00:28:41,252 --> 00:28:43,321

and you see a lot of

emissions, there's my favorite,

710

00:28:43,354 --> 00:28:45,323
snakes going whizzing by us.

711

00:28:46,724 --> 00:28:49,393
And what we're looking
at, is we're in the disc

712

00:28:49,426 --> 00:28:50,295
of the Milky Way.

713

00:28:51,495 --> 00:28:54,398
And so, our galaxy is
seeing edge on to us,

714

00:28:54,431 --> 00:28:56,267
so when we look at
the entire galaxy,

715

00:28:56,300 --> 00:28:57,769
it's a strip in the sky.

716

00:28:57,802 --> 00:28:59,003
If you look up in
a really dark sky,

717

00:28:59,036 --> 00:29:01,005
you see the Milky Way, you know,

718

00:29:01,038 --> 00:29:04,041
a glowing band of light, and
it's dark in some places,

719

00:29:04,074 --> 00:29:06,344
which is where you have the
dust that's obscuring it.

720

00:29:06,377 --> 00:29:07,812

Well, you're seeing
the dust now,

721
00:29:07,845 --> 00:29:09,380
and you're seeing
the stars behind it.

722
00:29:09,413 --> 00:29:11,516
In fact, in the infrared light,

723
00:29:11,549 --> 00:29:14,252
you're seeing more stars than
you can see in visible light,

724
00:29:14,285 --> 00:29:17,522
because of all that gas
and dust between us.

725
00:29:17,555 --> 00:29:19,357
And you'll see something,
objects that are red,

726
00:29:19,390 --> 00:29:22,527
you'll see bubbles,
where stars that are hot

727
00:29:22,560 --> 00:29:25,363
have blown the gas and
dust away from them,

728
00:29:25,396 --> 00:29:27,431
that's a kind of
common feature you see.

729
00:29:27,464 --> 00:29:29,066
This is a star
forming region here,

730
00:29:29,099 --> 00:29:31,202
we see all these

pillars and chimneys,

731

00:29:31,235 --> 00:29:35,506
as the mass of stars are born
they carve out the material

732

00:29:35,539 --> 00:29:38,142
into structures which you'll
see repeated over and over,

733

00:29:38,175 --> 00:29:40,478
and then as we get
towards the outer galaxy,

734

00:29:40,511 --> 00:29:42,180
you don't see much
of anything at all,

735

00:29:42,213 --> 00:29:45,616
because most of the action
is going towards the center.

736

00:29:45,649 --> 00:29:47,685
But basically, in this
image, if I let it play,

737

00:29:47,718 --> 00:29:49,654
and I'm not gonna go
all the way through,

738

00:29:49,687 --> 00:29:54,458
90% of all the stars in the
galaxy are in this strip.

739

00:29:54,491 --> 00:29:56,327
And most of the
material that stars

740

00:29:56,360 --> 00:29:58,029
are made out of is in the strip.

741

00:29:58,062 --> 00:30:00,331

There's plenty of
other material around,

742

00:30:00,364 --> 00:30:03,367

but most of the action
is in a very narrow band,

743

00:30:03,400 --> 00:30:05,269

which we call the Milky
Way, it's our edge,

744

00:30:05,302 --> 00:30:08,472

that's the, you know, we're
seeing our galaxy edge on.

745

00:30:08,505 --> 00:30:09,941

And what we're able
to do with Spitzer,

746

00:30:09,974 --> 00:30:13,511

with its infrared eyes, is
look at all the stars in that.

747

00:30:15,112 --> 00:30:17,815

And when we did it,
we're able to come up

748

00:30:17,848 --> 00:30:19,750

with an idea what the
galaxy looks like,

749

00:30:19,783 --> 00:30:21,986

so this is an excellent
artist concept,

750

00:30:22,019 --> 00:30:24,222

by one of my
colleagues, Robert Hurt.

751

00:30:24,255 --> 00:30:26,991

All the graphics you see, or
pretty much all the graphics,

752

00:30:27,024 --> 00:30:28,860

Robert and his colleague
Tim Pile have made,

753

00:30:28,893 --> 00:30:30,995

they're fantastic in that.

754

00:30:31,028 --> 00:30:33,197

They're able to do
scientific visualization,

755

00:30:33,230 --> 00:30:35,733

which is scientifically
accurate for the most part,

756

00:30:35,766 --> 00:30:39,203

and I'll tell you when
it isn't, if I remember.

757

00:30:39,236 --> 00:30:41,839

But it also is pretty
pleasing to the eye.

758

00:30:41,872 --> 00:30:43,441

So this is our
best understanding

759

00:30:43,474 --> 00:30:45,610

of what the Milky
Way looks like.

760

00:30:45,643 --> 00:30:48,179

Based on mapping stars as seen

761

00:30:48,212 --> 00:30:49,914
with Spitzer in the infrared.

762
00:30:49,947 --> 00:30:52,083
We used a very particular
type of star in this case,

763
00:30:52,116 --> 00:30:53,985
something called
a Red Clump Giant,

764
00:30:54,018 --> 00:30:54,952
where you know what
the brightness

765
00:30:54,985 --> 00:30:56,754
of that star
should be,

766
00:30:56,787 --> 00:30:58,890
so if you know the
brightness of the star

767
00:30:58,923 --> 00:31:00,491
and you see how...

768
00:31:00,524 --> 00:31:03,261
You see the brightness
you measure,

769
00:31:03,294 --> 00:31:06,297
then you can determine how far
away it is, because you know,

770
00:31:06,330 --> 00:31:09,700
every distance that a
star moves away from you,

771
00:31:09,733 --> 00:31:11,602
if it's twice as far

away its brightness

772

00:31:11,635 --> 00:31:13,004
drops by a factor of four.

773

00:31:13,037 --> 00:31:14,639
So you can actually
figure out the distance

774

00:31:14,672 --> 00:31:16,841
by measuring how
bright a star is,

775

00:31:16,874 --> 00:31:18,976
if you know what the
brightness should be.

776

00:31:19,009 --> 00:31:20,444
It's a standard candle.

777

00:31:20,477 --> 00:31:22,046
And we can see
most of the stars,

778

00:31:22,079 --> 00:31:25,116
because we're looking
through the gas and dust.

779

00:31:25,149 --> 00:31:27,785
But not quite, so this
is a great artist concept

780

00:31:27,818 --> 00:31:29,453
and it's showing us,
so we're like, here.

781

00:31:29,486 --> 00:31:31,255
This is where the Earth is,

782

00:31:31,288 --> 00:31:34,258

kind of in between two spiral
arms, we got a nice structure,

783

00:31:34,291 --> 00:31:37,962

and we can see to the bar
in the center of the galaxy.

784

00:31:37,995 --> 00:31:41,799

It doesn't serve alcohol,
it's just a bar of stars,

785

00:31:41,832 --> 00:31:44,101

but what's going on in
the back, we don't know.

786

00:31:44,134 --> 00:31:45,503

That's kind of
conjecture actually,

787

00:31:45,536 --> 00:31:47,538

because we can only see
so far with Spitzer,

788

00:31:47,571 --> 00:31:50,708

we can see to about, like this.

789

00:31:50,741 --> 00:31:53,978

And the reason is, there's so
many stars, it's so crowded,

790

00:31:54,011 --> 00:31:57,114

that you need a bigger
telescope with higher resolution

791

00:31:57,147 --> 00:31:59,850

to be able to look to the
far side of the galaxy.

792

00:31:59,883 --> 00:32:02,586

Which is something that a
new mission, called WFIRST,

793

00:32:02,619 --> 00:32:05,323

which is in the planning
stages, should be able to do.

794

00:32:05,356 --> 00:32:07,224

If we point it at our Milky Way,

795

00:32:07,257 --> 00:32:08,693

we'll be able to
map the structure

796

00:32:08,726 --> 00:32:11,396

of the entire galaxy,
which is pretty fantastic.

797

00:32:13,464 --> 00:32:15,433

Okay, so that brings
us to the next,

798

00:32:15,466 --> 00:32:16,901

and this is something
we never thought

799

00:32:16,934 --> 00:32:18,135

we would do at Spitzer.

800

00:32:18,168 --> 00:32:19,603

Because usually, when you do it,

801

00:32:19,636 --> 00:32:22,807

you build an observatory,
a science observatory,

802

00:32:22,840 --> 00:32:24,208

you come up with a science case,

803

00:32:24,241 --> 00:32:26,711
and then you design
the telescope

804
00:32:26,744 --> 00:32:28,980
and the instruments to
support that science case,

805
00:32:29,013 --> 00:32:30,881
so you can do the
science you want it to.

806
00:32:30,914 --> 00:32:32,817
And Spitzer had that
and had four goals,

807
00:32:32,850 --> 00:32:34,652
and to be honest, I can't
remember what they are now,

808
00:32:34,685 --> 00:32:36,053
they were all very
exciting, though.

809
00:32:36,086 --> 00:32:37,722
And we were able to do them all.

810
00:32:37,755 --> 00:32:40,725
But one of the things we
did not have as a goal,

811
00:32:40,758 --> 00:32:43,694
was to study exoplanets,
mainly because there was like,

812
00:32:43,727 --> 00:32:45,563
one exoplanet that
was discovered

813
00:32:45,596 --> 00:32:47,398

when Spitzer was getting built,

814

00:32:47,431 --> 00:32:50,234
and we did not know
that we'd be able

815

00:32:50,267 --> 00:32:52,403
to learn about
exoplanets with Spitzer.

816

00:32:52,436 --> 00:32:54,772
And it ends up, though,
Spitzer is a fantastic

817

00:32:54,805 --> 00:32:57,708
observatory to learn
about exoplanets.

818

00:32:57,741 --> 00:32:59,276
The types of exoplanets we
learn about with Spitzer,

819

00:32:59,309 --> 00:33:02,079
there's several different
ways you can study exoplanets,

820

00:33:02,112 --> 00:33:04,849
one is, if it's far
enough away from its star,

821

00:33:04,882 --> 00:33:09,120
and its mass big enough,
like a super Jupiter,

822

00:33:09,153 --> 00:33:10,588
you could directly image it.

823

00:33:10,621 --> 00:33:14,091
And there's a few planets that
have been imaged that way.

824

00:33:14,124 --> 00:33:18,562

Another way, is by looking
at the spectra of the star

825

00:33:18,595 --> 00:33:20,898

and all the spectra
for stars have...

826

00:33:22,266 --> 00:33:25,736

lines, like sodium
vapor lamps, in,

827

00:33:25,769 --> 00:33:27,838

street lamps,
actually, have lines,

828

00:33:27,871 --> 00:33:29,673

if you were to
point a spectrometer

829

00:33:29,706 --> 00:33:32,309

which breaks the light up into
its different wavelengths,

830

00:33:32,342 --> 00:33:34,378

or a prism will do that for you.

831

00:33:34,411 --> 00:33:37,615

And what you see
with a spectrometer,

832

00:33:37,648 --> 00:33:40,551

is that those lines
will move back and forth

833

00:33:40,584 --> 00:33:42,987

because the star's getting
tugged by something.

834

00:33:43,020 --> 00:33:45,589

So if a planet's around it
and it's in a right orbit,

835

00:33:45,622 --> 00:33:48,025

and it's massive enough,
it'll tug the star enough

836

00:33:48,058 --> 00:33:51,429

that you can actually
measure that motion.

837

00:33:51,462 --> 00:33:53,597

Just like police
officers measure

838

00:33:53,630 --> 00:33:55,366

our motion with a radar gun.

839

00:33:55,399 --> 00:33:57,668

It's a very similar
thing, they're doing the,

840

00:33:57,701 --> 00:34:00,237

they're using a doppler
shift with your car.

841

00:34:00,270 --> 00:34:04,575

You can also do that with
emission lines from stars,

842

00:34:04,608 --> 00:34:07,178

if they're getting
tugged by a planet,

843

00:34:07,211 --> 00:34:09,046

and that's another
technique that's done.

844

00:34:09,079 --> 00:34:10,347

Spitzer doesn't do
either of those,

845

00:34:10,380 --> 00:34:12,216

it does something,
one thing very well,

846

00:34:12,249 --> 00:34:14,318

it looks for
transiting exoplanets.

847

00:34:14,351 --> 00:34:16,320

So these are planets
just by geometry,

848

00:34:16,353 --> 00:34:18,222

we're just lucky enough,
there's the planets

849

00:34:18,255 --> 00:34:21,392

orbiting around its
star, as we see it.

850

00:34:21,425 --> 00:34:23,627

So here's the star,
planet goes around,

851

00:34:23,660 --> 00:34:25,863

and then goes in
front of the star.

852

00:34:25,896 --> 00:34:28,466

Like this, and then what
happens is that planet

853

00:34:28,499 --> 00:34:30,167

blocks out a portion
of the star light,

854

00:34:30,200 --> 00:34:32,570
because the planet isn't
brighter than the star,

855
00:34:32,603 --> 00:34:33,771
and that's what we see here.

856
00:34:33,804 --> 00:34:36,273
So if we're looking
here, so this is a plot,

857
00:34:36,306 --> 00:34:38,176
as a function of
time essentially.

858
00:34:39,576 --> 00:34:42,746
Actually time measured in units
of the year of that planet,

859
00:34:42,779 --> 00:34:44,715
that's what this
orbital phase means.

860
00:34:44,748 --> 00:34:47,418
And then you see this dip here,
so this is the star light,

861
00:34:47,451 --> 00:34:49,320
and all of a sudden,
it goes, "dip", drops.

862
00:34:49,353 --> 00:34:52,089
Because the planet's blocking
out some of the star light.

863
00:34:52,122 --> 00:34:54,425
It's not a very big dip,
if you can read this,

864
00:34:54,458 --> 00:34:59,230

it's like one, and this is .975,
it's only a couple percent,

865

00:34:59,263 --> 00:35:02,099

because the planet is much
smaller than the star.

866

00:35:02,132 --> 00:35:04,135

But the size of that
dip tells us the size

867

00:35:04,168 --> 00:35:05,469

of the planet relative the star,

868

00:35:05,502 --> 00:35:07,271

so if you know the
size of the star,

869

00:35:07,304 --> 00:35:09,974

and astronomers can figure out
sizes of stars pretty well,

870

00:35:10,007 --> 00:35:11,475

you know what the
size of the planet is,

871

00:35:11,508 --> 00:35:14,512

just by watching it go
in front of the star.

872

00:35:14,545 --> 00:35:16,680

Then, as the planet
goes around the star,

873

00:35:16,713 --> 00:35:18,682

now we look at the bottom
graph here, so this

874

00:35:18,715 --> 00:35:20,918

is the same plot, but

we've zoomed it in,

875

00:35:20,951 --> 00:35:22,153

so you don't see the
depth of the transit,

876

00:35:22,186 --> 00:35:24,889

gonna be down through
the floor here,

877

00:35:24,922 --> 00:35:26,757

but you see two more dips...

878

00:35:28,158 --> 00:35:30,528

Which are when the planet
goes behind the star,

879

00:35:30,561 --> 00:35:32,163

because we're looking
at the infrared,

880

00:35:32,196 --> 00:35:35,132

the planet's fairly warm, so
it's glowing in its own light,

881

00:35:35,165 --> 00:35:36,667

and when that day
side of the planet

882

00:35:36,700 --> 00:35:39,971

goes behind the star, you lose
the light from the planet.

883

00:35:41,405 --> 00:35:43,374

So, since you already know
the size of the planet,

884

00:35:44,508 --> 00:35:46,210

you can measure the
size of the dip,

885

00:35:46,243 --> 00:35:47,845

then you can figure
out the temperature

886

00:35:47,878 --> 00:35:50,147

of this day side of the planet.

887

00:35:50,180 --> 00:35:52,683

Based on the amount of
light that you've lost

888

00:35:52,716 --> 00:35:55,619

from the planet when it
goes behind the star.

889

00:35:55,652 --> 00:35:57,755

And now, most of
all the planets,

890

00:35:57,788 --> 00:36:01,192

we study with this
transiting exoplanet, are ...

891

00:36:02,759 --> 00:36:05,629

Are tidally locked to their
star, they're orbiting

892

00:36:05,662 --> 00:36:07,431

close enough to their stars,
usually, because otherwise,

893

00:36:07,464 --> 00:36:10,334

it would take a really
long time to see a transit,

894

00:36:11,868 --> 00:36:14,972

that they always
show the same face,

895

00:36:15,005 --> 00:36:17,041

the planet shows the
same face to the star,

896

00:36:17,074 --> 00:36:18,275

it's sort of like the moon,

897

00:36:18,308 --> 00:36:19,743

we only see one
face of the moon,

898

00:36:19,776 --> 00:36:23,414

as the moon orbits the
Earth, it also rotates,

899

00:36:23,447 --> 00:36:25,349

but it keeps the same
face facing the Earth,

900

00:36:25,382 --> 00:36:26,917

because it's
orbiting very close,

901

00:36:26,950 --> 00:36:28,819

these planets do the same thing.

902

00:36:28,852 --> 00:36:31,188

So, when it's going
around the orbit,

903

00:36:31,221 --> 00:36:34,725

we see the dark
side, the back side,

904

00:36:34,758 --> 00:36:38,596

of the planet in transit,
and then as it goes around,

905

00:36:38,629 --> 00:36:40,231

we see more and more
of the day side,

906
00:36:40,264 --> 00:36:41,832
and that's what
you're seeing here.

907
00:36:41,865 --> 00:36:44,501
So you see the day
side, you see the dip,

908
00:36:44,534 --> 00:36:46,370
do it going behind the star,

909
00:36:46,403 --> 00:36:48,439
which is when you
have no planet at all,

910
00:36:48,472 --> 00:36:50,741
and then you see
the smooth curve,

911
00:36:50,774 --> 00:36:54,144
as it goes from day to night.

912
00:36:54,177 --> 00:36:56,413
And then finally, it
transits and you block out

913
00:36:56,446 --> 00:36:59,316
some of the star, so
that changes everything.

914
00:36:59,349 --> 00:37:01,585
Now, going from day to
night, tells you about

915
00:37:01,618 --> 00:37:05,189
the temperature difference
between the day and night side.

916

00:37:05,222 --> 00:37:07,157

And if you don't see any
temperature difference

917

00:37:07,190 --> 00:37:09,159

between day and night, then
it tells you that something

918

00:37:09,192 --> 00:37:11,662

has to transport energy
from the day side,

919

00:37:11,695 --> 00:37:14,131

where the sunlight's hitting
it, to the night side.

920

00:37:15,866 --> 00:37:18,569

And even if it doesn't,
if it's moving,

921

00:37:18,602 --> 00:37:20,070

you know, you see
some difference,

922

00:37:20,103 --> 00:37:22,273

it tells you about how
energy's transported

923

00:37:22,306 --> 00:37:24,008

from the day side
to the night side.

924

00:37:24,041 --> 00:37:25,676

So this is a way
of telling us about

925

00:37:25,709 --> 00:37:29,413

the atmosphere and
the winds on planets.

926

00:37:29,446 --> 00:37:32,082

So we can actually say
something about winds

927

00:37:32,115 --> 00:37:33,917

and planets around other stars,

928

00:37:33,950 --> 00:37:35,986

just by looking at the
light curve of the star.

929

00:37:36,019 --> 00:37:37,421

So you have to remember here,

930

00:37:37,454 --> 00:37:38,989

none of this do we actually
see the planet, right,

931

00:37:39,022 --> 00:37:41,625

we're not resolving the
planet relative to its star,

932

00:37:41,658 --> 00:37:45,195

we're just seeing the change
in brightness of the star,

933

00:37:45,228 --> 00:37:47,031

when a planet passes
in front of it.

934

00:37:48,598 --> 00:37:50,567

Okay, but Spitzer wasn't
designed to do that,

935

00:37:50,600 --> 00:37:52,102

so we had to do some tricks,

936

00:37:52,135 --> 00:37:55,205

because when we tried to do
this, what we found out...

937
00:37:55,238 --> 00:37:57,541
I'll go a little bit
quick because it's so...

938
00:37:57,574 --> 00:38:00,177
This is a plot made by my
colleague, Jim Ingalls.

939
00:38:00,210 --> 00:38:02,646
Is that if we measure
the brightness of a star,

940
00:38:02,679 --> 00:38:05,883
on a part of the
camera for Spitzer,

941
00:38:05,916 --> 00:38:07,184
it's brighter in one spot,

942
00:38:07,217 --> 00:38:09,353
that's what the
purplish number means,

943
00:38:09,386 --> 00:38:11,789
and then as we go down to
white, it gets less bright.

944
00:38:11,822 --> 00:38:14,591
And this changes
by a few percent.

945
00:38:14,624 --> 00:38:18,629
Which, if we go back and
look at this HD189733,

946
00:38:18,662 --> 00:38:20,831
there's only a couple

percent for the transit,

947

00:38:20,864 --> 00:38:23,967

and for the eclipses,
it's much less than that.

948

00:38:24,000 --> 00:38:28,038

So we're trying to measure
very small changes here,

949

00:38:28,071 --> 00:38:30,841

with a camera where,
just the fact that

950

00:38:30,874 --> 00:38:35,045

a star's here instead of
here, it's a huge change.

951

00:38:35,078 --> 00:38:37,247

And this is only one pixel of
the camera, so what we do now,

952

00:38:37,280 --> 00:38:41,752

is we hold the star
steady on the camera,

953

00:38:41,785 --> 00:38:43,654

but just like my hand,
and of course I'm nervous,

954

00:38:43,687 --> 00:38:45,155

which is why my
hand's jittering,

955

00:38:45,188 --> 00:38:47,358

but the spacecraft
wobbles because we didn't

956

00:38:47,391 --> 00:38:48,892

design it not to do that, right,

957

00:38:48,925 --> 00:38:51,462
because there's no reason
to have it point that well

958

00:38:51,495 --> 00:38:54,231
to do all the things that
Spitzer was supposed to do,

959

00:38:54,264 --> 00:38:56,100
and then, so all scientists
said to the engineers,

960

00:38:56,133 --> 00:38:58,969
well, stop the wobble,
and they said, we can't,

961

00:38:59,002 --> 00:39:02,373
because it's part of the, you
know, we never designed it

962

00:39:02,406 --> 00:39:04,475
to do that but they
could do some things.

963

00:39:05,675 --> 00:39:06,643
Which I'll get to
in just a second,

964

00:39:06,676 --> 00:39:08,212
so if we look at
a light curve...

965

00:39:09,246 --> 00:39:10,981
From another
transiting exoplanet,

966

00:39:11,014 --> 00:39:12,783
and there's a transit
in here, actually,

967

00:39:12,816 --> 00:39:14,918

there's an eclipse in here,
you'll have to believe me.

968

00:39:14,951 --> 00:39:16,487

You see, you get these
percent variations,

969

00:39:16,520 --> 00:39:18,589

and that's due to the
wobble of the spacecraft

970

00:39:18,622 --> 00:39:21,058

and the fact that the
cameras aren't perfect.

971

00:39:22,859 --> 00:39:24,495

The engineers figured
out a way to keep the,

972

00:39:24,528 --> 00:39:26,730

and this is actually after
we cut the wobble down,

973

00:39:26,763 --> 00:39:28,932

by stopping the
cycling of a battery.

974

00:39:28,965 --> 00:39:30,701

I'm sorry, a heater
for a battery,

975

00:39:30,734 --> 00:39:32,936

because we needed
to keep the battery

976

00:39:32,969 --> 00:39:36,140

for Spitzer warm so
that it didn't freeze,

977

00:39:36,173 --> 00:39:38,041
because you know, we
keep it passively cooled,

978

00:39:38,074 --> 00:39:40,944
and ends up that heater
would flip on and off,

979

00:39:40,977 --> 00:39:43,480
and it would kind of shake
the telescope a little bit.

980

00:39:43,513 --> 00:39:44,848
And then we're turn,
they've allowed us

981

00:39:44,881 --> 00:39:46,316
to turn the heater setting down,

982

00:39:46,349 --> 00:39:48,318
so it only shook, it shook
it a little bit less,

983

00:39:48,351 --> 00:39:49,620
which was a good thing.

984

00:39:49,653 --> 00:39:51,321
But it still shook it.

985

00:39:51,354 --> 00:39:52,923
But then, going back just one,

986

00:39:52,956 --> 00:39:55,959
knowing this map, so
you know how it varies,

987

00:39:55,992 --> 00:39:59,196
and seeing it vary,

you can take that out.

988

00:39:59,229 --> 00:40:01,465

It's not magic, it's
data processing,

989

00:40:01,498 --> 00:40:03,367

which leads you to science.

990

00:40:03,400 --> 00:40:05,536

And folks like Jim
and Jessica Crick

991

00:40:05,569 --> 00:40:08,372

are really good at doing this,
and people in the community,

992

00:40:08,405 --> 00:40:10,274

and then okay, so you still
don't see the transit here

993

00:40:10,307 --> 00:40:11,809

because the data's still noisy,

994

00:40:11,842 --> 00:40:13,811

that's just normal
noise, so what you do,

995

00:40:13,844 --> 00:40:18,449

is you add data together,
sum it up in average,

996

00:40:18,482 --> 00:40:20,818

and then you can see
the dip for the eclipse.

997

00:40:20,851 --> 00:40:24,621

Which is, let's see, it's
like a tenth of a percent,

998

00:40:24,654 --> 00:40:26,724

it's a very small fluctuation.

999

00:40:27,891 --> 00:40:29,526

And then you can

fit a model to it,

1000

00:40:29,559 --> 00:40:32,863

and that model helps tell

you about the brightness,

1001

00:40:32,896 --> 00:40:34,364

the temperature of the planet,

1002

00:40:34,397 --> 00:40:37,168

the day side temperature of

the planet at this wavelength.

1003

00:40:38,935 --> 00:40:40,170

Okay.

1004

00:40:40,203 --> 00:40:41,271

And that's what we

do with Spitzer,

1005

00:40:41,304 --> 00:40:42,773

so the first

detections of emission,

1006

00:40:42,806 --> 00:40:44,308

thermal emission

from exoplanets,

1007

00:40:44,341 --> 00:40:46,543

was done by Spitzer,

just like I've told you.

1008

00:40:46,576 --> 00:40:49,179

And so that's by Dave

Charbonneau and Drake Deming,

1009

00:40:49,212 --> 00:40:50,581

they did almost
at the same time,

1010

00:40:50,614 --> 00:40:52,783

they had a joint press
release, it was very exciting,

1011

00:40:52,816 --> 00:40:54,084

and these planets
are hot, right,

1012

00:40:54,117 --> 00:40:56,019

they're thousands
of degrees Kelvin,

1013

00:40:56,052 --> 00:40:57,554

because if they
weren't that hot,

1014

00:40:57,587 --> 00:40:59,456

then they wouldn't emit
enough infrared radiation

1015

00:40:59,489 --> 00:41:01,091

for Spitzer to be
able to see them,

1016

00:41:01,124 --> 00:41:02,359

and this is commonplace now.

1017

00:41:02,392 --> 00:41:03,994

So these are things
called hot Jupiters,

1018

00:41:04,027 --> 00:41:05,496

they're about the
size of Jupiter,

1019

00:41:05,529 --> 00:41:08,398

but they're in much closer to
their star than Jupiter is,

1020

00:41:08,431 --> 00:41:10,100

they're more like in
the orbit of Mercury.

1021

00:41:10,133 --> 00:41:11,902

So they get heated up,
a high temperature,

1022

00:41:11,935 --> 00:41:14,938

and this is a class of planet
which we didn't know existed

1023

00:41:14,971 --> 00:41:17,808

until Spitzer and Kepler
started studying them.

1024

00:41:19,609 --> 00:41:20,844

Okay.

1025

00:41:20,877 --> 00:41:22,880

So then, actually,
and this was done

1026

00:41:22,913 --> 00:41:25,249

before Spitzer ran out
of CryoSys in 2006,

1027

00:41:25,282 --> 00:41:27,685

and then we ran out tank
shortly, well, in 2009.

1028

00:41:29,619 --> 00:41:31,788

So Spitzer heated up from
the 12 Kelvin we used

1029

00:41:31,821 --> 00:41:33,791

to operate the
telescope, to 28 Kelvin.

1030

00:41:34,791 --> 00:41:36,727

And we knew that we
could probably do this,

1031

00:41:36,760 --> 00:41:38,128

so we know that.

1032

00:41:38,161 --> 00:41:39,897

Two, we figured that
two of the cameras

1033

00:41:39,930 --> 00:41:41,331

on one instrument still
work, so this is IRAC

1034

00:41:41,364 --> 00:41:43,000

and this is the
shortest wavelength

1035

00:41:43,033 --> 00:41:45,769

the 3.6 and 4.5 micron cameras.

1036

00:41:45,802 --> 00:41:47,771

And they'd work the
same as they did before,

1037

00:41:47,804 --> 00:41:50,040

and this is the
first image we took

1038

00:41:50,073 --> 00:41:51,475

with them of a
star-forming region.

1039

00:41:51,508 --> 00:41:53,443

I got to pick the region...

1040

00:41:53,476 --> 00:41:55,746

I thought it looked
pretty cool and it did.

1041

00:41:55,779 --> 00:41:58,482

But, we'd never been
able to test this

1042

00:41:58,515 --> 00:42:00,717

because we weren't allowed to
test the extended operations

1043

00:42:00,750 --> 00:42:02,686

because, "Nah, you're
never gonna get that far."

1044

00:42:02,719 --> 00:42:04,421

And when we dialed
in the numbers

1045

00:42:04,454 --> 00:42:07,591

to set the temperatures and
everything, nothing worked.

1046

00:42:07,624 --> 00:42:11,261

It was a total... we tried to
stabilize the temperatures,

1047

00:42:11,294 --> 00:42:15,198

instead we railed the
heaters on the observatory,

1048

00:42:15,231 --> 00:42:17,601

and there were some choice
words said by people,

1049

00:42:17,634 --> 00:42:19,036

and we tried to figure

out what was going on.

1050

00:42:19,069 --> 00:42:21,739

And basically, we had sent a...

1051

00:42:22,839 --> 00:42:25,943

a 16-bit number to

control the temperature

1052

00:42:25,976 --> 00:42:27,444

because that's what

our documentation said,

1053

00:42:27,477 --> 00:42:30,113

and then when we looked at

the actual wiring diagrams,

1054

00:42:30,146 --> 00:42:32,916

my colleague Bill Gwacham

grabbed the wiring diagrams,

1055

00:42:32,949 --> 00:42:35,252

looked and said, "Well, you

can't pass a 16-bit thing

1056

00:42:35,285 --> 00:42:37,688

"to this controller because

it only takes 12 bits."

1057

00:42:37,721 --> 00:42:40,324

it's like "Oh, okay,

we made a mistake."

1058

00:42:40,357 --> 00:42:42,426

So we're able to correct

it, which is why there's

1059

00:42:42,459 --> 00:42:45,228

a little bit of lag between

when we ran out of cryogen,

1060

00:42:45,261 --> 00:42:46,697

and when we actually
started operating.

1061

00:42:46,730 --> 00:42:48,699

Because we had
clever engineering,

1062

00:42:48,732 --> 00:42:50,334

which said, we could continue,

1063

00:42:50,367 --> 00:42:52,736

but then we had to go
figure out how to operate it

1064

00:42:52,769 --> 00:42:56,073

because we'd never operated
in that mode before.

1065

00:42:56,106 --> 00:42:57,641

And you always have
to check things

1066

00:42:57,674 --> 00:42:59,509

and this isn't
some testing we did

1067

00:42:59,542 --> 00:43:01,211

on the ground prior to launch.

1068

00:43:02,779 --> 00:43:04,615

But we kinda knew
it could happen,

1069

00:43:04,648 --> 00:43:07,151

so we were upset, but
we figured it out.

1070

00:43:08,351 --> 00:43:09,586

Actually that was
a bad day for me,

1071

00:43:09,619 --> 00:43:11,822

because I was monitoring
the telemetry,

1072

00:43:11,855 --> 00:43:13,290

I saw that we were,
instead of being

1073

00:43:13,323 --> 00:43:16,259

at 28 Kelvin we were
like at 50 Kelvin

1074

00:43:16,292 --> 00:43:17,794

and I'm like, "Oh that's bad."

1075

00:43:17,827 --> 00:43:19,630

And then I had to
phone the folks...

1076

00:43:20,697 --> 00:43:21,598

who do the commanding
and I said,

1077

00:43:21,631 --> 00:43:22,799

"Turn off the instrument.

1078

00:43:22,832 --> 00:43:24,334

"Because we don't want
those heaters on."

1079

00:43:24,367 --> 00:43:25,836

Because we didn't know how
much heat we would put in

1080

00:43:25,869 --> 00:43:27,904

and how look it'd

take to cool down.

1081

00:43:27,937 --> 00:43:29,239

So you think,
okay, you only have

1082

00:43:29,272 --> 00:43:31,041

two cameras on one instrument.

1083

00:43:31,074 --> 00:43:34,211

This is not a good situation
around an observatory.

1084

00:43:34,244 --> 00:43:36,279

But, these wavelengths
are really good

1085

00:43:36,312 --> 00:43:38,749

for the things like exoplanets
and distant galaxies.

1086

00:43:38,782 --> 00:43:40,617

So it was even better
than we imagined,

1087

00:43:40,650 --> 00:43:42,653

because now we could spend
all our, not all our time,

1088

00:43:42,686 --> 00:43:43,854

but most of our time working on

1089

00:43:43,887 --> 00:43:45,455

exoplanets and distant galaxies.

1090

00:43:45,488 --> 00:43:47,591

And there are a lot of
astronomers who want to do this.

1091

00:43:47,624 --> 00:43:49,660

And there are a lot of
cool results from it.

1092

00:43:50,760 --> 00:43:52,996

One of the results I'll show,

1093

00:43:53,029 --> 00:43:54,331

is looking at
eclipse measurements

1094

00:43:54,364 --> 00:43:56,700

of another hot, not Jupiter,

1095

00:43:56,733 --> 00:43:58,735

because it's smaller than
Jupiter, its more Earth size.

1096

00:43:58,768 --> 00:44:01,104

A planet called 55
Cancri e, which is also

1097

00:44:01,137 --> 00:44:03,874

orbiting very
close to it's star.

1098

00:44:03,907 --> 00:44:05,342

And one thing we
notice looking at

1099

00:44:05,375 --> 00:44:08,912

these eclipse measurements
in 2012 and 2013,

1100

00:44:08,945 --> 00:44:11,982

is that the depths vary
from 50 parts per million

1101

00:44:12,015 --> 00:44:16,019

to over 200 parts per

million from 2012 to 2013.

1102

00:44:16,052 --> 00:44:18,522

So what that means, if you
convert that to temperature,

1103

00:44:18,555 --> 00:44:19,823

is that the low temperature,

1104

00:44:19,856 --> 00:44:22,426

like down here, from
the 2012 measurements,

1105

00:44:22,459 --> 00:44:25,328

was about 1300 Kelvin
for that planet.

1106

00:44:25,361 --> 00:44:27,831

And then it jumps up
to like 2800 Kelvin.

1107

00:44:27,864 --> 00:44:29,533

So what's going on right?

1108

00:44:29,566 --> 00:44:32,369

So now, this is good
because now we have data,

1109

00:44:32,402 --> 00:44:33,870

which is telling us the
temperature's changing,

1110

00:44:33,903 --> 00:44:35,372

so now this gets all the people

1111

00:44:35,405 --> 00:44:37,708

who model exoplanets
very excited,

1112

00:44:37,741 --> 00:44:39,876
because now they've got to
figure out what's going on.

1113
00:44:39,909 --> 00:44:42,512
And one hypothesis, and
we can't confirm it,

1114
00:44:42,545 --> 00:44:44,214
and this is just an
illustration, right?

1115
00:44:44,247 --> 00:44:46,717
We don't actually see the
planet in any of this,

1116
00:44:46,750 --> 00:44:49,219
we just see a star
and then we see it

1117
00:44:49,252 --> 00:44:53,190
get very fainter by little
tiny fluctuations, right?

1118
00:44:53,223 --> 00:44:54,124
You wouldn't even be able to see

1119
00:44:54,157 --> 00:44:55,759
this fluctuation with your eye.

1120
00:44:55,792 --> 00:44:56,993
If I passed the, you know, if I

1121
00:44:57,026 --> 00:44:58,862
flipped through the
images with you.

1122
00:44:58,895 --> 00:45:00,797
But what we think is
happening is that,

1123

00:45:00,830 --> 00:45:03,133

because it's in
close it's getting

1124

00:45:03,166 --> 00:45:05,769

tidally stretched and
stuff, there's volcanism.

1125

00:45:05,802 --> 00:45:07,904

Volcanoes on this planet.

1126

00:45:07,937 --> 00:45:10,207

And in 2012, it was
just less active

1127

00:45:10,240 --> 00:45:12,042

or maybe we're seeing
a different portion

1128

00:45:12,075 --> 00:45:14,311

of the planet because
maybe it rotates slowly.

1129

00:45:14,344 --> 00:45:16,713

And in 2013, it's more active.

1130

00:45:16,746 --> 00:45:18,648

Or we're seeing the
hotter side of it,

1131

00:45:18,681 --> 00:45:20,951

because maybe it isn't
totally tidally locked,

1132

00:45:20,984 --> 00:45:23,587

maybe it's rotating very
slowly like Mercury does.

1133

00:45:24,754 --> 00:45:26,089

So that's a really
exciting is that

1134

00:45:26,122 --> 00:45:27,624

we can start to
understand something like,

1135

00:45:27,657 --> 00:45:31,028

if you can call this weather,
weather on other planets.

1136

00:45:35,064 --> 00:45:37,634

And, in conjunction with Hubble,

1137

00:45:37,667 --> 00:45:39,970

we're able to identify
to most distant galaxy.

1138

00:45:41,104 --> 00:45:42,539

Okay, I'm gonna go through fast.

1139

00:45:42,572 --> 00:45:44,074

So this is some of the
lights that we could see.

1140

00:45:44,107 --> 00:45:46,176

This galaxy hasn't
aged, we see it

1141

00:45:46,209 --> 00:45:49,546

as it was 13.4
billion years ago.

1142

00:45:49,579 --> 00:45:51,014

It's about 1/100 the
size of the Milky Way

1143

00:45:51,047 --> 00:45:53,717

and we know this because we

can measure how far away it is.

1144

00:45:53,750 --> 00:45:57,254

It's redshift,
essentially, by when it...

1145

00:45:57,287 --> 00:45:58,722

we can see the light from it.

1146

00:45:59,856 --> 00:46:01,858

Because basically,
this line here

1147

00:46:01,891 --> 00:46:04,427

is when all the light that's
at shorter wavelength,

1148

00:46:04,460 --> 00:46:06,396

that gets redshifted out,

1149

00:46:06,429 --> 00:46:08,965

gets absorbed by the
gas in the galaxy.

1150

00:46:08,998 --> 00:46:10,400

So that's a very good...

1151

00:46:10,433 --> 00:46:12,402

You can model what the
galaxy should look like,

1152

00:46:12,435 --> 00:46:14,671

because you don't see
it in one Hubble band,

1153

00:46:14,704 --> 00:46:16,139

you see it in the second.

1154

00:46:16,172 --> 00:46:19,075

And then you see the blob
in the two IRAC bands.

1155
00:46:19,108 --> 00:46:23,213
So... what this is, is
that the Hubble data

1156
00:46:23,246 --> 00:46:26,750
allows you to get the
redshift or the time that...

1157
00:46:26,783 --> 00:46:28,552
You looking back to
observe the galaxy,

1158
00:46:28,585 --> 00:46:30,787
and then Spitzer gives the
mass and the age of the stars

1159
00:46:30,820 --> 00:46:32,956
because this is where
all the starlight is.

1160
00:46:34,524 --> 00:46:35,759
Okay.

1161
00:46:35,792 --> 00:46:37,260
One other thing
we're able to do is

1162
00:46:37,293 --> 00:46:38,795
there's another technique
for looking at planets.

1163
00:46:38,828 --> 00:46:41,965
And these are planets, that
you can't see any other way

1164
00:46:41,998 --> 00:46:43,834
because you can

directly image them

1165

00:46:43,867 --> 00:46:45,202

if they're pretty far
away from the star,

1166

00:46:45,235 --> 00:46:47,237

and you can use
radial velocities

1167

00:46:47,270 --> 00:46:49,139

and transits if
they're in close,

1168

00:46:49,172 --> 00:46:51,007

and they're either
affecting the star passing

1169

00:46:51,040 --> 00:46:53,677

in front of it, but how
about things like Jupiter.

1170

00:46:53,710 --> 00:46:54,878

How do you observe Jupiter?

1171

00:46:54,911 --> 00:46:56,346

Things that are
round or snow lined.

1172

00:46:56,379 --> 00:46:57,881

Well, if you get really lucky

1173

00:46:57,914 --> 00:47:00,116

and you look at a lot of stars,

1174

00:47:00,149 --> 00:47:03,620

when stars pass in
front of other stars...

1175

00:47:05,455 --> 00:47:06,490
Nope, I'm sorry...

1176
00:47:12,228 --> 00:47:14,364
If they perfectly align,

1177
00:47:14,397 --> 00:47:17,968
the foreground star
will gravitational,

1178
00:47:18,001 --> 00:47:19,836
and the gravity of
that star will focus

1179
00:47:19,869 --> 00:47:21,304
the light of the
background star,

1180
00:47:21,337 --> 00:47:22,973
and that's what you're
seeing here is this flip.

1181
00:47:23,006 --> 00:47:24,841
Is that the light gets
gravitationally focused

1182
00:47:24,874 --> 00:47:27,077
as the star passes in
front of the other star.

1183
00:47:27,110 --> 00:47:30,614
And if there's a
planet with that star,

1184
00:47:30,647 --> 00:47:32,682
that can also
gravitationally interact

1185
00:47:32,715 --> 00:47:36,519
if the geometry's right, so,

it doesn't happen that often.

1186

00:47:36,552 --> 00:47:38,822

If you look at a
few million stars

1187

00:47:38,855 --> 00:47:40,390

over the course of a few months,

1188

00:47:40,423 --> 00:47:41,625

which people do from the ground,

1189

00:47:41,658 --> 00:47:43,093

you may see a thousand
events where you see

1190

00:47:43,126 --> 00:47:45,629

a star brightened
by another star.

1191

00:47:45,662 --> 00:47:48,365

And you may get
three with a planet.

1192

00:47:48,398 --> 00:47:50,834

So that's what's done by
people who study microlensing,

1193

00:47:50,867 --> 00:47:53,536

every year, when they can look
at the center of our galaxy

1194

00:47:53,569 --> 00:47:56,506

where there's a lot of stars
and you have a lot of chances

1195

00:47:56,539 --> 00:47:58,475

of stars going in
front of other stars.

1196

00:48:00,677 --> 00:48:03,213

The problem with that
is, even if you do that,

1197

00:48:03,246 --> 00:48:06,049

you see the bump, you
know there's a planet,

1198

00:48:06,082 --> 00:48:11,088

you don't know, you can't
tell the mass and the distance

1199

00:48:11,955 --> 00:48:13,123

with just one measurement

1200

00:48:13,156 --> 00:48:14,691

because you only
get one measurement

1201

00:48:16,092 --> 00:48:17,928

and everything can be
closer and less massive

1202

00:48:17,961 --> 00:48:19,996

or it can be further
away and more massive.

1203

00:48:20,029 --> 00:48:22,332

And it's very hard to
disentangle between those

1204

00:48:22,365 --> 00:48:24,167

if all you have is
one light curve,

1205

00:48:24,200 --> 00:48:27,404

but since Spitzer's so
far away from the Earth,

1206

00:48:27,437 --> 00:48:28,972
if both Spitzer and Earth,

1207
00:48:29,005 --> 00:48:31,341
observe one of these
microlensing events,

1208
00:48:31,374 --> 00:48:34,244
the time between when
Spitzer observes the event,

1209
00:48:34,277 --> 00:48:37,948
which is the red, and when
the Earth sees the event,

1210
00:48:37,981 --> 00:48:41,518
allows you to disentangle
between mass and distance.

1211
00:48:41,551 --> 00:48:44,921
Because you're able to look at
from two different positions.

1212
00:48:44,954 --> 00:48:46,823
You're able to
pin-down the geometry.

1213
00:48:48,291 --> 00:48:49,426
And we're able to do this,
and we've been doing this

1214
00:48:49,459 --> 00:48:50,894
for quite some time.

1215
00:48:50,927 --> 00:48:52,930
But the first observation
we do with Spitzer...

1216
00:48:56,799 --> 00:48:57,968
Is that one there.

1217

00:48:58,001 --> 00:49:00,537

We actually got the
star, we actually saw...

1218

00:49:00,570 --> 00:49:02,272

So you see the
star curve and then

1219

00:49:02,305 --> 00:49:03,740

that dip is due to the planet,

1220

00:49:03,773 --> 00:49:06,276

so we have a star and
planet microlensing event

1221

00:49:06,309 --> 00:49:07,844

and we're able to determine
the mass of the star

1222

00:49:07,877 --> 00:49:09,079

is 0.5 Jupiters.

1223

00:49:10,847 --> 00:49:13,883

The planet mass is not... no,
I've got this the other way.

1224

00:49:13,916 --> 00:49:15,118

I'm very sorry.

1225

00:49:17,754 --> 00:49:20,390

The star mass is $7/10$ the sun,

1226

00:49:20,423 --> 00:49:21,858

so it's a little
smaller than the sun.

1227

00:49:21,891 --> 00:49:24,427

The planet is about

half of Jupiter mass,

1228

00:49:24,460 --> 00:49:25,795

which is kind of interesting,

1229

00:49:25,828 --> 00:49:27,030

and it's the distance of three

1230

00:49:27,063 --> 00:49:30,533

astronomical units

from it's star,

1231

00:49:30,566 --> 00:49:32,769

which we couldn't

see any other way.

1232

00:49:32,802 --> 00:49:35,772

And Spitzer and the ground

routine, we do this every year,

1233

00:49:35,805 --> 00:49:38,074

we look at a handful of planets

with Spitzer and the ground

1234

00:49:38,107 --> 00:49:39,776

and we're learning about planets

1235

00:49:39,809 --> 00:49:41,644

that you can't see

in any other way.

1236

00:49:41,677 --> 00:49:42,879

The only problem

with this technique

1237

00:49:42,912 --> 00:49:44,214

is that once that

alignment's gone,

1238

00:49:44,247 --> 00:49:46,116

that's the last time you
ever see that planet.

1239

00:49:46,149 --> 00:49:47,384

Which is a real bummer.

1240

00:49:47,417 --> 00:49:48,918

You can't go back and
re-observe it because

1241

00:49:48,951 --> 00:49:51,521

you could never
see, you don't see,

1242

00:49:51,554 --> 00:49:52,956

the lens in the first place.

1243

00:49:54,957 --> 00:49:56,126

Okay.

1244

00:49:56,159 --> 00:49:58,828

Alright, so it gets here
to the coolest thing

1245

00:49:58,861 --> 00:50:00,563

that I've ever had
a chance to work on,

1246

00:50:00,596 --> 00:50:03,333

which is the observations
of the TRAPPIST-1 system,

1247

00:50:03,366 --> 00:50:05,035

which maybe some
of you heard about.

1248

00:50:05,068 --> 00:50:06,870

So this was a star,
that was only discovered

1249

00:50:06,903 --> 00:50:07,804
in the year 2000.

1250

00:50:07,837 --> 00:50:10,240
Its a very cold, red star,

1251

00:50:10,273 --> 00:50:12,409
and was discovered with
another infrared survey

1252

00:50:12,442 --> 00:50:15,779
which was done with JPL
and Caltech called 2MASS.

1253

00:50:15,812 --> 00:50:18,615
It's at 40 light years
away, but it's very small.

1254

00:50:18,648 --> 00:50:20,917
It's only 8/100 of a solar mass,

1255

00:50:20,950 --> 00:50:22,719
and it's about half the
temperature of the sun,

1256

00:50:22,752 --> 00:50:24,220
and it's only a little
bit bigger than Jupiter.

1257

00:50:24,253 --> 00:50:26,823
It's something called an
ultra-cool dwarf, M dwarf.

1258

00:50:28,257 --> 00:50:32,028
And because it's so cold, it's
four thousand times brighter

1259

00:50:32,061 --> 00:50:35,198

in the infrared than it is in
the visible, which is good.

1260

00:50:35,231 --> 00:50:37,434

And since it's small, that means

1261

00:50:37,467 --> 00:50:39,569

that when a planet
passes in front of it,

1262

00:50:39,602 --> 00:50:40,937

smaller planets
are easier to see

1263

00:50:40,970 --> 00:50:43,606

around smaller
stars, which is nice.

1264

00:50:43,639 --> 00:50:47,510

And we just happened to
see, so from the ground,

1265

00:50:47,543 --> 00:50:49,612

an astronomer named
Caglioni was looking

1266

00:50:49,645 --> 00:50:52,282

to see if he could find
planets around very cold stars,

1267

00:50:52,315 --> 00:50:54,117

because we didn't know
if they would have them,

1268

00:50:54,150 --> 00:50:58,288

and he saw some transit-like
things, but it looked weird.

1269

00:50:58,321 --> 00:51:00,457

It had this weird extra

hump to this and this,

1270

00:51:00,490 --> 00:51:01,858

and he wasn't sure
what's going on.

1271

00:51:01,891 --> 00:51:03,626

So he asked for
some Spitzer time

1272

00:51:03,659 --> 00:51:07,297

and then we got more odd
looking bumps as well.

1273

00:51:07,330 --> 00:51:09,633

So we didn't know what
was going on with this.

1274

00:51:11,100 --> 00:51:14,537

And so, we ended up spending
a lot of time with Spitzer.

1275

00:51:14,570 --> 00:51:17,841

We spent 500 hours to
just stare at the system,

1276

00:51:17,874 --> 00:51:19,576

which is something you
can do with Spitzer

1277

00:51:19,609 --> 00:51:21,311

since it's not orbiting the...

1278

00:51:21,344 --> 00:51:22,812

it's not on the Earth, so
you don't have to worry

1279

00:51:22,845 --> 00:51:24,848

about the sun coming
up and ruining

1280

00:51:24,881 --> 00:51:27,050

your observations every
eight to 16 hours,

1281

00:51:27,083 --> 00:51:29,152

and it's not orbiting around
the Earth like Hubble.

1282

00:51:29,185 --> 00:51:31,521

Every time Hubble
looks at something,

1283

00:51:31,554 --> 00:51:33,823

Hubble's orbit, it's 90 minutes,

1284

00:51:33,856 --> 00:51:35,525

so it can look at something
for about 40 minutes

1285

00:51:35,558 --> 00:51:36,659

and then it goes
behind the Earth

1286

00:51:36,692 --> 00:51:38,128

and can't see that source again

1287

00:51:38,161 --> 00:51:40,263

until it comes back
around the other side.

1288

00:51:40,296 --> 00:51:41,965

But with Spitzer, we
can look at something

1289

00:51:41,998 --> 00:51:44,667

between 40 days to a whole year

1290

00:51:44,700 --> 00:51:46,236

if we want to, and
it, with TRAPPIST,

1291
00:51:46,269 --> 00:51:48,004
we could look at it for 40 days,

1292
00:51:48,037 --> 00:51:49,973
we spent 20 days looking at it.

1293
00:51:50,006 --> 00:51:51,875
And this is what we saw...
So...

1294
00:51:53,509 --> 00:51:55,011
I'll give you the
punch line is that

1295
00:51:55,044 --> 00:51:57,680
there's seven transiting
planets around TRAPPIST-1.

1296
00:51:57,713 --> 00:51:59,482
The system has a set of planets

1297
00:51:59,515 --> 00:52:02,152
that are very closely
packed, and remember,

1298
00:52:02,185 --> 00:52:03,520
because if for them to transit,

1299
00:52:03,553 --> 00:52:05,522
they have to pass
between us and the star.

1300
00:52:05,555 --> 00:52:08,925
So all their orbits are
in a nice, tight plane.

1301

00:52:08,958 --> 00:52:11,594

Which is a little bit surprising, but not impossible.

1302

00:52:11,627 --> 00:52:14,330

So, we got kind of lucky with this, and this is a graphic.

1303

00:52:14,363 --> 00:52:16,499

And then, here's the data coming up,

1304

00:52:16,532 --> 00:52:18,368

so this is the Spitzer data,

1305

00:52:18,401 --> 00:52:19,903

and you can see there's the star

1306

00:52:19,936 --> 00:52:21,104

and there's a little bit of noise,

1307

00:52:21,137 --> 00:52:23,072

and then you see these periodic dips.

1308

00:52:23,105 --> 00:52:24,541

And when we saw this we thought,

1309

00:52:24,574 --> 00:52:26,509

"Well, wait a minute, there's a lot of transits.

1310

00:52:26,542 --> 00:52:28,778

"What the heck is going on?"

1311

00:52:28,811 --> 00:52:30,847

And you can see the transits

1312

00:52:30,880 --> 00:52:33,716
of the same size keep appearing.

1313
00:52:33,749 --> 00:52:35,118
Like this, you keep seeing,

1314
00:52:35,151 --> 00:52:37,187
well that one's during a
downlink, so you don't see it...

1315
00:52:37,220 --> 00:52:39,556
You also see some
flares when the star

1316
00:52:39,589 --> 00:52:41,391
gets a little hot and burps.

1317
00:52:41,424 --> 00:52:45,962
But you can keep seeing
repeated dips of the same depth,

1318
00:52:45,995 --> 00:52:47,931
which means it's the
same size planet,

1319
00:52:47,964 --> 00:52:49,432
So it's the same planet.

1320
00:52:49,465 --> 00:52:50,934
And then you can
go and pick it out

1321
00:52:50,967 --> 00:52:53,803
and you can see the
spacing between the planet,

1322
00:52:53,836 --> 00:52:58,074
the dips in time, so this
is in days now we're seeing,

1323

00:52:58,107 --> 00:53:01,010

so every time you see
that planet repeat

1324

00:53:01,043 --> 00:53:02,712

you know what the
period of the planet is

1325

00:53:02,745 --> 00:53:03,880

because it's making one orbit.

1326

00:53:03,913 --> 00:53:06,583

So for planet B here,
that's 1.8 days.

1327

00:53:06,616 --> 00:53:09,352

So, you're able to tell
the size of the planet,

1328

00:53:09,385 --> 00:53:11,421

you're also able
to tell how long

1329

00:53:11,454 --> 00:53:13,189

it takes to go around it's star,

1330

00:53:13,222 --> 00:53:14,724

so that also tells
you the distance

1331

00:53:14,757 --> 00:53:16,226

of the planet from the star.

1332

00:53:16,259 --> 00:53:18,962

And since you know how hot
and bright the star is,

1333

00:53:18,995 --> 00:53:20,563

that also tells

you how much heat

1334

00:53:20,596 --> 00:53:22,632

the planet gets from the star.

1335

00:53:22,665 --> 00:53:25,001

It tells us something about
the temperature of the star.

1336

00:53:25,034 --> 00:53:26,670

So, we got a lot of information.

1337

00:53:27,770 --> 00:53:28,571

Now I've got to go
find the clicker again,

1338

00:53:28,604 --> 00:53:30,273

sorry about that...

1339

00:53:30,306 --> 00:53:31,774

Okay.

1340

00:53:31,807 --> 00:53:33,276

So the TRAPPIST-1 system
is much smaller than ours,

1341

00:53:33,309 --> 00:53:35,645

here's seven planets
closely packed system,

1342

00:53:35,678 --> 00:53:38,848

all would fit very comfortably
inside the orbit of Mercury.

1343

00:53:38,881 --> 00:53:41,985

In fact, it's more like
what the Galilean Moons

1344

00:53:42,018 --> 00:53:43,586

look like in Jupiter.

1345

00:53:43,619 --> 00:53:45,488

It's kind of, in between.

1346

00:53:45,521 --> 00:53:48,258

And the star's, sort of,
a little bit more massive

1347

00:53:48,291 --> 00:53:51,427

and about the same size
and radius as Jupiter,

1348

00:53:51,460 --> 00:53:54,130

so it's more similar to
what the Galilean system

1349

00:53:54,163 --> 00:53:55,999

looks like than our
own solar system.

1350

00:53:57,166 --> 00:53:58,601

But that's not all,

1351

00:53:58,634 --> 00:54:00,937

'cause those planets
are so closely packed...

1352

00:54:06,876 --> 00:54:10,713

They tend to gravitationally
interact with each other.

1353

00:54:10,746 --> 00:54:12,215

Not only are they closely packed

1354

00:54:12,248 --> 00:54:15,318

but they're in these things
called resonance orbits.

1355

00:54:15,351 --> 00:54:17,520

What that means is that
every time B orbits,

1356

00:54:17,553 --> 00:54:19,989

hang on I can't find
B, there it goes,

1357

00:54:20,022 --> 00:54:22,925

for eight orbits of
B, C orbits five times

1358

00:54:22,958 --> 00:54:24,560

and D orbits three times,

1359

00:54:24,593 --> 00:54:26,429

during these three
body resonances.

1360

00:54:26,462 --> 00:54:28,031

And what that means is
there's a lot of times

1361

00:54:28,064 --> 00:54:30,566

when they pass in front of
each other in regular patterns,

1362

00:54:30,599 --> 00:54:33,570

and the whole pattern repeats
about every 38.6 days.

1363

00:54:34,937 --> 00:54:36,873

And because of that,
planets keep whizzing by,

1364

00:54:36,906 --> 00:54:39,309

they gravitationally
interact with each other.

1365

00:54:39,342 --> 00:54:41,744

So they tug and
pull on each other,

1366
00:54:41,777 --> 00:54:44,580
and that tug and pull, if
you look at the transits,

1367
00:54:44,613 --> 00:54:46,215
so this is for TRAPPIST-1 D,

1368
00:54:46,248 --> 00:54:49,719
and I'm just showing you
different transits observed

1369
00:54:49,752 --> 00:54:52,922
over a span of many months now.

1370
00:54:52,955 --> 00:54:55,625
And what you see is, if you
look at the orange line,

1371
00:54:55,658 --> 00:54:58,027
that's where they
all, all the midpoints

1372
00:54:58,060 --> 00:55:00,997
should line up if it's
just orbiting around

1373
00:55:01,030 --> 00:55:02,799
in the period space constant.

1374
00:55:02,832 --> 00:55:04,834
But what we find is,
it's not orbiting

1375
00:55:04,867 --> 00:55:06,202
around that period
staying constant,

1376

00:55:06,235 --> 00:55:08,338

it's changing by minutes,

1377

00:55:08,371 --> 00:55:10,540

and the reason it's

changing by minutes

1378

00:55:10,573 --> 00:55:14,210

is because the other

planets, C and E,

1379

00:55:14,243 --> 00:55:15,712

are gravitationally interacting.

1380

00:55:15,745 --> 00:55:17,947

So they tug it one way and

they tug it the other way.

1381

00:55:17,980 --> 00:55:21,050

So they speed it up and they

slow it down in it's orbit.

1382

00:55:21,083 --> 00:55:23,153

So they change the

timing of the transit.

1383

00:55:24,053 --> 00:55:25,855

And if you take enough data,

1384

00:55:25,888 --> 00:55:27,056

and you have a big

enough computer,

1385

00:55:27,089 --> 00:55:28,024

and you're really clever,

1386

00:55:28,057 --> 00:55:29,525

and your name's Simon Grimm,

1387

00:55:29,558 --> 00:55:31,427

who's a really
excellent astronomer,

1388

00:55:31,460 --> 00:55:32,829

you can take all
that information,

1389

00:55:32,862 --> 00:55:35,198

because now you know
the timing change,

1390

00:55:35,231 --> 00:55:38,034

you could figure out the
masses of the planets.

1391

00:55:38,067 --> 00:55:39,302

And that's amazing, right?

1392

00:55:39,335 --> 00:55:42,138

So now we know the size
and we know the mass.

1393

00:55:42,171 --> 00:55:44,207

So since we know the
size of the planets,

1394

00:55:44,240 --> 00:55:45,441

they're all about Earth-size,

1395

00:55:45,474 --> 00:55:47,310

and the mass they're
all about Earth-mass,

1396

00:55:47,343 --> 00:55:48,778

D's a little bit smaller,

1397

00:55:48,811 --> 00:55:51,013

we could figure out the

density of these planets.

1398

00:55:51,046 --> 00:55:53,149

And this is amazing
because this tells-

1399

00:55:53,182 --> 00:55:55,451

we can tell something
about the bulk composition.

1400

00:55:55,484 --> 00:55:57,587

We could tell if they're
little balls of iron,

1401

00:55:57,620 --> 00:56:00,390

or big fluff balls of water
or something in between.

1402

00:56:00,423 --> 00:56:02,392

They're all
something in between.

1403

00:56:02,425 --> 00:56:03,626

And because of that then,

1404

00:56:03,659 --> 00:56:04,861

we can take it to
the graphics folks,

1405

00:56:04,894 --> 00:56:06,229

because we have all
this information,

1406

00:56:06,262 --> 00:56:08,431

if fact we have more
information about the planets

1407

00:56:08,464 --> 00:56:12,502

in this system than any other
system other than our own.

1408

00:56:12,535 --> 00:56:14,437

Where we can actually
go and see the planets.

1409

00:56:14,470 --> 00:56:16,105

We know the densities
of all these planets

1410

00:56:16,138 --> 00:56:18,908

to about 10% or better,
which is outstanding,

1411

00:56:18,941 --> 00:56:21,611

because it's amazing, because
these 40 light years away,

1412

00:56:21,644 --> 00:56:23,246

we can't even see these objects,

1413

00:56:23,279 --> 00:56:25,448

yet we know what
they're densities are

1414

00:56:25,481 --> 00:56:28,251

and we know what their
surface gravities are.

1415

00:56:28,284 --> 00:56:30,420

And because of that we
can make conjectures

1416

00:56:30,453 --> 00:56:31,954

about what they
should look like,

1417

00:56:31,987 --> 00:56:33,956

what their composition
should look like.

1418

00:56:33,989 --> 00:56:35,892

So the things in
close, actually,

1419

00:56:35,925 --> 00:56:38,628

have a fair amount of
water or gas or something,

1420

00:56:38,661 --> 00:56:41,931

because their densities are
lower than the Earth's density.

1421

00:56:41,964 --> 00:56:43,833

They're more like
Venus densities.

1422

00:56:43,866 --> 00:56:46,903

So we think C is probably
an analog to Venus.

1423

00:56:46,936 --> 00:56:49,939

D is probably something
that's, it has, let's see,

1424

00:56:49,972 --> 00:56:52,041

it's density is less than Earth,

1425

00:56:52,074 --> 00:56:54,177

so it's probably got a
fair amount of something

1426

00:56:54,210 --> 00:56:57,580

lighter than rock on it,
water, gas, we don't know,

1427

00:56:57,613 --> 00:57:00,016

we're thinking
maybe it's waterish.

1428

00:57:00,049 --> 00:57:02,518

And then E is the one
that's most Earth-like

1429

00:57:02,551 --> 00:57:05,221

in terms of density, it's about
the same density as Earth.

1430

00:57:05,254 --> 00:57:06,722

And as we get further out,

1431

00:57:06,755 --> 00:57:09,725

these planets are slightly
less than dense than Earth,

1432

00:57:09,758 --> 00:57:12,028

which means that they
have things like,

1433

00:57:13,195 --> 00:57:15,565

lighter than rock, so
that's some sort of

1434

00:57:15,598 --> 00:57:17,900

like carbon-monoxide,
water, methane,

1435

00:57:17,933 --> 00:57:19,635

what-have-you, that are lighter.

1436

00:57:19,668 --> 00:57:21,604

And those are probably
some form of atmosphere,

1437

00:57:21,637 --> 00:57:24,140

but since they're further
away it's probably cold,

1438

00:57:24,173 --> 00:57:25,975

so it's probably

in the form of ice.

1439

00:57:27,443 --> 00:57:29,312

Okay, I'm running over time here, I'm sorry about that.

1440

00:57:29,345 --> 00:57:32,515

So just compare it quickly to the solar system, if we map,

1441

00:57:32,548 --> 00:57:35,451

so this is the plot of density here, and there's the Earth,

1442

00:57:35,484 --> 00:57:37,086

and then illumination from the host star,

1443

00:57:37,119 --> 00:57:38,354

relative to Sun/Earth.

1444

00:57:38,387 --> 00:57:40,289

So what that tells us it that if it's on one-one,

1445

00:57:40,322 --> 00:57:41,791

it should be very similar to the Earth,

1446

00:57:41,824 --> 00:57:44,727

so D has about the same amount of radiation coming from it,

1447

00:57:44,760 --> 00:57:46,662

so it might be about the same temperature.

1448

00:57:46,695 --> 00:57:51,000

And E is slightly cooler, but has about the same density,

1449

00:57:51,033 --> 00:57:53,302

so it could be very similar
to Earth in properties,

1450

00:57:53,335 --> 00:57:55,037

but a colder version.

1451

00:57:55,070 --> 00:57:57,073

And then F and G are
sort of like Mars,

1452

00:57:57,106 --> 00:57:58,774

so these extended
envelopes, well,

1453

00:57:58,807 --> 00:58:00,042

it could be arid like Mars,

1454

00:58:00,075 --> 00:58:02,278

or it also could have
icy compositions,

1455

00:58:02,311 --> 00:58:04,480

we don't know, but we know
a lot about the system

1456

00:58:04,513 --> 00:58:06,949

and we can continue to explore.

1457

00:58:06,982 --> 00:58:08,518

So looking to the future,

1458

00:58:08,551 --> 00:58:09,919

Spitzer's going to
keep operating

1459

00:58:09,952 --> 00:58:13,356

until November 2019, and

then for budgetary reasons

1460

00:58:13,389 --> 00:58:16,392
we're not going to continue,
at least up til this point.

1461

00:58:16,425 --> 00:58:19,762
And we're gonna keep looking
for planets around cool stars

1462

00:58:19,795 --> 00:58:21,230
and things that are
even cooler than stars

1463

00:58:21,263 --> 00:58:24,200
called brown dwarfs, very
similar to TRAPPIST-1.

1464

00:58:24,233 --> 00:58:25,835
Another thing we may
do is measure the mass

1465

00:58:25,868 --> 00:58:27,770
of an isolated stellar
mass black hole

1466

00:58:28,938 --> 00:58:30,806
and we're really looking
forward to the launch

1467

00:58:30,839 --> 00:58:34,443
of the James Webb Space
Telescope in 2021.

1468

00:58:34,476 --> 00:58:37,446
Which if you think of,
take Hubble and Spitzer

1469

00:58:37,479 --> 00:58:39,649
and combine them, so James Webb,

1470

00:58:39,682 --> 00:58:42,585

would be like the love
child of Spitzer and Hubble,

1471

00:58:42,618 --> 00:58:43,853

and it's bigger and better.

1472

00:58:43,886 --> 00:58:46,122

And one of the things
we'll be able to do

1473

00:58:46,155 --> 00:58:51,160

is actually start to give us
ideas about the composition.

1474

00:58:52,261 --> 00:58:53,496

So are these pictures
correct or not?

1475

00:58:53,529 --> 00:58:55,465

We'll be able to figure
that out, with, well...

1476

00:58:56,432 --> 00:58:57,600

Okay.

1477

00:58:57,633 --> 00:58:59,502

Well thank you very
much for your attention.

1478

00:58:59,535 --> 00:59:01,838

[applause]

1479

00:59:07,176 --> 00:59:10,913

So if you have any questions,
please use the mic,

1480

00:59:10,946 --> 00:59:13,249

which is right in the
center of the auditorium,

1481
00:59:13,282 --> 00:59:15,018
and just, yeah,
come on up and ask.

1482
00:59:28,964 --> 00:59:30,232
>> Hi...

1483
00:59:30,265 --> 00:59:33,035
I had wondered if Spitzer

1484
00:59:33,068 --> 00:59:38,074
focused in on anything
since SNR HBH3.

1485
00:59:40,609 --> 00:59:43,512
>> SNR HBH3, I'm not familiar
with that, so you'll have to

1486
00:59:43,545 --> 00:59:48,184
tell me a little bit more
>> Supernova remnant HBH3.

1487
00:59:48,217 --> 00:59:52,188
In the new star system
that's just forming.

1488
00:59:53,288 --> 00:59:55,024
>> We haven't because
no one submitted

1489
00:59:55,057 --> 00:59:57,727
a proposal to the
best of my knowledge.

1490
00:59:57,760 --> 01:00:00,463
Somebody could go and do that.

1491

01:00:00,496 --> 01:00:02,331

One of the considerations
with Spitzer is that

1492

01:00:02,364 --> 01:00:05,468

we don't get to see all of
the sky all of the time.

1493

01:00:05,501 --> 01:00:07,403

We get to view a
strip of the sky

1494

01:00:07,436 --> 01:00:08,704

because depending
upon our geometry

1495

01:00:08,737 --> 01:00:10,306

with respect
to the Sun.

1496

01:00:10,339 --> 01:00:12,775

So, maybe that that system
isn't available yet.

1497

01:00:12,808 --> 01:00:15,578

So, it's quite possible
that somebody right now

1498

01:00:15,611 --> 01:00:17,246

is writing a proposal
and we'll be able

1499

01:00:17,279 --> 01:00:19,248

to observe it within the year.

1500

01:00:19,281 --> 01:00:20,883

>> Thank you.

>> Carey: You're welcome.

1501

01:00:22,751 --> 01:00:24,854

>> Thanks for the great talk.

>> Carey: You're welcome.

1502

01:00:24,887 --> 01:00:27,723

>> Two questions, on
the TRAPPIST system,

1503

01:00:27,756 --> 01:00:31,060

has there been any
atmospheric spectroscopy

1504

01:00:31,093 --> 01:00:35,531

that's been teased out of
any infrared signatures?

1505

01:00:35,564 --> 01:00:38,868

>> So, we tried a little
bit, by looking at

1506

01:00:38,901 --> 01:00:41,837

the two Spitzer channels,
the 3.6 and 4.5 micron

1507

01:00:41,870 --> 01:00:44,273

to see if we could see a
difference in the depth,

1508

01:00:44,306 --> 01:00:46,142

which would be indicative
of an atmosphere

1509

01:00:46,175 --> 01:00:48,144

because you're selectively
blocking light,

1510

01:00:48,177 --> 01:00:50,246

and there wasn't enough
signal to do that.

1511

01:00:50,279 --> 01:00:52,281
Now, Hubble's also looked at it

1512
01:00:52,314 --> 01:00:54,150
and they get a depth
very similar to Spitzer's

1513
01:00:54,183 --> 01:00:55,651
so what they're
able to rule out,

1514
01:00:55,684 --> 01:00:57,720
with a shorter
wavelength spectroscopy,

1515
01:00:57,753 --> 01:01:00,923
is that these planets
don't, at least B, C, and D,

1516
01:01:00,956 --> 01:01:02,925
which I think is all
Hubble's observed,

1517
01:01:02,958 --> 01:01:05,561
don't have extended
hydrogen envelopes,

1518
01:01:05,594 --> 01:01:07,530
which is good if you're
interested in thinking about

1519
01:01:07,563 --> 01:01:09,866
things that aren't just
big balls of hydrogen.

1520
01:01:11,066 --> 01:01:14,270
>> And second
question, on 55 Cancri,

1521
01:01:14,303 --> 01:01:16,806

the jump in heat after
all the volcanism,

1522

01:01:17,673 --> 01:01:19,275
is there thoughts on that?

1523

01:01:19,308 --> 01:01:21,711
That it's atmospheric blanketing

1524

01:01:21,744 --> 01:01:25,581
where it's keeping it in or...

1525

01:01:25,614 --> 01:01:26,949
Is there other ways to rule out

1526

01:01:26,982 --> 01:01:29,719
shadowing from the atmosphere?

1527

01:01:29,752 --> 01:01:32,254
>> So, there's no conclusive
to go one way or the other.

1528

01:01:32,287 --> 01:01:35,491
So, yeah, the atmospheric
properties and blanketing

1529

01:01:35,524 --> 01:01:39,895
due to high level
particulates, is one scenario.

1530

01:01:39,928 --> 01:01:41,764
Another one is just geometry,

1531

01:01:41,797 --> 01:01:43,799
and we're seeing some
change in the properties

1532

01:01:43,832 --> 01:01:46,102
because it is not

tidally locked,

1533

01:01:47,536 --> 01:01:49,472
and there's no way, with
just the data points we have

1534

01:01:49,505 --> 01:01:52,374
to distinguish between those.

1535

01:01:52,407 --> 01:01:53,909
One of the things though
will be interesting,

1536

01:01:53,942 --> 01:01:55,878
and people are continuing
to take data on this system,

1537

01:01:55,911 --> 01:01:58,581
is to see if they see
any repeating patterns

1538

01:01:58,614 --> 01:02:00,416
or something that,
which would be cyclical,

1539

01:02:00,449 --> 01:02:01,917
and then you could
say something about...

1540

01:02:01,950 --> 01:02:05,187
You know, if you see something
reoccurring on some cadence,

1541

01:02:05,220 --> 01:02:08,991
then that will in credence
to some hypothesis.

1542

01:02:09,024 --> 01:02:11,360
But yeah, no, there's nothing
that distinguishes between,

1543

01:02:11,393 --> 01:02:13,863

I think there's like four
or five different ways

1544

01:02:13,896 --> 01:02:16,465

of potentially explaining
the change in temperature

1545

01:02:16,498 --> 01:02:17,666

that was observed.

1546

01:02:17,699 --> 01:02:18,534

>> Thanks.

1547

01:02:21,537 --> 01:02:23,539

>> Good evening.

My question is...

1548

01:02:23,572 --> 01:02:27,243

Do you see any potential
in finding an exomoon...

1549

01:02:27,276 --> 01:02:28,778

using Spitzer?

1550

01:02:28,811 --> 01:02:30,246

Because I know that,

1551

01:02:30,279 --> 01:02:32,214

potentially if you have a large
enough planet you might have

1552

01:02:32,247 --> 01:02:33,582

like an Earth size moon

>> Carey: Yep.

1553

01:02:33,615 --> 01:02:35,184

>> or possibly even

slightly larger.

1554

01:02:35,217 --> 01:02:37,586

So it's not totally
outlandish, I think.

1555

01:02:37,619 --> 01:02:40,055

>> No, it's certainly
possible to do that.

1556

01:02:40,088 --> 01:02:41,323

In fact with the TRAPPIST,

1557

01:02:41,356 --> 01:02:43,492

with the very odd
transit signatures,

1558

01:02:43,525 --> 01:02:46,195

that was one of the hypotheses
that was batted about.

1559

01:02:46,228 --> 01:02:49,131

But then when people tried
to fit a two-body system,

1560

01:02:49,164 --> 01:02:52,468

you know, a planet with a fairly

1561

01:02:52,501 --> 01:02:55,037

reasonably-sized moon,
it didn't work out.

1562

01:02:55,070 --> 01:02:57,173

So, it's certainly possible...

1563

01:02:58,440 --> 01:02:59,875

People are looking for that,

1564

01:02:59,908 --> 01:03:03,445

primarily with ground
based observations, now.

1565
01:03:03,478 --> 01:03:05,548
And haven't come up
with any moons yet,

1566
01:03:05,581 --> 01:03:07,316
so that's, I think that's
telling us something.

1567
01:03:07,349 --> 01:03:10,319
Maybe that's telling
us that, yet again,

1568
01:03:10,352 --> 01:03:14,990
that our solar system
is maybe not common.

1569
01:03:15,023 --> 01:03:16,258
>> Inquirer: Okay.
>> Yeah, so...

1570
01:03:16,291 --> 01:03:17,793
but people are looking
for things like that.

1571
01:03:17,826 --> 01:03:19,728
>> Okay, and my
second question is,

1572
01:03:19,761 --> 01:03:21,764
If you've somehow
had infinite budget,

1573
01:03:21,797 --> 01:03:24,800
how long could you ride
Spitzer down in flames

1574
01:03:24,833 --> 01:03:26,535

before it just could not
give you data anymore?

1575
01:03:26,568 --> 01:03:27,903
>> That's a really
good question,

1576
01:03:27,936 --> 01:03:32,241
and I don't have a very
crisp answer to that

1577
01:03:32,274 --> 01:03:35,177
because we try not to look
so far into the future.

1578
01:03:35,210 --> 01:03:38,614
Right now, everything is
fully redundant on Spitzer,

1579
01:03:38,647 --> 01:03:40,616
all the, most of the
parts on Spitzer,

1580
01:03:40,649 --> 01:03:42,351
because it's a
telescope in space,

1581
01:03:42,384 --> 01:03:44,119
and if it breaks
you can't fix it,

1582
01:03:44,152 --> 01:03:45,287
so we have two of things, like

1583
01:03:45,320 --> 01:03:46,655
there's two star
trackers for instance.

1584
01:03:46,688 --> 01:03:48,858
The only thing we

have one of are

1585

01:03:48,891 --> 01:03:51,460

the arrays and the
mirror, obviously.

1586

01:03:52,761 --> 01:03:55,097

I think Spitzer could
take useful data

1587

01:03:55,130 --> 01:03:59,635

out to 2021, for
sure... possibly.

1588

01:03:59,668 --> 01:04:00,970

It could go further than that,

1589

01:04:01,003 --> 01:04:02,471

but it'd be taking
less and less data,

1590

01:04:02,504 --> 01:04:04,607

and of course sooner or later
something's going to break.

1591

01:04:04,640 --> 01:04:05,975

If I had to bet on
what would break,

1592

01:04:06,008 --> 01:04:07,243

it would be the reaction wheels.

1593

01:04:07,276 --> 01:04:08,978

The things that help
drive Spitzer around

1594

01:04:09,011 --> 01:04:09,979

because they're spinning parts,

1595

01:04:10,012 --> 01:04:11,647
they're continuously spinning,

1596
01:04:11,680 --> 01:04:13,816
and we're way beyond
warranty on those.

1597
01:04:13,849 --> 01:04:15,284
[crowd chuckles]

1598
01:04:15,317 --> 01:04:17,653
Yeah, the only good thing,
is I think we got a good set,

1599
01:04:17,686 --> 01:04:19,622
so we bought 'em on a Wednesday
or something and didn't

1600
01:04:19,655 --> 01:04:21,156
do bargain in basement.
[audience laughs]

1601
01:04:21,189 --> 01:04:24,159
Which speaks very well to
project management at JPL,

1602
01:04:24,192 --> 01:04:25,027
I might add.

1603
01:04:26,662 --> 01:04:29,532
>> Thank you very much.
>> Carey: You're welcome.

1604
01:04:30,732 --> 01:04:33,435
>> Hi, you mentioned
about the redshift,

1605
01:04:33,468 --> 01:04:34,970
>> Carey: Yes.
>> Yeah, so...

1606

01:04:35,003 --> 01:04:37,306

how do you determine
whether the celestial object

1607

01:04:37,339 --> 01:04:40,943

was starting with some
wavelength or is it,

1608

01:04:40,976 --> 01:04:45,314

was it initially red and not
white, so to have shifted?

1609

01:04:45,347 --> 01:04:47,383

>> So, you make the
assumption that when

1610

01:04:47,416 --> 01:04:51,621

you look at the distant
galaxies that they have...

1611

01:04:53,488 --> 01:04:56,025

Emission, like a spectral
energy distribution

1612

01:04:56,058 --> 01:04:58,661

that the light coming, it
is a functional wavelength,

1613

01:04:58,694 --> 01:05:01,230

looks like a galaxy.

1614

01:05:01,263 --> 01:05:03,165

Okay, and then you
try to fit different,

1615

01:05:03,198 --> 01:05:04,400

and there are different ways.

1616

01:05:04,433 --> 01:05:05,901

So you can have galaxies
that don't have dust,

1617

01:05:05,934 --> 01:05:08,537

galaxies that have dust,
galaxies that form stars,

1618

01:05:08,570 --> 01:05:11,974

so the things that have dust
or form stars may be redder.

1619

01:05:12,007 --> 01:05:13,776

And then you fit
that to the data,

1620

01:05:13,809 --> 01:05:15,077

and then, basically,
what you have to do

1621

01:05:15,110 --> 01:05:16,779

is see if you can get a good fit

1622

01:05:16,812 --> 01:05:19,214

by progressively shifting
the different models

1623

01:05:19,247 --> 01:05:22,351

back and forth with redshift
until you get to one

1624

01:05:22,384 --> 01:05:24,420

that fits very well,
and that was done.

1625

01:05:24,453 --> 01:05:26,121

The other thing that
Spitzer allows you to do

1626

01:05:26,154 --> 01:05:29,258

is rule out nearby,
but dusty galaxies

1627
01:05:29,291 --> 01:05:32,828
which give you a sort of
similar shape in the visible,

1628
01:05:32,861 --> 01:05:34,396
because you don't see the
short wavelength light

1629
01:05:34,429 --> 01:05:36,398
'cause it gets blocked out.

1630
01:05:36,431 --> 01:05:39,234
So it could either
be dust or redshift.

1631
01:05:39,267 --> 01:05:40,736
Does that help, does
that answer you question?

1632
01:05:40,769 --> 01:05:45,140
>> Yes, so, is that based on
the prior observations, right,

1633
01:05:45,173 --> 01:05:47,309
of the galaxies and
what wavelengths

1634
01:05:47,342 --> 01:05:48,844
do they generally emit?

1635
01:05:48,877 --> 01:05:50,746
>> Yes, that's right,
so it's based on

1636
01:05:51,680 --> 01:05:54,083
measurements of nearby galaxies

1637

01:05:54,116 --> 01:05:56,518

and then also modeling
based on what, you know,

1638

01:05:56,551 --> 01:05:58,921

we know what the constituents
of galaxies should be.

1639

01:05:58,954 --> 01:06:01,123

So then you can put those
together in a model as well.

1640

01:06:01,156 --> 01:06:04,093

So it's a combination
of, use models,

1641

01:06:04,126 --> 01:06:05,861

but they're informed
by observations

1642

01:06:05,894 --> 01:06:07,529

of nearby
objects, yes.

1643

01:06:07,562 --> 01:06:12,568

>> Okay... my second question
is, you use this spectroscopy

1644

01:06:13,969 --> 01:06:16,338

to find out the chemical
composition as well, right?

1645

01:06:16,371 --> 01:06:21,377

>> Yes, well, when Spitzer had
a working spectrograph we did.

1646

01:06:22,778 --> 01:06:24,813

Hubble still does that, so,
actually that galaxy I showed

1647

01:06:24,846 --> 01:06:28,150

was spectroscopically
confirmed by Hubble

1648

01:06:28,183 --> 01:06:30,019

because they were able to
actually look for lines

1649

01:06:30,052 --> 01:06:31,887

that they knew where
they should be at,

1650

01:06:31,920 --> 01:06:32,955

and then they were
able to measure

1651

01:06:32,988 --> 01:06:35,324

the redshift directly from that.

1652

01:06:35,357 --> 01:06:38,260

>> Okay, so, in case
there is a chemical

1653

01:06:38,293 --> 01:06:41,397

which is not known to us,
like this spectroscopy,

1654

01:06:41,430 --> 01:06:43,499

we don't about some chemical...

1655

01:06:43,532 --> 01:06:45,768

so it is possible that
we can extrapolate

1656

01:06:45,801 --> 01:06:48,504

from the power of observations
and what we observe now,

1657

01:06:48,537 --> 01:06:51,140

to find out that might
be a new chemical

1658
01:06:51,173 --> 01:06:53,242
which we are seeing
in the spectroscopy.

1659
01:06:53,275 --> 01:06:54,777
>> Yeah, that's
certainly possible,

1660
01:06:54,810 --> 01:06:56,211
with the spectroscopy here,

1661
01:06:56,244 --> 01:06:58,180
it usually doesn't have
high enough resolution

1662
01:06:58,213 --> 01:07:01,016
to be able to see things
we don't understand.

1663
01:07:01,049 --> 01:07:02,718
It, longer wavelengths
than the radio

1664
01:07:02,751 --> 01:07:04,353
and the sub-millimeter,
in particular.

1665
01:07:04,386 --> 01:07:07,256
There are a lot of lines
that are unidentified still

1666
01:07:07,289 --> 01:07:09,591
and chemists are working
very hard on those.

1667
01:07:09,624 --> 01:07:11,727
>> Inquirer: Thank you.

>> You're welcome.

1668

01:07:15,263 --> 01:07:16,732

>> Would there be...

1669

01:07:18,433 --> 01:07:22,538

Is Mars atmosphere strong
enough to have life?

1670

01:07:22,571 --> 01:07:26,375

Because, like, the gulleys...

1671

01:07:28,310 --> 01:07:31,480

they could have been carved
by water because, like...

1672

01:07:33,048 --> 01:07:34,650

>> Right, so you might
know more about Mars

1673

01:07:34,683 --> 01:07:36,452

than I do actually
because I don't study

1674

01:07:36,485 --> 01:07:39,288

our solar system, so, my
understanding is that Mars

1675

01:07:39,321 --> 01:07:41,824

had a more
significant atmosphere

1676

01:07:41,857 --> 01:07:44,126

and most of that is left
because the density of Mars

1677

01:07:44,159 --> 01:07:47,863

is too low to hold a very
significant atmosphere.

1678

01:07:47,896 --> 01:07:49,231

So, there was
probably water on it,

1679

01:07:49,264 --> 01:07:50,633

which is what we're seeing.

1680

01:07:51,967 --> 01:07:53,869

And some of the planets
on the TRAPPIST system

1681

01:07:53,902 --> 01:07:55,370

have similar densities to Mars,

1682

01:07:55,403 --> 01:07:57,639

so they might also
be very Mars-like,

1683

01:07:57,672 --> 01:08:01,643

or they could also
have smaller...

1684

01:08:01,676 --> 01:08:03,212

they could have fairly
significant cores,

1685

01:08:03,245 --> 01:08:06,482

with a much larger envelope
and atmosphere still,

1686

01:08:06,515 --> 01:08:08,517

and we don't know the
answer to that yet.

1687

01:08:08,550 --> 01:08:10,018

So, they could be
very Mars-like,

1688

01:08:10,051 --> 01:08:11,587

like you've mentioned.

1689

01:08:12,821 --> 01:08:15,624

>> And my second question is...

1690

01:08:15,657 --> 01:08:18,760

I've heard that in

2020 they're gonna make

1691

01:08:18,793 --> 01:08:23,799

a telescope that can

see past several...

1692

01:08:31,139 --> 01:08:34,810

Galaxies, like, I can't

think of the name...

1693

01:08:36,244 --> 01:08:37,746

>> Are you thinking of

the James Webb Telescope?

1694

01:08:37,779 --> 01:08:39,715

Because the James Webb Telescope

1695

01:08:39,748 --> 01:08:41,350

is a much larger

collecting area.

1696

01:08:41,383 --> 01:08:44,653

Will it be able to see even

farther back in the universe

1697

01:08:44,686 --> 01:08:47,289

than the combination

of Spitzer and Hubble?

1698

01:08:47,322 --> 01:08:48,524

And that's certainly true,

1699

01:08:48,557 --> 01:08:50,859

one of the things
we will have to,

1700

01:08:50,892 --> 01:08:52,528

one of the things that
Webb was designed to do

1701

01:08:52,561 --> 01:08:55,063

was to go back and look at
the epic of first stars.

1702

01:08:55,096 --> 01:08:56,798

And I think from
what we understand

1703

01:08:56,831 --> 01:08:57,899

with Spitzer and Hubble

1704

01:08:57,932 --> 01:09:00,335

is that stars formed a lot
earlier in the universe

1705

01:09:00,368 --> 01:09:01,870

than we had anticipated,

1706

01:09:01,903 --> 01:09:04,873

so Webb may not actually be
able to see the first stars,

1707

01:09:04,906 --> 01:09:07,843

but it will see a lot of
the very earliest galaxies.

1708

01:09:09,110 --> 01:09:10,513

>> Thank you.

_ [Carey] You're welcome.

1709

01:09:12,981 --> 01:09:14,416

>> Hi, thanks for the talk.

1710

01:09:14,449 --> 01:09:16,318

My question is actually very similar to his question,

1711

01:09:16,351 --> 01:09:19,188

I was wondering in what ways will,

1712

01:09:19,221 --> 01:09:20,956

is Spitzer gonna be a precursor

1713

01:09:20,989 --> 01:09:22,624

for James Webb Space Telescope,

1714

01:09:22,657 --> 01:09:24,259

and how can it inform that mission?

1715

01:09:24,292 --> 01:09:25,427

>> Yeah, it's a good question.

1716

01:09:25,460 --> 01:09:26,929

And I think the combining,

1717

01:09:26,962 --> 01:09:31,233

in terms of understanding the high redshift universe,

1718

01:09:31,266 --> 01:09:33,402

the combination of Hubble and Spitzer

1719

01:09:33,435 --> 01:09:37,406

has already told us that Webb will not see the first stars.

1720

01:09:37,439 --> 01:09:38,740

The combination's

also telling us

1721

01:09:38,773 --> 01:09:41,543

some of the objects that
Webb should look at,

1722

01:09:41,576 --> 01:09:42,878

some of the most
distant galaxies

1723

01:09:42,911 --> 01:09:44,680

that have already
been identified.

1724

01:09:44,713 --> 01:09:48,116

So those are the first
targets that Webb will use

1725

01:09:48,149 --> 01:09:51,186

to, with its spectrographs
to disperse the light

1726

01:09:51,219 --> 01:09:52,721

and really characterize them.

1727

01:09:52,754 --> 01:09:54,790

So, Webb will give
us an understanding

1728

01:09:54,823 --> 01:09:57,493

of the star formation rate,

1729

01:09:58,660 --> 01:10:01,496

and how metal and rich
those galaxies are,

1730

01:10:01,529 --> 01:10:03,298

which will tell us something
about if there were

1731

01:10:03,331 --> 01:10:05,801

previous episodes of
star formation in those.

1732

01:10:05,834 --> 01:10:07,536

Which at some point there
won't be any, right?

1733

01:10:07,569 --> 01:10:11,139

You're gonna see just that
first primordial star formation,

1734

01:10:11,172 --> 01:10:13,041

but Webb will be able
to actually measure

1735

01:10:13,074 --> 01:10:15,911

the metal content in the
gas of those galaxies

1736

01:10:15,944 --> 01:10:17,947

and that will be very
powerful, I think.

1737

01:10:19,214 --> 01:10:20,349

>> Thank you.

>> Carey: You're welcome.

1738

01:10:22,550 --> 01:10:24,086

>> If you could indulge
one other question,

1739

01:10:24,119 --> 01:10:25,354

>> Carey: Absolutely.

1740

01:10:25,387 --> 01:10:26,955

>> The Mars topic made
me think of something.

1741

01:10:26,988 --> 01:10:30,826

So, Mars lost a lot
of it's atmosphere

1742

01:10:30,859 --> 01:10:34,896

because the core freezing
out lost the magnetism,

1743

01:10:34,929 --> 01:10:38,100

on the TRAPPIST system
for the Mars-like objects,

1744

01:10:38,133 --> 01:10:40,902

is it possible, is
the resolution to see

1745

01:10:40,935 --> 01:10:45,073

or to infer magnetic
fields from Zeeman lines

1746

01:10:45,106 --> 01:10:48,377

or is that not feasible?

1747

01:10:48,410 --> 01:10:52,314

>> I don't think that'll be
feasible with any technology

1748

01:10:52,347 --> 01:10:55,851

that can be done
in...in, uh, yeah...

1749

01:10:55,884 --> 01:10:58,754

I think that's a
very hard observation

1750

01:10:58,787 --> 01:11:02,190

to see the Zeeman splitting,
there's not much signal.

1751

01:11:02,223 --> 01:11:05,995

Remember the transits are 1%

1752

01:11:07,095 --> 01:11:08,630
and what you're gonna
talk about then,

1753

01:11:08,663 --> 01:11:12,334
is looking at the
atmospheric constituents,

1754

01:11:12,367 --> 01:11:17,272
so you figure the atmosphere
is at most 1/100th of that,

1755

01:11:17,305 --> 01:11:19,841
so now you're down
another factor of hundred

1756

01:11:19,874 --> 01:11:21,843
and then you have to have
enough signal to noise

1757

01:11:21,876 --> 01:11:24,212
and a very narrow
wavelength range,

1758

01:11:24,245 --> 01:11:26,081
to be able to resolve the lines.

1759

01:11:26,114 --> 01:11:27,716
So, I think, you'd
need an enormous

1760

01:11:27,749 --> 01:11:28,950
collecting area to do that.

1761

01:11:28,983 --> 01:11:30,119
I think that's...

1762

01:11:32,220 --> 01:11:34,222

You would need a
gigantic telescope,

1763

01:11:34,255 --> 01:11:35,824

[laughter]

1764

01:11:35,857 --> 01:11:37,893

I can't even figure out
how big the telescope

1765

01:11:37,926 --> 01:11:39,728

would need to be, which
is what you're asking.

1766

01:11:39,761 --> 01:11:42,364

So, I think it's, that'd be
really far in the future.

1767

01:11:42,397 --> 01:11:45,000

I'd be very happy
if, with these,

1768

01:11:45,033 --> 01:11:50,005

we were able to actually get
a measurement of constituents,

1769

01:11:50,038 --> 01:11:52,007

chemical constituents
in the atmosphere.

1770

01:11:52,040 --> 01:11:54,143

If we're able to
see a low resolution

1771

01:11:55,310 --> 01:11:58,714

specter of the
atmosphere in transit

1772

01:11:58,747 --> 01:12:01,583

that showed us a dipped
for methane or CO2,

1773

01:12:01,616 --> 01:12:03,385

could tell us something
about, what those...

1774

01:12:03,418 --> 01:12:04,953

First all, if there is
an atmosphere right?

1775

01:12:04,986 --> 01:12:06,822

That's the first thing,
and then the second,

1776

01:12:06,855 --> 01:12:09,057

what would that
atmosphere be composed of?

1777

01:12:09,090 --> 01:12:11,760

And I know based on
work people have done

1778

01:12:11,793 --> 01:12:14,963

in planning for observations
with James Webb of TRAPPIST

1779

01:12:14,996 --> 01:12:18,100

and a couple other systems
that that's entirely feasible.

1780

01:12:18,133 --> 01:12:21,470

It just, in a couple years,
we'll have an answer to that

1781

01:12:21,503 --> 01:12:22,404

which I think is real exciting,

1782

01:12:22,437 --> 01:12:24,239

because we know what to look at

1783

01:12:24,272 --> 01:12:26,141
and we have a
telescope very soon

1784

01:12:26,174 --> 01:12:28,243
that will allow us to
do that, so, you know,

1785

01:12:28,276 --> 01:12:29,745
wait a couple of years
and somebody will give you

1786

01:12:29,778 --> 01:12:33,415
a von Kármán Lecture
in 2022, hopefully,

1787

01:12:33,448 --> 01:12:35,517
and we'll have some
of those answers.

1788

01:12:35,550 --> 01:12:39,388
>> Would any of the large
Earth proposed, large scale

1789

01:12:39,421 --> 01:12:41,490
space station would
ferrometers be capable of

1790

01:12:41,523 --> 01:12:44,259
getting down to that
detection level, or not?

1791

01:12:44,292 --> 01:12:45,660
>> It's not a question
of resolution,

1792

01:12:45,693 --> 01:12:47,629
it's a question of
collecting area, I think.

1793

01:12:47,662 --> 01:12:50,632

For things like the
Zeeman splitting.

1794

01:12:50,665 --> 01:12:55,404

So you want a massive single
aperture and I think...

1795

01:12:57,105 --> 01:12:59,908

my gut is telling
me that, what you,

1796

01:12:59,941 --> 01:13:01,643

for that particular
experiment you need something

1797

01:13:01,676 --> 01:13:04,513

way beyond anything that
we'd be able to assemble

1798

01:13:04,546 --> 01:13:06,281

in the next 20 years.

1799

01:13:06,314 --> 01:13:07,816

>> Inquirer: Thanks.

>> You're welcome.

1800

01:13:09,083 --> 01:13:10,652

>> I have a question about,

1801

01:13:10,685 --> 01:13:13,321

since you've reached
that far in the galaxy

1802

01:13:13,354 --> 01:13:16,057

what about the dark matter?

1803

01:13:16,090 --> 01:13:19,828

Have you ever considered,
since you talked about masses

1804

01:13:19,861 --> 01:13:23,866
and taking that [mumbles]
the controversial...

1805

01:13:26,234 --> 01:13:29,638
Aspect of dark matter
and they're trying

1806

01:13:29,671 --> 01:13:32,140
right now to change
the equation.

1807

01:13:32,173 --> 01:13:34,309
>> Carey: Yeah, for the...
>> Have you looked at that?

1808

01:13:34,342 --> 01:13:37,379
>> Not for, with Spitzer,
not for our own Milky Way,

1809

01:13:39,080 --> 01:13:41,016
I know for external galaxies

1810

01:13:41,049 --> 01:13:42,584
there's been a lot
of observations

1811

01:13:42,617 --> 01:13:46,254
in conjunction with either
ground based spectrographs

1812

01:13:46,287 --> 01:13:49,291
or Hubble to get some measure
of the velocity dispersion.

1813

01:13:49,324 --> 01:13:50,992
Spitzer gives you very well,

1814

01:13:51,025 --> 01:13:54,796

the visible mass
density of the galaxy.

1815

01:13:54,829 --> 01:13:57,566

So the combination of we're
getting rotation curves

1816

01:13:57,599 --> 01:13:59,734

and visible masses
help to determine

1817

01:13:59,767 --> 01:14:04,439

what the dark matter halos are,
for fairly nearby galaxies.

1818

01:14:04,472 --> 01:14:06,174

So, and you know...

1819

01:14:06,207 --> 01:14:10,412

>> I was also wondering, the
Webb might be able to actually

1820

01:14:11,379 --> 01:14:14,783

look at that more accurately?

1821

01:14:14,816 --> 01:14:18,353

>> Yeah, actually Webb will be
able to do that as well, yeah.

1822

01:14:18,386 --> 01:14:21,723

>> Okay, I want to make
a final comment here

1823

01:14:21,756 --> 01:14:25,060

about the budgeting
and thing with that.

1824

01:14:25,093 --> 01:14:29,164

We had, for the
Magellan Spacecraft,

1825

01:14:29,197 --> 01:14:31,666

we had the design for one year

1826

01:14:31,699 --> 01:14:34,369

and that were to
operate for 40 years

1827

01:14:34,402 --> 01:14:38,707

and they cut the
funding after that,

1828

01:14:38,740 --> 01:14:41,643

although it could operate
for much longer than that.

1829

01:14:43,511 --> 01:14:47,182

Unfortunately, people who make
decision to cut the funding

1830

01:14:47,215 --> 01:14:50,252

are not the one who
actually do the work...

1831

01:14:50,285 --> 01:14:52,587

>> Yeah, no that's
a fair comment.

1832

01:14:52,620 --> 01:14:53,822

I think there's a
lot of good science

1833

01:14:53,855 --> 01:14:55,056

that could continue to be done

1834

01:14:55,089 --> 01:14:57,125

with a lot of

existing facilities,

1835

01:14:57,158 --> 01:14:58,627

and it's just a
question of priority.

1836

01:14:58,660 --> 01:15:01,429

So, I understand, the folks
who make those decisions

1837

01:15:01,462 --> 01:15:04,199

actually have a really
hard job in prioritizing.

1838

01:15:05,300 --> 01:15:07,402

[inaudible]

1839

01:15:07,435 --> 01:15:10,839

Oh yeah, let me put my
glasses on... okay...

1840

01:15:10,872 --> 01:15:13,075

So we have a couple
from the web, I guess.

1841

01:15:14,876 --> 01:15:18,046

So Hassid asked, "Are
there any other telescopes

1842

01:15:18,079 --> 01:15:20,782

"working infrared in space?"

1843

01:15:22,517 --> 01:15:25,320

Well James Webb will
be working very soon.

1844

01:15:25,353 --> 01:15:28,957

There's the WISE mission, which
is actually doing a survey,

1845

01:15:28,990 --> 01:15:30,825

it's in it's extended mission,

1846

01:15:30,858 --> 01:15:33,161

so it does a, it's

a survey of the sky

1847

01:15:33,194 --> 01:15:34,896

and it's operating

in bands very close

1848

01:15:34,929 --> 01:15:37,532

to what IRAC is doing

now for Spitzer,

1849

01:15:37,565 --> 01:15:38,767

so it's very complimentary,

1850

01:15:38,800 --> 01:15:40,835

and one of the things

WISE is doing actually,

1851

01:15:40,868 --> 01:15:43,038

is looking for

near-Earth objects.

1852

01:15:43,071 --> 01:15:45,006

Near-Earth asteroids and comets

1853

01:15:45,039 --> 01:15:47,309

using the infrared,

so that's one.

1854

01:15:47,342 --> 01:15:51,846

And then, not in space, but

very close to space is Sophia,

1855

01:15:51,879 --> 01:15:54,215

which has a huge

compliment of instruments

1856

01:15:54,248 --> 01:15:57,218
because they can change them
out because it's on a plane.

1857

01:15:57,251 --> 01:15:59,421
So, that's another
telescope that's working in,

1858

01:15:59,454 --> 01:16:01,923
sort of near, space
in the infrared.

1859

01:16:01,956 --> 01:16:03,792
Okay, and then I have
one from Will here,

1860

01:16:03,825 --> 01:16:05,761
Okay, he asked, "How
much gas is left?"

1861

01:16:07,362 --> 01:16:08,630
"Could you line
up the telescopes

1862

01:16:08,663 --> 01:16:11,232
"with CubeSats to make
communication link?"

1863

01:16:11,265 --> 01:16:13,268
Those are very good questions.

1864

01:16:13,301 --> 01:16:15,403
So, I think the first
one is about the gas,

1865

01:16:15,436 --> 01:16:16,771
the reaction gas.

1866

01:16:16,804 --> 01:16:18,974

So Spitzer has a
tank of nitrogen,

1867

01:16:19,007 --> 01:16:22,010

which is used to dump momentum
from the reaction wheels.

1868

01:16:22,043 --> 01:16:26,114

We had 15 kilograms to start,
we have more than seven now.

1869

01:16:26,147 --> 01:16:28,350

So we have plenty
of gas to do that.

1870

01:16:28,383 --> 01:16:30,885

Otherwise, we move entirely
on the reaction wheels.

1871

01:16:30,918 --> 01:16:32,954

So the big thing with Spitzer is

1872

01:16:32,987 --> 01:16:35,290

if a reaction wheel breaks,
then it's harder to move.

1873

01:16:35,323 --> 01:16:39,427

We have four, we could
operate on three very easily,

1874

01:16:39,460 --> 01:16:42,364

two would make engineers do
things they don't want to do,

1875

01:16:42,397 --> 01:16:44,733

and we'd not be
able to afford it.

1876

01:16:44,766 --> 01:16:47,235
Linking up with CubeSats to
make the communications link.

1877
01:16:47,268 --> 01:16:48,737
I think the answer
to that is no.

1878
01:16:48,770 --> 01:16:50,672
Because the CubeSats
are too small

1879
01:16:50,705 --> 01:16:53,575
to provide enough collecting
area to be a repeater.

1880
01:16:53,608 --> 01:16:55,710
I mean, because you
would need something

1881
01:16:55,743 --> 01:16:58,446
with as much power as
probably the Spitzer,

1882
01:16:58,479 --> 01:17:00,015
or a high gain
antenna to do that,

1883
01:17:00,048 --> 01:17:01,516
and I don't think
you could fit that

1884
01:17:01,549 --> 01:17:04,319
in a CubeSat form factor, but
that's an interesting idea.

1885
01:17:04,352 --> 01:17:05,687
Okay, so I think those
are from the web,

1886

01:17:05,720 --> 01:17:06,921
and you had a question sir?

1887

01:17:06,954 --> 01:17:08,189
>> Yes, first of all,
I'd just like to say

1888

01:17:08,222 --> 01:17:09,557
thank you very much for
your time this evening,

1889

01:17:09,590 --> 01:17:11,159
it's been very, very
informational...

1890

01:17:11,192 --> 01:17:12,360
>> Carey: Thank you.

1891

01:17:12,393 --> 01:17:13,795
>> One question that
I've taken away,

1892

01:17:13,828 --> 01:17:15,597
is so far with the discovery
of all the exoplanets

1893

01:17:15,630 --> 01:17:18,233
that Spitzer's of
course been involved in,

1894

01:17:18,266 --> 01:17:20,502
am I to infer from
this that we're finding

1895

01:17:20,535 --> 01:17:23,271
an extraordinarily
high percentage

1896

01:17:23,304 --> 01:17:24,773
that are actually

tidally locked?

1897

01:17:24,806 --> 01:17:27,509

And if so, is there
a reason for that,

1898

01:17:27,542 --> 01:17:29,577

that they've been
able to ascertain?

1899

01:17:29,610 --> 01:17:31,713

>> So, the ones tidally locked

1900

01:17:31,746 --> 01:17:34,916

are because of
proximity to the star.

1901

01:17:34,949 --> 01:17:38,987

It's just the, it's a
question of orbital dynamics.

1902

01:17:39,020 --> 01:17:41,423

So, it's a selection
effect, I think,

1903

01:17:41,456 --> 01:17:45,460

in that the planets
that are orbiting...

1904

01:17:45,493 --> 01:17:48,630

closer in, are easier to
observe if the geometry's right

1905

01:17:48,663 --> 01:17:50,632

from transiting and
they're also the ones

1906

01:17:50,665 --> 01:17:52,534

that we can
characterize the best.

1907

01:17:52,567 --> 01:17:55,837

So, you see this
population preferentially.

1908

01:17:57,305 --> 01:18:00,975

I'm blanking on what
Kepler's shown in terms of

1909

01:18:01,008 --> 01:18:04,112

total planetary statistics
about the distribution.

1910

01:18:04,145 --> 01:18:06,414

I mean, the idea of these
in-close, hot Jupiters

1911

01:18:06,447 --> 01:18:09,050

was something that people
who modeled systems

1912

01:18:09,083 --> 01:18:12,654

before they were
discovered hadn't expected.

1913

01:18:12,687 --> 01:18:14,823

Just because dynamically
you had to figure out

1914

01:18:14,856 --> 01:18:17,759

how to get them there,
but now I think they've,

1915

01:18:17,792 --> 01:18:19,961

the models accommodate
this very well.

1916

01:18:19,994 --> 01:18:22,530

But I think really
when we focus on it,

1917

01:18:22,563 --> 01:18:23,965

it's really just a
selection effect.

1918

01:18:23,998 --> 01:18:25,300

It's not that these
are more prevalent,

1919

01:18:25,333 --> 01:18:26,735

but they're very interesting.

1920

01:18:26,768 --> 01:18:27,936

>> Inquirer: Got ya.

>> Okay.

1921

01:18:27,969 --> 01:18:28,737

>> Inquirer: Thank

you very much.

1922

01:18:28,770 --> 01:18:29,504

>> You're welcome.

1923

01:18:33,241 --> 01:18:35,110

Well, thank you for your time.