1
00:00:01,634 --> 00:00:05,138
- [Narrator] NASA's Jet
Propulsion Laboratory presents

2
00:00:05,138 --> 00:00:08,608
the Von Kármán Lecture, a
series of talks by scientists

3
00:00:08,608 --> 00:00:11,911
and engineers who are
exploring our planet,

4
00:00:11,911 --> 00:00:15,515
our solar system, and
all that lies beyond.

5
00:00:28,394 --> 00:00:30,663
- Hey, good evening
ladies and gentlemen.

6
00:00:30,663 --> 00:00:32,631
How's everyone tonight?

7
00:00:32,631 --> 00:00:33,999
Good, good, good.

8
00:00:33,999 --> 00:00:35,001
I'm well, thanks.

9
00:00:35,001 --> 00:00:36,402
(laughs)

10
00:00:36,402 --> 00:00:37,704
Well, thanks for
everybody for coming out.

11
00:00:37,704 --> 00:00:39,072
We really appreciate you
coming out to visit us.

12
00:00:39,072 --> 00:00:40,573
So, here we go.

13
00:00:40,573 --> 00:00:43,876
Scheduled to launch in 2018,
the James Webb Space Telescope,

14
00:00:43,876 --> 00:00:48,181
or JWST, will revolutionize
our study of the cosmos.

15
00:00:48,181 --> 00:00:50,550
Built to address the questions
asked by the Hubble and

16
00:00:50,550 --> 00:00:53,920
Spitzer Space Telescopes,
but out of their reach,

17
00:00:53,920 --> 00:00:58,691
JWST will look deeper than
either of those telescopes at

18
00:00:58,691 --> 00:01:01,561
infrared wavelengths with a
suite of instruments that have

19
00:01:01,561 --> 00:01:04,663
capabilities that were
not previously available.

20
00:01:04,663 --> 00:01:07,499
Tonight's talk will
describe JWST as a whole,

21
00:01:07,499 --> 00:01:11,170
but will focus on
the mid-infrared
instrument, or MIRI,

22
00:01:11,170 --> 00:01:14,207
one of the four instruments
attached to JWST,

23
00:01:14,207 --> 00:01:16,609
which was built as a
partnership between JPL and

24
00:01:16,609 --> 00:01:20,013
a consortium of European
astronomical institutes.

25
00:01:20,013 --> 00:01:23,316
Tonight's guest is the JPL
project scientist for MIRI,

26
00:01:23,316 --> 00:01:25,751
and it's his responsibility
to ensure that the JPL

27
00:01:25,751 --> 00:01:28,754
contributions to MIRI will
enable it to perform the

28
00:01:28,754 --> 00:01:32,091
observations desired by
the astronomical community.

29
00:01:32,091 --> 00:01:34,093
He received his Bachelors
Degree in Physics

30
00:01:34,093 --> 00:01:37,363
from MIT in 1986, following
by a PhD in Astronomy

31
00:01:37,363 --> 00:01:41,801
from the University of
Hawaii at Manoa in 1992.

32
00:01:41,801 --> 00:01:44,670
He came to JPL after graduation
as a National Research

33
00:01:44,670 --> 00:01:46,673
Council post-doctoral fellow,

34
00:01:46,673 --> 00:01:49,575
and joined the
JPL staff in 1994.

35
00:01:49,575 --> 00:01:51,610
He's been involved in
building infrared astronomical

36
00:01:51,610 --> 00:01:53,813
instruments since he
was an undergraduate,

37
00:01:53,813 --> 00:01:56,282
and has specialized in
understanding the design and

38
00:01:56,282 --> 00:01:59,518
operation of the detectors
in these instruments.

39
00:01:59,518 --> 00:02:02,154
Ground-based instruments he
has worked on have been used

40
00:02:02,154 --> 00:02:05,591
on the Keck Telescopes, the
Palomar 200-inch telescope,

41
00:02:05,591 --> 00:02:08,995
and the three-meter NASA
infrared telescope facility.

42
00:02:08,995 --> 00:02:11,164
He is also a member of the
science team, and is a detector

43
00:02:11,164 --> 00:02:14,667
specialist for the
WISE All-Sky Survey,

44
00:02:14,667 --> 00:02:17,537
where he had the distinction
of having the first scientific

45
00:02:17,537 --> 00:02:20,773
paper published using
results from that mission.

46
00:02:20,773 --> 00:02:23,042
His scientific interests
focus on the early stages of

47
00:02:23,042 --> 00:02:25,778
the formation of stars, but
he has also been involved in

48
00:02:25,778 --> 00:02:28,681
a broad range of research
topics from asteroid studies

49
00:02:28,681 --> 00:02:31,284
to infrared bright galaxies.

50
00:02:31,284 --> 00:02:32,818
Ladies and gentlemen,
please help me welcome

51
00:02:32,818 --> 00:02:35,321
tonight's guest,
Dr. Michael Ressler.

52

00:02:35,321 --> 00:02:37,557
(applause)

53
00:02:42,996 --> 00:02:44,230
- Thanks, Mark.

54
00:02:45,598 --> 00:02:47,066
Good evening, and thank
you all for coming.

55
00:02:47,066 --> 00:02:50,570
This is great, and I am pleased
to talk a little bit about

56
00:02:50,570 --> 00:02:53,572
the James Webb Space
Telescope, which is NASA's next

57
00:02:53,572 --> 00:02:55,941
flagship space observatory.

58
00:02:55,941 --> 00:03:00,179
The Hubble Space Telescope
is an amazing instrument.

59
00:03:00,179 --> 00:03:04,083
It's had an immense impact
on how we understand

60
00:03:05,985 --> 00:03:07,554
our universe.

61
00:03:07,554 --> 00:03:09,989
It's taken images of
things from galaxies at the

62
00:03:09,989 --> 00:03:12,492
far edge of our universe
right down to Mars

63
00:03:12,492 --> 00:03:14,661
and everything in between.

64
00:03:15,861 --> 00:03:19,365
Its images inspire
us, they amaze us,

65
00:03:19,365 --> 00:03:22,368
and occasionally
they even amuse us.

66
00:03:23,302 --> 00:03:25,004
(laughing)

67
00:03:25,004 --> 00:03:27,740
So the universe is
smiling back at you.

68
00:03:27,740 --> 00:03:31,010
But this image is actually
very scientifically important

69
00:03:31,010 --> 00:03:34,614
as well as being a neat
little smiley face.

70
00:03:36,082 --> 00:03:39,786
These yellowish galaxies are
relatively nearby galaxies,

71
00:03:40,720 --> 00:03:42,155
and they're mature.

72
00:03:42,155 --> 00:03:44,690
They have sort of normal
stars like we'd see in our sky

73
00:03:44,690 --> 00:03:49,262
right now, things that

are millions to billions

74
00:03:49,262 --> 00:03:54,033
of years old, and so they're
very mature galaxies.

75
00:03:54,033 --> 00:03:57,704
The gravity from these
galaxies acts as a lens so that

76
00:03:57,704 --> 00:04:01,207
galaxies behind other galaxies
behind them are actually

77
00:04:01,207 --> 00:04:05,911
focused by the gravity
from these older galaxies.

78
00:04:05,911 --> 00:04:08,814
Why this is important is
these streaks that make up

79
00:04:08,814 --> 00:04:13,019
our smiley face are very
young galaxies that we see

80
00:04:13,019 --> 00:04:14,820
much farther back in time.

81
00:04:14,820 --> 00:04:17,756
They started to form
closer to the beginning of

82
00:04:17,756 --> 00:04:20,292
the universe, near the Big Bang.

83
00:04:20,292 --> 00:04:24,163
And so these brightish blue
streaks are where the stars

84
00:04:24,163 --> 00:04:26,732
are being formed
in these galaxies.

85
00:04:26,732 --> 00:04:30,436
Part of the reason this is
important is the gravity lens

86
00:04:30,436 --> 00:04:33,305
makes them appear brighter
than they would otherwise,

87
00:04:33,305 --> 00:04:35,708
which means that with our
telescopes they're easier

88
00:04:35,708 --> 00:04:37,509
for us to see.

89
00:04:37,509 --> 00:04:39,912
And until this spring in
fact, the farthest galaxies

90
00:04:39,912 --> 00:04:42,348
that we knew about were
all these gravitationally

91
00:04:42,348 --> 00:04:43,982
lensed galaxies.

92
00:04:43,982 --> 00:04:46,452
This was the only way
that we could see them.

93
00:04:46,452 --> 00:04:50,189
Then in March it was announced,
well I should back up.

94
00:04:50,189 --> 00:04:52,558

One of the things that Hubble
has done is taken a number of

95
00:04:52,558 --> 00:04:55,361
deep fields, these are
regions of sky that we thought

96
00:04:55,361 --> 00:04:58,864
were pretty blank, but Hubble
pointed at them for many,

97
00:04:58,864 --> 00:05:01,300
many hours, many
hours of exposures.

98
00:05:01,300 --> 00:05:04,771
And when we look at them, we
see fields that look like this.

99
00:05:04,771 --> 00:05:08,874
Almost everything in this
image is a galaxy except for

100
00:05:08,874 --> 00:05:10,643
that one star
sitting right there.

101
00:05:10,643 --> 00:05:12,377
Everything else is a galaxy.

102
00:05:12,377 --> 00:05:15,581
When we looked carefully at
this image, there is a little

103
00:05:15,581 --> 00:05:19,652
speck that when you zoom
it in looks like a blob.

104
00:05:21,154 --> 00:05:23,989
My wife would say everything

I look at is a fuzzy blob.

105
00:05:23,989 --> 00:05:27,593
But it's this little galaxy
that turns out to have formed

106
00:05:27,593 --> 00:05:31,797
about 300 million years
after the Big Bang.

107
00:05:31,797 --> 00:05:33,165
It's very, very far away.

108
00:05:33,165 --> 00:05:36,135
It happens to be very bright.

109
00:05:36,135 --> 00:05:38,937
It's intrinsically bright,
and so we could detect it

110
00:05:38,937 --> 00:05:40,439
with Hubble.

111
00:05:40,439 --> 00:05:43,809
Most of the others we have
to rely on the universe

112
00:05:43,809 --> 00:05:46,278
lensing it for us using
other galaxies as telescopes

113
00:05:46,278 --> 00:05:48,680
to help us see these things.

114
00:05:48,680 --> 00:05:50,649
But these are some of the
breakthroughs that Hubble

115
00:05:50,649 --> 00:05:53,218

has helped us make when
we're trying to understand

116
00:05:53,218 --> 00:05:54,654
the far universe.

117
00:05:57,623 --> 00:05:59,291
This is actually one of
my favorite pictures that

118
00:05:59,291 --> 00:06:00,526
Hubble has taken.

119
00:06:00,526 --> 00:06:02,928
This is a planetary nebula.

120
00:06:02,928 --> 00:06:05,864
This is a nearby star within
our own galaxy that's at

121
00:06:05,864 --> 00:06:08,968
the end, nearing
the end of its life.

122
00:06:10,135 --> 00:06:12,538
Stars as they age, if
they're massive enough,

123
00:06:12,538 --> 00:06:16,375
if they're big enough, start
to blow off their outer layers.

124
00:06:16,375 --> 00:06:19,244
Stars are kinda like
onions, they have layers.

125
00:06:19,244 --> 00:06:22,482
But at the end phases they
become a little unstable,

126
00:06:22,482 --> 00:06:25,851
and they start, the energy
from the star starts pushing

127
00:06:25,851 --> 00:06:27,854
those outer layers away.

128
00:06:29,255 --> 00:06:31,990
Occasionally if there's two
stars in here, so the old dying

129
00:06:31,990 --> 00:06:35,327
star and another star
that's orbiting with it,

130
00:06:35,327 --> 00:06:38,097
it can shape the planetary
nebula, and it produces these

131
00:06:38,097 --> 00:06:39,965
beautiful structures.

132
00:06:39,965 --> 00:06:44,336
This is called the Twin Jet
Nebula because it looks like

133
00:06:44,336 --> 00:06:47,139
it has jets material shooting
away both directions.

134
00:06:47,139 --> 00:06:49,541
And one of the things I
like about this image,

135
00:06:49,541 --> 00:06:52,578
not only because it's pretty,
it has lots of neat colors,

136
00:06:52,578 --> 00:06:55,280

but if you look carefully and
notice, there's some bright

137
00:06:55,280 --> 00:06:58,016
spots in here on both sides.

138
00:06:58,016 --> 00:07:00,419
I think what's going on, and
I haven't talked to scientists

139
00:07:00,419 --> 00:07:03,322
that have done these
observations, but
what they think is

140
00:07:03,322 --> 00:07:08,261
going on is that there's a lot
of material near that star,

141
00:07:08,261 --> 00:07:11,964
a lot of dust and material
that blew off from the star

142
00:07:11,964 --> 00:07:15,033
that's condensing, but it's
kind of patchy like clouds

143
00:07:15,033 --> 00:07:16,502
in the sky.

144
00:07:16,502 --> 00:07:18,604
And so if you go out some
night where it's partly cloudy

145
00:07:18,604 --> 00:07:21,173
and see the sunset, there
are rays of sunlight that

146
00:07:21,173 --> 00:07:24,110
burst through little

patches in the clouds.

147
00:07:24,110 --> 00:07:26,378
Well, we think that's
what's going on here.

148
00:07:26,378 --> 00:07:28,881
So there's starlight that's
escaping through those

149
00:07:28,881 --> 00:07:32,318
little patches, and then
lighting up the walls with

150
00:07:32,318 --> 00:07:36,489
a little more starlight than
other places are getting.

151
00:07:37,857 --> 00:07:39,492
And then just the overall
structure, the fact that you see

152
00:07:39,492 --> 00:07:42,327
all this fine detail, it's
really a spectacular image,

153
00:07:42,327 --> 00:07:44,997
and I do think it's very pretty.

154
00:07:46,398 --> 00:07:50,369
So Hubble has done, this is
the amazing and inspiring part.

155
00:07:51,803 --> 00:07:53,873
To talk about a successor to
Hubble I actually have to talk

156
00:07:53,873 --> 00:07:56,241
a little bit about
another space telescope.

157
00:07:56,241 --> 00:07:58,777
This is the Spitzer Space
Telescope that was launched in

158
00:07:58,777 --> 00:08:02,882
2003, and that was actually a
mission managed here at JPL.

159
00:08:06,052 --> 00:08:08,520
Spitzer also looked at some
of those deep fields that

160
00:08:08,520 --> 00:08:12,024
Hubble looked at, and
this is one of them.

161
00:08:12,024 --> 00:08:14,794
Not the same one I showed you
before, but it's another one.

162
00:08:14,794 --> 00:08:18,630
Every one of these little
red dots in here is a galaxy

163
00:08:18,630 --> 00:08:20,499
that Spitzer detected.

164
00:08:20,499 --> 00:08:25,037
Again, that's very far
away, very young in terms of

165
00:08:25,037 --> 00:08:27,339
the age of the universe.

166
00:08:27,339 --> 00:08:29,508
And what they found is there
are far more of these galaxies

167

00:08:29,508 --> 00:08:31,677
than we had expected.

168
00:08:31,677 --> 00:08:33,845
To have this many galaxies
within a few hundred million

169
00:08:34,413 --> 00:08:38,017
years of the Big Bang implies
that the process of forming

170
00:08:38,951 --> 00:08:40,786
galaxies happens very early.

171
00:08:40,786 --> 00:08:43,488
We might have expected that
you form a few stars first,

172
00:08:43,488 --> 00:08:46,559
and then more stars would
form, and then eventually

173
00:08:46,559 --> 00:08:48,427
there would be enough of
them that the gravity between

174
00:08:48,427 --> 00:08:50,630
the stars would start
making galaxies.

175
00:08:50,630 --> 00:08:54,900
But this implies that that
one at a time sort of thing

176
00:08:54,900 --> 00:08:56,401
isn't the way it works.

177
00:08:56,401 --> 00:08:59,772
Somehow we form galaxies and
stars almost at the same time

178
00:08:59,772 --> 00:09:00,907
very early on.

179
00:09:03,909 --> 00:09:06,311
Some people know what
images with infrared cameras

180
00:09:06,311 --> 00:09:08,213
look like, and they're
not often very good.

181
00:09:08,213 --> 00:09:09,916
So people wonder well, can
an infrared telescope take

182
00:09:09,916 --> 00:09:11,250
pretty pictures?

183
00:09:12,151 --> 00:09:13,819
Well, the answer is yes.

184
00:09:13,819 --> 00:09:15,855
This is an image from the
Spitzer Space Telescope

185
00:09:15,855 --> 00:09:17,889
of a star forming region.

186
00:09:17,889 --> 00:09:20,392
You see a lot of young
stars in a cluster here

187
00:09:20,392 --> 00:09:22,795
near the most, there's a
lot of material right here

188
00:09:22,795 --> 00:09:26,331
that forms stars, and it's

just a very impressive picture.

189
00:09:26,331 --> 00:09:30,503
So yes, infrared telescopes
can take pretty pictures, too.

190
00:09:32,204 --> 00:09:35,040
Looking at the results
of Spitzer and of Hubble,

191
00:09:35,040 --> 00:09:38,810
astronomers actually 20 years
ago already started asking,

192
00:09:38,810 --> 00:09:40,746
what do we do after Hubble?

193
00:09:40,746 --> 00:09:44,750
What science questions
do we think will still be

194
00:09:44,750 --> 00:09:47,519
out there that we need
something even more than Hubble

195
00:09:47,519 --> 00:09:49,822
can help us understand?

196
00:09:49,822 --> 00:09:53,859
And so over the years scientists
collected results that

197
00:09:53,859 --> 00:09:56,262
they were obtaining and said
okay, well here are some of

198
00:09:56,262 --> 00:09:57,730
the open questions.

199

00:09:57,730 --> 00:10:00,098
And so there were four science
themes, four science goals

200
00:10:00,098 --> 00:10:04,270
that were set before the
people designing the Webb Space

201
00:10:05,938 --> 00:10:08,440
Telescope, and said here's
what we wanna be able to do.

202
00:10:08,440 --> 00:10:09,875
And here's what they are.

203
00:10:09,875 --> 00:10:12,744
We wanna discover and confirm
the first light-emitting

204
00:10:12,744 --> 00:10:14,679
objects in the universe.

205
00:10:14,679 --> 00:10:17,516
So right after the Big
Bang, stars had to start

206
00:10:17,516 --> 00:10:18,951
forming somehow.

207
00:10:18,951 --> 00:10:20,252
How did that happen?

208
00:10:20,252 --> 00:10:22,488
We'd like to see what
those stars looked like,

209
00:10:22,488 --> 00:10:24,823
what their properties are.

210

00:10:24,823 --> 00:10:26,659
Next we'd like to
understand how those early

211
00:10:26,659 --> 00:10:28,026
galaxies formed.

212
00:10:28,026 --> 00:10:31,563
If they didn't from
pulling stars together,

213
00:10:31,563 --> 00:10:34,166
just how did that process work?

214
00:10:35,634 --> 00:10:37,836
In that Spitzer image that
I showed you a lot of those

215
00:10:37,836 --> 00:10:41,440
galaxies aren't the big things
that we see nearby us today.

216
00:10:41,440 --> 00:10:44,810
They're these little clumps
of stars, maybe hundreds of

217
00:10:44,810 --> 00:10:47,646
thousands of stars forming
that little galaxy,

218
00:10:47,646 --> 00:10:49,381
and so they had
to merge somehow.

219
00:10:49,381 --> 00:10:50,883
How did that work?

220
00:10:52,083 --> 00:10:53,752
We'd like to look at the
earliest steps of the

221
00:10:53,752 --> 00:10:56,522
birth of stars, even
in our own galaxy.

222
00:10:56,522 --> 00:10:59,024
We'll talk about why you
need infrared telescopes

223
00:10:59,024 --> 00:11:02,727
to study star formation,
but we want more information

224
00:11:02,727 --> 00:11:04,730
on how they work.

225
00:11:04,730 --> 00:11:06,765
We wanna see the stars that
are a thousand years old

226
00:11:06,765 --> 00:11:08,767
to 10 thousand years old.

227
00:11:08,767 --> 00:11:10,803
What we typically see now is
in the hundreds of thousands

228
00:11:10,803 --> 00:11:12,038
of years range.

229
00:11:13,372 --> 00:11:15,607
And then finally, planets
form around stars.

230
00:11:15,607 --> 00:11:18,644
Thanks to the Kepler
Telescope we now know of

231
00:11:18,644 --> 00:11:22,214

thousands of planets
that orbit stars in those

232
00:11:22,214 --> 00:11:24,349
particular patches of sky.

233
00:11:24,349 --> 00:11:26,051
We'd like to know more
about those planets.

234
00:11:26,051 --> 00:11:28,554
What can we say about
how the planets evolved?

235
00:11:28,554 --> 00:11:33,192
And ultimately, if we're
lucky, do they have conditions

236
00:11:33,192 --> 00:11:34,993
that would support life?

237
00:11:34,993 --> 00:11:36,628
So these are some of the
things that we'd like the

238
00:11:36,628 --> 00:11:39,465
Webb Telescope to
help us address.

239
00:11:41,233 --> 00:11:44,336
And this is the concept
they came up with.

240
00:11:44,336 --> 00:11:47,873
I'll just point out a couple
of things before we move along.

241
00:11:47,873 --> 00:11:50,009
All telescopes have
a primary mirror.

242
00:11:50,009 --> 00:11:52,077
All large telescopes have
a primary mirror that

243
00:11:52,077 --> 00:11:53,645
collects the light.

244
00:11:53,645 --> 00:11:56,314
So light comes in from your
object, it reflects off that

245
00:11:56,314 --> 00:12:00,052
primary mirror, bounces off
a small secondary mirror that

246
00:12:00,052 --> 00:12:03,489
relays the light back through
a hole in the primary mirror,

247
00:12:03,489 --> 00:12:05,691
and then there are scientific
instruments that sit

248
00:12:05,691 --> 00:12:09,161
behind the mirror that
either collect it as images

249
00:12:09,161 --> 00:12:13,399
or break it into spectra
where we can study what the

250
00:12:13,399 --> 00:12:15,868
composition of
those sources are.

251
00:12:15,868 --> 00:12:18,603
There is a big tennis
court sized sunshield.

252
00:12:18,603 --> 00:12:20,605
It's that diamond-shaped
structure.

253
00:12:20,605 --> 00:12:22,875
This protects the
telescope from sunlight and

254
00:12:22,875 --> 00:12:25,611
earth light because both
of them are bad for our

255
00:12:25,611 --> 00:12:27,746
scientific observations.

256
00:12:27,746 --> 00:12:30,582
And then not visible
underneath is a spacecraft bus

257
00:12:30,582 --> 00:12:34,754
that has the propulsion systems
and all that sort of stuff.

258
00:12:36,187 --> 00:12:39,758
The difference between Webb
and Hubble is primarily size,

259
00:12:39,758 --> 00:12:42,527
but there are a
few more details.

260
00:12:42,527 --> 00:12:46,198
That primary mirror of Hubble,
the light collecting mirror

261
00:12:46,198 --> 00:12:49,067
up here is about 2.4
meters in diameter,

262

00:12:49,067 --> 00:12:51,437
roughly eight feet in diameter.

263
00:12:51,437 --> 00:12:55,107
If you draw a circle around
the primary mirror of the

264
00:12:55,107 --> 00:12:57,710
James Webb Space Telescope,
it's about six and a half

265
00:12:57,710 --> 00:12:59,678
meters in diameter.

266
00:12:59,678 --> 00:13:02,014
That's cheating a little bit
because part of the mirror

267
00:13:02,014 --> 00:13:05,150
is missing, so on average
it's about a six meter mirror,

268
00:13:05,150 --> 00:13:06,985
and that's a lot easier to say.

269
00:13:06,985 --> 00:13:10,188
But you'll notice there
are 18 hexagonal segments

270
00:13:10,188 --> 00:13:12,591
that make up the primary mirror.

271
00:13:12,591 --> 00:13:16,728
So not only does each individual
mirror have to be very

272
00:13:16,728 --> 00:13:19,732
precisely shaped, we have to
be able to get all 18 mirrors

273
00:13:19,732 --> 00:13:22,835
to work together as
one large mirror.

274
00:13:25,170 --> 00:13:27,038
You'll also notice that the
Hubble Space Telescope has

275
00:13:27,038 --> 00:13:29,441
a shield that baffles
it against stray light,

276
00:13:29,441 --> 00:13:31,376
whereas Webb is wide open.

277
00:13:31,376 --> 00:13:34,546
So if there's any sources
off to the side that are

278
00:13:34,546 --> 00:13:38,884
shining into the telescope,
we will see them.

279
00:13:38,884 --> 00:13:43,789
So while Webb is bigger than
Hubble, it's not a replacement.

280
00:13:43,789 --> 00:13:45,590
Early on we heard people
talking about there's a

281
00:13:45,590 --> 00:13:46,925
replacement for Hubble.

282
00:13:46,925 --> 00:13:48,560
Not really.

283
00:13:48,560 --> 00:13:52,364
Webb is designed to complement

and extend with what both

284
00:13:52,364 --> 00:13:54,600
Hubble and Spitzer
have been able to do.

285
00:13:54,600 --> 00:13:57,903
And the key feature of
Webb in order to do that is

286
00:13:57,903 --> 00:14:00,939
it has to work at
infrared wavelengths.

287
00:14:00,939 --> 00:14:03,609
So I'm gonna explain a
little bit about what

288
00:14:03,609 --> 00:14:06,878
the infrared is, why it's
important, why it's really neat,

289
00:14:06,878 --> 00:14:07,880
why I do it.

290
00:14:10,115 --> 00:14:12,717
If we shine, I
should have waited.

291
00:14:12,717 --> 00:14:15,220
If we shine a white
light through a prism,

292
00:14:15,220 --> 00:14:16,422
we get the rainbow thing.

293
00:14:16,422 --> 00:14:17,422
We've all seen that.

294

00:14:17,422 --> 00:14:18,790
You've seen rainbows in the sky.

295
00:14:18,790 --> 00:14:20,626
It's the same principle.

296
00:14:20,626 --> 00:14:23,195
It's very natural to ask
well, what's over here?

297
00:14:23,195 --> 00:14:24,663
What's past the violet?

298
00:14:24,663 --> 00:14:27,432
We also might ask
what's over here?

299
00:14:27,432 --> 00:14:29,168
What's below the red?

300
00:14:30,836 --> 00:14:33,806
William Herschel in 1800 did
an experiment where he was

301
00:14:33,806 --> 00:14:38,110
trying to measure
the temperature of
the colors of light.

302
00:14:38,110 --> 00:14:41,246
He thought that maybe
individual colors might have

303
00:14:41,246 --> 00:14:42,547
a different temperature.

304
00:14:42,547 --> 00:14:44,616
It was a good
experiment to try to do.

305
00:14:44,616 --> 00:14:47,118
So what he did is he put
a thermometer over here,

306
00:14:47,118 --> 00:14:50,022
and another thermometer of
over here as his controls,

307
00:14:50,022 --> 00:14:52,591
and then moved a thermometer
through the different

308
00:14:52,591 --> 00:14:54,226
colors of light.

309
00:14:54,226 --> 00:14:56,961
Well, what he noticed was that
the purple light was coldest,

310
00:14:56,961 --> 00:14:59,298
and the red light was warmest.

311
00:14:59,298 --> 00:15:01,300
So he did what a good
scientist would do and said,

312
00:15:01,300 --> 00:15:03,334
well gee, if it's warmest
here, what if I move off

313
00:15:03,334 --> 00:15:05,470
just to the side a little bit?

314
00:15:05,470 --> 00:15:07,806
I should see the
temperature drop, right?

315
00:15:07,806 --> 00:15:11,109
Well, it turned out that

dark space below the red

316
00:15:11,109 --> 00:15:15,514
was the warmest of all,
and that's the discovery of

317
00:15:15,514 --> 00:15:18,450
infrared radiation,
or infrared light.

318
00:15:18,450 --> 00:15:21,353
And that was the first time
we actually discovered energy,

319
00:15:21,353 --> 00:15:24,756
that light energy that we
couldn't see with our eyes.

320
00:15:24,756 --> 00:15:28,560
So it was a huge thing,
and it took a long time to

321
00:15:28,560 --> 00:15:30,695
develop instruments that
would work in the infrared,

322
00:15:30,695 --> 00:15:33,132
but it came along eventually.

323
00:15:34,666 --> 00:15:36,701
What can we do with
infrared light?

324
00:15:36,701 --> 00:15:40,339
Well, we can take
pictures of meerkats.

325
00:15:40,339 --> 00:15:41,807
I'm not sure where this
visible wavelength picture

326
00:15:41,807 --> 00:15:45,143
was taken, but this is
what meerkats look like in

327
00:15:45,143 --> 00:15:48,913
the thermal infrared, and I
think this is a lot of fun.

328
00:15:48,913 --> 00:15:51,583
You can actually learn a
lot about meerkats based on

329
00:15:51,583 --> 00:15:54,720
an infrared image of the
meerkats because you notice

330
00:15:54,720 --> 00:15:56,955
the eyes are bright.

331
00:15:56,955 --> 00:15:59,725
Your eyes are deep in your head.

332
00:15:59,725 --> 00:16:01,760
They're surrounded
by very warm tissue,

333
00:16:01,760 --> 00:16:05,898
and so they're gonna be
warmer than the average.

334
00:16:05,898 --> 00:16:07,532
Their noses on the
other hand are dark.

335
00:16:07,532 --> 00:16:09,368
You know, your nose
sticks out a little bit,

336

00:16:09,368 --> 00:16:11,603
and so it cools off
a little bit more,

337
00:16:11,603 --> 00:16:14,272
and there's not as much
blood supply in your nose,

338
00:16:14,272 --> 00:16:16,141
so it actually looks
a little bit cooler.

339
00:16:16,141 --> 00:16:19,044
Actually if you go over
to the Von Karman Museum

340
00:16:19,044 --> 00:16:21,813
just next door there is a
thermal infrared camera there,

341
00:16:21,813 --> 00:16:23,482
and you can see what
your own face looks like.

342
00:16:23,482 --> 00:16:26,118
And it won't look like a
meerkat, but it will have

343
00:16:26,118 --> 00:16:27,585
some of the same features.

344
00:16:27,585 --> 00:16:30,188
You'll also notice that
their toes are cold because

345
00:16:30,188 --> 00:16:33,592
they're on the rocks that don't
generate heat on their own.

346
00:16:33,592 --> 00:16:36,128

And so maybe we don't
learn a lot about meerkats

347
00:16:36,128 --> 00:16:39,230
in the infrared, but we
see some of the things.

348
00:16:39,230 --> 00:16:41,366
The gaps in fur are brighter
because you can see down

349
00:16:41,366 --> 00:16:43,836
closer to their skins, and
so that's why their fur

350
00:16:43,836 --> 00:16:45,070
looks so funny.

351
00:16:46,405 --> 00:16:47,505
Well, there are more
important uses for infrared,

352
00:16:47,505 --> 00:16:50,175
and one of them is firefighting.

353
00:16:51,610 --> 00:16:53,946
If you're in a room full
of smoke, it's hard to see

354
00:16:53,946 --> 00:16:58,283
anything, but infrared
wavelengths, or
smoke is actually

355
00:16:58,283 --> 00:17:01,453
relatively transparent
to infrared wavelengths.

356
00:17:01,453 --> 00:17:04,256
So if we look at the scene

with an infrared camera,

357
00:17:04,256 --> 00:17:05,991
we see there's a person
on the floor that needs

358
00:17:05,991 --> 00:17:07,159
to be rescued.

359
00:17:08,560 --> 00:17:11,029
And so same sort of thing,
he's got a bright face because

360
00:17:11,029 --> 00:17:12,564
there's a lot of
blood in your face.

361
00:17:12,564 --> 00:17:14,199
The clothing is a
little bit cooler.

362
00:17:14,199 --> 00:17:15,967
I thought it was cool the
oxygen tank on the back of

363
00:17:15,967 --> 00:17:18,871
the firefighter is
relatively cold compared to

364
00:17:18,871 --> 00:17:21,640
everything else, and
so it's very dark.

365
00:17:21,640 --> 00:17:23,942
So this demonstrates a
couple of things that we can

366
00:17:23,942 --> 00:17:25,777
take advantage of
in the infrared.

367
00:17:25,777 --> 00:17:27,679
We can see the
temperatures of things.

368
00:17:27,679 --> 00:17:31,349
We can see warm and cold, and
we can also see through smoke.

369
00:17:31,349 --> 00:17:33,384
Well, we can use those
same things in astronomy

370
00:17:33,384 --> 00:17:36,522
to help us understand
the universe around us.

371
00:17:36,522 --> 00:17:39,024
This is a little cloud of
gas and dust that's zipping

372
00:17:39,024 --> 00:17:40,592
around in our own galaxy.

373
00:17:40,592 --> 00:17:42,894
It's fairly close to us.

374
00:17:42,894 --> 00:17:45,630
All the stars you see here are
farther away than the cloud,

375
00:17:45,630 --> 00:17:49,534
so there should just be a
carpet of stars all over this.

376
00:17:49,534 --> 00:17:52,904
But because the dust in
the cloud absorbs visible

377

00:17:52,904 --> 00:17:55,673
wavelength light the same
way that smoke absorbs light,

378
00:17:55,673 --> 00:17:57,876
we can't see through the cloud.

379
00:17:57,876 --> 00:18:00,579
But if we get an infrared
camera and take another image

380
00:18:00,579 --> 00:18:03,715
of that cloud, we can see
those stars through it.

381
00:18:03,715 --> 00:18:06,117
So it turns out there's not
much going on in this cloud.

382
00:18:06,117 --> 00:18:08,620
It's just kind of quiet,
sitting there not doing much

383
00:18:08,620 --> 00:18:09,621
of anything.

384
00:18:11,723 --> 00:18:14,158
This is a visible wavelength
image of a patch of sky

385
00:18:14,158 --> 00:18:16,662
in the constellation Cassiopeia.

386
00:18:16,662 --> 00:18:18,830
We see a couple of
cool things in here.

387
00:18:18,830 --> 00:18:21,699
There's a star that must be
emitting a lot of ultraviolet

388
00:18:21,699 --> 00:18:24,803
light, and it's causing
some gas around it to glow.

389
00:18:24,803 --> 00:18:26,972
That's why it has
that red color.

390
00:18:26,972 --> 00:18:29,774
But in the rest of the
frame you see there are some

391
00:18:29,774 --> 00:18:33,611
dark streaks all along
the edges over here.

392
00:18:33,611 --> 00:18:35,681
And it's not because
there are not stars there.

393
00:18:35,681 --> 00:18:37,148
The stars aren't missing.

394
00:18:37,148 --> 00:18:40,185
There's stuff in front of
the stars blocking the light.

395
00:18:40,185 --> 00:18:43,121
So if we take an infrared
image of the same area,

396
00:18:43,121 --> 00:18:45,357
we see a number of
things popping up.

397
00:18:45,357 --> 00:18:47,425
First of all, there's a
lot of dust that's glowing

398
00:18:47,425 --> 00:18:50,328
brightly in here, but
all these very red stars

399
00:18:50,328 --> 00:18:53,332
suddenly pop into
our field of view.

400
00:18:54,766 --> 00:18:58,136
Stars form in clouds of gas
and dust, so these clouds,

401
00:18:58,136 --> 00:19:03,007
there's enough material
there that gravity pulls that

402
00:19:03,007 --> 00:19:07,378
dust together and heats up
and begins to form stars.

403
00:19:07,378 --> 00:19:09,514
And so these are the stars
that I were talking about.

404
00:19:09,514 --> 00:19:12,617
These are the things that
are kind of 10,000 years old,

405
00:19:12,617 --> 00:19:14,552
sort of the baby stars.

406
00:19:14,552 --> 00:19:18,122
And we can't see them any
other way than in the infrared

407
00:19:18,122 --> 00:19:20,792
because the dust absorbs them.

408
00:19:20,792 --> 00:19:23,094

And so with our infrared
cameras, if we wanna study how

409
00:19:23,094 --> 00:19:25,764
stars form, this
is how we do it.

410
00:19:25,764 --> 00:19:27,766
We go into the infrared.

411
00:19:29,201 --> 00:19:31,202
You'll notice this little
box over here that still has

412
00:19:31,202 --> 00:19:33,137
the visible wavelength image.

413
00:19:33,137 --> 00:19:37,576
If I put the infrared part of
there, you see this big ring

414
00:19:37,576 --> 00:19:39,544
of gas and dust.

415
00:19:39,544 --> 00:19:43,414
There was a supernova there
in 1572, Tycho Supernova,

416
00:19:43,414 --> 00:19:46,051
that blew out this shell of
material, but the material is

417
00:19:46,051 --> 00:19:48,019
actually still very cold.

418
00:19:48,019 --> 00:19:50,522
So the only way we see it
is at infrared wavelengths

419

00:19:50,522 --> 00:19:53,292
where we detect
the heat from it.

420
00:19:53,292 --> 00:19:55,026
Now it's much colder than
the room temperature,

421
00:19:55,026 --> 00:19:57,162
but it's warm enough
that we can see it.

422
00:19:57,162 --> 00:19:59,897
So in this image we
demonstrated those two features

423
00:19:59,897 --> 00:20:01,566
of the infrared that we like.

424
00:20:01,566 --> 00:20:04,736
We can see through dust,
and we can also see

425
00:20:04,736 --> 00:20:06,238
very cold objects.

426
00:20:09,174 --> 00:20:11,209
So there's one more scientific
technique I need to talk

427
00:20:11,209 --> 00:20:13,811
a little bit about, and
that's spectroscopy,

428
00:20:13,811 --> 00:20:16,147
taking the spectrum of a source.

429
00:20:16,147 --> 00:20:19,217
So if you remember when we
shone white light through

430
00:20:19,217 --> 00:20:22,019
the prism, we got that
colored rainbow, so we got all

431
00:20:22,019 --> 00:20:24,656
the colors from the white light.

432
00:20:24,656 --> 00:20:27,659
If I take a tube of hydrogen
gas and pass an electric

433
00:20:27,659 --> 00:20:31,429
current through it, it turns
the hydrogen into a plasma,

434
00:20:31,429 --> 00:20:35,066
and it glows this kind of
pinkish purplish color.

435
00:20:35,066 --> 00:20:37,202
Well, if I look at that
tube through a prism,

436
00:20:37,202 --> 00:20:41,172
what I'll see is multiple
images of the tube,

437
00:20:41,172 --> 00:20:43,741
but I only see very
discrete colors.

438
00:20:43,741 --> 00:20:45,643
I don't see a full rainbow.

439
00:20:45,643 --> 00:20:49,348
Well, it turns out all
atoms have a signature,

440

00:20:49,348 --> 00:20:50,882
a thumbprint.

441
00:20:50,882 --> 00:20:54,653
And so if I measure the
wavelength of these lines,

442
00:20:55,853 --> 00:20:58,924
I always see these lines
at these wavelengths.

443
00:20:58,924 --> 00:21:01,726
So if I look at something,
and I see a wavelength

444
00:21:01,726 --> 00:21:05,263
of 656 nanometers, I
know right away that

445
00:21:05,263 --> 00:21:07,266
that came from hydrogen.

446
00:21:09,634 --> 00:21:13,905
The neat thing is if I
have hot gas, hot hydrogen,

447
00:21:13,905 --> 00:21:16,241
it glows at those
specific colors.

448
00:21:16,241 --> 00:21:18,843
If I have a cold
container of hydrogen,

449
00:21:18,843 --> 00:21:22,046
and put it in front of
a white light source,

450
00:21:22,046 --> 00:21:25,517
I see absorption, I see

dark lines at exactly

451
00:21:25,517 --> 00:21:27,319
those same wavelengths.

452
00:21:27,319 --> 00:21:29,955
So whether I have hot
hydrogen glowing on its own,

453
00:21:29,955 --> 00:21:32,156
or whether I have cold
hydrogen that's absorbing

454
00:21:32,156 --> 00:21:36,328
background starlight, I
know there's hydrogen there.

455
00:21:38,196 --> 00:21:40,765
I mentioned every element
has its own fingerprint.

456
00:21:40,765 --> 00:21:43,735
So hydrogen is a very
simple atom, one proton,

457
00:21:43,735 --> 00:21:46,338
one electron, and so it has
a very simple set of lines

458
00:21:46,338 --> 00:21:48,306
that it emits.

459
00:21:48,306 --> 00:21:51,509
Helium has two protons, two
neutrons, two electrons.

460
00:21:51,509 --> 00:21:53,145
It's a bit more complex.

461

00:21:53,145 --> 00:21:55,180
As we get heavier and
heavier we get more lines,

462
00:21:55,180 --> 00:21:59,584
more complexity, but they are
all a very unique fingerprint.

463
00:21:59,584 --> 00:22:01,720
So if I look at a star,
and I take its spectrum,

464
00:22:01,720 --> 00:22:04,389
I can figure out what's
there just by looking for

465
00:22:04,389 --> 00:22:06,658
all these fingerprints.

466
00:22:06,658 --> 00:22:08,793
And in fact, if I take
a spectrum of the sun,

467
00:22:08,793 --> 00:22:10,929
this is what it looks like.

468
00:22:10,929 --> 00:22:13,231
Normally if you just, well
you shouldn't look at the sun,

469
00:22:13,231 --> 00:22:15,867
but if you do look at the
sun, it's kind of whiteish,

470
00:22:15,867 --> 00:22:18,470
yellowish, you don't see
anything particularly funny.

471
00:22:18,470 --> 00:22:22,540
But if you look at it through

a high resolution spectrograph

472
00:22:22,540 --> 00:22:24,642
this is what you see.

473
00:22:24,642 --> 00:22:28,112
And there's a big notch
over in the red wavelengths.

474
00:22:28,112 --> 00:22:31,783
I said aha, hydrogen has
an absorption line at

475
00:22:31,783 --> 00:22:35,954
red wavelengths, so I know
the sun has hydrogen in it.

476
00:22:37,155 --> 00:22:39,357
And in fact, people that
do this for a living say

477
00:22:39,357 --> 00:22:43,528
there are 69 elements that
we've discovered in sunlight.

478
00:22:44,929 --> 00:22:49,301
Hydrogen accounts for 92.1%
of the atoms in the sun.

479
00:22:49,301 --> 00:22:53,938
Helium for 7.8%, and
everything else, those other 67

480
00:22:53,938 --> 00:22:58,776
elements form less that
0.1% of the sun's surface,

481
00:22:58,776 --> 00:23:00,278
but we know it's there.

482
00:23:00,278 --> 00:23:02,981
Mostly hydrogen, little bit
of helium, and that's a common

483
00:23:02,981 --> 00:23:05,817
refrain whenever
we look at stars.

484
00:23:07,986 --> 00:23:10,755
Another thing that spectra
tells us is they can tell us

485
00:23:10,755 --> 00:23:13,124
how fast an object is moving.

486
00:23:13,124 --> 00:23:16,060
You've all heard a
siren coming toward you.

487
00:23:16,060 --> 00:23:19,063
The pitch of the siren
sounds higher than when it's

488
00:23:19,063 --> 00:23:20,865
stationery right next to you.

489
00:23:20,865 --> 00:23:23,468
And if it goes whizzing past
you, the pitch is lower.

490
00:23:23,468 --> 00:23:25,069
It's the Doppler shift.

491
00:23:25,069 --> 00:23:27,238
Well, light does
exactly the same thing.

492
00:23:27,238 --> 00:23:31,443
And so if I have my laboratory

spectrum sitting right

493
00:23:31,443 --> 00:23:35,046
in front of me, and I compare
it to the spectrum of a star,

494
00:23:35,046 --> 00:23:37,348
the lines are pretty
much the same place.

495
00:23:37,348 --> 00:23:41,653
This drawing exaggerates it
a little bit, but in general

496
00:23:41,653 --> 00:23:46,023
stars are at rest compared
with us in the grand scheme

497
00:23:46,023 --> 00:23:49,060
of things, and so the
wavelengths are all the same.

498
00:23:49,060 --> 00:23:51,763
But for galaxies that are
nearby, and then some that are

499
00:23:51,763 --> 00:23:54,399
not so nearby, they're all
receding from us because

500
00:23:54,399 --> 00:23:56,634
the universe is expanding.

501
00:23:56,634 --> 00:24:00,205
And so the wavelength of those
lines shifts toward the red,

502
00:24:00,205 --> 00:24:02,840
and so we call
this the red shift.

503
00:24:02,840 --> 00:24:06,677
So this galaxy actually
isn't that far away.

504
00:24:06,677 --> 00:24:09,046
We'd say that that had a
red shift of about a third,

505
00:24:09,046 --> 00:24:10,781
point three.

506
00:24:10,781 --> 00:24:12,984
That galaxy I showed you
at the very beginning,

507
00:24:12,984 --> 00:24:15,554
that fuzzy little blod
has a red shift of 11,

508
00:24:15,554 --> 00:24:18,856
which means that the wavelength
of light has been shifted

509
00:24:18,856 --> 00:24:22,227
a factor of 12 from what it
would be in the laboratory.

510
00:24:22,227 --> 00:24:26,797
So that means that visible
light from that galaxy

511
00:24:26,797 --> 00:24:29,700
has now been shifted way
into the mid-infrared,

512
00:24:29,700 --> 00:24:32,203
just where my MIRI
instrument works.

513
00:24:32,203 --> 00:24:35,773
And so if we wanna see
galaxies near the fringe of

514
00:24:35,773 --> 00:24:38,343
the universe, we have to
look in the infrared to see

515
00:24:38,343 --> 00:24:42,913
the light that we're used to
seeing in nearby galaxies.

516
00:24:42,913 --> 00:24:44,616
Okay, just a quick side note.

517
00:24:44,616 --> 00:24:46,651
As pretty as the rainbows
are, they really aren't very

518
00:24:46,651 --> 00:24:49,254
useful in terms of
analyzing things.

519
00:24:49,254 --> 00:24:52,090
So we plot the brightness of
the spectrum as a function

520
00:24:52,090 --> 00:24:54,725
of wavelengths, so
we always see plots.

521
00:24:54,725 --> 00:24:56,627
And so where there
is a bright line,

522
00:24:56,627 --> 00:24:58,429
that's a spike on this spectrum.

523
00:24:58,429 --> 00:25:00,565

And if there were a spike
downward, that would tell you

524
00:25:00,565 --> 00:25:02,700
there's an absorption
line there.

525
00:25:02,700 --> 00:25:04,669
That's important because
when we work in the infrared

526
00:25:04,669 --> 00:25:08,907
we don't get rainbows because
our eyes don't see that.

527
00:25:08,907 --> 00:25:10,375
This is a very young star.

528
00:25:10,375 --> 00:25:13,078
This is one of those baby
stars that I'm interested in.

529
00:25:13,078 --> 00:25:15,146
And baby stars tend
to be very messy,

530
00:25:15,146 --> 00:25:16,481
just like human babies.

531
00:25:16,481 --> 00:25:18,182
They tend to burp
up bubbles of stuff,

532
00:25:18,182 --> 00:25:20,185
and throw things around.

533
00:25:20,185 --> 00:25:23,321
But we'd like to get a
spectrum of this thing

534
00:25:23,321 --> 00:25:27,525
just to understand what
kind of material is there.

535
00:25:27,525 --> 00:25:30,461
If we do, this is a
infrared spectrum.

536
00:25:30,461 --> 00:25:32,397
I should have said that
at visible wavelengths

537
00:25:32,397 --> 00:25:34,065
we see mostly atoms.

538
00:25:34,065 --> 00:25:36,835
At infrared wavelengths
we see mostly molecules.

539
00:25:36,835 --> 00:25:39,971
They're larger, they tend
to have lower energy states

540
00:25:39,971 --> 00:25:41,406
that we're looking at.

541
00:25:41,406 --> 00:25:45,142
So this the spectrum
of that baby star.

542
00:25:45,142 --> 00:25:47,378
There is a big absorption
feature here that's

543
00:25:47,378 --> 00:25:48,746
labeled Silicates.

544
00:25:48,746 --> 00:25:50,382
Silicates are a type of rock.

545
00:25:50,382 --> 00:25:52,116
If you go down to
Santa Monica Beach,

546
00:25:52,116 --> 00:25:54,118
you're surrounded by silicates.

547
00:25:54,118 --> 00:25:57,221
Sand grains are
formed of silicates.

548
00:25:57,221 --> 00:25:58,789
There also things
like water-ice,

549
00:25:58,789 --> 00:26:01,225
a little bit of
carbon dioxide-ice,

550
00:26:01,225 --> 00:26:04,361
and there's even a little
bit of methane gas here.

551
00:26:04,361 --> 00:26:07,865
Now being a good scientists
I employ my prodigious powers

552
00:26:07,865 --> 00:26:10,768
of scientific reasoning,
and come to the very firm

553
00:26:10,768 --> 00:26:13,638
conclusion that there
are cows in space.

554
00:26:13,638 --> 00:26:15,473
(laughing)

555

00:26:15,473 --> 00:26:16,975
okay, this is a joke.

556
00:26:16,975 --> 00:26:18,476
I don't want this to show
up in the tabloids tomorrow.

557
00:26:18,476 --> 00:26:21,145
A top NASA scientist did
not announce the discovery

558
00:26:21,145 --> 00:26:23,047
of cows in space.

559
00:26:23,047 --> 00:26:27,218
But it's important because
these are the molecules

560
00:26:28,486 --> 00:26:31,890
that are important
for life on Earth.

561
00:26:31,890 --> 00:26:36,727
And so it's good, maybe
reassuring, that the molecules

562
00:26:36,727 --> 00:26:39,798
that we depend on here
are actually relatively

563
00:26:39,798 --> 00:26:41,298
common in space.

564
00:26:41,298 --> 00:26:44,936
And so it helps us understand
how our solar system formed,

565
00:26:44,936 --> 00:26:47,906
how when stars form they
form out of the same stuff

566
00:26:47,906 --> 00:26:51,576
that we find on Earth
that drives life here.

567
00:26:53,845 --> 00:26:57,782
Another thing that we can
learn from infrared light is

568
00:26:57,782 --> 00:27:00,818
as we start studying
planets around nearby stars,

569
00:27:00,818 --> 00:27:03,454
you know, we like to study
their atmospheres and whether

570
00:27:03,454 --> 00:27:05,890
they're rocky or whether like
Earth, or whether they're

571
00:27:05,890 --> 00:27:08,026
gaseous like Jupiter.

572
00:27:08,026 --> 00:27:11,562
So if we know that we've
got a star and a planet

573
00:27:11,562 --> 00:27:16,301
with the planet orbiting the
star, we can't separate them.

574
00:27:16,301 --> 00:27:19,570
So usually we can't take an
image of here's the star,

575
00:27:19,570 --> 00:27:21,038
here's the planet.

576

00:27:21,038 --> 00:27:23,675
Generally we only see the light
from both of them together.

577
00:27:23,675 --> 00:27:26,945
But if we know that a
planet crosses in front of

578
00:27:26,945 --> 00:27:30,314
a star's transit, maybe you've
heard about the Venus transit

579
00:27:30,314 --> 00:27:33,718
a couple of years back where
Venus passed in front of

580
00:27:33,718 --> 00:27:35,452
the face of the sun.

581
00:27:35,452 --> 00:27:37,688
When a planet passes
in front of the star,

582
00:27:37,688 --> 00:27:40,891
it blocks some of the light,
and so the apparent intensity

583
00:27:40,891 --> 00:27:43,127
of the star drops a little bit.

584
00:27:43,127 --> 00:27:45,329
But then there's a phase when
we see both of them together

585
00:27:45,329 --> 00:27:47,932
before the planet hides behind
the star at the other end.

586
00:27:47,932 --> 00:27:51,302
But this part is interesting

because if there is a big

587
00:27:51,302 --> 00:27:53,871
difference in temperature
of the planet between the

588
00:27:53,871 --> 00:27:56,741
daytime side of the planet
and the nighttime side of

589
00:27:56,741 --> 00:28:00,712
the planet, we'll actually
see a little bit more infrared

590
00:28:00,712 --> 00:28:04,115
or a little bit less
infrared, depending on where

591
00:28:04,115 --> 00:28:05,883
the planet is in its orbit.

592
00:28:05,883 --> 00:28:09,053
So if we're seeing the
backside, nighttime side of

593
00:28:09,053 --> 00:28:11,389
the planet, there's
a little less light.

594
00:28:11,389 --> 00:28:15,092
As it swings around to the
day side from our view,

595
00:28:15,092 --> 00:28:17,228
it's actually a little brighter.

596
00:28:17,228 --> 00:28:21,466
So the fact that the light
from the planet and star

597
00:28:21,466 --> 00:28:24,501
rose a little bit as we
went to the daytime side

598
00:28:24,501 --> 00:28:27,806
tells us that there's a pretty
good temperature difference

599
00:28:27,806 --> 00:28:31,075
between the day side and the
night side of this planet,

600
00:28:31,075 --> 00:28:33,711
and so it probably doesn't
have a really thick

601
00:28:33,711 --> 00:28:35,279
atmosphere like Venus.

602
00:28:35,279 --> 00:28:37,248
It's something a little
bit more transparent

603
00:28:37,248 --> 00:28:38,583
maybe like ours.

604
00:28:40,185 --> 00:28:41,853
So that's exciting.

605
00:28:41,853 --> 00:28:46,024
Hey, we found out a little
bit about this other planet.

606
00:28:47,458 --> 00:28:49,360
We've been able to do a
little bit with atmospheres

607
00:28:49,360 --> 00:28:50,295
of planets.

608
00:28:51,896 --> 00:28:56,167
This is a model spectrum
of an atmosphere.

609
00:28:56,167 --> 00:28:58,336
And this is what the
Spitzer Space Telescope was

610
00:28:58,336 --> 00:28:59,804
able to observe.

611
00:28:59,804 --> 00:29:02,273
It was only able to look at
this in three different colors,

612
00:29:02,273 --> 00:29:04,942
and they noticed that it
was a little bit dimmer at

613
00:29:04,942 --> 00:29:07,411
3.8 microns than they
thought it should be,

614
00:29:07,411 --> 00:29:09,447
and a little bit brighter
out here at six microns.

615
00:29:09,447 --> 00:29:12,183
And so they fit that
atmospheric model and said yeah,

616
00:29:12,183 --> 00:29:14,185
this might be able to work.

617
00:29:14,185 --> 00:29:17,021
One of the things that the
Webb Telescope will do,

618

00:29:17,021 --> 00:29:18,957
it will actually let
us get this spectrum.

619
00:29:18,957 --> 00:29:21,425
And so maybe we'll actually
see that curve and confirm

620
00:29:21,425 --> 00:29:25,730
that the atmosphere
really worked that way.

621
00:29:25,730 --> 00:29:28,032
So if the infrared is so neat,
and I hope I convinced you

622
00:29:28,032 --> 00:29:29,500
that it is.

623
00:29:29,500 --> 00:29:31,502
It's really a lot
of fun to play with.

624
00:29:31,502 --> 00:29:33,638
Why doesn't everybody in
the world and their dog

625
00:29:33,638 --> 00:29:36,974
have an infrared telescope
in their backyard?

626
00:29:36,974 --> 00:29:38,876
Well, there are three
things that make this a

627
00:29:38,876 --> 00:29:41,880
difficult place to
have your career.

628
00:29:43,013 --> 00:29:45,783

First is room
temperature emission,

629
00:29:45,783 --> 00:29:47,117
and I'll explain what I mean.

630
00:29:47,117 --> 00:29:49,153
Second thing is the atmosphere,

631
00:29:49,153 --> 00:29:50,921
and I'll explain
what that means.

632
00:29:50,921 --> 00:29:53,858
And then third, just the
sensors that we use for infrared

633
00:29:53,858 --> 00:29:58,029
astronomy can cause a fair
amount of trouble on their own.

634
00:29:59,463 --> 00:30:02,399
Any object that's at a finite
temperature emits radiation

635
00:30:02,399 --> 00:30:05,469
with a very characteristic
spectrum, and we call this

636
00:30:05,469 --> 00:30:07,905
a black body spectrum.

637
00:30:07,905 --> 00:30:11,910
Stars that are extremely hot,
10,000 to 100,000 degrees,

638
00:30:11,910 --> 00:30:14,545
actually emit most of
their light in ultraviolet

639
00:30:14,545 --> 00:30:15,547
wavelengths.

640
00:30:17,115 --> 00:30:19,951
More normal stars like the
sun emit most of their light

641
00:30:19,951 --> 00:30:22,953
at visible wavelengths,
which makes sense because

642
00:30:22,953 --> 00:30:25,323
that's what our eyes see,
and so it makes sense for

643
00:30:25,323 --> 00:30:28,325
our eyes to have adapted
to what our star puts out.

644
00:30:28,325 --> 00:30:30,461
So that's why we have
visible wavelengths,

645
00:30:30,461 --> 00:30:33,264
and that's where the sun emits.

646
00:30:33,264 --> 00:30:35,599
Those clouds of gas and dust
that I mentioned where we

647
00:30:35,599 --> 00:30:39,237
form stars, they tend to be
very cold, 15 to 30 degrees

648
00:30:39,237 --> 00:30:41,205
above absolute zero.

649
00:30:41,205 --> 00:30:43,908
So they actually emit most of

their light, their radiation

650
00:30:43,908 --> 00:30:47,244
at very long far
infrared wavelengths.

651
00:30:47,244 --> 00:30:49,814
And then the cosmic
microwave background,

652
00:30:49,814 --> 00:30:51,849
which is a little bit
under three degrees above

653
00:30:51,849 --> 00:30:54,351
absolute zero, emits
in the millimeter.

654
00:30:54,351 --> 00:30:56,954
That leaves this nice
curve in the middle.

655
00:30:56,954 --> 00:30:58,956
That red curve is
in the mid-infrared.

656
00:30:58,956 --> 00:31:01,525
It's wavelengths around 10
microns, exactly where my

657
00:31:01,525 --> 00:31:03,594
instrument works.

658
00:31:03,594 --> 00:31:05,763
And that's where
the Earth emits,

659
00:31:05,763 --> 00:31:09,934
and where the atmosphere emits,
and where astronomers emit.

660
00:31:11,035 --> 00:31:14,372
Everything in the
mid-infrared is glowing.

661
00:31:15,740 --> 00:31:17,975
One of the infrared astronomers
quoted, "Observing in the

662
00:31:17,975 --> 00:31:20,277
"infrared is like
observing in broad daylight

663
00:31:20,277 --> 00:31:22,947
"with a telescope made
out of lightbulbs."

664
00:31:22,947 --> 00:31:25,449
(laughing)

665
00:31:25,449 --> 00:31:28,519
Where do the stars
go during the day?

666
00:31:28,519 --> 00:31:30,420
They're still there, right?

667
00:31:30,420 --> 00:31:32,724
Stars don't move
compared to us very much,

668
00:31:32,724 --> 00:31:35,626
so they're still there, but
we can't see them because

669
00:31:35,626 --> 00:31:39,163
the Earth's atmosphere scatters
blue light from the sun,

670

00:31:39,163 --> 00:31:42,433
and the glow of that scattered
light just washes out

671
00:31:42,433 --> 00:31:44,835
our ability to see stars.

672
00:31:44,835 --> 00:31:46,904
If you got a telescope out
in the middle of the day,

673
00:31:46,904 --> 00:31:49,172
you actually could see a few
stars, but it's really hard

674
00:31:49,172 --> 00:31:51,542
because the sky is so bright.

675
00:31:51,542 --> 00:31:53,845
Well, that's what it is
like all the time in the

676
00:31:53,845 --> 00:31:55,279
mid-infrareds.

677
00:31:55,279 --> 00:31:57,849
So when I said I built
instruments that went on Keck

678
00:31:57,849 --> 00:32:00,885
and on Palomar, we were
fighting the atmospheric glow.

679
00:32:00,885 --> 00:32:03,521
It didn't matter if we were
observing daytime or nighttime,

680
00:32:03,521 --> 00:32:05,023
it's always bad.

681
00:32:05,023 --> 00:32:09,693
So that's one reason why we
wanna put things in space.

682
00:32:09,693 --> 00:32:13,164
The second is our
Earth's atmosphere
isn't very cooperative.

683
00:32:13,164 --> 00:32:15,399
That same atmosphere that
makes it possible for us

684
00:32:15,399 --> 00:32:18,235
to be alive also likes
to make it difficult for

685
00:32:18,235 --> 00:32:19,871
infrared astronomers.

686
00:32:19,871 --> 00:32:23,574
At visible wavelengths in
this range most of the light

687
00:32:23,574 --> 00:32:25,810
gets through the atmosphere
down to the ground,

688
00:32:25,810 --> 00:32:28,145
so that's why big telescopes
on the ground work.

689
00:32:28,145 --> 00:32:31,648
But there are certain
wavelengths where molecules in

690
00:32:31,648 --> 00:32:34,852
our atmosphere absorb all the
light, and so the atmosphere

691
00:32:34,852 --> 00:32:39,022
is actually opaque
at those wavelengths.

692
00:32:39,022 --> 00:32:41,292
A lot of it's just
from water vapor.

693
00:32:41,292 --> 00:32:43,361
Some of it's carbon dioxide.

694
00:32:43,361 --> 00:32:46,130
There's even a little bit
of absorption from ozone

695
00:32:46,130 --> 00:32:47,732
in our atmosphere.

696
00:32:47,732 --> 00:32:50,467
Well, the weathermen love
this because they build

697
00:32:50,467 --> 00:32:53,905
satellites that
observe at six microns.

698
00:32:53,905 --> 00:32:58,376
And if you've ever gone to
NOAA website or Wunderground

699
00:32:58,376 --> 00:33:00,978
or whatever, you might
have seen water vapor maps

700
00:33:00,978 --> 00:33:03,146
that tell us where
the storms are,

701
00:33:03,146 --> 00:33:06,016

where all the water moisture is.

702
00:33:06,016 --> 00:33:08,286
So there's a big band of
moisture blowing up through

703
00:33:08,286 --> 00:33:10,922
northern Mexico and Texas.

704
00:33:10,922 --> 00:33:13,757
Southern California
is a little drier.

705
00:33:13,757 --> 00:33:16,627
There's a big band out over
the ocean just north of

706
00:33:16,627 --> 00:33:19,597
the Hawaiian Islands where
there's very little water vapor.

707
00:33:19,597 --> 00:33:22,032
And so you see all the way down
to the surface of the Earth.

708
00:33:22,032 --> 00:33:23,534
That's why it's so dark.

709
00:33:23,534 --> 00:33:25,036
So weatherman like it.

710
00:33:25,036 --> 00:33:28,272
Astronomers on the
ground, not so much.

711
00:33:29,473 --> 00:33:31,475
And then finally the
sensors themselves.

712

00:33:31,475 --> 00:33:33,577
It sounds a little funny,
but if you have a sensor

713
00:33:33,577 --> 00:33:37,949
that's sensitive to temperature,
the sensor has to be colder

714
00:33:37,949 --> 00:33:39,683
than the stuff it's
trying to detect,

715
00:33:39,683 --> 00:33:41,452
otherwise it detects itself.

716
00:33:41,452 --> 00:33:44,188
So we have to cool things
in the infrared to very

717
00:33:44,188 --> 00:33:45,723
cold temperatures.

718
00:33:45,723 --> 00:33:49,292
And if you do that in the air,
air freezes on your detectors

719
00:33:49,292 --> 00:33:51,095
and that messes everything up.

720
00:33:51,095 --> 00:33:54,097
There are also some false
signals that are generated

721
00:33:54,097 --> 00:33:56,867
by the detectors, and so we
have to get them even colder.

722
00:33:56,867 --> 00:34:00,104
Most of the, three of the
instruments on James Webb

723
00:34:00,104 --> 00:34:04,142
need to be cooled to 40 degrees
above absolute zero to work.

724
00:34:04,142 --> 00:34:06,844
MIRI, the instrument I work
on, needs to be cooled to

725
00:34:06,844 --> 00:34:09,947
about six degrees above
absolute zero in order to work.

726
00:34:09,947 --> 00:34:13,183
So all these things
together, radiation of room

727
00:34:13,183 --> 00:34:16,287
temperature things, the
atmosphere and just our sensors

728
00:34:16,287 --> 00:34:19,256
really does mean we wanna
put our infrared telescopes

729
00:34:19,256 --> 00:34:22,760
up in space so we can
see what's going on.

730
00:34:24,428 --> 00:34:27,031
So to address the scientific
questions, to make things work

731
00:34:27,031 --> 00:34:29,566
in the infrared we're
building the Webb Telescope.

732
00:34:29,566 --> 00:34:33,170
So Webb is a six-meter
infrared-optimized telescope.

733
00:34:33,170 --> 00:34:36,107
You'll notice the primary
mirror is coated with gold

734
00:34:36,107 --> 00:34:37,808
rather than silver.

735
00:34:37,808 --> 00:34:39,977
Gold is actually a
better reflector of
infrared wavelengths

736
00:34:39,977 --> 00:34:42,012
than silver is.

737
00:34:42,012 --> 00:34:46,951
It has four instruments
that cover .7 to 28 microns.

738
00:34:46,951 --> 00:34:49,853
Now I know that doesn't mean
much, but the reddest color

739
00:34:49,853 --> 00:34:53,324
your eyes can see is
right about .7 microns.

740
00:34:53,324 --> 00:34:57,360
So James Webb takes off right
where your vision fails,

741
00:34:57,360 --> 00:35:00,564
so into the infrared past that.

742
00:35:00,564 --> 00:35:03,534
Webb is a partnership
between NASA,

743

00:35:03,534 --> 00:35:07,004
the European Space Agency and
the Canadian Space Agency.

744
00:35:07,004 --> 00:35:08,438
None of us can go it alone.

745
00:35:08,438 --> 00:35:10,707
We gotta work together
on this stuff.

746
00:35:10,707 --> 00:35:13,944
And it's gonna be launched on
a European Arianne 5 rocket.

747
00:35:13,944 --> 00:35:18,082
Now you saw the picture of
Webb sitting in the clean room

748
00:35:18,082 --> 00:35:20,417
at Goddard all unfolded.

749
00:35:20,417 --> 00:35:24,589
That does not fit in any
rocket currently in production.

750
00:35:26,023 --> 00:35:27,858
We've gotta fold it up,
and so you'll notice that

751
00:35:27,858 --> 00:35:30,594
three of the mirror panels
on this side and three on

752
00:35:30,594 --> 00:35:32,896
the other side fold back.

753
00:35:32,896 --> 00:35:34,966
That secondary mirror that's
supposed to be out here

754
00:35:34,966 --> 00:35:36,033
is up on top.

755
00:35:37,468 --> 00:35:40,505
The sun shade is folded up
kind of like butterfly wings

756
00:35:40,505 --> 00:35:42,272
tucked in there.

757
00:35:42,272 --> 00:35:45,943
And so James Webb Telescope
is an origami telescope.

758
00:35:45,943 --> 00:35:48,178
It's gotta unfold.

759
00:35:48,178 --> 00:35:50,347
After it launches,
the fairing separates,

760
00:35:50,347 --> 00:35:52,582
things begin to expand.

761
00:35:52,582 --> 00:35:54,585
So first we gotta get
our solar panels out so

762
00:35:54,585 --> 00:35:56,086
we can get power.

763
00:35:56,086 --> 00:35:58,656
There is a lock on the antenna.

764
00:36:00,090 --> 00:36:01,425
We pitch the telescope a
little bit, and we do some

765
00:36:01,425 --> 00:36:03,027
course corrections.

766
00:36:11,001 --> 00:36:13,504
A long course
correction apparently.

767
00:36:13,504 --> 00:36:15,506
Pitch back a little bit.

768
00:36:18,842 --> 00:36:21,211
We extend our antenna so
we can establish high speed

769
00:36:21,211 --> 00:36:23,313
communications with the Earth.

770
00:36:23,313 --> 00:36:24,982
It's all low speed
up to that point.

771
00:36:24,982 --> 00:36:27,818
Another little
course correction.

772
00:36:27,818 --> 00:36:30,554
Then we begin to unfold stuff.

773
00:36:30,554 --> 00:36:33,457
So first we're gonna
start with that sunshield.

774
00:36:33,457 --> 00:36:37,394
So first the structures that
actually hold the sunshield

775
00:36:37,394 --> 00:36:39,329
fold back from the telescope.

776
00:36:39,329 --> 00:36:41,566
We do the front side first.

777
00:36:52,676 --> 00:36:55,179
Then the back side comes down.

778
00:37:00,450 --> 00:37:04,054
Now to help the telescope
clear that sunshield

779
00:37:04,054 --> 00:37:06,590
the telescope itself is
actually on a tower that

780
00:37:06,590 --> 00:37:08,459
separates it from the
rest of the spacecraft,

781
00:37:08,459 --> 00:37:12,530
and that tower has to extend
about six feet in order that

782
00:37:12,530 --> 00:37:15,232
nothing in that sun shade
touches the telescope.

783
00:37:15,232 --> 00:37:18,268
So that was that
tower deployment.

784
00:37:18,268 --> 00:37:20,837
The covers come off the
top of the sunshield.

785
00:37:20,837 --> 00:37:22,707
And this is all packaged
like some little tin foiled

786
00:37:22,707 --> 00:37:24,041

wrapping things.

787
00:37:26,243 --> 00:37:28,979
We release a couple of locks,
and then these booms deploy

788
00:37:28,979 --> 00:37:33,351
that stretch out that sunshield
from where it's folded up

789
00:37:33,351 --> 00:37:34,518
in the center.

790
00:37:38,922 --> 00:37:42,693
So we do one side first,
then the other side.

791
00:37:44,895 --> 00:37:48,866
Now that sunshield is actually
five layers of material,

792
00:37:48,866 --> 00:37:52,403
and it's very important that
those five layers separate

793
00:37:52,403 --> 00:37:56,874
because on the sun side the
temperature of this first layer

794
00:37:56,874 --> 00:38:00,044
is about room temperature,
about 300 degrees above

795
00:38:00,044 --> 00:38:01,645
absolute zero.

796
00:38:01,645 --> 00:38:03,547
But the telescope needs
to be 50 degrees above

797
00:38:03,547 --> 00:38:07,385
absolute zero, so this
top shade has to be 50.

798
00:38:07,385 --> 00:38:10,487
So if there's any touching
in between, it will heat up

799
00:38:10,487 --> 00:38:13,624
the next layer, and we
won't get cold enough.

800
00:38:13,624 --> 00:38:16,460
So that's one of
our big concerns.

801
00:38:18,195 --> 00:38:21,865
Now we're getting ready to
release the secondary mirror,

802
00:38:21,865 --> 00:38:24,635
and so you see the
structure starting to move.

803
00:38:24,635 --> 00:38:27,738
Then the secondary mirror,
which is here, swings forward

804
00:38:27,738 --> 00:38:31,475
and moves to the front
of the primary mirror.

805
00:38:35,012 --> 00:38:38,115
And then finally the side
wings of the telescope

806
00:38:38,115 --> 00:38:40,951
primary mirror
move into position.

807
00:38:45,122 --> 00:38:47,291
Here comes the other side.

808
00:38:49,760 --> 00:38:52,096
That whole process
takes two weeks.

809
00:38:52,096 --> 00:38:54,298
(laughing)

810
00:38:54,298 --> 00:38:56,666
So the Mars had seven minutes
of terror while they were

811
00:38:56,666 --> 00:38:59,035
trying to land a rover on Mars.

812
00:38:59,035 --> 00:39:01,372
We got two weeks of
terror waiting for our

813
00:39:01,372 --> 00:39:03,040
telescope to deploy.

814
00:39:04,474 --> 00:39:07,344
After it's fully unfolded, it
then begins the long process

815
00:39:07,344 --> 00:39:10,280
of the whole telescope
has to cool down.

816
00:39:10,280 --> 00:39:12,316
Our instruments
have to cool down.

817
00:39:12,316 --> 00:39:16,086
Until everything is settled,
we've made sure everything

818
00:39:16,086 --> 00:39:20,190
works, we do our calibrations,
it's six months after launch

819
00:39:20,190 --> 00:39:23,227
before we're ready to start
taking scientific data,

820
00:39:23,227 --> 00:39:24,795
so it's a long one.

821
00:39:27,631 --> 00:39:31,301
Another thing different
between Webb and Hubble is

822
00:39:31,301 --> 00:39:33,904
where it's located in space.

823
00:39:33,904 --> 00:39:36,273
Hubble actually orbits the
Earth just a few hundred

824
00:39:36,273 --> 00:39:39,610
miles up, so it actually orbits
the Earth every 90 minutes.

825
00:39:39,610 --> 00:39:42,078
And some evenings when
Hubble goes overhead you can

826
00:39:42,078 --> 00:39:44,815
watch it streak across the sky.

827
00:39:44,815 --> 00:39:47,384
Webb is gonna be located a
million miles from Earth,

828
00:39:47,384 --> 00:39:49,686

four times the
distance of the moon.

829
00:39:49,686 --> 00:39:53,858
There are five spots between
the Earth and the sun

830
00:39:55,459 --> 00:39:58,829
where the gravity of the
Earth and sun balance the

831
00:39:58,829 --> 00:40:01,965
tendency of the spacecraft
go to running off on its own.

832
00:40:01,965 --> 00:40:04,401
These are called Lagrange
points after the mathematician

833
00:40:04,401 --> 00:40:06,070
who discovered them.

834
00:40:07,504 --> 00:40:09,940
The second Lagrange point
nicknamed L2 is actually

835
00:40:09,940 --> 00:40:12,777
a really nice place to
put spacecraft because our

836
00:40:12,777 --> 00:40:15,913
sunshield will always
shield the Earth, the moon

837
00:40:15,913 --> 00:40:19,149
and the sun from shining
on the telescope.

838
00:40:19,149 --> 00:40:22,285
We've sent a number of

spacecraft out there.

839
00:40:22,285 --> 00:40:25,289
Webb will be joining
the collection.

840
00:40:27,357 --> 00:40:29,493
So I mentioned Webb
has four instruments,

841
00:40:29,493 --> 00:40:30,994
so I'd like to describe
them very quickly.

842
00:40:30,994 --> 00:40:33,863
NIRCAM is our near
infrared camera.

843
00:40:33,863 --> 00:40:36,967
It's primarily to take
pictures of things.

844
00:40:36,967 --> 00:40:40,971
It has a tool called a
chronograph, which I'll explain

845
00:40:40,971 --> 00:40:45,142
in a second, and it does some
very simple spectroscopy.

846
00:40:46,643 --> 00:40:49,713
So the top is some images from
the Hubble Space Telescope

847
00:40:49,713 --> 00:40:52,916
with the wide field
camera number three,

848
00:40:52,916 --> 00:40:56,253
which has limited

infrared capabilities.

849
00:40:57,454 --> 00:41:00,857
If we were to image this
same galaxy with Webb,

850
00:41:00,857 --> 00:41:04,094
not only do we see fainter
galaxies around it because

851
00:41:04,094 --> 00:41:05,796
we have so much more
collecting area,

852
00:41:05,796 --> 00:41:08,699
but we begin to see some
of the spots that are just

853
00:41:08,699 --> 00:41:10,900
sort of fuzzy in
the Hubble image.

854
00:41:10,900 --> 00:41:13,203
And again, this is a simulation.

855
00:41:13,203 --> 00:41:15,673
We don't have anything yet.

856
00:41:15,673 --> 00:41:18,809
But these spots might be
regions where stars are being

857
00:41:18,809 --> 00:41:21,879
actively formed, or they
might be remnants of those

858
00:41:21,879 --> 00:41:24,815
little galaxies that
collided, that merged together

859
00:41:24,815 --> 00:41:26,483
to form a larger galaxy.

860
00:41:26,483 --> 00:41:29,086
But that's the kind of stuff
we wanna find out with Webb.

861
00:41:29,086 --> 00:41:32,289
And so it will be a great
tool for examining these

862
00:41:32,289 --> 00:41:33,958
very early galaxies.

863
00:41:35,359 --> 00:41:39,797
A chronograph is an instrument
that blocks the starlight.

864
00:41:39,797 --> 00:41:41,765
So whatever is right in the
center of the chronograph,

865
00:41:41,765 --> 00:41:43,600
the light from
that gets blocked.

866
00:41:43,600 --> 00:41:45,402
So we'll put a star
right in the center,

867
00:41:45,402 --> 00:41:49,039
and so where the star
was gets blocked out.

868
00:41:49,039 --> 00:41:51,742
So we don't see the starlight
at all, but that allows us

869
00:41:51,742 --> 00:41:55,178

to see other structures
around the star that normally

870
00:41:55,178 --> 00:41:57,414
are lost in the glare.

871
00:41:57,414 --> 00:41:59,950
The star is so bright that
we can't see these things.

872
00:41:59,950 --> 00:42:04,154
This is a star called Beta
Pictoris, and we saw these

873
00:42:04,154 --> 00:42:06,356
kind of disk structure.

874
00:42:06,356 --> 00:42:10,127
And we said in our solar
system we have a similar

875
00:42:10,127 --> 00:42:11,595
sort of thing.

876
00:42:11,595 --> 00:42:13,998
We have zodiacal light,
which is dust near the Earth

877
00:42:13,998 --> 00:42:16,600
that on a good dark night
out in the desert you might

878
00:42:16,600 --> 00:42:19,169
be able to see as
a band of light.

879
00:42:19,169 --> 00:42:21,772
Well, this is much thicker
than in our own solar system,

880
00:42:21,772 --> 00:42:23,841
but we said hey, that's
kind of a signature of a

881
00:42:23,841 --> 00:42:25,075
solar system.

882
00:42:25,075 --> 00:42:26,943
Wonder if there are
planets in there?

883
00:42:26,943 --> 00:42:31,882
Well, a few years later after
our chronographs improved

884
00:42:31,882 --> 00:42:34,751
we have a chronograph
which is much tighter,

885
00:42:34,751 --> 00:42:39,589
and we noticed there was
a spot next to that star.

886
00:42:39,589 --> 00:42:42,326
And it turned out, they imaged
it again six months later,

887
00:42:42,326 --> 00:42:46,329
and that spot was on the
other side of the star.

888
00:42:46,329 --> 00:42:48,566
Turns out this is a planet.

889
00:42:49,900 --> 00:42:52,402
So I don't remember
what the period is,

890
00:42:52,402 --> 00:42:56,473

some number of years, but we
saw it in part of its orbit,

891
00:42:56,473 --> 00:42:58,642
and it'll go around for
quite a while before it gets

892
00:42:58,642 --> 00:43:00,310
all the way around.

893
00:43:00,310 --> 00:43:02,545
But with these chronographs
we can actually take direct

894
00:43:02,545 --> 00:43:04,214
images of planets.

895
00:43:04,214 --> 00:43:06,049
So if the planet is far
enough from the star,

896
00:43:06,049 --> 00:43:08,419
we might be able to detect it.

897
00:43:08,419 --> 00:43:10,787
So that is something that people
are very, very eager to do

898
00:43:10,787 --> 00:43:12,790
with the Webb Telescope.

899
00:43:13,957 --> 00:43:15,726
NIRSpec is our big spectrometer.

900
00:43:15,726 --> 00:43:19,129
Couple of interesting
things about it.

901
00:43:19,129 --> 00:43:22,866

It has two ways of
making a spectrum.

902
00:43:22,866 --> 00:43:26,069
It uses microshutters, and it
has an integral field unit,

903
00:43:26,069 --> 00:43:27,938
which are really technical
terms, but I'll explain

904
00:43:27,938 --> 00:43:29,539
what they mean.

905
00:43:29,539 --> 00:43:32,543
With a microshutter, it's
like shutters that you put

906
00:43:32,543 --> 00:43:34,010
on your windows.

907
00:43:34,010 --> 00:43:36,179
You have all the slats, and
you can open some of the slats,

908
00:43:36,179 --> 00:43:38,982
if it's maybe broken, to
let in light from one slat

909
00:43:38,982 --> 00:43:40,584
and not the others.

910
00:43:41,751 --> 00:43:43,687
So if we have an image
of galaxies on the sky,

911
00:43:43,687 --> 00:43:47,424
we can put the microshutter
array in front of them,

912
00:43:47,424 --> 00:43:50,794
and then we can choose which
shutters to open so that we get

913
00:43:50,794 --> 00:43:54,798
spectra of just the galaxies
that we're interested in.

914
00:43:54,798 --> 00:43:58,969
So here we've opened a few
shutters, and maybe that one

915
00:44:00,337 --> 00:44:02,005
corresponds to that galaxy,
this one to that one,

916
00:44:02,005 --> 00:44:03,407
and that to that.

917
00:44:03,407 --> 00:44:05,242
I don't know, the
drawing wasn't very good,

918
00:44:05,242 --> 00:44:07,110
but the point is we can
get spectra of those three

919
00:44:07,110 --> 00:44:09,679
galaxies at exactly
the same time.

920
00:44:09,679 --> 00:44:12,515
In fact, we can do up
to 100 at one time,

921
00:44:12,515 --> 00:44:14,984
which when you have a
big expensive telescope

922

00:44:14,984 --> 00:44:18,755
it's good to do as many things
at the same time as you can.

923
00:44:18,755 --> 00:44:21,091
So this is one way to get
information on many different

924
00:44:21,091 --> 00:44:24,094
objects, so that's we call
the microshutter array

925
00:44:24,094 --> 00:44:25,929
with the spectrometer.

926
00:44:27,397 --> 00:44:30,967
The other thing, the integral
field unit, take a tiny square

927
00:44:30,967 --> 00:44:33,470
of sky and slices it up.

928
00:44:33,470 --> 00:44:37,173
So it uses a special mirror
that has these steps on it

929
00:44:37,173 --> 00:44:40,778
so that the top slice gets
put into the spectrometer

930
00:44:40,778 --> 00:44:44,782
on the left edge, the next
slice next to it, and so forth.

931
00:44:44,782 --> 00:44:47,951
So we spread these six slices
out and get the spectra

932
00:44:47,951 --> 00:44:51,388
simultaneously, and so it's

another way to get information

933
00:44:51,388 --> 00:44:54,324
over a larger area
all at one time.

934
00:44:56,125 --> 00:44:58,228
One of the neat things
you can do with this is

935
00:44:58,228 --> 00:45:01,998
if you put such an integral
field unit on a galaxy,

936
00:45:01,998 --> 00:45:04,901
remember I talked about
red shifts and blue shifts.

937
00:45:04,901 --> 00:45:07,103
You can see those Doppler
shifts in the stars

938
00:45:07,103 --> 00:45:10,040
in the galaxy, and so we
can actually tell which way

939
00:45:10,040 --> 00:45:11,541
the galaxy is rotating.

940
00:45:11,541 --> 00:45:14,544
This top galaxy, the lower
end is coming toward us,

941
00:45:14,544 --> 00:45:16,046
it's blue shifted.

942
00:45:16,046 --> 00:45:19,115
The top end is moving away
from us, from the red shift.

943
00:45:19,115 --> 00:45:22,118
This galaxy, sort of the same
thing, so in both of these

944
00:45:22,118 --> 00:45:25,088
galaxies we see strong
signatures of rotation.

945
00:45:25,088 --> 00:45:27,724
We can tell how fast it's
rotating, which tells us how big

946
00:45:27,724 --> 00:45:28,892
the galaxy is.

947
00:45:30,293 --> 00:45:33,463
And so it's an important
tool for understanding those

948
00:45:33,463 --> 00:45:37,634
galaxies at the far fringers,
understanding how they formed.

949
00:45:39,870 --> 00:45:42,672
The Fine Guidance Sensor
NIRISS is actually sort of

950
00:45:42,672 --> 00:45:44,675
two instruments in one.

951
00:45:44,675 --> 00:45:48,011
I should have said NIRCAM
is being built, was built by

952
00:45:48,011 --> 00:45:50,947
the University of Arizona,
and NIRSPEC was built by

953
00:45:50,947 --> 00:45:53,216

the European Space Agency.

954
00:45:53,216 --> 00:45:57,020
FGS/NIRISS was built by
the Canadian Space Agency.

955
00:45:57,020 --> 00:46:00,357
It serves as the fine guidance
sensor to help us actually

956
00:46:00,357 --> 00:46:02,659
point the telescope
and lock onto stars.

957
00:46:02,659 --> 00:46:06,730
The Near-Infrared Imager
and Slitless Spectrograph

958
00:46:06,730 --> 00:46:10,500
is sort of a specialized
imager and spectrograph.

959
00:46:10,500 --> 00:46:12,503
It doesn't duplicate what
the other two near infrared

960
00:46:12,503 --> 00:46:13,771
instruments do.

961
00:46:16,039 --> 00:46:18,942
One of the neat things it does
do is it has the ability to

962
00:46:18,942 --> 00:46:23,480
take spectra of the same fields
in two different directions.

963
00:46:23,480 --> 00:46:25,915
So there's a pair of stars
here, and in this image

964
00:46:25,915 --> 00:46:29,619
the starlight is
spread horizontally.

965
00:46:29,619 --> 00:46:32,589
The same two stars are over
here, and this way the light

966
00:46:32,589 --> 00:46:33,957
is spread vertically.

967
00:46:33,957 --> 00:46:35,859
What's the big deal?

968
00:46:35,859 --> 00:46:38,028
Well, if you're getting
spectra of all these objects

969
00:46:38,028 --> 00:46:42,766
at the same time, it's
inevitable that two stars,

970
00:46:42,766 --> 00:46:45,602
the spectra overlap each
other one direction.

971
00:46:45,602 --> 00:46:47,504
But when I get the spectra
in the other direction,

972
00:46:47,504 --> 00:46:49,038
they're well separated.

973
00:46:49,038 --> 00:46:52,209
And so one image or the other
will give me a good spectrum

974
00:46:52,209 --> 00:46:55,879

of the sources that
I'm interested in.

975
00:46:55,879 --> 00:46:57,614
Okay, finally the fourth
instruments, this is MIRI.

976
00:46:57,614 --> 00:46:59,649
This is the instrument
that we've been working on

977
00:46:59,649 --> 00:47:01,417
here at JPL.

978
00:47:01,417 --> 00:47:03,320
The other three instruments
all work from about one

979
00:47:03,320 --> 00:47:04,620
to five microns.

980
00:47:04,620 --> 00:47:07,323
MIRI works five to 28 microns.

981
00:47:07,323 --> 00:47:09,792
Because we're the only
instrument that works at

982
00:47:09,792 --> 00:47:11,795
these wavelengths, we have
to do all the things that

983
00:47:11,795 --> 00:47:13,329
the other instruments do.

984
00:47:13,329 --> 00:47:15,999
So we have an imaging
capability, we
have chronographs,

985
00:47:15,999 --> 00:47:18,268
and we have a spectrometer.

986
00:47:19,736 --> 00:47:22,539
I forgot to point out, at
JPL we're responsible for

987
00:47:22,539 --> 00:47:24,474
the detectors.

988
00:47:24,474 --> 00:47:28,678
And every image of MIRI
that I can find on the web,

989
00:47:28,678 --> 00:47:30,413
they always hide my detectors.

990
00:47:30,413 --> 00:47:32,882
So gratuitous self-promotion.

991
00:47:32,882 --> 00:47:35,084
This is what one of the
JPL lead detectors actually

992
00:47:35,084 --> 00:47:35,986
looks like.

993
00:47:37,153 --> 00:47:39,356
Yes, that's me, you can
tell by the eyebrows.

994
00:47:39,356 --> 00:47:40,890
(laughing)

995
00:47:40,890 --> 00:47:43,360
This is (mumbling),
who was until recently

996

00:47:43,360 --> 00:47:45,094
our project manager.

997
00:47:45,094 --> 00:47:47,663
So this was early on when we
first delivered the detectors

998
00:47:47,663 --> 00:47:51,401
to be bolted onto the
rest of the instrument.

999
00:47:52,936 --> 00:47:55,238
A few words on why we want
a mid-infrared instrument

1000
00:47:55,238 --> 00:47:56,706
in the first place.

1001
00:47:56,706 --> 00:47:58,207
If we can learn a lot from
the near-infrared instruments,

1002
00:47:58,207 --> 00:48:01,044
why do we need a
mid-infrared instrument?

1003
00:48:01,044 --> 00:48:05,382
Near-infrared, we detect
mostly the ultraviolet light

1004
00:48:05,382 --> 00:48:09,185
from those galaxies that are
very far away that have been

1005
00:48:09,185 --> 00:48:12,589
red shifted from ultraviolet
to the near infrared.

1006
00:48:12,589 --> 00:48:15,325
Well, the visible light

from those galaxies gets

1007
00:48:15,325 --> 00:48:17,927
red shifted into
the mid-infrared.

1008
00:48:17,927 --> 00:48:21,131
So if we wanna study the
normal stars in those really

1009
00:48:21,131 --> 00:48:23,267
far away galaxies, we need
to look at them in the

1010
00:48:23,267 --> 00:48:25,001
mid-infrared.

1011
00:48:25,001 --> 00:48:28,605
We see mostly atoms
and molecules in high
energy conditions,

1012
00:48:28,605 --> 00:48:31,474
high temperatures in
the near-infrared.

1013
00:48:31,474 --> 00:48:33,710
We see molecules in lower
energy conditions in

1014
00:48:33,710 --> 00:48:35,112
the mid-infrared.

1015
00:48:36,679 --> 00:48:38,849
If we look at stars that
are forming planets,

1016
00:48:38,849 --> 00:48:42,318
we see the more mature
stars in the mid-infrared.

1017
00:48:42,318 --> 00:48:44,821
If you wanna see the very
young stars that are still

1018
00:48:44,821 --> 00:48:47,156
themselves in the
process of forming,

1019
00:48:47,156 --> 00:48:49,225
we see that in the mid-infrared.

1020
00:48:49,225 --> 00:48:51,928
And finally, if you're looking
at the planets themselves,

1021
00:48:51,928 --> 00:48:56,699
in the near-infrared we tend
to see the really hot planets

1022
00:48:56,699 --> 00:48:59,903
that are close to the stars,
things that are 1,000 degrees,

1023
00:48:59,903 --> 00:49:02,406
some place we definitely
don't wanna visit.

1024
00:49:02,406 --> 00:49:05,541
If you wanna study planets
that are more room temperature,

1025
00:49:05,541 --> 00:49:07,911
more like the Earth, then
we'll wanna look at those

1026
00:49:07,911 --> 00:49:09,412
in the mid-infrared.

1027

00:49:09,412 --> 00:49:11,248
And there are many, many more
reasons, but these are a few

1028
00:49:11,248 --> 00:49:14,717
of the things that
are important.

1029
00:49:14,717 --> 00:49:16,219
A little bit more about MIRI.

1030
00:49:16,219 --> 00:49:18,956
All the other instruments were
built, or at least there was

1031
00:49:18,956 --> 00:49:22,825
one organization responsible
for the instrument.

1032
00:49:22,825 --> 00:49:26,863
With MIRI it was a 50/50
partnership from the beginning.

1033
00:49:26,863 --> 00:49:30,833
JPL, it was responsible
for half the instrument,

1034
00:49:30,833 --> 00:49:34,437
the detectors, the electronics
to run the detectors.

1035
00:49:34,437 --> 00:49:37,273
And the cooler that gets
us down to that six kelvin

1036
00:49:37,273 --> 00:49:41,277
temperature were all the
responsibility of JPL.

1037
00:49:41,277 --> 00:49:43,980

Twenty-four astronomical
institutes in 10 different

1038
00:49:43,980 --> 00:49:46,949
European countries were
responsible for the optics

1039
00:49:46,949 --> 00:49:49,986
and the structure
of the instrument.

1040
00:49:49,986 --> 00:49:52,488
And when this was first proposed
to our senior management

1041
00:49:52,488 --> 00:49:54,524
here at JPL, they all shook
their head and said it's

1042
00:49:54,524 --> 00:49:56,693
never gonna work.

1043
00:49:56,693 --> 00:49:59,729
I'm pleased to say it worked
actually very, very well.

1044
00:49:59,729 --> 00:50:02,899
We had great people on
both sides of the pond,

1045
00:50:02,899 --> 00:50:07,070
so to speak, and I think we
have a really great instrument.

1046
00:50:08,270 --> 00:50:10,841
What do I wanna look at myself?

1047
00:50:12,209 --> 00:50:14,977
In the introduction Mark
explained that I'm interested

1048
00:50:14,977 --> 00:50:16,446
in star formation.

1049
00:50:16,446 --> 00:50:19,916
I do have a little bit
of time of my own on Webb

1050
00:50:19,916 --> 00:50:22,885
where I can point it
at anything I please,

1051
00:50:22,885 --> 00:50:25,855
and so what do I wanna look at?

1052
00:50:25,855 --> 00:50:28,124
Well, I got some questions.

1053
00:50:28,124 --> 00:50:31,494
I'd like to understand
how binary stars form.

1054
00:50:31,494 --> 00:50:34,797
About half the stars that you
see in the nighttime sky are

1055
00:50:34,797 --> 00:50:38,134
actually binaries, two stars
that are orbiting each other.

1056
00:50:38,134 --> 00:50:40,870
When we look at very young
stars, the stars that are

1057
00:50:40,870 --> 00:50:42,238
still in the process of forming,

1058
00:50:42,238 --> 00:50:44,474
it's more like 80%

to 90% of them.

1059
00:50:44,474 --> 00:50:48,345
So why do stars form as
binaries, and then lose their

1060
00:50:48,345 --> 00:50:50,313
companions along the way?

1061
00:50:50,313 --> 00:50:54,651
So I'd like to understand a
little bit about these binaries.

1062
00:50:54,651 --> 00:50:57,787
Also I mentioned that planetary
nebulae with that kind of

1063
00:50:57,787 --> 00:51:02,325
little wing-shaped structure,
generally you need binary

1064
00:51:02,325 --> 00:51:03,993
stars to form
structures like that.

1065
00:51:03,993 --> 00:51:06,229
So the common theme
is binary stars.

1066
00:51:06,229 --> 00:51:07,997
So I'd like to know a
little bit more about what

1067
00:51:07,997 --> 00:51:10,400
shapes the planetary nebulae.

1068
00:51:12,702 --> 00:51:14,670
This is a very young star.

1069

00:51:14,670 --> 00:51:16,105
It's actually a triple system,

1070
00:51:16,105 --> 00:51:18,241
so there are three stars here.

1071
00:51:18,241 --> 00:51:20,643
The bluish color of these
two stars generally indicate

1072
00:51:20,643 --> 00:51:23,146
that they are hotter.

1073
00:51:23,146 --> 00:51:27,483
They might even be almost normal
stars, whereas this yellow

1074
00:51:27,483 --> 00:51:30,220
reddish color, because this
is a mid-infrared image,

1075
00:51:30,220 --> 00:51:34,157
this we would normally
interpret as a very young star.

1076
00:51:34,157 --> 00:51:37,394
Well, if they're gravitationally
bound to each other,

1077
00:51:37,394 --> 00:51:39,195
they had to have formed
at the same time.

1078
00:51:39,195 --> 00:51:41,531
So how is it that you can
have two older looking stars,

1079
00:51:41,531 --> 00:51:43,767
and a younger looking star?

1080
00:51:46,135 --> 00:51:49,739
If you get crude spectra of
these stars, the two top sources

1081
00:51:49,739 --> 00:51:51,640
are the white and
red curves up here.

1082
00:51:51,640 --> 00:51:54,310
They're kind of normal and flat.

1083
00:51:54,310 --> 00:51:56,312
This is relative to a
normal star spectrum,

1084
00:51:56,312 --> 00:51:58,014
so they look about normal.

1085
00:51:58,014 --> 00:52:02,119
But this yellowish star has
much more infrared radiation,

1086
00:52:04,820 --> 00:52:06,723
and getting toward the visible.

1087
00:52:06,723 --> 00:52:09,659
So it's much colder in
apparent temperature.

1088
00:52:09,659 --> 00:52:13,229
But the important thing is
that the solid lines were data

1089
00:52:13,229 --> 00:52:15,531
that was taken at
one period of time,

1090
00:52:15,531 --> 00:52:18,201
and then the dash lines

was three years later.

1091
00:52:18,201 --> 00:52:20,537
So these two stars
stayed roughly constant,

1092
00:52:20,537 --> 00:52:24,007
but this star actually not
only did it get brighter

1093
00:52:24,007 --> 00:52:27,410
at short wavelengths, the
temperature actually got

1094
00:52:27,410 --> 00:52:29,446
apparently hotter.

1095
00:52:29,446 --> 00:52:31,114
So what's going on?

1096
00:52:31,114 --> 00:52:35,051
So one of the ideas is that
that gas and dust that forms

1097
00:52:35,051 --> 00:52:37,453
a star is still
streaming onto that star,

1098
00:52:37,453 --> 00:52:40,957
and as it falls onto
the star it heats up

1099
00:52:40,957 --> 00:52:44,261
and causes the changes in
temperatures and so forth.

1100
00:52:44,261 --> 00:52:46,929
So with Webb I'd like to
study that a little bit more.

1101
00:52:46,929 --> 00:52:49,431
I should be able to see material
actually around the star

1102
00:52:49,431 --> 00:52:52,002
perhaps flowing into that star.

1103
00:52:54,504 --> 00:52:58,040
On the planetary nebula side,
this is a different planetary

1104
00:52:58,040 --> 00:53:00,243
nebula called the Egg Nebula.

1105
00:53:00,243 --> 00:53:02,878
The image on the right
was taken with Hubble.

1106
00:53:02,878 --> 00:53:06,549
And so it shows these neat
lobes that are blowing out

1107
00:53:06,549 --> 00:53:08,952
from a star that you
actually can't see.

1108
00:53:08,952 --> 00:53:12,322
There's a big disc of dust
around the center that's

1109
00:53:12,322 --> 00:53:14,791
absorbing all the
starlight in the center.

1110
00:53:14,791 --> 00:53:18,227
This image was data that I
took with the Keck Telescope

1111
00:53:18,227 --> 00:53:21,497

with my mid-infrared
camera on the ground,

1112
00:53:21,497 --> 00:53:23,400
where it's really
hard to see stuff.

1113
00:53:23,400 --> 00:53:27,270
But even so, you can trace
the lobes of that planetary

1114
00:53:27,270 --> 00:53:28,871
right down to the center.

1115
00:53:28,871 --> 00:53:30,740
We still don't quite
see the central star.

1116
00:53:30,740 --> 00:53:33,843
That's just a blob of dust,
that's not the star itself.

1117
00:53:33,843 --> 00:53:36,346
It's hard to see here, but
there's also sort of a halo

1118
00:53:36,346 --> 00:53:39,482
around it where that warm
dust in the disc is glowing,

1119
00:53:39,482 --> 00:53:41,484
emitting it's own light.

1120
00:53:42,919 --> 00:53:45,321
This is another
planetary nebula.

1121
00:53:45,321 --> 00:53:46,822
This one looks a little normal.

1122
00:53:46,822 --> 00:53:49,291
It's kind of round, and it's
a little bubbly in the center,

1123
00:53:49,291 --> 00:53:51,560
but it's fairly unremarkable.

1124
00:53:51,560 --> 00:53:53,696
But when we looked at this
planetary nebula with the

1125
00:53:53,696 --> 00:53:58,267
WISE All-Sky Survey, we
discovered that it had a pair of

1126
00:53:58,267 --> 00:54:00,035
concentric rings around it.

1127
00:54:00,035 --> 00:54:02,004
So how did that structure form?

1128
00:54:02,004 --> 00:54:06,142
This also requires a
binary star to shape it.

1129
00:54:06,142 --> 00:54:09,011
And so we're still trying to
understand how does that work?

1130
00:54:09,011 --> 00:54:10,980
What makes those shapes?

1131
00:54:10,980 --> 00:54:13,450
And so I'd like to use Webb
to get information about

1132
00:54:13,450 --> 00:54:16,519
those rings, what they're
composed of, what the energy

1133
00:54:16,519 --> 00:54:20,423
situation is like, to see if
we can understand a little bit

1134
00:54:20,423 --> 00:54:25,128
better what's going on
with that planetary nebula.

1135
00:54:25,128 --> 00:54:27,463
Okay, what's Webb's
status, and what's up next?

1136
00:54:27,463 --> 00:54:31,034
So MIRI was the first
instrument delivered.

1137
00:54:32,601 --> 00:54:35,505
It was installed into
the science instrument
module in 2013.

1138
00:54:35,505 --> 00:54:37,507
And I do have to point out
the detectors are on the

1139
00:54:37,507 --> 00:54:39,976
back side, and so you
can't see them again.

1140
00:54:39,976 --> 00:54:42,211
(sighs)

1141
00:54:42,211 --> 00:54:45,081
All the instruments
were onboard by 2014,

1142
00:54:45,081 --> 00:54:47,550
within the year after that.

1143
00:54:47,550 --> 00:54:49,853
And then it went through a
number of rounds of testing.

1144
00:54:49,853 --> 00:54:52,288
We wanted to make sure that
the instruments made it to

1145
00:54:52,288 --> 00:54:54,323
the Goddard Space Flight
Center in one piece.

1146
00:54:54,323 --> 00:54:57,160
We wanted to make sure that
the computers that are gonna

1147
00:54:57,160 --> 00:55:01,264
run the science instrument
module were actually able to

1148
00:55:02,265 --> 00:55:04,300
control the instruments.

1149
00:55:04,300 --> 00:55:06,502
And they went through a
number of test to make sure

1150
00:55:06,502 --> 00:55:10,273
they'd survive launch and
all that sort of stuff.

1151
00:55:10,273 --> 00:55:12,908
Just earlier this year,
you may have seen some of

1152
00:55:12,908 --> 00:55:16,312
these pictures, the telescope
itself was completed.

1153

00:55:16,312 --> 00:55:19,716
And then just a few months
ago that instrument module

1154
00:55:19,716 --> 00:55:22,819
in the previous picture was
lowered onto the back side

1155
00:55:22,819 --> 00:55:25,055
of the telescope, so it
was installed behind the

1156
00:55:25,055 --> 00:55:26,655
primary mirror.

1157
00:55:26,655 --> 00:55:28,892
And so that whole assembly
is now ready to go through

1158
00:55:28,892 --> 00:55:30,226
its own testing.

1159
00:55:32,761 --> 00:55:35,665
It's next stop is actually the
Johnson Space Flight Center

1160
00:55:35,665 --> 00:55:39,102
down in Houston, where it
will go into Chamber A.

1161
00:55:39,102 --> 00:55:41,571
This is a huge vacuum
chamber that was used during

1162
00:55:41,571 --> 00:55:45,074
the Apollo missions where they'd
test the Apollo spacecraft.

1163
00:55:45,074 --> 00:55:48,211
In fact, they would throw

people inside there,

1164
00:55:48,211 --> 00:55:51,147
the astronauts, because they
needed to train to work in

1165
00:55:51,147 --> 00:55:52,782
a vacuum environment.

1166
00:55:52,782 --> 00:55:56,652
So it's been repurposed to
test the Webb Telescope.

1167
00:55:56,652 --> 00:55:58,721
This is what the
telescope will look like

1168
00:55:58,721 --> 00:56:01,090
inside the chamber, and
then there are a bunch of

1169
00:56:01,090 --> 00:56:03,193
light sources and other
instruments up on the top to

1170
00:56:03,193 --> 00:56:06,095
measure the properties of
the optics of the telescope

1171
00:56:06,095 --> 00:56:08,998
to make sure they're what
they're supposed to be.

1172
00:56:08,998 --> 00:56:13,169
We can't refurbish Webb, so
it has to work the first time.

1173
00:56:15,571 --> 00:56:17,807
So after the testing at
Johnson, the telescope will make

1174
00:56:17,807 --> 00:56:20,009
it's way to Northrop
Grumman right down here in

1175
00:56:20,009 --> 00:56:21,777
Redondo Beach.

1176
00:56:21,777 --> 00:56:25,714
The spacecraft, the propulsion
system and all that stuff,

1177
00:56:25,714 --> 00:56:28,717
and the sunshield will
be bolted together.

1178
00:56:28,717 --> 00:56:32,288
The telescope will then
be connected with it.

1179
00:56:32,288 --> 00:56:36,125
We'll have a completed
observatory in early 2018.

1180
00:56:36,125 --> 00:56:39,495
There will be some short,
it's probably still a couple

1181
00:56:39,495 --> 00:56:41,564
of months, but a short
functional test to make sure

1182
00:56:41,564 --> 00:56:43,899
everything is ready to go.

1183
00:56:43,899 --> 00:56:47,503
Then in October 2018
hopefully we launch.

1184

00:56:47,503 --> 00:56:50,440
And with any luck you'll invite
me back in about three years

1185
00:56:50,440 --> 00:56:53,710
to give you a few of
the first results.

1186
00:56:54,978 --> 00:56:56,045
So that's it.

1187
00:56:57,713 --> 00:56:59,182
Hope you learned a little
bit, and I'd be happy to

1188
00:56:59,182 --> 00:57:00,183
take questions.

1189
00:57:00,183 --> 00:57:02,419
(applause)

1190
00:57:10,626 --> 00:57:11,861
So if you do have questions,

1191
00:57:11,861 --> 00:57:13,562
please come up to
the microphone.

1192
00:57:13,562 --> 00:57:15,064
- [Attendee] Did you say
when Webb goes operational,

1193
00:57:15,064 --> 00:57:17,000
Hubble will still
be in operation?

1194
00:57:17,000 --> 00:57:18,468
- We hope so.

1195

00:57:18,468 --> 00:57:21,237
The only thing really limiting
it is whether any of the

1196
00:57:21,237 --> 00:57:24,873
gyroscopes in Hubble break,
and whether there's enough

1197
00:57:24,873 --> 00:57:28,378
funding to actually operate
both of them at the same time.

1198
00:57:28,378 --> 00:57:31,347
But we think we'll get at
least a year or two of overlap.

1199
00:57:31,347 --> 00:57:33,483
At least, fingers crossed.

1200
00:57:33,483 --> 00:57:34,851
Yes?

1201
00:57:34,851 --> 00:57:36,352
- Thanks for a great talk.

1202
00:57:36,352 --> 00:57:39,555
I was interested in learning
more about the six kelvin

1203
00:57:39,555 --> 00:57:43,593
requirement for MIRI, and
how you plan to achieve

1204
00:57:43,593 --> 00:57:46,196
the six kelvin requirement,
and how long it has to be

1205
00:57:46,196 --> 00:57:49,198
at that six kelvin
temperature range when you're

1206
00:57:49,198 --> 00:57:50,699
taking measurements.

1207
00:57:50,699 --> 00:57:52,768
- Okay, so all the other
instruments operate at about

1208
00:57:52,768 --> 00:57:56,338
40 kelvin, and we can get to
that temperature just based on

1209
00:57:56,338 --> 00:57:57,774
cooling of space.

1210
00:57:58,941 --> 00:58:01,010
We call it radiative cooling.

1211
00:58:01,010 --> 00:58:04,547
MIRI, to get down to six kelvin,
actually requires a cooler,

1212
00:58:04,547 --> 00:58:05,715
a cryo-cooler.

1213
00:58:07,550 --> 00:58:10,787
Comparing it to your
refrigerator in your house isn't

1214
00:58:10,787 --> 00:58:13,122
really fair, but it's kind
of the like the refrigerator

1215
00:58:13,122 --> 00:58:15,191
or freezer in your house.

1216
00:58:15,191 --> 00:58:18,761
It is a mechanical cooler,
so it should last for a

1217
00:58:18,761 --> 00:58:20,696
very, very long time.

1218
00:58:20,696 --> 00:58:23,833
In fact, we think the final
limit to the lifetime of Webb

1219
00:58:23,833 --> 00:58:27,270
is actually the propulsion,
our ability to steer.

1220
00:58:27,270 --> 00:58:29,805
If nothing breaks, if
everything survives launch,

1221
00:58:29,805 --> 00:58:33,042
everything should be able
to go at least 10 years,

1222
00:58:33,042 --> 00:58:34,210
that's the goal.

1223
00:58:34,210 --> 00:58:35,678
Five years for sure.

1224
00:58:35,678 --> 00:58:40,082
Hopefully 10 years, maybe
longer, but it is a mechanical

1225
00:58:40,082 --> 00:58:42,919
cooler that gets
us to six kelvin.

1226
00:58:46,255 --> 00:58:48,024
- Couple of question.

1227
00:58:49,391 --> 00:58:50,893
First one, I'll just

rattle out the questions.

1228
00:58:50,893 --> 00:58:52,528
You can pick them in order.

1229
00:58:52,528 --> 00:58:55,297
First one is, what's the
difference a slit spectrograph

1230
00:58:55,297 --> 00:58:57,900
and a slitless spectrograph?

1231
00:58:57,900 --> 00:59:02,005
Second question, is there any
plans for using a star shield,

1232
00:59:03,840 --> 00:59:07,911
or solar shield in
conjunction for a chronograph?

1233
00:59:09,044 --> 00:59:10,547
Third, I noticed--

1234
00:59:12,748 --> 00:59:14,250
- [Michael] I have to
remember all these.

1235
00:59:14,250 --> 00:59:16,185
- I noticed some flags at
the back end, aft end of

1236
00:59:16,185 --> 00:59:17,420
the instrument.

1237
00:59:18,854 --> 00:59:21,623
Can you tell us a little
bit about station keeping,

1238
00:59:21,623 --> 00:59:24,093

and what's involved with that?

1239
00:59:24,093 --> 00:59:27,897
- Okay, so let's
see, first question.

1240
00:59:27,897 --> 00:59:29,965
(laughing)
Uh oh.

1241
00:59:29,965 --> 00:59:31,233
- [Attendee] Slit and slitless.

1242
00:59:31,233 --> 00:59:33,403
- Slitless and slitted, okay.

1243
00:59:33,403 --> 00:59:37,873
So normally we wanna limit
the light that enters

1244
00:59:37,873 --> 00:59:42,045
the spectrograph, and so
we use a small slit so that

1245
00:59:42,045 --> 00:59:45,348
it isolates the galaxy or
star that we're looking at.

1246
00:59:45,348 --> 00:59:48,184
What it is does is eliminates
all the background from

1247
00:59:48,184 --> 00:59:50,153
the rest of the field of view,
and so it lets us concentrate

1248
00:59:50,153 --> 00:59:52,221
on that one object.

1249

00:59:52,221 --> 00:59:55,358
In a slitless spectrograph
we still use the prism

1250
00:59:55,358 --> 00:59:58,461
or grating or whatever
the spectrograph uses,

1251
00:59:58,461 --> 01:00:02,532
but now we don't isolate it,
so we get light from every

1252
01:00:02,532 --> 01:00:05,635
point in the sky that
enters the instrument.

1253
01:00:05,635 --> 01:00:09,004
So what happens is with a
slitted spectrograph you'll have

1254
01:00:09,004 --> 01:00:13,075
one micron light here,
five micron light there,

1255
01:00:13,075 --> 01:00:14,710
and you know exactly
where everything is.

1256
01:00:14,710 --> 01:00:19,381
With slitless one star's
one micron light be here,

1257
01:00:19,381 --> 01:00:22,518
but another star's one micron
light might be over here.

1258
01:00:22,518 --> 01:00:25,688
And so you have a mixture
of things, and so it's not

1259

01:00:25,688 --> 01:00:28,624
as sensitive, but if you
have a lot of bright objects,

1260
01:00:28,624 --> 01:00:32,628
it lets you get crude spectra
of many things all at once.

1261
01:00:32,628 --> 01:00:34,630
So there are advantages to both.

1262
01:00:34,630 --> 01:00:38,734
Most of the time we use some
version of a slit spectrograph.

1263
01:00:38,734 --> 01:00:40,836
But occasionally we
don't care so much.

1264
01:00:40,836 --> 01:00:42,504
We just wanna look at
something really bright,

1265
01:00:42,504 --> 01:00:45,408
and then we'll use the slitless.

1266
01:00:45,408 --> 01:00:49,145
Little crazy, but
it's all good stuff.

1267
01:00:49,145 --> 01:00:51,681
Okay, you're gonna
have to do it again.

1268
01:00:51,681 --> 01:00:53,749
- [Attendee] Second question
was if there was any plans

1269
01:00:53,749 --> 01:00:57,587
for a non-colocated,

non-circular chronograph.

1270
01:00:58,988 --> 01:01:02,991
- So there are studies of
whether you could fly something

1271
01:01:02,991 --> 01:01:06,696
in front of James Webb at
some point in the future.

1272
01:01:06,696 --> 01:01:08,163
They're studies.

1273
01:01:08,163 --> 01:01:10,232
It's probably not gonna
work with Webb itself.

1274
01:01:10,232 --> 01:01:12,335
The timing just isn't right.

1275
01:01:12,335 --> 01:01:15,838
They'll probably need a
dedicated mission to do

1276
01:01:15,838 --> 01:01:17,540
something like that.

1277
01:01:17,540 --> 01:01:21,410
It's a neat concept, and
it will happen someday,

1278
01:01:21,410 --> 01:01:23,746
but I don't thing the Webb
is quite the right time

1279
01:01:23,746 --> 01:01:25,114
to do that.

1280
01:01:25,114 --> 01:01:27,616

And then the third one was?

1281
01:01:27,616 --> 01:01:28,918
- Station keeping.

1282
01:01:28,918 --> 01:01:30,453
- Station keeping, yeah.

1283
01:01:30,453 --> 01:01:32,955
Okay, in that little video
you saw some momentum flaps

1284
01:01:32,955 --> 01:01:36,959
on the back, so it's a
somewhat standard system.

1285
01:01:38,394 --> 01:01:40,896
It uses reaction wheels, it
uses those momentum flaps

1286
01:01:40,896 --> 01:01:43,232
to help move things around.

1287
01:01:43,232 --> 01:01:45,768
When it needs to do a small
course correction to keep it

1288
01:01:45,768 --> 01:01:48,438
in that orbit around L2,
then it does use a little bit

1289
01:01:48,438 --> 01:01:50,239
of propellant.

1290
01:01:50,239 --> 01:01:53,075
So it's sort of a mixture
of all of them to make sure

1291
01:01:53,075 --> 01:01:56,111

it's pointing where
we want it to point.

1292
01:01:56,111 --> 01:01:57,146
Okay?

1293
01:01:57,146 --> 01:01:58,147
- Thank you.

1294
01:02:00,316 --> 01:02:03,119
- So I had a very fundamental
question about the early,

1295
01:02:03,119 --> 01:02:04,386
early galaxies.

1296
01:02:04,386 --> 01:02:07,423
So how do we actually see them?

1297
01:02:07,423 --> 01:02:09,525
So everything started
with the Big Bang and went

1298
01:02:09,525 --> 01:02:12,761
away from it, so how, I
guess how is that light not

1299
01:02:12,761 --> 01:02:14,931
already, like how do
we actually see them?

1300
01:02:14,931 --> 01:02:16,431
How has that light not passed
us since we don't travel

1301
01:02:16,431 --> 01:02:18,100
faster than light?

1302
01:02:18,100 --> 01:02:20,803

- So yeah, the universe is
kind of a big time machine.

1303
01:02:20,803 --> 01:02:23,539
It takes a certain amount
of time for light from

1304
01:02:23,539 --> 01:02:25,942
that galaxy to get to us.

1305
01:02:25,942 --> 01:02:30,113
So those galaxies that we see
13.4 billion light years away,

1306
01:02:33,682 --> 01:02:36,385
that light left that long ago.

1307
01:02:36,385 --> 01:02:39,288
So we only see the
galaxy at that age.

1308
01:02:39,288 --> 01:02:41,057
We have no idea what
it looks like now.

1309
01:02:41,057 --> 01:02:45,794
So as the universe is expanding,
that light is red shifted,

1310
01:02:45,794 --> 01:02:48,230
and that's why we see
it in the infrared.

1311
01:02:48,230 --> 01:02:51,333
But we really are seeing
it a long time ago.

1312
01:02:51,333 --> 01:02:55,071
So I don't know if I
answered that very well,

1313
01:02:56,539 --> 01:02:59,642
but we are seeing the light
that travelled a long time

1314
01:02:59,642 --> 01:03:01,143
to get to us.

1315
01:03:01,143 --> 01:03:03,712
- Okay, so it lasted long
enough for us to essentially

1316
01:03:03,712 --> 01:03:05,915
travel all that distance,
and then kept emitting.

1317
01:03:05,915 --> 01:03:07,817
- Right, right, so that
light's catching up to us

1318
01:03:07,817 --> 01:03:10,052
as that galaxy's
receding away from us.

1319
01:03:10,052 --> 01:03:10,887
Okay?

1320
01:03:14,556 --> 01:03:17,793
- My question has two parts,
but it's basically about

1321
01:03:17,793 --> 01:03:18,961
the sunshield.

1322
01:03:20,362 --> 01:03:24,233
So is it true that this really
huge sunshield allows you

1323
01:03:27,503 --> 01:03:32,408

to do the cooling without
having like liquid hydrogen

1324
01:03:32,408 --> 01:03:35,444
or liquid helium or something,
and so therefore you won't

1325
01:03:35,444 --> 01:03:38,113
run out like you
did with Spitzer?

1326
01:03:38,113 --> 01:03:39,581
- Right, that's right.

1327
01:03:39,581 --> 01:03:42,084
So the sunshield provides an
environment where the telescope

1328
01:03:42,084 --> 01:03:45,254
and three of the four
instruments can cool to 40

1329
01:03:45,254 --> 01:03:47,423
to 50 kelvin on their own.

1330
01:03:47,423 --> 01:03:49,725
There are some other radiators
that are kind of tucked

1331
01:03:49,725 --> 01:03:51,927
around the back to
help with that process,

1332
01:03:51,927 --> 01:03:55,764
but yeah, that sunshield
has to work exactly the way

1333
01:03:55,764 --> 01:03:57,332
it's supposed to in order to--

1334
01:03:57,332 --> 01:03:58,901
- So that's a more
ambitious sunshield than you

1335
01:03:58,901 --> 01:04:00,002
ever had before.

1336
01:04:00,002 --> 01:04:01,504
- [Michael] Yes, absolutely.

1337
01:04:01,504 --> 01:04:05,641
- So then the next question,
part of it is how much of

1338
01:04:05,641 --> 01:04:07,943
a constraint is the
sunshield as far as where you

1339
01:04:07,943 --> 01:04:09,612
point the telescope?

1340
01:04:10,979 --> 01:04:13,482
Obviously you can't
point it towards the sun.

1341
01:04:13,482 --> 01:04:15,017
- [Michael] Right.

1342
01:04:15,017 --> 01:04:19,088
- So can you still see like
half the space at one time?

1343
01:04:21,023 --> 01:04:23,726
- Yeah, unfortunately I
deleted that slide to save

1344
01:04:23,726 --> 01:04:26,528
some time, but I have the
slide on exactly that.

1345
01:04:26,528 --> 01:04:30,132
So if you imagine a plane
between the sun and the Earth,

1346
01:04:30,132 --> 01:04:34,337
JWST can point essentially
straight up or straight out

1347
01:04:35,971 --> 01:04:37,072
so there's kind of a
ring that we can spin the

1348
01:04:37,072 --> 01:04:38,574
telescope around.

1349
01:04:38,574 --> 01:04:41,510
We can't point directly away
from the sun because then

1350
01:04:41,510 --> 01:04:45,548
that would slide the telescope
around into the field

1351
01:04:45,548 --> 01:04:47,516
of view of the sun because
the sunshade wouldn't

1352
01:04:47,516 --> 01:04:49,051
block us anymore.

1353
01:04:49,051 --> 01:04:51,887
So there's actually a band
about 45 degrees wide,

1354
01:04:51,887 --> 01:04:55,190
kind of ringed around the
sky that we can observe

1355

01:04:55,190 --> 01:04:56,959
at any given time.

1356
01:04:56,959 --> 01:04:59,061
- But then you just wait
until the Earth moves around.

1357
01:04:59,061 --> 01:05:01,764
- Right, so if your object
happens to be directly apart

1358
01:05:01,764 --> 01:05:03,632
from the sun, you get to
wait four or five months

1359
01:05:03,632 --> 01:05:06,535
before you have a
chance to look at it.

1360
01:05:06,535 --> 01:05:07,569
- Thank you.

1361
01:05:07,569 --> 01:05:09,504
- [Michael] You're welcome.

1362
01:05:09,504 --> 01:05:11,006
- Well, I have two questions.

1363
01:05:11,006 --> 01:05:13,275
The first is I'd love to
hear about how James Webb

1364
01:05:13,275 --> 01:05:15,444
will be used to
study exoplanets.

1365
01:05:15,444 --> 01:05:19,181
And in particular will it be
taking a look at the planet

1366
01:05:19,181 --> 01:05:21,216
around Proxima Centauri?

1367
01:05:21,216 --> 01:05:23,952
How will it help us learn
more about their atmosphere as

1368
01:05:23,952 --> 01:05:27,189
a potential nearby
Earth-like worlds?

1369
01:05:27,189 --> 01:05:32,027
And my second question is will
JWST help with figuring out

1370
01:05:32,027 --> 01:05:35,397
what makes up dark
matter and dark energy?

1371
01:05:35,397 --> 01:05:36,932
- So yes to both of the above.

1372
01:05:36,932 --> 01:05:40,336
Exoplanets is actually a
very hot topic right now

1373
01:05:40,336 --> 01:05:41,170
of course.

1374
01:05:42,538 --> 01:05:45,274
Certain people think they oughta
just take 25% of Webb time

1375
01:05:45,274 --> 01:05:48,610
and devote it to exoplanets
right off the top.

1376
01:05:48,610 --> 01:05:50,546
The rest of us that don't

care so much about exoplanets

1377
01:05:50,546 --> 01:05:52,715
are gonna fight that.

1378
01:05:52,715 --> 01:05:54,317
- No, don't, don't.

1379
01:05:56,252 --> 01:05:58,754
- So exoplanets are a
very big thing of course.

1380
01:05:58,754 --> 01:06:00,689
So I showed a couple of
examples of things that

1381
01:06:00,689 --> 01:06:02,157
we might be able to do.

1382
01:06:02,157 --> 01:06:05,127
Studying exoplanets, yeah.

1383
01:06:05,127 --> 01:06:06,762
They are very clever.

1384
01:06:06,762 --> 01:06:09,398
They will come up with ways
to observe these things.

1385
01:06:09,398 --> 01:06:14,303
The problem from my
perspective is we built a very

1386
01:06:14,303 --> 01:06:17,273
exquisitely sensitive
instrument that was designed to

1387
01:06:17,273 --> 01:06:21,443
look at these galaxies 13.8

billion light years away,

1388
01:06:21,443 --> 01:06:24,680
and they're gonna point it
at the 10 brightest stars

1389
01:06:24,680 --> 01:06:26,215
in the sky.

1390
01:06:26,215 --> 01:06:28,384
Ah, it drives me nuts.

1391
01:06:28,384 --> 01:06:30,085
(laughing)

1392
01:06:30,085 --> 01:06:32,521
But it's great science,
it needs to be done.

1393
01:06:32,521 --> 01:06:36,358
It is gonna be tricky because
the stars are so bright.

1394
01:06:36,358 --> 01:06:38,093
The instruments are
gonna have some problems

1395
01:06:38,093 --> 01:06:39,628
dealing with all that.

1396
01:06:39,628 --> 01:06:42,898
But we're studying ways to do
the observations to make sure

1397
01:06:42,898 --> 01:06:45,100
they can actually be done, and
that we can get the science

1398
01:06:45,100 --> 01:06:46,502

that we're after.

1399
01:06:48,170 --> 01:06:51,339
So that was the exoplanet
question, and on dark matter,

1400
01:06:51,339 --> 01:06:54,510
there are actually other
missions coming along that will

1401
01:06:54,510 --> 01:06:56,145
do a better job.

1402
01:06:56,145 --> 01:06:58,346
But certainly there are
aspects of dark matter studies

1403
01:06:58,346 --> 01:07:00,683
that Webb will be able to do.

1404
01:07:02,151 --> 01:07:05,788
Certainly the gravitational
lensing helps us understand

1405
01:07:07,223 --> 01:07:10,225
the distribution of matter
in the galaxy clusters that

1406
01:07:10,225 --> 01:07:11,760
act as the lenses.

1407
01:07:11,760 --> 01:07:14,897
So we can't see all of
what that matter is,

1408
01:07:14,897 --> 01:07:18,734
so some component of that has
got to be the dark matter.

1409

01:07:18,734 --> 01:07:23,439
But there are other missions
that are being studied

1410
01:07:23,439 --> 01:07:26,475
that will actually be able
to let us look at a much

1411
01:07:26,475 --> 01:07:30,145
broader part of the sky
and look for the very tiny

1412
01:07:30,145 --> 01:07:34,116
gravitational influences that
will help map dark matter

1413
01:07:34,116 --> 01:07:35,617
around the sky.

1414
01:07:35,617 --> 01:07:38,620
So somewhat yes, but there are
actually, it sounds a little

1415
01:07:38,620 --> 01:07:41,590
funny, but there are somewhat
better ways to do it.

1416
01:07:41,590 --> 01:07:44,760
And so Webb's part of it, and
then there'll be other things

1417
01:07:44,760 --> 01:07:46,995
that do it as well.

1418
01:07:46,995 --> 01:07:48,497
- And dark energy?

1419
01:07:49,665 --> 01:07:52,268
- Ummm, now we're
getting tricky.

1420
01:07:54,837 --> 01:07:56,271
Actually I think I'm gonna
have to say I don't know

1421
01:07:56,271 --> 01:07:57,273
on this one.

1422
01:07:58,741 --> 01:08:01,343
I know a little bit about the
field, but not enough to know

1423
01:08:01,343 --> 01:08:03,745
whether Webb can
really help out.

1424
01:08:03,745 --> 01:08:06,815
I mean, certainly we'll be
able to contribute to our

1425
01:08:06,815 --> 01:08:09,418
understanding of the expansion
and acceleration rate

1426
01:08:09,418 --> 01:08:13,288
of the universe, but I haven't
thought about it enough

1427
01:08:13,288 --> 01:08:16,191
to know what we can really do,

1428
01:08:16,191 --> 01:08:19,194
so I don't wanna
answer incorrectly.

1429
01:08:19,194 --> 01:08:20,196
- Thank you.

1430
01:08:23,165 --> 01:08:24,699

- Yes?

1431
01:08:24,699 --> 01:08:26,235
- Thanks for the presentation.

1432
01:08:26,235 --> 01:08:28,103
Wondering what kind of
redundancy is built into the

1433
01:08:28,103 --> 01:08:32,274
sensors, seeing as L2 is a
bit far for a repair mission?

1434
01:08:34,043 --> 01:08:38,580
- Yeah, so that was a hot
topic when we first started

1435
01:08:38,580 --> 01:08:42,684
designing our instruments
and the observatory.

1436
01:08:42,684 --> 01:08:45,253
We want things redundant
so if something does fail

1437
01:08:45,253 --> 01:08:48,190
we can switch from the
A side to the B side

1438
01:08:48,190 --> 01:08:49,859
and let us continue.

1439
01:08:52,494 --> 01:08:56,831
The sensors themselves are
so hard to manufacture that

1440
01:08:56,831 --> 01:09:01,003
almost all of them are not
redundant, meaning that if

1441
01:09:01,003 --> 01:09:03,405
the imaging, we have
three detectors in MIRI.

1442
01:09:03,405 --> 01:09:06,041
There's one for the
imager part and two for

1443
01:09:06,041 --> 01:09:07,676
the spectrometer.

1444
01:09:07,676 --> 01:09:10,512
If any one of those detectors
fails, we actually lose our

1445
01:09:10,512 --> 01:09:14,116
ability to do science
with that capability.

1446
01:09:14,116 --> 01:09:17,953
Now the electronics that drives
the detectors are redundant.

1447
01:09:17,953 --> 01:09:19,821
We have an A and a B side.

1448
01:09:19,821 --> 01:09:23,291
But because of constraints
when we were doing the design,

1449
01:09:23,291 --> 01:09:25,994
the sensors themselves are not.

1450
01:09:25,994 --> 01:09:30,599
So I'm gonna have six
months of terror waiting to

1451
01:09:30,599 --> 01:09:33,001
make sure that everything in

the instrument is actually

1452
01:09:33,001 --> 01:09:35,904
working really as
well as it can.

1453
01:09:35,904 --> 01:09:39,441
It's actually closer to
two and a half months,

1454
01:09:39,441 --> 01:09:42,177
but until the instrument is
cold enough where I can see

1455
01:09:42,177 --> 01:09:44,746
all the detectors
working properly.

1456
01:09:44,746 --> 01:09:46,581
But yeah, that's
absolute a concern.

1457
01:09:46,581 --> 01:09:49,384
That's part of why all
our tests take so long.

1458
01:09:49,384 --> 01:09:52,087
The tests that we did on
the instrument module,

1459
01:09:52,087 --> 01:09:55,957
each of the three tests was
about three months long.

1460
01:09:55,957 --> 01:09:58,661
We're doing all the testing
to make sure that they will

1461
01:09:58,661 --> 01:10:02,464
survive vibration, they'll

survive cooling down,

1462
01:10:02,464 --> 01:10:06,635
because we can't afford
to have anything go wrong.

1463
01:10:08,003 --> 01:10:11,507
So some redundancy, but maybe
not as much as I'd like.

1464
01:10:11,507 --> 01:10:13,041
- Thanks.

1465
01:10:13,041 --> 01:10:17,146
- How much of the cost of
the space telescope is in

1466
01:10:18,513 --> 01:10:20,749
the design and mission
planning, and how much of it

1467
01:10:20,749 --> 01:10:22,884
is in manufacturing?

1468
01:10:22,884 --> 01:10:25,054
Like so if you have a launch
failure, how difficult is it

1469
01:10:25,054 --> 01:10:28,790
to spin back up and
relaunch a similar mission?

1470
01:10:28,790 --> 01:10:31,693
- Yes, that's actually
a really great question,

1471
01:10:31,693 --> 01:10:34,329
and it's good because people
often see the price tag

1472
01:10:34,329 --> 01:10:37,365
of the Webb Telescope
and say, holy cow,

1473
01:10:37,365 --> 01:10:39,468
how expensive is that thing?

1474
01:10:39,468 --> 01:10:42,638
Well, the cost numbers that
you see actually cover all

1475
01:10:42,638 --> 01:10:46,875
phases of the development
and operation of Webb.

1476
01:10:46,875 --> 01:10:50,779
So I can't give you
exact numbers because
I don't know them.

1477
01:10:50,779 --> 01:10:52,781
Maybe the folks over
at Goddard want to take

1478
01:10:52,781 --> 01:10:54,750
a crack at that one.

1479
01:10:54,750 --> 01:10:58,420
But there was money that went
into the original concept

1480
01:10:58,420 --> 01:11:02,223
studies, then money to do the
designs, the construction.

1481
01:11:02,223 --> 01:11:05,894
The cost numbers that you see
actually include five years

1482

01:11:05,894 --> 01:11:08,597
operation, so they include
launch and five years of

1483
01:11:08,597 --> 01:11:10,431
operation after that.

1484
01:11:10,431 --> 01:11:12,334
Most of the money goes
into the construction of

1485
01:11:12,334 --> 01:11:16,138
the telescope, of course,
but it does include from the

1486
01:11:16,138 --> 01:11:19,241
first idea to the
end of the mission.

1487
01:11:20,575 --> 01:11:21,410
Okay?

1488
01:11:23,411 --> 01:11:24,847
We have some online questions.

1489
01:11:24,847 --> 01:11:26,247
Oh, go ahead.

1490
01:11:26,247 --> 01:11:29,184
- [Attendee] I got one question.

1491
01:11:29,184 --> 01:11:31,219
How long, I may have missed
it, how long does it take

1492
01:11:31,219 --> 01:11:32,688
actually to get
from Earth to L2?

1493

01:11:32,688 --> 01:11:33,989
A million miles?

1494
01:11:33,989 --> 01:11:36,959
- So that actually takes
most of those two weeks.

1495
01:11:36,959 --> 01:11:40,662
There is a point where
we actually go into orbit

1496
01:11:40,662 --> 01:11:42,397
around the L2 point.

1497
01:11:42,397 --> 01:11:44,833
It's not that we go to
a point and park there.

1498
01:11:44,833 --> 01:11:47,035
We actually do sort of
a lazy six-month orbit

1499
01:11:47,035 --> 01:11:48,437
around that spot.

1500
01:11:50,072 --> 01:11:52,207
It's somewhere between two
weeks and a month before

1501
01:11:52,207 --> 01:11:53,475
we actually get--

1502
01:11:53,475 --> 01:11:55,010
- And what does it
use for propulsion?

1503
01:11:55,010 --> 01:11:56,512
Does it have a rocket on
it when it's going there?

1504
01:11:56,512 --> 01:11:58,313
Or how does it--

1505
01:11:58,313 --> 01:11:59,581
- Yeah, little thrusters.

1506
01:11:59,581 --> 01:12:01,683
I'm not sure what the
propellant actually is,

1507
01:12:01,683 --> 01:12:04,386
but it's kind of typical
thrusters that we use.

1508
01:12:04,386 --> 01:12:07,056
- And the power source
is just solenoid?

1509
01:12:07,056 --> 01:12:09,758
- Yeah, solar panels,
big solar panels that are

1510
01:12:09,758 --> 01:12:11,192
underneath that sunshield.

1511
01:12:11,192 --> 01:12:12,494
- All right.

1512
01:12:12,494 --> 01:12:13,829
- Okay.

1513
01:12:13,829 --> 01:12:15,797
So got a couple
online questions.

1514
01:12:15,797 --> 01:12:19,133
Kieran, Kieran asks, I've
heard ozone in the Earth's

1515
01:12:19,133 --> 01:12:21,570
atmosphere absorbs UV radiation.

1516
01:12:21,570 --> 01:12:25,474
Does it also absorb infrared
but not visible light?

1517
01:12:25,474 --> 01:12:28,210
I can't say whether it
absorbs anything at visible

1518
01:12:28,210 --> 01:12:31,613
wavelengths, but I had a
slide way back that showed

1519
01:12:31,613 --> 01:12:34,816
the absorption spectrum
of Earth's atmosphere.

1520
01:12:34,816 --> 01:12:38,520
And at 9.7 microns there
is a fairly strong ozone

1521
01:12:38,520 --> 01:12:40,121
absorption band.

1522
01:12:40,121 --> 01:12:44,293
So a telescope looking on
the ground pointing up can

1523
01:12:45,727 --> 01:12:49,831
actually see the absorption
of ozone at those wavelengths.

1524
01:12:49,831 --> 01:12:54,436
So yes, we definitely do
see some in the infrared.

1525
01:12:54,436 --> 01:12:55,437

What's that?

1526
01:12:57,038 --> 01:13:01,910
Okay, Scara, hopefully I'm
pronouncing that right.

1527
01:13:01,910 --> 01:13:04,046
Scara asks, the ability
to service Hubble saved

1528
01:13:04,046 --> 01:13:05,581
and improved it.

1529
01:13:05,581 --> 01:13:07,249
Worried about Webb.

1530
01:13:07,249 --> 01:13:08,817
Please talk about
how well it is built

1531
01:13:08,817 --> 01:13:10,719
and alleviate my worries.

1532
01:13:10,719 --> 01:13:12,754
(laughing)

1533
01:13:12,754 --> 01:13:15,090
okay, so we talked a
little bit about this with

1534
01:13:15,090 --> 01:13:17,793
one of the previous
questions with redundancy.

1535
01:13:17,793 --> 01:13:21,696
So as many of the systems
as possible we do make

1536
01:13:21,696 --> 01:13:24,900

redundant so that
if one half fails,

1537
01:13:24,900 --> 01:13:26,902
we switch over to
the other half.

1538
01:13:26,902 --> 01:13:30,671
And the other thing we
do is we do a lot of what

1539
01:13:30,671 --> 01:13:32,641
we call environmental testing.

1540
01:13:32,641 --> 01:13:36,578
We took each of the instruments
to a vibration table.

1541
01:13:36,578 --> 01:13:39,014
We bolted it onto these tables
that then shake like crazy

1542
01:13:39,014 --> 01:13:41,516
to simulate the
launch of the rocket.

1543
01:13:41,516 --> 01:13:44,419
After we delivered the
instruments into that science

1544
01:13:44,419 --> 01:13:46,654
instrument module, that whole
science instrument module

1545
01:13:46,654 --> 01:13:47,556
was shaken.

1546
01:13:48,857 --> 01:13:51,526
Then when the science instrument
module was bolted onto

1547
01:13:51,526 --> 01:13:53,161
the telescope, it
was shaken again.

1548
01:13:53,161 --> 01:13:54,329
We keep shaking things.

1549
01:13:54,329 --> 01:13:55,831
Like hey guys, you're
gonna break it.

1550
01:13:55,831 --> 01:13:59,534
But we do these tests not
quite to launch levels,

1551
01:13:59,534 --> 01:14:03,205
but we do these tests to
make sure that things are

1552
01:14:03,205 --> 01:14:05,941
properly mounted, that
something's not gonna break

1553
01:14:05,941 --> 01:14:09,143
loose and fail, and that the
way be built the instruments

1554
01:14:09,143 --> 01:14:13,081
and the telescope in the first
place can survive all that.

1555
01:14:13,081 --> 01:14:15,750
We've actually cooled the
instruments down to their

1556
01:14:15,750 --> 01:14:17,619
operating temperature.

1557

01:14:17,619 --> 01:14:19,688
Well, the instruments
themselves have been down to

1558
01:14:19,688 --> 01:14:21,657
operating temperature
at least a few times.

1559
01:14:21,657 --> 01:14:24,559
And then as a science instrument
package, that's also been

1560
01:14:24,559 --> 01:14:27,595
cooled down to operating
temperatures three times.

1561
01:14:27,595 --> 01:14:30,866
So we do a number of these
tests to try to make sure

1562
01:14:30,866 --> 01:14:35,237
everything really is functioning
the way it's supposed to,

1563
01:14:35,237 --> 01:14:38,440
and that it's robust, that
we don't expect it to break.

1564
01:14:38,440 --> 01:14:40,775
It is true we
cannot service Webb.

1565
01:14:40,775 --> 01:14:43,745
We really do have to get
it to work the first time.

1566
01:14:43,745 --> 01:14:46,915
But you know, we learned a
lot of things from Hubble,

1567

01:14:46,915 --> 01:14:50,551
so hopefully we won't make
the same mistakes twice.

1568
01:14:50,551 --> 01:14:52,588
Hopefully we don't make
too many new mistakes.

1569
01:14:52,588 --> 01:14:56,391
But that's also part of why
these things cost so much.

1570
01:14:56,391 --> 01:14:59,727
We have to do a lot of testing
to make sure that everything

1571
01:14:59,727 --> 01:15:03,965
is gonna make it to where
it's supposed to be.

1572
01:15:03,965 --> 01:15:07,636
So hopefully I've
reassured you a little bit.

1573
01:15:07,636 --> 01:15:10,539
I'm gonna be holding my breath
too, and have every body part

1574
01:15:10,539 --> 01:15:14,042
I can come up with crossed
as well when we launch.

1575
01:15:14,042 --> 01:15:16,644
So I know that's not perfect
assurance, but we're doing

1576
01:15:16,644 --> 01:15:20,082
our best to make sure
that it's all okay.

1577

01:15:21,049 --> 01:15:23,418
Okay, any other questions.

1578
01:15:23,418 --> 01:15:24,552
Yes?

1579
01:15:24,552 --> 01:15:26,688
- I have question.

1580
01:15:26,688 --> 01:15:30,792
I was wondering how is the
hexagonal primary mirror

1581
01:15:30,792 --> 01:15:34,963
of Webb is a better choice,
so to say, than a round mirror

1582
01:15:36,731 --> 01:15:37,566
of Hubble?

1583
01:15:39,534 --> 01:15:42,604
- Okay, because the mirror had
the fold, that's why we use

1584
01:15:42,604 --> 01:15:44,139
the hexagonal segments.

1585
01:15:44,139 --> 01:15:47,609
The Keck telescopes in Hawaii
actually had a similar design

1586
01:15:47,609 --> 01:15:50,311
where they have
hexagonal mirrors.

1587
01:15:50,311 --> 01:15:53,748
They actually have 36 mirrors
where we only have 18.

1588

01:15:53,748 --> 01:15:57,019
On the back of each mirror
is a system of actuators

1589
01:15:57,019 --> 01:16:01,123
that moves each segment
little bits to make sure that

1590
01:16:02,524 --> 01:16:05,293
each segment lines up exactly
where it's supposed to be,

1591
01:16:05,293 --> 01:16:09,864
and that the entire system
works like one big mirror

1592
01:16:09,864 --> 01:16:12,300
rather than 18 little mirrors.

1593
01:16:12,300 --> 01:16:16,171
So it's that correction,
that ability to position each

1594
01:16:16,171 --> 01:16:19,441
mirror properly that
allows it to work.

1595
01:16:20,876 --> 01:16:22,510
Is there a little bit
more to your question?

1596
01:16:22,510 --> 01:16:23,345
- No.

1597
01:16:24,779 --> 01:16:28,983
Is folding is the only reason
why it has to be hexagonal?

1598
01:16:28,983 --> 01:16:32,887
Or is there any other

advantage to that?

1599
01:16:32,887 --> 01:16:35,624
- Yeah, it's probably the
biggest reason because it does

1600
01:16:35,624 --> 01:16:36,725
have to fold.

1601
01:16:38,126 --> 01:16:40,829
It's also easier to make
lots of smaller mirrors,

1602
01:16:40,829 --> 01:16:44,099
even if each mirror has to
have it's own specific shape,

1603
01:16:44,099 --> 01:16:46,101
it's easier to make small
mirrors than it is one

1604
01:16:46,101 --> 01:16:48,103
gigantic mirror.

1605
01:16:48,103 --> 01:16:50,772
The biggest single mirror
telescopes on the ground

1606
01:16:50,772 --> 01:16:52,740
are about eight
meters in diameter.

1607
01:16:52,740 --> 01:16:55,276
So what's that, about
27 feet in diameter.

1608
01:16:55,276 --> 01:16:58,546
The bigger ones, the 10
meter telescopes like Keck

1609
01:16:58,546 --> 01:17:01,883
all use the hexagonal
mirrored structure.

1610
01:17:03,418 --> 01:17:06,087
So manufacturing and the fact
that we have to fold it up

1611
01:17:06,087 --> 01:17:08,323
is what drove it.

1612
01:17:08,323 --> 01:17:09,324
- Thank you.

1613
01:17:11,392 --> 01:17:15,897
- Just curious, given that
the mirror is exposed to space

1614
01:17:15,897 --> 01:17:20,434
like it is, as opposed to
inside the tube in Hubble,

1615
01:17:20,434 --> 01:17:25,039
how vulnerable is it to stuff,
you know, just random stuff?

1616
01:17:25,039 --> 01:17:27,275
I know there's less of it
out at L2 than there is in

1617
01:17:27,275 --> 01:17:29,845
Earth orbit, but still,
is there any risk to that?

1618
01:17:29,845 --> 01:17:32,747
- Yeah, we're gonna
get hit by stuff.

1619
01:17:32,747 --> 01:17:36,918

That big sunshield is a great
micro meteorite collector.

1620
01:17:38,319 --> 01:17:41,089
So you know, we are worried
about things zipping in

1621
01:17:41,089 --> 01:17:44,659
and dinging the mirrors
or plowing holes through

1622
01:17:44,659 --> 01:17:46,427
the sunshield.

1623
01:17:46,427 --> 01:17:49,330
So we have tried to
model all those effects.

1624
01:17:49,330 --> 01:17:52,533
So we have a beginning of
life performance of the

1625
01:17:52,533 --> 01:17:55,136
primary mirror, and then
there's an end of life

1626
01:17:55,136 --> 01:17:59,140
performance model where we
try to take into account

1627
01:17:59,140 --> 01:18:00,608
all those things.

1628
01:18:00,608 --> 01:18:03,377
There will be damage over
time, and so we think we know

1629
01:18:03,377 --> 01:18:06,314
how well it will still work
five years, 10 years on.

1630
01:18:06,314 --> 01:18:10,986
And things are designed
to deal with that as well

1631
01:18:10,986 --> 01:18:13,388
as we can, but when you
have an exposed mirror,

1632
01:18:13,388 --> 01:18:14,923
you are gonna get hit.

1633
01:18:14,923 --> 01:18:17,826
It's just going to happen, and
so you have to make sure that

1634
01:18:17,826 --> 01:18:20,528
things are large, that
you use materials that are

1635
01:18:20,528 --> 01:18:23,932
good enough that you
can control it somewhat,

1636
01:18:23,932 --> 01:18:25,867
and that at the end of
life you'll still have

1637
01:18:25,867 --> 01:18:27,535
really good performance.

1638
01:18:27,535 --> 01:18:31,072
So yeah, absolutely it is
gonna degrade with time.

1639
01:18:31,072 --> 01:18:33,908
We just did our best to
make sure it doesn't degrade

1640

01:18:33,908 --> 01:18:36,378
faster than we
think it's going to.

1641
01:18:36,378 --> 01:18:38,212
The other thing we have to
worry about, when we launch it,

1642
01:18:38,212 --> 01:18:39,947
it's gonna be in
Earth's atmosphere.

1643
01:18:39,947 --> 01:18:41,750
It's gonna carry some
of that up with it,

1644
01:18:41,750 --> 01:18:45,753
and so we'll have ice
potentially freezing on things.

1645
01:18:45,753 --> 01:18:49,157
And so we do have heaters
to keep critical parts of

1646
01:18:49,157 --> 01:18:52,393
the telescope and the
instruments a little bit warmer

1647
01:18:52,393 --> 01:18:54,295
than the not so critical stuff.

1648
01:18:54,295 --> 01:18:57,098
So hopefully the ice freezes
on the support struts

1649
01:18:57,098 --> 01:18:59,000
and all the things that
we don't care about,

1650
01:18:59,000 --> 01:19:03,504

and leaves the optical
surfaces relatively clean.

1651
01:19:03,504 --> 01:19:06,641
So we do try to make sure
we've caught all those things

1652
01:19:06,641 --> 01:19:08,410
as we think about it.

1653
01:19:10,044 --> 01:19:11,479
Okay?

1654
01:19:11,479 --> 01:19:15,784
- So a lot of your sensors
work at very cold temperatures,

1655
01:19:15,784 --> 01:19:19,387
and you obviously test
their function at those cold

1656
01:19:19,387 --> 01:19:21,890
temperatures by
cooling them down.

1657
01:19:21,890 --> 01:19:25,794
How do you prevent any of those
sensors from being damaged

1658
01:19:25,794 --> 01:19:28,196
from the heat cycles, from
the heating and cooling

1659
01:19:34,369 --> 01:19:29,431
of the sensors.

1660
01:19:34,369 --> 01:19:37,572
They have to be designed in
a robust manner to make sure

1661
01:19:37,572 --> 01:19:40,008
that they don't
fracture when they cool.

1662
01:19:40,008 --> 01:19:43,979
So I know the sensors in
MIRI the best obviously.

1663
01:19:43,979 --> 01:19:48,150
So the circuit board that
our sensors are attached to

1664
01:19:50,285 --> 01:19:53,955
were specifically chosen to
contract and expand at the

1665
01:19:53,955 --> 01:19:57,559
same rate that the sensors
themselves expand and contract.

1666
01:19:57,559 --> 01:19:59,828
So we don't want the thing
that's holding the detector

1667
01:19:59,828 --> 01:20:02,296
to crush it because it
contracted faster than

1668
01:20:02,296 --> 01:20:04,031
the detector did.

1669
01:20:04,031 --> 01:20:07,101
And so we do those material
analyses all through the

1670
01:20:07,101 --> 01:20:11,205
design process to make sure
that we're not gonna do

1671

01:20:11,205 --> 01:20:13,241
anything to crack them.

1672
01:20:13,241 --> 01:20:17,412
And then the detector vendors
that we contracted with

1673
01:20:18,813 --> 01:20:21,916
to actually develop them,
they have their own processes

1674
01:20:21,916 --> 01:20:24,252
for making sure that
the sensors can survive

1675
01:20:24,252 --> 01:20:25,753
in the first place.

1676
01:20:25,753 --> 01:20:27,822
And sometimes it takes a
few years to get it right.

1677
01:20:27,822 --> 01:20:31,993
But we use light detectors,
so if things that we don't

1678
01:20:33,394 --> 01:20:35,897
intend to fly, but that
were built at the same time,

1679
01:20:35,897 --> 01:20:38,133
and we actually torture
test those things.

1680
01:20:38,133 --> 01:20:41,169
So one of the MIRI sensors we
put through 100 thermal cycles

1681
01:20:41,169 --> 01:20:43,237
going down to six

kelvin, going back up to,

1682
01:20:43,237 --> 01:20:45,239
well we cheated a little bit.

1683
01:20:45,239 --> 01:20:47,241
We only went to 77 kelvin
and then back up to

1684
01:20:47,241 --> 01:20:48,843
room temperature.

1685
01:20:48,843 --> 01:20:51,646
If it can survive that, it
will survive six kelvin.

1686
01:20:51,646 --> 01:20:54,348
So we made sure it could
go many, many, many cycles

1687
01:20:54,348 --> 01:20:56,418
without anything happening.

1688
01:20:56,418 --> 01:20:59,086
And that gives us confidence
that only cooling it

1689
01:20:59,086 --> 01:21:01,489
five or six times
will be just fine.

1690
01:21:01,489 --> 01:21:06,027
So it is something we study
with those flight light parts

1691
01:21:06,027 --> 01:21:10,731
to make sure that there are no
issues with it being cooled.

1692

01:21:10,731 --> 01:21:13,501
- Thank you for the lecture.

1693
01:21:13,501 --> 01:21:17,772
Given the cost of the telescope
itself, and assuming that

1694
01:21:17,772 --> 01:21:20,441
everything is work just
fine, do you have any plan

1695
01:21:20,441 --> 01:21:22,777
when there's done admission?

1696
01:21:24,679 --> 01:21:27,515
Like after five
year, after 10 year?

1697
01:21:27,515 --> 01:21:30,051
What do you planning to
do because for the cost,

1698
01:21:30,051 --> 01:21:33,454
this cost a lot of money, do
you plan to have something

1699
01:21:33,454 --> 01:21:35,323
like repair it back to Earth?

1700
01:21:35,323 --> 01:21:37,458
Or are you just gonna
leave it in space?

1701
01:21:37,458 --> 01:21:40,595
- So at this point the plan
is just leave it there.

1702
01:21:40,595 --> 01:21:43,164
Eventually it will
run out of propellant,

1703
01:21:43,164 --> 01:21:45,399
and then it will start
to drift away from L2,

1704
01:21:45,399 --> 01:21:49,303
and it will just go into
orbit around the sun.

1705
01:21:49,303 --> 01:21:51,973
So it's not gonna be a
hazard to anything else.

1706
01:21:51,973 --> 01:21:55,609
But as I say, hopefully
it is the propellant that

1707
01:21:55,609 --> 01:21:58,113
eventually stops this working.

1708
01:21:59,280 --> 01:22:01,549
We hope maybe we can
get 15 years out of it,

1709
01:22:01,549 --> 01:22:03,418
maybe even a little more
depending up on frugal we are

1710
01:22:03,418 --> 01:22:05,620
with the propellant.

1711
01:22:05,620 --> 01:22:08,856
But eventually yeah,
it's just gonna go away.

1712
01:22:08,856 --> 01:22:11,358
- [Attendee] Thank you.

1713
01:22:11,358 --> 01:22:13,461

- [Attendee] Had
two more questions.

1714
01:22:13,461 --> 01:22:15,063
- Okay.

1715
01:22:15,063 --> 01:22:17,966
- First one's an easy one.

1716
01:22:17,966 --> 01:22:20,968
If you could talk a little
bit about the mechanics

1717
01:22:20,968 --> 01:22:22,470
of the deployment.

1718
01:22:23,905 --> 01:22:26,607
So obviously it's a pretty
complex sequence of events.

1719
01:22:26,607 --> 01:22:30,779
Second question has to do
with mirror segment geometry.

1720
01:22:32,213 --> 01:22:35,450
It makes sense obviously
to have hexagonal tiles in

1721
01:22:35,450 --> 01:22:37,752
the interstitial portion,
but on the outer point,

1722
01:22:37,752 --> 01:22:41,323
are there any defraction
artifacts in band,

1723
01:22:41,323 --> 01:22:44,259
and what would be the
reason for leaving all the

1724
01:22:44,259 --> 01:22:47,161
hexagonal edges as opposed
to making a giant disk

1725
01:22:47,161 --> 01:22:49,964
out of it at the periphery?

1726
01:22:49,964 --> 01:22:51,232
- Right.

1727
01:22:51,232 --> 01:22:53,367
Okay, so complexity
of the mechanisms.

1728
01:22:53,367 --> 01:22:55,302
All I can really say because
I'm not involved in the

1729
01:22:55,302 --> 01:22:57,472
mechanical design
of the telescope,

1730
01:22:57,472 --> 01:23:01,909
early on the scientific working
group asked Northrup Grumman

1731
01:23:01,909 --> 01:23:04,812
whether this was the
most complex thing
they've ever built.

1732
01:23:04,812 --> 01:23:07,281
And the answer was no, it's
the fourth most complex thing

1733
01:23:07,281 --> 01:23:09,216
they've ever built, but we
can't tell you about the

1734

01:23:09,216 --> 01:23:10,785
other three.

1735
01:23:10,785 --> 01:23:12,954
(laughing)

1736
01:23:12,954 --> 01:23:15,789
So I'm trusting they
know what they're doing.

1737
01:23:15,789 --> 01:23:18,860
Then in terms of the
mirror segments, yes,

1738
01:23:18,860 --> 01:23:21,629
that actually is very
much of an issue.

1739
01:23:21,629 --> 01:23:24,431
If you look at the defraction
pattern, what a star looks

1740
01:23:24,431 --> 01:23:28,470
like in JWST, it's not
a nice round thing.

1741
01:23:28,470 --> 01:23:30,705
It does have kind of ripples
and stuff that follow that

1742
01:23:30,705 --> 01:23:33,041
hexagonal overall structure.

1743
01:23:34,242 --> 01:23:37,645
It's not bad enough
to be a real issue.

1744
01:23:37,645 --> 01:23:39,480
Our images will still
look really pretty.

1745
01:23:39,480 --> 01:23:43,751
We'll still be able to
do really good science.

1746
01:23:43,751 --> 01:23:47,155
They might have been able to
round the edges to give it

1747
01:23:47,155 --> 01:23:49,557
a more traditional round shape,
but that's a lot of extra

1748
01:23:49,557 --> 01:23:53,694
manufacturing cost that just
wasn't worth it in the end.

1749
01:23:53,694 --> 01:23:58,433
Each of the instruments,
as we focus the starlight

1750
01:23:58,433 --> 01:24:01,169
there's actually a point
in the optics where the

1751
01:24:01,169 --> 01:24:03,805
telescope mirror itself
comes into focus.

1752
01:24:03,805 --> 01:24:06,174
So the stars are out of focus,
but the telescope mirror

1753
01:24:06,174 --> 01:24:09,010
is in focus, and we
call that a pupil.

1754
01:24:09,010 --> 01:24:13,047
We actually put metal barriers
at that pupil to make sure

1755
01:24:13,047 --> 01:24:16,951
that no light is sneaking
around through those gaps.

1756
01:24:16,951 --> 01:24:21,355
Those rough edges, so that we
block out any stray starlight

1757
01:24:21,355 --> 01:24:24,091
that might be trying to
sneak around those cutouts.

1758
01:24:24,091 --> 01:24:27,294
So the instruments were all
designed with that shape in mind

1759
01:24:27,294 --> 01:24:29,864
to do the best they can with it.

1760
01:24:29,864 --> 01:24:33,834
And even our chronographs
have some really interesting

1761
01:24:33,834 --> 01:24:38,038
shaped pupil masks to try to
block out any scattered light

1762
01:24:38,038 --> 01:24:40,007
that might be
associated with that.

1763
01:24:40,007 --> 01:24:42,477
So yeah, it'd be nice
if it was really round,

1764
01:24:42,477 --> 01:24:46,314
but we can design
our instruments to
take it into account

1765
01:24:46,314 --> 01:24:48,249
as best we can.

1766
01:24:48,249 --> 01:24:49,250
- Thank you.

1767
01:24:51,485 --> 01:24:54,054
- Hi, I feel like you might
have just mentioned that

1768
01:24:54,054 --> 01:24:56,124
you can't answer my question,
but I was wondering if

1769
01:24:56,124 --> 01:24:59,193
you could talk a little more
about the actual materials

1770
01:24:59,193 --> 01:25:01,862
of like the structure
of the telescope?

1771
01:25:01,862 --> 01:25:06,034
Yeah, of the telescope, and
like how much it weighs,

1772
01:25:07,735 --> 01:25:09,970
and if that was taken
into consideration in like

1773
01:25:09,970 --> 01:25:12,039
what the goal was?

1774
01:25:12,039 --> 01:25:14,042
- Okay, I did not look
up how much JWST weighs.

1775
01:25:14,042 --> 01:25:17,645

I should have done it because
that's a really good question.

1776
01:25:17,645 --> 01:25:20,481
It's lighter than a lot of
conventional telescopes because

1777
01:25:20,481 --> 01:25:23,184
we do have to launch it, we
have to put it in a rocket.

1778
01:25:23,184 --> 01:25:28,088
For example, the mirrors are
actually made of beryllium.

1779
01:25:28,088 --> 01:25:30,991
It's a very lightweight metal,
and it's really nasty stuff

1780
01:25:30,991 --> 01:25:33,594
to work with, but it's strong.

1781
01:25:33,594 --> 01:25:37,531
It's relatively easy to shape,
and it's been used in other

1782
01:25:37,531 --> 01:25:40,334
space telescope, so we
know it's good material.

1783
01:25:40,334 --> 01:25:41,969
It's a robust material.

1784
01:25:41,969 --> 01:25:45,106
And then that beryllium surface
is coated with the gold,

1785
01:25:45,106 --> 01:25:47,141
so the gold coating that
you see is supported by

1786
01:25:47,141 --> 01:25:49,477
beryllium mirrors.

1787
01:25:49,477 --> 01:25:53,581
A lot of the support
structure, some of the support

1788
01:25:53,581 --> 01:25:57,752
structures at least are carbon
fiber composite materials,

1789
01:25:59,153 --> 01:26:02,356
which are very lightweight
and very thermally insulating.

1790
01:26:02,356 --> 01:26:04,692
A lot of it's just aluminum.

1791
01:26:06,227 --> 01:26:10,231
So they took every opportunity
they could to lightweight

1792
01:26:10,231 --> 01:26:13,300
things, but make sure that
things are still strong enough

1793
01:26:13,300 --> 01:26:15,770
that they'll survive the launch.

1794
01:26:15,770 --> 01:26:18,639
So hopefully that's at
least a partial answer

1795
01:26:18,639 --> 01:26:21,543
to your question.
- Yeah, thank you.

1796
01:26:22,977 --> 01:26:26,114

- Hi, I was wondering, so
if the Hubble Telescope,

1797
01:26:26,114 --> 01:26:29,984
this is going back to a
gentlemen's previous question,

1798
01:26:29,984 --> 01:26:32,787
but if the Hubble Telescope
has a shroud to protect

1799
01:26:32,787 --> 01:26:36,958
the mirror, what was the
reasoning behind the JWST

1800
01:26:37,859 --> 01:26:39,260
not having a shroud?

1801
01:26:39,260 --> 01:26:41,462
Was it because you
couldn't like keep it to a

1802
01:26:41,462 --> 01:26:42,964
cold enough temperature?

1803
01:26:42,964 --> 01:26:46,166
Or just the complexity of
having something be able to

1804
01:26:46,166 --> 01:26:48,869
extend that far since it's
such a like wide diameter?

1805
01:26:48,869 --> 01:26:52,207
Why would they, because
if it causes damage later?

1806
01:26:52,207 --> 01:26:55,977
- Yeah, it's just
structurally very challenging.

1807
01:26:55,977 --> 01:26:59,814
And anything that would be
light enough to actually be

1808
01:26:59,814 --> 01:27:03,517
a light shield is gonna take
all those micro meteorites

1809
01:27:03,517 --> 01:27:04,953
and stuff anyway.

1810
01:27:06,387 --> 01:27:08,922
So it just wasn't practical
with something this size,

1811
01:27:08,922 --> 01:27:11,526
particularly because it had
to fold up to have any kind of

1812
01:27:11,526 --> 01:27:13,193
structure around it.

1813
01:27:13,193 --> 01:27:16,030
So micro meteorites are
going so fast I'm not sure a

1814
01:27:16,030 --> 01:27:19,701
Hubble-like shield would
stop a lot of them anyway.

1815
01:27:19,701 --> 01:27:23,071
I don't know how many
have actually hit Hubble,

1816
01:27:23,071 --> 01:27:26,240
but since it's lower Earth
orbit, it's a bit more shielded

1817

01:27:26,240 --> 01:27:28,509
than we're gonna be out at L2.

1818
01:27:28,509 --> 01:27:31,045
But I think it's mostly just
a matter of practicality.

1819
01:27:31,045 --> 01:27:33,981
There's just no easy way to
build a structure like that

1820
01:27:33,981 --> 01:27:35,949
that would do the job.

1821
01:27:35,949 --> 01:27:39,253
And so we're relying on good
baffling inside the telescope

1822
01:27:39,253 --> 01:27:41,356
to block out that stray light.

1823
01:27:41,356 --> 01:27:42,823
- Okay, thanks.

1824
01:27:42,823 --> 01:27:43,658
- Okay.

1825
01:27:45,526 --> 01:27:46,361
Hi.

1826
01:27:47,828 --> 01:27:52,633
- How many steps did it take
to make the full deployment?

1827
01:27:52,633 --> 01:27:53,468
- Oh boy.

1828
01:27:55,336 --> 01:27:56,337
There are...

1829
01:27:58,606 --> 01:28:00,174
So the question, in case
you didn't catch it,

1830
01:28:00,174 --> 01:28:02,076
how many steps are there
to do the full deployment?

1831
01:28:02,076 --> 01:28:04,111
I'm actually not sure.

1832
01:28:04,111 --> 01:28:06,113
It's gotta be in the hundreds
because you see all those

1833
01:28:06,113 --> 01:28:07,681
little things unfolding.

1834
01:28:07,681 --> 01:28:10,317
There are mechanisms
all over the place.

1835
01:28:10,317 --> 01:28:12,620
There are five
layers of sunshield.

1836
01:28:12,620 --> 01:28:15,389
I don't know the right
number unfortunately,

1837
01:28:15,389 --> 01:28:17,158
but there are a lot.

1838
01:28:17,158 --> 01:28:19,060
That's why it looks so
complex in that video with

1839
01:28:19,060 --> 01:28:21,529

everything popping
out, you know.

1840
01:28:21,529 --> 01:28:23,397
It's like a Transformer
robot or something,

1841
01:28:23,397 --> 01:28:26,000
building the final telescope.

1842
01:28:26,000 --> 01:28:28,168
So yes, there are definitely
many, but I don't know

1843
01:28:28,168 --> 01:28:30,237
the exact number.

1844
01:28:30,237 --> 01:28:31,905
- [Attendee] Okay.

1845
01:28:31,905 --> 01:28:33,774
- When Hubble was brought
online, it was found to be

1846
01:28:33,774 --> 01:28:34,775
nearsighted.

1847
01:28:34,775 --> 01:28:36,310
That's not happening, right?

1848
01:28:36,310 --> 01:28:37,679
(laughing)

1849
01:28:37,679 --> 01:28:39,480
- So this is why I
specifically mentioned that we

1850
01:28:39,480 --> 01:28:41,149
learned our lessons.

1851
01:28:42,583 --> 01:28:46,454
We have a test that was just
completed just a few days ago

1852
01:28:47,855 --> 01:28:52,359
was to actually measure the
curvature of the primary mirror

1853
01:28:52,359 --> 01:28:54,962
to make sure that that the
curvature was the right shape,

1854
01:28:54,962 --> 01:28:56,997
right dimensions and all that.

1855
01:28:56,997 --> 01:29:00,233
So we are doing the tests
to make sure optics are

1856
01:29:00,233 --> 01:29:02,870
what they are supposed to be.

1857
01:29:02,870 --> 01:29:05,639
We are doublechecking, so we're
not throwing out one result

1858
01:29:05,639 --> 01:29:09,477
that doesn't quite agree
with everything else.

1859
01:29:10,944 --> 01:29:13,046
It's still an observatory
designed by human beings,

1860
01:29:13,046 --> 01:29:14,715
and occasionally we miss stuff.

1861
01:29:14,715 --> 01:29:17,151

So we're doing our best to make
sure we don't miss anything.

1862
01:29:17,151 --> 01:29:19,720
Again, this has to
work the first time.

1863
01:29:19,720 --> 01:29:23,891
But you know, we did learn
lessons, and so we have

1864
01:29:25,058 --> 01:29:26,961
procedures in place that
are designed to catch

1865
01:29:26,961 --> 01:29:29,096
mistakes like that.

1866
01:29:29,096 --> 01:29:30,865
Humans are inventive.

1867
01:29:30,865 --> 01:29:33,067
I'm sure we'll come up
with new mistakes to make,

1868
01:29:33,067 --> 01:29:35,670
but at least for the things
we know about we're doing

1869
01:29:35,670 --> 01:29:38,639
our best to make sure that we
don't make that mistake again.

1870
01:29:38,639 --> 01:29:39,474
Yes?

1871
01:29:40,941 --> 01:29:42,976
- Since the propellant's the
first thing to possibly go,

1872
01:29:42,976 --> 01:29:47,482
hopefully, is there room
for possibly sending a

1873
01:29:47,482 --> 01:29:49,316
refuel mission?

1874
01:29:49,316 --> 01:29:51,418
(laughing)

1875
01:29:51,418 --> 01:29:55,188
- So even though we have no
way, no current way of servicing

1876
01:29:55,188 --> 01:29:58,893
the Webb Telescope,
it was decreed that
there would at least

1877
01:29:58,893 --> 01:30:02,596
be kind of a grappling hook or
some sort of attachment point

1878
01:30:02,596 --> 01:30:06,267
that a future rocket
could attach itself to.

1879
01:30:08,468 --> 01:30:11,071
I don't think there's
any way to do a refuel,

1880
01:30:11,071 --> 01:30:13,908
even if you did get
a spacecraft there.

1881
01:30:13,908 --> 01:30:16,744
I don't know where the
propellant tanks are.

1882

01:30:16,744 --> 01:30:20,214
I'm guessing they're
fairly buried,

1883
01:30:20,214 --> 01:30:22,250
but this is mostly
conjecture on my part,

1884
01:30:22,250 --> 01:30:24,385
so don't take what
I say as fact.

1885
01:30:24,385 --> 01:30:26,720
But I don't believe there's
any way to actually do it,

1886
01:30:26,720 --> 01:30:30,158
even though we've all
had that same idea.

1887
01:30:31,592 --> 01:30:33,894
Okay, thanks for coming.

1888
01:30:33,894 --> 01:30:37,465
Great questions.
(applause)