PUBLIC LECTURE SERIES

Unveiling the Cosmos: Key Inventions behind the Modern Telescope

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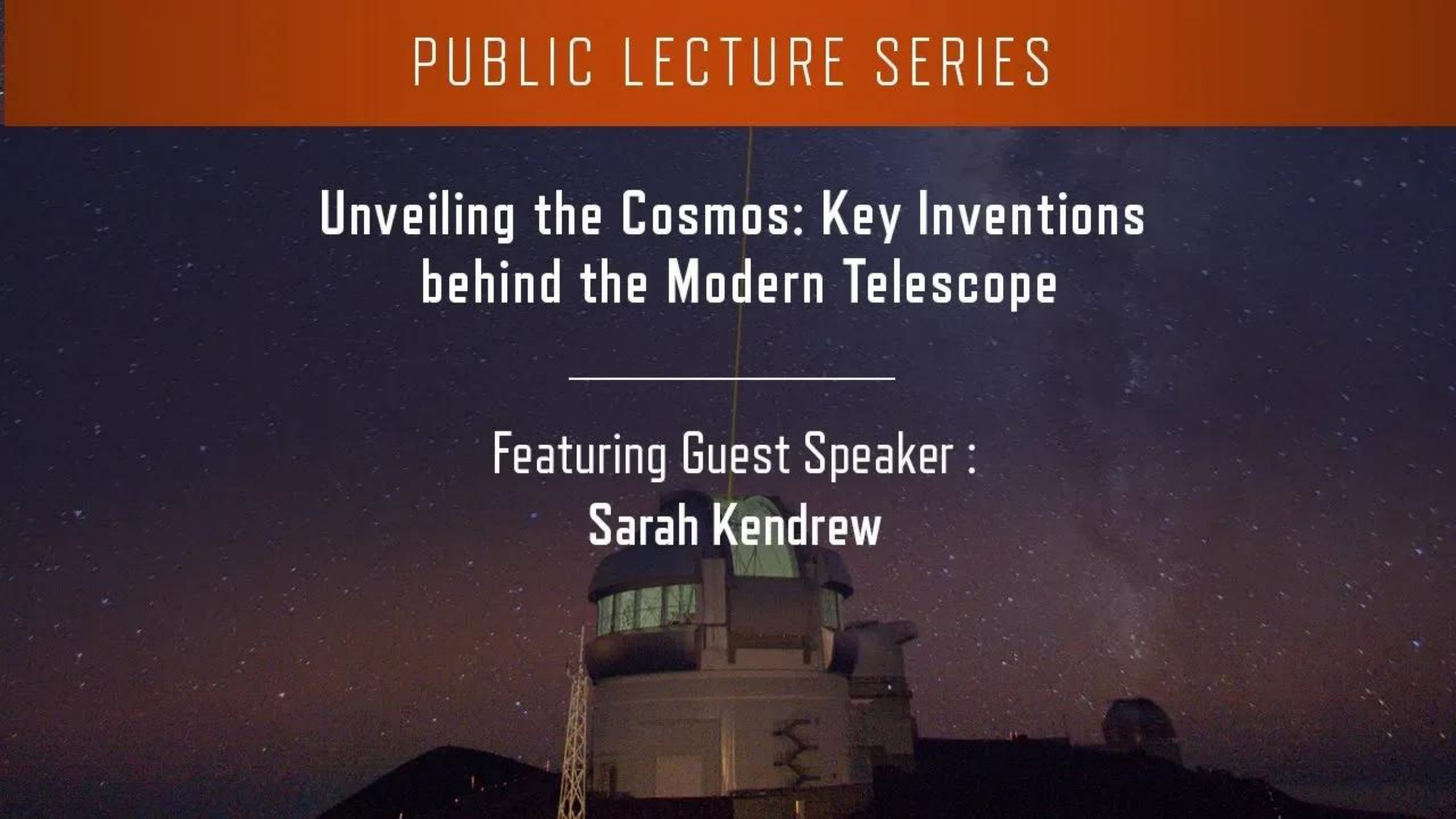
Featuring Guest Speaker :

Sarah Kendrew



1
00:00:04,940 --> 00:00:01,969
ooh welcome to the Space Telescope

2
00:00:06,710 --> 00:00:04,950
public lecture series I'm dr. Frank

3
00:00:08,780 --> 00:00:06,720
summers in the office of public outreach

4
00:00:11,930 --> 00:00:08,790
and it's my pleasure to be your host

5
00:00:15,049 --> 00:00:11,940
tonight if you did not get one on the

6
00:00:17,390 --> 00:00:15,059
way in we are giving away our wonderful

7
00:00:20,170 --> 00:00:17,400
lithographs and the lithograph tonight

8
00:00:22,429 --> 00:00:20,180
is called a horse of a different color

9
00:00:25,130 --> 00:00:22,439
it's such a different color that you

10
00:00:28,250 --> 00:00:25,140
can't even see this color it is infrared

11
00:00:30,800 --> 00:00:28,260
this is a horse head nebula seen in

12
00:00:32,900 --> 00:00:30,810
infrared light and if you want to know

13
00:00:35,360 --> 00:00:32,910

all about what that means turn over to

14
00:00:36,709 --> 00:00:35,370
the back and we've got about 300 words

15
00:00:38,360 --> 00:00:36,719
to talk about it

16
00:00:42,979 --> 00:00:38,370
it didn't get one on the way in please

17
00:00:43,280 --> 00:00:42,989
grab one on the way out ah so oh I'm

18
00:00:45,650 --> 00:00:43,290
sorry

19
00:00:46,940 --> 00:00:45,660
here is the lithograph right there all

20
00:00:49,610 --> 00:00:46,950
right

21
00:00:52,729 --> 00:00:49,620
I always forget that I have this year

22
00:00:53,689 --> 00:00:52,739
all right if you want the PDF version of

23
00:00:56,869 --> 00:00:53,699
it you don't want to actually take

24
00:00:59,569 --> 00:00:56,879
physical copies home this web address

25
00:01:03,470 --> 00:00:59,579
down here tells you where you can get it

26
00:01:05,420 --> 00:01:03,480
on our amazing space web site okay it's

27
00:01:07,460 --> 00:01:05,430
actually resource number 29 so it's one

28
00:01:11,990 --> 00:01:07,470
of the first ones we added to amazing

29
00:01:15,590 --> 00:01:12,000
space long long ago all right uh we did

30
00:01:18,080 --> 00:01:15,600
the Electronics nag tonight unveiling

31
00:01:21,620 --> 00:01:18,090
the cosmos key inventions behind the

32
00:01:23,179 --> 00:01:21,630
modern telescope by Sarah Kendrew and

33
00:01:24,620 --> 00:01:23,189
I'm really excited to have her here

34
00:01:27,999 --> 00:01:24,630
tonight because she's a wonderful

35
00:01:31,789 --> 00:01:28,009
speaker and she will wow you tonight

36
00:01:34,219 --> 00:01:31,799
coming up on December 3rd serge Dietrich

37
00:01:36,710 --> 00:01:34,229
and red and brown dwarfs understanding

38
00:01:40,219 --> 00:01:36,720

our smallest and closest substellar

39
00:01:43,929 --> 00:01:40,229
neighbors we had a talk here for our

40
00:01:47,050 --> 00:01:43,939
colloquium just a week or so ago it said

41
00:01:48,740 --> 00:01:47,060
74% of the stars in the universe

42
00:01:52,760 --> 00:01:48,750
three-quarters of the stars in the

43
00:01:55,700 --> 00:01:52,770
universe are red dwarfs ok the meek have

44
00:01:58,399 --> 00:01:55,710
inherited the universe all right this is

45
00:02:01,520 --> 00:01:58,409
going to go even not only red dwarfs but

46
00:02:04,999 --> 00:02:01,530
do brown dwarfs okay all the small stuff

47
00:02:07,249 --> 00:02:05,009
okay of the universe in January we will

48
00:02:08,900 --> 00:02:07,259
not be doing January 7th because that is

49
00:02:11,059 --> 00:02:08,910
during the SS meeting the American

50
00:02:13,130 --> 00:02:11,069
Astronomical Society meeting I will

51
00:02:13,740 --> 00:02:13,140
actually be at the SS meeting so we

52
00:02:17,220 --> 00:02:13,750
can't do it

53
00:02:19,200 --> 00:02:17,230
and and we have our infamous TBA we also

54
00:02:21,180 --> 00:02:19,210
have our infamous TBA repeating their

55
00:02:23,670 --> 00:02:21,190
talk on February 4th

56
00:02:26,280 --> 00:02:23,680
now you may all look at this and go okay

57
00:02:28,170 --> 00:02:26,290
Frank has just been lazy this fall he

58
00:02:32,630 --> 00:02:28,180
hasn't gotten any speakers and that's

59
00:02:36,150 --> 00:02:32,640
only partially true okay we have a

60
00:02:37,590 --> 00:02:36,160
something coming up we have building

61
00:02:39,500 --> 00:02:37,600
construction coming up here in this

62
00:02:42,240 --> 00:02:39,510
Space Telescope Science Institute okay

63
00:02:43,830 --> 00:02:42,250

they're doing a complete redesign of the

64
00:02:45,240 --> 00:02:43,840
lobby they're tearing it all apart and

65
00:02:47,400 --> 00:02:45,250
rebuilding at all putting it all back

66
00:02:50,790 --> 00:02:47,410
together and that will affect the

67
00:02:52,380 --> 00:02:50,800
January February and March 2020 public

68
00:02:54,210 --> 00:02:52,390
lectures okay

69
00:02:56,610 --> 00:02:54,220
such to a point that I wasn't sure we

70
00:02:58,699 --> 00:02:56,620
were going to be able to have them I was

71
00:03:01,560 --> 00:02:58,709
confirmed yesterday and today that

72
00:03:04,170 --> 00:03:01,570
absolutely 100% we will be able to have

73
00:03:05,940 --> 00:03:04,180
these public lectures okay so I sort of

74
00:03:08,340 --> 00:03:05,950
was lazy and not scheduling speakers

75
00:03:11,310 --> 00:03:08,350
because hey if I didn't have to have

76
00:03:13,260 --> 00:03:11,320
scheduled them all right I didn't we

77
00:03:15,390 --> 00:03:13,270
will for these three lectures probably

78
00:03:19,140 --> 00:03:15,400
be using an alternate entrance to the

79
00:03:22,770 --> 00:03:19,150
building okay so pay attention to the

80
00:03:25,500 --> 00:03:22,780
signs when you get here and wheelchair

81
00:03:27,090 --> 00:03:25,510
access could also be affected okay the

82
00:03:29,160 --> 00:03:27,100
point is is that these entrance over

83
00:03:30,600 --> 00:03:29,170
here and this entrance over here go

84
00:03:32,490 --> 00:03:30,610
directly into the lobby that will be a

85
00:03:34,680 --> 00:03:32,500
construction zone and these these

86
00:03:37,110 --> 00:03:34,690
entrances may not be open all right and

87
00:03:39,780 --> 00:03:37,120
this is where a wheelchair ramp is all

88
00:03:41,580 --> 00:03:39,790

right so I will have more information

89
00:03:44,340 --> 00:03:41,590
next month but I just want to put this

90
00:03:46,410 --> 00:03:44,350
seed in your head that building

91
00:03:49,110 --> 00:03:46,420
construction January February March will

92
00:03:51,870 --> 00:03:49,120
be affected okay all right but I will

93
00:03:56,069 --> 00:03:51,880
have speakers for you okay I always do

94
00:03:57,870 --> 00:03:56,079
okay great let's see our website where

95
00:04:00,960 --> 00:03:57,880
we will have all the information about

96
00:04:04,319 --> 00:04:00,970
said speakers when I get them if you

97
00:04:06,449 --> 00:04:04,329
would like to watch the webcasts you can

98
00:04:11,130 --> 00:04:06,459
see right here our YouTube playlist as

99
00:04:13,380 --> 00:04:11,140
well as our STScI webcast archive email

100
00:04:16,560 --> 00:04:13,390
you can sign up for the lecture

101
00:04:18,840 --> 00:04:16,570
announcements down here just enter your

102
00:04:21,630 --> 00:04:18,850
email address and hit that subscribe and

103
00:04:25,020 --> 00:04:21,640
you'll get our once a month update of

104
00:04:27,240 --> 00:04:25,030
what's coming up also on the website we

105
00:04:31,140 --> 00:04:27,250
have the upcoming lectures

106
00:04:33,690 --> 00:04:31,150
as well as for each lecture we have that

107
00:04:37,500 --> 00:04:33,700
has gone we have both the STScI webcast

108
00:04:39,960 --> 00:04:37,510
as well as our YouTube of recording of

109
00:04:41,430 --> 00:04:39,970
the lectures so lots and lots of ways to

110
00:04:44,990 --> 00:04:41,440
watch lectures we've been doing and

111
00:04:48,600 --> 00:04:45,000
recording these lectures since 2005 okay

112
00:04:50,370 --> 00:04:48,610
it's a 14 years worth of lectures you

113
00:04:52,200 --> 00:04:50,380

can binge watch it'll take you more than

114
00:04:56,160 --> 00:04:52,210
a weekend to binge watch these okay

115
00:04:57,930 --> 00:04:56,170
alright so I know that that binge

116
00:04:59,580 --> 00:04:57,940
watching is just ever so popular these

117
00:05:02,280 --> 00:04:59,590
days

118
00:05:05,280 --> 00:05:02,290
email announcements through sign up the

119
00:05:07,410 --> 00:05:05,290
website if you can't handle digital

120
00:05:09,360 --> 00:05:07,420
technology why are you using email

121
00:05:11,010 --> 00:05:09,370
anyways but you could always write it

122
00:05:13,800 --> 00:05:11,020
down on a piece of paper and hand it to

123
00:05:16,560 --> 00:05:13,810
me and I will give it to you if you have

124
00:05:21,270 --> 00:05:16,570
comments or questions send them to

125
00:05:23,070 --> 00:05:21,280
public lecture at STScI dot edu social

126
00:05:26,100 --> 00:05:23,080
media we are on Facebook we're on

127
00:05:28,680 --> 00:05:26,110
Twitter or on YouTube we're on Instagram

128
00:05:31,470 --> 00:05:28,690
I don't think we're on snapchat but you

129
00:05:34,230 --> 00:05:31,480
know or you know one of the or tik-tok

130
00:05:35,760 --> 00:05:34,240
or whatever those things are right we

131
00:05:37,950 --> 00:05:35,770
have all of these channels for if you

132
00:05:40,230 --> 00:05:37,960
would like to follow us I myself do a

133
00:05:44,700 --> 00:05:40,240
tiny bit on Facebook and Twitter every

134
00:05:46,620 --> 00:05:44,710
now and then after the lecture tonight

135
00:05:49,110 --> 00:05:46,630
the Maryland Space Grant Observatory

136
00:05:52,080 --> 00:05:49,120
tells me it is clear enough out that

137
00:05:54,330 --> 00:05:52,090
they will be doing observing although we

138
00:05:56,850 --> 00:05:54,340

got a large audience tonight Sarah you

139
00:05:59,760 --> 00:05:56,860
drew them in I mean this is a this is a

140
00:06:01,890 --> 00:05:59,770
big audience okay and they can only take

141
00:06:05,310 --> 00:06:01,900
a certain number of people if you have

142
00:06:07,230 --> 00:06:05,320
already gone to the observatory recently

143
00:06:10,890 --> 00:06:07,240
they ask that you let others who haven't

144
00:06:13,080 --> 00:06:10,900
gone to the observatory go but basically

145
00:06:16,050 --> 00:06:13,090
uh everyone who wants to go collects

146
00:06:18,930 --> 00:06:16,060
down here at the end of the lecture if I

147
00:06:22,560 --> 00:06:18,940
forget somebody remind me okay

148
00:06:24,990 --> 00:06:22,570
if you cannot go tonight they have their

149
00:06:29,550 --> 00:06:25,000
open houses on Friday evenings if you go

150
00:06:32,040 --> 00:06:29,560
to MD that's MD dot space grant o RG

151
00:06:33,960 --> 00:06:32,050
you'll find this webpage with their

152
00:06:37,260 --> 00:06:33,970
about their open houses and this

153
00:06:39,930 --> 00:06:37,270
Observatory status bar right there tell

154
00:06:41,040 --> 00:06:39,940
will be filled in by the evening on

155
00:06:44,119 --> 00:06:41,050
Friday and tell you

156
00:06:47,460 --> 00:06:44,129
not the reopen on Friday evenings okay

157
00:06:50,969 --> 00:06:47,470
all right now my segment the news from

158
00:06:55,850 --> 00:06:50,979
the universe for November 2019

159
00:07:00,809 --> 00:06:55,860
our first story it came from outer space

160
00:07:04,320 --> 00:07:00,819
part 2 the sequel the dive-bombing comet

161
00:07:06,629 --> 00:07:04,330
alright so the people remember the first

162
00:07:08,490 --> 00:07:06,639
movie right all right well let's go back

163
00:07:13,379 --> 00:07:08,500

over the first movie the first movie was

164
00:07:17,369 --> 00:07:13,389
about this object one-eye 2017 you won

165
00:07:19,439 --> 00:07:17,379
Oh mwah yes that's actually the name

166
00:07:21,930 --> 00:07:19,449
that they came up with all right and

167
00:07:27,209 --> 00:07:21,940
that one eyes says it is the first

168
00:07:29,999 --> 00:07:27,219
interstellar object okay and this is an

169
00:07:32,010 --> 00:07:30,009
artist's impression of it around about

170
00:07:35,029 --> 00:07:32,020
the time that Hubble took an image of it

171
00:07:37,980 --> 00:07:35,039
way back when and Hubble got you know

172
00:07:41,040 --> 00:07:37,990
not great data on it okay matter of fact

173
00:07:45,029 --> 00:07:41,050
the data on Oh moon will all sort of

174
00:07:48,420 --> 00:07:45,039
look like this yeah

175
00:07:50,580 --> 00:07:48,430
the problem with oh mama was that it was

176
00:07:53,730 --> 00:07:50,590
not discovered until it was already

177
00:07:56,070 --> 00:07:53,740
leaving the solar system okay it came in

178
00:07:58,589 --> 00:07:56,080
made a nice tight loop past the Sun and

179
00:08:01,950 --> 00:07:58,599
it was discovered and we really didn't

180
00:08:04,379 --> 00:08:01,960
get great observations of it this was

181
00:08:07,860 --> 00:08:04,389
it's it's its orbit it actually came

182
00:08:09,629 --> 00:08:07,870
inside the orbit of mercury and it was

183
00:08:12,149 --> 00:08:09,639
discovered and it was on its way out and

184
00:08:14,640 --> 00:08:12,159
we really didn't get great observations

185
00:08:18,209 --> 00:08:14,650
of omamo we weren't able to truly

186
00:08:20,909 --> 00:08:18,219
characterize it much all right so while

187
00:08:23,249 --> 00:08:20,919
it was an exception it was the first

188
00:08:26,100 --> 00:08:23,259

interstellar object and it was that was

189
00:08:28,619 --> 00:08:26,110
exciting it wasn't exciting enough for

190
00:08:30,300 --> 00:08:28,629
us geeks because we didn't get details

191
00:08:32,730 --> 00:08:30,310
of what it's really like all's we got

192
00:08:34,649 --> 00:08:32,740
was that it's probably very elongated

193
00:08:37,980 --> 00:08:34,659
and had an interesting spin cycle to it

194
00:08:39,329 --> 00:08:37,990
and everything all right and so you know

195
00:08:41,870 --> 00:08:39,339
we knew that there could be other things

196
00:08:44,430 --> 00:08:41,880
coming through so once you've got one

197
00:08:46,590 --> 00:08:44,440
object that you know it's possible to

198
00:08:48,060 --> 00:08:46,600
find inter-cell objects what are we

199
00:08:51,810 --> 00:08:48,070
gonna do we're gonna keep our eyes open

200
00:08:53,940 --> 00:08:51,820
all right and this year we did find

201
00:08:59,550 --> 00:08:53,950
another one okay this

202
00:09:03,660 --> 00:08:59,560
is C 2019 q4 Borissov and again you can

203
00:09:09,120 --> 00:09:03,670
see yeah it's just this tiny little dot

204
00:09:13,230 --> 00:09:09,130
okay but Borissov was discovered on its

205
00:09:15,329 --> 00:09:13,240
way into the solar system okay and at

206
00:09:18,030 --> 00:09:15,339
first we were like oh it looks like it

207
00:09:19,829 --> 00:09:18,040
could be an inner cell or object it was

208
00:09:21,329 --> 00:09:19,839
discovered in August and they had to

209
00:09:23,310 --> 00:09:21,339
look through it and and they kept

210
00:09:25,410 --> 00:09:23,320
following in September and October and

211
00:09:29,550 --> 00:09:25,420
they finally were able to conclude that

212
00:09:31,460 --> 00:09:29,560
yes it is a hyperbolic orbit it is not

213
00:09:34,650 --> 00:09:31,470

from this solar system it is not

214
00:09:39,300 --> 00:09:34,660
gravitationally bound to the Sun okay

215
00:09:41,900 --> 00:09:39,310
and whereas Omonoia had this orbit that

216
00:09:44,759 --> 00:09:41,910
came in and went back out really sharply

217
00:09:47,759 --> 00:09:44,769
Borissov I call it a dive-bombing comet

218
00:09:49,860 --> 00:09:47,769
because it came up and down it's coming

219
00:09:53,639 --> 00:09:49,870
down through the plane of the solar

220
00:09:55,800 --> 00:09:53,649
system on a much long elongated orbit so

221
00:10:00,000 --> 00:09:55,810
catching it as it's coming down were

222
00:10:02,519 --> 00:10:00,010
able to watch it going through and as we

223
00:10:05,600 --> 00:10:02,529
studied it further and further we saw

224
00:10:10,050 --> 00:10:05,610
that it's not just a dot but it's a dot

225
00:10:13,319 --> 00:10:10,060
with some fuzz around it okay it's it

226
00:10:18,689 --> 00:10:13,329
looks like a comet all right so this is

227
00:10:21,290 --> 00:10:18,699
the first confirmed interstellar comet

228
00:10:23,850 --> 00:10:21,300
all right we could not confirm what Oh

229
00:10:26,280 --> 00:10:23,860
Momo was it's more considered to be more

230
00:10:29,189 --> 00:10:26,290
asteroid like than comet like this is

231
00:10:31,650 --> 00:10:29,199
confirmed to be comet like so what's

232
00:10:35,220 --> 00:10:31,660
going to happen every telescope that can

233
00:10:35,939 --> 00:10:35,230
is going to study Borissov who you gonna

234
00:10:41,550 --> 00:10:35,949
call

235
00:10:46,050 --> 00:10:41,560
took a look at it to try and get a look

236
00:10:49,860 --> 00:10:46,060
at it and so Hubble got a very very

237
00:10:53,009 --> 00:10:49,870
clear picture of a very very fuzzy

238
00:10:55,319 --> 00:10:53,019

object this is Hubble's image of

239
00:10:58,410 --> 00:10:55,329
Borissov now it's much more at much

240
00:10:59,850 --> 00:10:58,420
higher resolution but you know as as we

241
00:11:01,590 --> 00:10:59,860
as we predicted we're sending in the

242
00:11:03,360 --> 00:11:01,600
news meeting like yeah it's gonna be a

243
00:11:06,150 --> 00:11:03,370
really high resolution picture of

244
00:11:07,190 --> 00:11:06,160
something that's just a fuzz ball and it

245
00:11:09,950 --> 00:11:07,200
is and that's

246
00:11:12,800 --> 00:11:09,960
comets are because the comet nucleus is

247
00:11:15,620 --> 00:11:12,810
actually hidden deep down inside the

248
00:11:17,960 --> 00:11:15,630
coma of the comet the gases that escape

249
00:11:20,270 --> 00:11:17,970
from the comet hide the shape of the

250
00:11:21,530 --> 00:11:20,280
comet inside it you actually have to fly

251
00:11:23,750 --> 00:11:21,540
up to it

252
00:11:25,190 --> 00:11:23,760
which of course is not possible for

253
00:11:27,530 --> 00:11:25,200
something traveling at the kind of speed

254
00:11:29,360 --> 00:11:27,540
and interstellar comet as as flying at

255
00:11:31,220 --> 00:11:29,370
we can't catch up to this we would have

256
00:11:34,790 --> 00:11:31,230
had to started planning about five years

257
00:11:35,900 --> 00:11:34,800
ago in order to be able to catch up to

258
00:11:38,450 --> 00:11:35,910
something like this and see what it

259
00:11:42,560 --> 00:11:38,460
really looks like however this is still

260
00:11:44,660 --> 00:11:42,570
on its way inward okay so our coming

261
00:11:48,710 --> 00:11:44,670
attractions are that it reaches

262
00:11:50,600 --> 00:11:48,720
perihelion on December 7th 2019 at that

263
00:11:52,790 --> 00:11:50,610

time it'll be about 300 million

264
00:11:55,310 --> 00:11:52,800
kilometers about two astronomical units

265
00:11:58,340 --> 00:11:55,320
from the Sun as well as about the same

266
00:12:00,110 --> 00:11:58,350
two au from Earth okay so we will get a

267
00:12:02,300 --> 00:12:00,120
reasonably good view of this all right

268
00:12:04,730 --> 00:12:02,310
as it passes through it will be a blur

269
00:12:06,650 --> 00:12:04,740
servable through late 2020 one of the

270
00:12:07,970 --> 00:12:06,660
predictions I saw said through September

271
00:12:10,180 --> 00:12:07,980
of next year

272
00:12:12,380 --> 00:12:10,190
we'll be able to follow it all right and

273
00:12:13,850 --> 00:12:12,390
we're gonna look at it and try and see

274
00:12:16,700 --> 00:12:13,860
what if we can figure out its actual

275
00:12:18,080 --> 00:12:16,710
size underneath all that fuzz whether or

276
00:12:19,970 --> 00:12:18,090
not there's shape because you can get

277
00:12:22,460 --> 00:12:19,980
the light curve of the road if it's

278
00:12:23,750 --> 00:12:22,470
rotating and such but more importantly

279
00:12:27,380 --> 00:12:23,760
what I think is most important is the

280
00:12:29,500 --> 00:12:27,390
composition our other solar systems

281
00:12:31,880 --> 00:12:29,510
where this comet would have formed

282
00:12:33,620 --> 00:12:31,890
formed out of the same types of

283
00:12:36,110 --> 00:12:33,630
materials that form in our solar system

284
00:12:38,690 --> 00:12:36,120
we look at the gases we can get the

285
00:12:41,360 --> 00:12:38,700
composition of that Comet and compare it

286
00:12:44,000 --> 00:12:41,370
to the gases of comets that we see in

287
00:12:45,350 --> 00:12:44,010
our own solar system that to me is going

288
00:12:49,010 --> 00:12:45,360

to be the coolest thing we're gonna find

289
00:12:52,250 --> 00:12:49,020
out so stay tuned it will be at least be

290
00:12:54,230 --> 00:12:52,260
a trilogy if not even more in terms of

291
00:12:57,860 --> 00:12:54,240
the number of sequels that we'll have

292
00:12:59,930 --> 00:12:57,870
about the comet Borissov but wait till

293
00:13:01,480 --> 00:12:59,940
after December when we go to repair

294
00:13:03,340 --> 00:13:01,490
healing we'll have some good

295
00:13:05,510 --> 00:13:03,350
observations okay

296
00:13:09,050 --> 00:13:05,520
another thing happening in our solar

297
00:13:12,260 --> 00:13:09,060
system that you will hear about is the

298
00:13:17,689 --> 00:13:12,270
transit of mercury on November 11th 2019

299
00:13:19,220 --> 00:13:17,699
which is what next Monday right okay

300
00:13:22,340 --> 00:13:19,230
do y'all remember that we had a transit

301
00:13:24,109 --> 00:13:22,350
of Venus in 2012 yeah this was my

302
00:13:28,249 --> 00:13:24,119
favorite picture of the transit of Venus

303
00:13:29,659 --> 00:13:28,259
I think this is that Metro Center she

304
00:13:31,759 --> 00:13:29,669
was transferring from the orange line to

305
00:13:34,159 --> 00:13:31,769
the blue line oh and such

306
00:13:37,789 --> 00:13:34,169
now the transit of Venus actually is

307
00:13:40,909 --> 00:13:37,799
about when the planet Venus passes in

308
00:13:43,970 --> 00:13:40,919
front of the Sun all right and here you

309
00:13:46,699 --> 00:13:43,980
see this black spot right here that is

310
00:13:48,559 --> 00:13:46,709
the shadow of Venus on the surface of

311
00:13:51,289 --> 00:13:48,569
the Sun and transits of Venus are

312
00:13:52,970 --> 00:13:51,299
extremely rare you get to eight years

313
00:13:55,280 --> 00:13:52,980

apart and then there's another hundred

314
00:13:59,329 --> 00:13:55,290
years or so before you get another one

315
00:14:01,549 --> 00:13:59,339
all right and we had our - in 2004 2012

316
00:14:04,549 --> 00:14:01,559
and we will not have another one in our

317
00:14:06,259 --> 00:14:04,559
lifetimes okay it'll be 21 something or

318
00:14:08,269 --> 00:14:06,269
other before there's another transit of

319
00:14:10,549 --> 00:14:08,279
Venus so you are not going to see

320
00:14:12,169 --> 00:14:10,559
another transit Venus unless you're

321
00:14:14,479 --> 00:14:12,179
cryogenically frozen and somehow

322
00:14:17,720 --> 00:14:14,489
survived for another hundred years I

323
00:14:20,809 --> 00:14:17,730
don't really plan on that transits of

324
00:14:23,199 --> 00:14:20,819
mercury however are not so uncommon they

325
00:14:26,529 --> 00:14:23,209
occur about six times every century okay

326
00:14:28,759 --> 00:14:26,539
and so there is the transit of Venus and

327
00:14:34,189 --> 00:14:28,769
see if you can find the transit of

328
00:14:35,900 --> 00:14:34,199
mercury here yeah I'm sure some of you

329
00:14:39,679 --> 00:14:35,910
can but just in case you can't it's

330
00:14:41,449 --> 00:14:39,689
right there all right it looks like a

331
00:14:43,759 --> 00:14:41,459
another sunspot except for it's a

332
00:14:46,759 --> 00:14:43,769
perfectly circular small sunspot all

333
00:14:50,960 --> 00:14:46,769
right so the transit of mercury is a lot

334
00:14:51,829 --> 00:14:50,970
harder to see okay and so it occurs on

335
00:14:55,819 --> 00:14:51,839
November 11th

336
00:14:58,400 --> 00:14:55,829
it starts at 7:35 a.m. Eastern Standard

337
00:14:59,929 --> 00:14:58,410
Time finishes around 1:00 p.m. Eastern

338
00:15:02,090 --> 00:14:59,939

Standard Time

339
00:15:05,179 --> 00:15:02,100
and you know I have to warn you if you

340
00:15:07,639 --> 00:15:05,189
try to look at it never look directly at

341
00:15:09,169 --> 00:15:07,649
the Sun we always that's a part of our

342
00:15:11,059 --> 00:15:09,179
astronomers creed that we have to say

343
00:15:12,769 --> 00:15:11,069
that every single time you need to use

344
00:15:15,439 --> 00:15:12,779
things like solar safe filters remember

345
00:15:16,849 --> 00:15:15,449
these Eclipse glasses from the 2017

346
00:15:19,609 --> 00:15:16,859
eclipse I hope you save them for the

347
00:15:21,579 --> 00:15:19,619
2024 Eclipse you can use them to look at

348
00:15:25,879 --> 00:15:21,589
the Sun for the transit of mercury and

349
00:15:28,999 --> 00:15:25,889
you will not see it it's just too small

350
00:15:30,350 --> 00:15:29,009
okay the human eye tried today I was

351
00:15:30,990 --> 00:15:30,360
like staring at the Sun going could I

352
00:15:32,970 --> 00:15:31,000
possibly

353
00:15:36,240 --> 00:15:32,980
see the transit of mercury not now it's

354
00:15:37,860 --> 00:15:36,250
to Smiley's my old eyes could not would

355
00:15:39,540 --> 00:15:37,870
never be able to do without an

356
00:15:41,880 --> 00:15:39,550
assistance see the transit of mercury

357
00:15:44,370 --> 00:15:41,890
alright so if you're if people who are

358
00:15:47,040 --> 00:15:44,380
going to kind of see it will want to use

359
00:15:48,840 --> 00:15:47,050
telescopes and if you're going to do it

360
00:15:51,510 --> 00:15:48,850
with a telescope you'll want to go to a

361
00:15:54,840 --> 00:15:51,520
place like eclipse wise comm where Fred

362
00:15:57,390 --> 00:15:54,850
Aspen act guru of Clips Asst has

363
00:15:59,400 --> 00:15:57,400

diagrams like this to show you where in

364
00:16:01,710 --> 00:15:59,410
the world it is going to be visible and

365
00:16:04,830 --> 00:16:01,720
if you do look at it with the telescope

366
00:16:08,760 --> 00:16:04,840
what path you can expect mercury to take

367
00:16:10,260 --> 00:16:08,770
across the face so you're not going to

368
00:16:12,600 --> 00:16:10,270
be able to see the transit of mercury

369
00:16:15,450 --> 00:16:12,610
but this is sort of a good excuse for me

370
00:16:17,940 --> 00:16:15,460
to show what you can see with a small

371
00:16:20,280 --> 00:16:17,950
telescope okay because this was posted

372
00:16:22,740 --> 00:16:20,290
on Facebook by the Harford County a

373
00:16:27,980 --> 00:16:22,750
strong Astronomical Society just a few

374
00:16:30,600 --> 00:16:27,990
weeks ago this transit is the

375
00:16:32,820 --> 00:16:30,610
International Space Station transiting

376
00:16:36,870 --> 00:16:32,830
across the Sun okay

377
00:16:38,520 --> 00:16:36,880
it takes one point six seconds for the

378
00:16:41,370 --> 00:16:38,530
International Space Station to transit

379
00:16:44,340 --> 00:16:41,380
across the Sun and they got the pic okay

380
00:16:48,630 --> 00:16:44,350
Richard fence got the pic not only did

381
00:16:50,540 --> 00:16:48,640
he get this pic he got fifty pictures of

382
00:16:53,280 --> 00:16:50,550
the International Space Station

383
00:16:55,920 --> 00:16:53,290
transiting across the Sun in that one

384
00:16:58,140 --> 00:16:55,930
point six seconds right and this is a

385
00:17:00,990 --> 00:16:58,150
small telescope up in Harford County

386
00:17:02,730 --> 00:17:01,000
okay and they just was an amazing sight

387
00:17:04,380 --> 00:17:02,740
thing I saw it on Facebook I immediately

388
00:17:06,300 --> 00:17:04,390

wrote to him said please let me use this

389
00:17:08,670 --> 00:17:06,310
in my public talks because that's just a

390
00:17:10,679 --> 00:17:08,680
really cool pic of the International

391
00:17:12,960 --> 00:17:10,689
Space Station transiting so transits

392
00:17:15,689 --> 00:17:12,970
they're kind of cool alright alright

393
00:17:19,110 --> 00:17:15,699
finally one last thing let's talk about

394
00:17:21,980 --> 00:17:19,120
galaxies Goulash and some of you may

395
00:17:24,870 --> 00:17:21,990
think I'm misspelling here but I am NOT

396
00:17:27,390 --> 00:17:24,880
because we all know about Goulash right

397
00:17:29,760 --> 00:17:27,400
Hungarian Goulash okay it's a mixture of

398
00:17:31,560 --> 00:17:29,770
meat and vegetables and a good hearty

399
00:17:34,500 --> 00:17:31,570
stew great for these these fall days

400
00:17:36,930 --> 00:17:34,510
like this and so we have this goulash

401
00:17:39,240 --> 00:17:36,940
but there can be considered galaxies

402
00:17:40,770 --> 00:17:39,250
goulash okay and what would we consider

403
00:17:42,750 --> 00:17:40,780
galaxies goulash well that would be a

404
00:17:44,409 --> 00:17:42,760
big mixture of all these galaxies all

405
00:17:46,479 --> 00:17:44,419
mixed up together

406
00:17:48,700 --> 00:17:46,489
sort of like what we did for Hubble's

407
00:17:50,710 --> 00:17:48,710
18th anniversary released all these

408
00:17:52,509 --> 00:17:50,720
images of galaxy collisions and galaxies

409
00:17:56,529 --> 00:17:52,519
interactions and the galaxies are all

410
00:17:58,090 --> 00:17:56,539
mixed up and together so where do we get

411
00:18:02,200 --> 00:17:58,100
the name galaxy

412
00:18:05,560 --> 00:18:02,210
goo-losh all right well it's win one of

413
00:18:10,539 --> 00:18:05,570

these galaxy collisions and fir has a

414
00:18:12,399 --> 00:18:10,549
really spooky look to it where you've

415
00:18:15,009 --> 00:18:12,409
got the cores of the galaxies forming

416
00:18:17,049 --> 00:18:15,019
the eyes and all of the tidal tails and

417
00:18:20,070 --> 00:18:17,059
all that bright star formation forming

418
00:18:24,310 --> 00:18:20,080
the head of as the press release said

419
00:18:26,919 --> 00:18:24,320
interesting of looking ghoul although I

420
00:18:29,229 --> 00:18:26,929
gotta say when I looked at it it didn't

421
00:18:31,840 --> 00:18:29,239
really look like a ghoul to me or spooky

422
00:18:39,519 --> 00:18:31,850
its kind of remember resembled something

423
00:18:44,590 --> 00:18:39,529
from Star Trek Star Wars

424
00:18:54,239 --> 00:18:44,600
I saw c-3po in it okay so I had to

425
00:18:56,919 --> 00:18:54,249
create this animated gif so that was our

426
00:18:59,200 --> 00:18:56,929
Halloween release of these these

427
00:19:01,269 --> 00:18:59,210
ghoulish galaxies that work together

428
00:19:03,759 --> 00:19:01,279
forming making a sort of a ghoulish head

429
00:19:05,440 --> 00:19:03,769
out of the galaxy configuration all

430
00:19:08,979 --> 00:19:05,450
right and that's our news for the

431
00:19:11,889 --> 00:19:08,989
universe for November let's go on to our

432
00:19:14,680 --> 00:19:11,899
featured speaker our speaker tonight is

433
00:19:17,830 --> 00:19:14,690
dr. Sarah Kendra she is from the

434
00:19:20,349 --> 00:19:17,840
European Space Agency but she is here at

435
00:19:22,539 --> 00:19:20,359
the Space Telescope Science Institute we

436
00:19:26,859 --> 00:19:22,549
have how many ISA employees do we have

437
00:19:27,970 --> 00:19:26,869
in the building about 15 okay so there's

438
00:19:29,979 --> 00:19:27,980

a you know the we talk about

439
00:19:31,330 --> 00:19:29,989
collaborations between NASA and ISA and

440
00:19:33,039 --> 00:19:31,340
you think if we're here and they're

441
00:19:35,830 --> 00:19:33,049
there no no we got people you know

442
00:19:37,720 --> 00:19:35,840
working together and she works on the

443
00:19:41,099 --> 00:19:37,730
James Webb Space Telescope the

444
00:19:45,609 --> 00:19:41,109
mid-infrared instrument called Miri and

445
00:19:49,389 --> 00:19:45,619
she's also one of the amazing people who

446
00:19:51,700 --> 00:19:49,399
works on the dot Astro conference which

447
00:19:53,680 --> 00:19:51,710
is a conference that tries to reinvent

448
00:19:54,669 --> 00:19:53,690
how we do astronomy so she's very

449
00:19:57,710 --> 00:19:54,679
forward-thinking

450
00:19:58,820 --> 00:19:57,720
and how she approaches astronomy

451
00:20:01,820 --> 00:19:58,830
and she's been working on

452
00:20:04,580 --> 00:20:01,830
instrumentation her entire career she

453
00:20:07,310 --> 00:20:04,590
got her PhD at University College London

454
00:20:08,930 --> 00:20:07,320
and I can't remember the various

455
00:20:11,119 --> 00:20:08,940
postdocs she did but she did a lot of

456
00:20:13,279 --> 00:20:11,129
very prestigious things she's an amazing

457
00:20:14,390 --> 00:20:13,289
person ladies and gentlemen dr. Sarah

458
00:20:29,680 --> 00:20:14,400
Kendra

459
00:20:38,680 --> 00:20:35,890
all right so I was going to start with

460
00:20:46,810 --> 00:20:38,690
introducing myself but Frank has done

461
00:20:56,950 --> 00:20:46,820
that very well you're on one aren't you

462
00:20:56,960 --> 00:21:01,520
all right

463
00:21:06,290 --> 00:21:03,500

so thank you all very much for coming

464
00:21:08,180 --> 00:21:06,300
tonight and I'm very pleased to be here

465
00:21:11,720 --> 00:21:08,190
and I get to talk about my my pet

466
00:21:13,910 --> 00:21:11,730
subject so as Frank said I work for the

467
00:21:15,830 --> 00:21:13,920
European Space Agency but based here

468
00:21:18,560 --> 00:21:15,840
working on one of the James Webb Space

469
00:21:20,540 --> 00:21:18,570
Telescope instruments I've been here for

470
00:21:25,070 --> 00:21:20,550
about three and a half about three and a

471
00:21:27,470 --> 00:21:25,080
half years yeah so as you know here from

472
00:21:30,080 --> 00:21:27,480
the building we are responsible for

473
00:21:33,980 --> 00:21:30,090
their scientific operations of the

474
00:21:37,250 --> 00:21:33,990
Hubble Space Telescope which has been in

475
00:21:39,590 --> 00:21:37,260
space doing amazing science gathering

476
00:21:41,480 --> 00:21:39,600
amazing data for the for the world's

477
00:21:45,560 --> 00:21:41,490
astronomy community for almost 30 years

478
00:21:47,930 --> 00:21:45,570
now and in a few years time it will be

479
00:21:49,940 --> 00:21:47,940
joined by its successor the James Webb

480
00:21:52,220 --> 00:21:49,950
Space Telescope this is a very recent

481
00:21:55,280 --> 00:21:52,230
picture of James Webb in the cleanroom

482
00:21:57,590 --> 00:21:55,290
at Northrop Grumman in California the

483
00:21:59,660 --> 00:21:57,600
observatory is fully assembled you can

484
00:22:02,510 --> 00:21:59,670
see the mirror and the Sun the Sun

485
00:22:06,050 --> 00:22:02,520
shields and the instruments are also all

486
00:22:09,830 --> 00:22:06,060
fully assembled now but of course our

487
00:22:13,070 --> 00:22:09,840
telescopes are not all in space we have

488
00:22:15,590 --> 00:22:13,080

numerous large large and small

489
00:22:17,540 --> 00:22:15,600
telescopes all over the world many of

490
00:22:21,110 --> 00:22:17,550
them are in these beautiful remote

491
00:22:23,420 --> 00:22:21,120
locations or very high mountain tops we

492
00:22:25,460 --> 00:22:23,430
have telescopes that every night now

493
00:22:28,940 --> 00:22:25,470
shoot lasers into the sky which is just

494
00:22:31,400 --> 00:22:28,950
amazing so I've worked my whole career

495
00:22:33,500 --> 00:22:31,410
on basically developing instruments and

496
00:22:37,520 --> 00:22:33,510
technology for telescopes both on the

497
00:22:40,100 --> 00:22:37,530
ground and in space and for me the role

498
00:22:42,890 --> 00:22:40,110
of Technology in in Australia me and how

499
00:22:47,120 --> 00:22:42,900
it drives astronomy is like a really

500
00:22:49,580 --> 00:22:47,130
fascinating subject so with the aid of

501
00:22:52,340 --> 00:22:49,590
all these telescopes we have been able

502
00:22:55,010 --> 00:22:52,350
to build up an amazing picture of the

503
00:22:57,740 --> 00:22:55,020
entire universe so we know the universe

504
00:22:59,650 --> 00:22:57,750
came into being in this big cataclysmic

505
00:23:03,200 --> 00:22:59,660
event that we call the Big Bang around

506
00:23:04,820 --> 00:23:03,210
13.7 billion years ago and you know

507
00:23:07,580 --> 00:23:04,830
after after this period of rapid

508
00:23:09,620 --> 00:23:07,590
expansion that we call inflation the

509
00:23:12,710 --> 00:23:09,630
kind of hot soup of the universe cooled

510
00:23:13,810 --> 00:23:12,720
into atoms forming the first stars and

511
00:23:18,759 --> 00:23:13,820
galaxies that Alou

512
00:23:21,219 --> 00:23:18,769
and ionized the universe today we know

513
00:23:23,979 --> 00:23:21,229

that the universe is expanding all

514
00:23:26,919 --> 00:23:23,989
around us and even more we actually know

515
00:23:29,080 --> 00:23:26,929
this expansion is accelerating under the

516
00:23:30,969 --> 00:23:29,090
influence of this very bizarre force

517
00:23:32,680 --> 00:23:30,979
that we call dark energy that we have

518
00:23:36,489 --> 00:23:32,690
absolutely no idea what it actually is

519
00:23:39,580 --> 00:23:36,499
so we've got this huge picture but lots

520
00:23:43,840 --> 00:23:39,590
of open questions as well one of my

521
00:23:46,659 --> 00:23:43,850
favorite amazing discoveries is the the

522
00:23:48,789 --> 00:23:46,669
fact the the discovery that we have a

523
00:23:51,219 --> 00:23:48,799
supermassive black hole at the heart of

524
00:23:53,109 --> 00:23:51,229
our Milky Way galaxy and the way we know

525
00:23:56,649 --> 00:23:53,119
that is that we've been able to trace

526
00:23:59,589 --> 00:23:56,659
the motions of stars right at the heart

527
00:24:01,690 --> 00:23:59,599
of the galaxy basically whizzing around

528
00:24:03,909 --> 00:24:01,700
this central point which is basically

529
00:24:06,879 --> 00:24:03,919
the heart of the galaxy the center of

530
00:24:09,399 --> 00:24:06,889
the galaxy and by tracking these stars

531
00:24:11,649 --> 00:24:09,409
over over about more than 20 years now

532
00:24:13,899 --> 00:24:11,659
we're able to basically measure the mass

533
00:24:15,719 --> 00:24:13,909
of this central object and deduce that

534
00:24:18,129 --> 00:24:15,729
this is in supermassive black hole

535
00:24:23,799 --> 00:24:18,139
weighing as much as about four million

536
00:24:27,489 --> 00:24:23,809
Suns we have discovered an amazing

537
00:24:30,639 --> 00:24:27,499
wealth of planetary systems outside of

538
00:24:33,219 --> 00:24:30,649

our own so just you know the first ever

539
00:24:38,229 --> 00:24:33,229
exoplanet around a normal son like star

540
00:24:40,330 --> 00:24:38,239
was only discovered just in 1995 so

541
00:24:42,759 --> 00:24:40,340
fairly recently but this is a field that

542
00:24:45,519 --> 00:24:42,769
has absolutely exploded and we now know

543
00:24:48,519 --> 00:24:45,529
that our solar system isn't unique and

544
00:24:50,619 --> 00:24:48,529
that planetary systems are probably just

545
00:24:53,169 --> 00:24:50,629
natural byproducts of the formation of

546
00:24:55,119 --> 00:24:53,179
stars and so you just see here this is

547
00:24:57,940 --> 00:24:55,129
an actual representation of known

548
00:25:00,969 --> 00:24:57,950
exoplanet systems in our solar

549
00:25:05,289 --> 00:25:00,979
neighborhood so you can see we are very

550
00:25:07,029 --> 00:25:05,299
much not alone so those are some of them

551
00:25:08,379 --> 00:25:07,039
that's kind of like that some of the

552
00:25:11,859 --> 00:25:08,389
really exciting things that we've

553
00:25:14,859 --> 00:25:11,869
learned in in you know our type in

554
00:25:16,769 --> 00:25:14,869
modern astronomy but you know astronomy

555
00:25:19,629 --> 00:25:16,779
is is actually like one of the most

556
00:25:22,570 --> 00:25:19,639
ancient natural sciences probably the

557
00:25:25,160 --> 00:25:22,580
most ancient natural science so there's

558
00:25:27,710 --> 00:25:25,170
evidence going back thousands of years

559
00:25:31,160 --> 00:25:27,720
not even tens of thousands of years that

560
00:25:33,590 --> 00:25:31,170
early humans and civilizations were

561
00:25:35,450 --> 00:25:33,600
actively watching the night sky and

562
00:25:38,150 --> 00:25:35,460
watching celestial objects and tracking

563
00:25:41,060 --> 00:25:38,160

their motions and it's very normal

564
00:25:43,130 --> 00:25:41,070
because they were basically this was the

565
00:25:45,910 --> 00:25:43,140
way that they kept time it was the first

566
00:25:49,310 --> 00:25:45,920
kind of timekeeping timekeeping system

567
00:25:51,680 --> 00:25:49,320
and it will tell those humans you know

568
00:25:54,620 --> 00:25:51,690
about changes in the seasons and in the

569
00:25:56,830 --> 00:25:54,630
weather which were kind of heralds you

570
00:26:01,850 --> 00:25:56,840
know changes in the availability of food

571
00:26:03,560 --> 00:26:01,860
so really this you know as had a kind of

572
00:26:05,000 --> 00:26:03,570
really outsized influence on their day

573
00:26:06,950 --> 00:26:05,010
to day life so this is you know

574
00:26:10,010 --> 00:26:06,960
stargazing is you know as old as

575
00:26:13,010 --> 00:26:10,020
humanity itself really and because of

576
00:26:15,040 --> 00:26:13,020
this made this huge influence of the

577
00:26:17,720 --> 00:26:15,050
night sky and celestial objects on

578
00:26:20,180 --> 00:26:17,730
people's day-to-day lives also means it

579
00:26:23,330 --> 00:26:20,190
was very closely tied into their belief

580
00:26:25,070 --> 00:26:23,340
systems and gods and and worship and

581
00:26:26,390 --> 00:26:25,080
this is actually something I've always

582
00:26:28,490 --> 00:26:26,400
really liked astronomy and that it

583
00:26:31,940 --> 00:26:28,500
really kind of ties together science and

584
00:26:35,840 --> 00:26:31,950
discovery with traditions and culture in

585
00:26:38,000 --> 00:26:35,850
that way so in in that context

586
00:26:42,620 --> 00:26:38,010
telescopes are incredibly recent

587
00:26:44,570 --> 00:26:42,630
invention in astronomy telescopes were

588
00:26:46,520 --> 00:26:44,580

not even the first ever instruments that

589
00:26:49,250 --> 00:26:46,530
people started using for looking at this

590
00:26:50,510 --> 00:26:49,260
looking at stars or at the night sky so

591
00:26:52,940 --> 00:26:50,520
there's a whole range of early

592
00:26:59,090 --> 00:26:52,950
instruments from you know sextant to

593
00:27:00,950 --> 00:26:59,100
Astro labs to blanking on the name of

594
00:27:05,630 --> 00:27:00,960
the thing at the end of time is fear

595
00:27:08,060 --> 00:27:05,640
Tannis fear this beautiful astronomical

596
00:27:10,130 --> 00:27:08,070
clocks a lot of all of these particular

597
00:27:12,410 --> 00:27:10,140
instruments predates the invention of

598
00:27:16,010 --> 00:27:12,420
the first telescope so these were used

599
00:27:18,350 --> 00:27:16,020
to predict their locations of stars in

600
00:27:20,510 --> 00:27:18,360
the sky or to measure the positions of

601
00:27:23,300 --> 00:27:20,520
stars in the sky or certain angular

602
00:27:25,940 --> 00:27:23,310
distances and it's it's actually really

603
00:27:28,130 --> 00:27:25,950
when whenever I read about this it's

604
00:27:30,440 --> 00:27:28,140
really fascinating how much knowledge we

605
00:27:32,030 --> 00:27:30,450
had actually already gathered before the

606
00:27:37,110 --> 00:27:32,040
first telescopes were even you know

607
00:27:39,850 --> 00:27:37,120
invented we had had

608
00:27:41,279 --> 00:27:39,860
catalogs have stars huge catalogs of

609
00:27:45,909 --> 00:27:41,289
stars and their positions already

610
00:27:47,710 --> 00:27:45,919
charted things like you know the planets

611
00:27:49,960 --> 00:27:47,720
and motions of the planets had been

612
00:27:52,450 --> 00:27:49,970
traced in huge amount of detail the

613
00:27:56,019 --> 00:27:52,460

actual laws of planetary motion were

614
00:27:57,730 --> 00:27:56,029
derived from naked eye observations and

615
00:27:59,379 --> 00:27:57,740
so there was actually a huge amount of

616
00:28:02,440 --> 00:27:59,389
knowledge already gathered before the

617
00:28:04,360 --> 00:28:02,450
telescope even arrived so that's kind of

618
00:28:08,320 --> 00:28:04,370
setting the scene for what I want to

619
00:28:10,450 --> 00:28:08,330
talk about here telescopes have really

620
00:28:11,649 --> 00:28:10,460
kind of supercharged discovery in

621
00:28:13,649 --> 00:28:11,659
astronomy but we shouldn't forget

622
00:28:16,269 --> 00:28:13,659
everything that became before either

623
00:28:18,700 --> 00:28:16,279
so astronomy is a kind of an

624
00:28:21,669 --> 00:28:18,710
experimental science is very unique in

625
00:28:23,529 --> 00:28:21,679
that we can't perform experiments on our

626
00:28:27,249 --> 00:28:23,539
subjects in the same way that other

627
00:28:29,919 --> 00:28:27,259
sciences do so we can't grow things in a

628
00:28:32,129 --> 00:28:29,929
petri dish or we can't put galaxies in

629
00:28:35,080 --> 00:28:32,139
MRI scanners or anything like that and

630
00:28:38,799 --> 00:28:35,090
we we have to just make do with what we

631
00:28:40,419 --> 00:28:38,809
see we have just one laboratory but our

632
00:28:43,960 --> 00:28:40,429
laboratory is the size of the entire

633
00:28:46,539 --> 00:28:43,970
universe so our job really is to kind of

634
00:28:50,019 --> 00:28:46,549
just gather as much information as we

635
00:28:51,669 --> 00:28:50,029
possibly can with as many different

636
00:28:53,950 --> 00:28:51,679
methods as we thought as we can and then

637
00:28:56,080 --> 00:28:53,960
try to kind of build up this story of

638
00:28:58,119 --> 00:28:56,090

this picture of the past and the present

639
00:29:01,590 --> 00:28:58,129
and the future to try and like piece

640
00:29:04,419 --> 00:29:01,600
everything together in the simplest form

641
00:29:06,279 --> 00:29:04,429
observational astronomy is you know

642
00:29:08,950 --> 00:29:06,289
catching photons from space

643
00:29:12,090 --> 00:29:08,960
so photons are the carrier particles for

644
00:29:15,340 --> 00:29:12,100
electromagnetic magnetic radiation

645
00:29:17,799 --> 00:29:15,350
photons can come in a huge range of

646
00:29:19,720 --> 00:29:17,809
different energies and these different

647
00:29:21,610 --> 00:29:19,730
energies we call by different names you

648
00:29:24,190 --> 00:29:21,620
know from the lowest energy which we

649
00:29:27,249 --> 00:29:24,200
call radio waves through to microwaves

650
00:29:29,230 --> 00:29:27,259
infrared visible lights to the very

651
00:29:31,659 --> 00:29:29,240
highest energies which are x-rays and

652
00:29:34,480 --> 00:29:31,669
gamma rays and so we want all of these

653
00:29:38,110 --> 00:29:34,490
photons in astronomy basically because

654
00:29:40,029 --> 00:29:38,120
all these different energies in the

655
00:29:42,159 --> 00:29:40,039
radiation kind of tell a different part

656
00:29:44,019 --> 00:29:42,169
of the story and we have observatories

657
00:29:46,210 --> 00:29:44,029
to detect all these different types of

658
00:29:47,860 --> 00:29:46,220
radiation and each of them use you know

659
00:29:50,390 --> 00:29:47,870
I could give this talk for each of these

660
00:29:52,220 --> 00:29:50,400
different parts of the electromagnetic

661
00:29:54,230 --> 00:29:52,230
spectrum because each of these you know

662
00:29:56,390 --> 00:29:54,240
uses very different technologies and

663
00:29:58,820 --> 00:29:56,400

have have their own history that is

664
00:30:00,950 --> 00:29:58,830
really interesting but so for this talk

665
00:30:05,420 --> 00:30:00,960
I am going to focus on the kind of

666
00:30:09,020 --> 00:30:05,430
visible and near-infrared range so you

667
00:30:11,960 --> 00:30:09,030
know just visible light astronomy just

668
00:30:14,770 --> 00:30:11,970
to caveat for my caching photons from

669
00:30:17,420 --> 00:30:14,780
space this is not fully true so we also

670
00:30:20,150 --> 00:30:17,430
have telescopes that detect high-energy

671
00:30:23,180 --> 00:30:20,160
cosmic rays coming from Astrophysical

672
00:30:26,180 --> 00:30:23,190
sources and since very recently which is

673
00:30:29,480 --> 00:30:26,190
very exciting we can also detect

674
00:30:31,880 --> 00:30:29,490
gravitational waves from from

675
00:30:33,680 --> 00:30:31,890
Astrophysical sources and this is a

676
00:30:37,160 --> 00:30:33,690
whole new area of science these were

677
00:30:39,020 --> 00:30:37,170
only first detected a few years ago so

678
00:30:42,130 --> 00:30:39,030
that's very exciting but will not be

679
00:30:45,290 --> 00:30:42,140
talking about that today very much a

680
00:30:47,570 --> 00:30:45,300
basic principle of a telescope visible

681
00:30:50,870 --> 00:30:47,580
light telescope it's just a big bucket

682
00:30:53,150 --> 00:30:50,880
for light for collecting light the

683
00:30:55,250 --> 00:30:53,160
telescope itself just collects the light

684
00:30:57,530 --> 00:30:55,260
and then brings it to a focus in a

685
00:30:59,870 --> 00:30:57,540
convenient location so that can be to an

686
00:31:02,200 --> 00:30:59,880
eyepiece or it can be to a camera or

687
00:31:04,880 --> 00:31:02,210
another different kind of instrument I'm

688
00:31:06,770 --> 00:31:04,890

the bigger the telescope the bigger the

689
00:31:09,860 --> 00:31:06,780
bucket is the more light it can collect

690
00:31:11,870 --> 00:31:09,870
so a larger telescope can in principle

691
00:31:14,450 --> 00:31:11,880
detect fainter sources because it can

692
00:31:17,480 --> 00:31:14,460
collect more photons and a larger

693
00:31:19,280 --> 00:31:17,490
telescope can also achieve a higher

694
00:31:21,560 --> 00:31:19,290
resolution and what that means is that

695
00:31:24,860 --> 00:31:21,570
you see here that the diagram is that

696
00:31:27,250 --> 00:31:24,870
you can see finer detail with them so

697
00:31:29,330 --> 00:31:27,260
that is basically a reason why you know

698
00:31:31,160 --> 00:31:29,340
as soon as we understood these

699
00:31:32,810 --> 00:31:31,170
principles you know we just wanted to

700
00:31:34,370 --> 00:31:32,820
keep building bigger telescopes and that

701
00:31:38,170 --> 00:31:34,380
has really was driven a lot of

702
00:31:41,660 --> 00:31:38,180
technological development so the first

703
00:31:45,860 --> 00:31:41,670
kind of aspect of technology I want to

704
00:31:49,610 --> 00:31:45,870
talk about is the is is how to build

705
00:31:53,540 --> 00:31:49,620
large mirrors so see here a nice graphic

706
00:31:57,260 --> 00:31:53,550
of you know Galileo performing his first

707
00:32:00,500 --> 00:31:57,270
astronomical observations that was in

708
00:32:02,490 --> 00:32:00,510
1609 so that was that's the date often

709
00:32:04,710 --> 00:32:02,500
quoted as you know the

710
00:32:06,120 --> 00:32:04,720
the telescope the invention of the

711
00:32:07,740 --> 00:32:06,130
telescope is actually like a really

712
00:32:09,720 --> 00:32:07,750
fascinating story there's all these

713
00:32:13,170 --> 00:32:09,730

theories about who knew what and when

714
00:32:14,670 --> 00:32:13,180
and who told what to whom and if you

715
00:32:18,540 --> 00:32:14,680
really kind of dig into the history of

716
00:32:22,890 --> 00:32:18,550
it it's actually really fun but we'll

717
00:32:25,530 --> 00:32:22,900
stick with 1609 here and so this first

718
00:32:28,050 --> 00:32:25,540
telescope that Galileo built immediately

719
00:32:30,660 --> 00:32:28,060
was used for a person really cool

720
00:32:33,930 --> 00:32:30,670
discoveries like the the moon - for big

721
00:32:35,700 --> 00:32:33,940
moons of Jupiter so it was immediately

722
00:32:39,510 --> 00:32:35,710
put to very good use and so this

723
00:32:41,730 --> 00:32:39,520
telescope was made with lenses but very

724
00:32:44,340 --> 00:32:41,740
quickly after these first models and

725
00:32:48,450 --> 00:32:44,350
telescopes started also getting built

726
00:32:51,270 --> 00:32:48,460
with mirrors mirrors have some distinct

727
00:32:54,960 --> 00:32:51,280
advantages they're a little easier to to

728
00:33:00,390 --> 00:32:54,970
manufacture and they're not not quite as

729
00:33:02,640 --> 00:33:00,400
cumbersome as lenses but both refractors

730
00:33:04,410 --> 00:33:02,650
using lenses and reflectors using

731
00:33:07,620 --> 00:33:04,420
mirrors were kind of used in parallel

732
00:33:09,930 --> 00:33:07,630
for quite a long time the astronomer who

733
00:33:13,680 --> 00:33:09,940
really perfected the art of making large

734
00:33:15,750 --> 00:33:13,690
mirrors was William Herschel who was a

735
00:33:18,510 --> 00:33:15,760
German astronomer they were working in

736
00:33:21,120 --> 00:33:18,520
the South of England and he was very

737
00:33:25,290 --> 00:33:21,130
good at making telescope mirrors and he

738
00:33:28,920 --> 00:33:25,300

had a number of telescopes in his own

739
00:33:32,460 --> 00:33:28,930
private Observatory which he and his

740
00:33:34,230 --> 00:33:32,470
sister Caroline used to you know watch

741
00:33:36,330 --> 00:33:34,240
the skies night after night and they

742
00:33:39,560 --> 00:33:36,340
made some absolutely amazing discoveries

743
00:33:41,930 --> 00:33:39,570
they were both incredibly accomplished

744
00:33:45,500 --> 00:33:41,940
but this was the combination of

745
00:33:49,080 --> 00:33:45,510
Herschel's kind of telescope building

746
00:33:53,160 --> 00:33:49,090
career this was Herschel's grand 40-foot

747
00:33:55,590 --> 00:33:53,170
telescope so the 40 40-foot refers to

748
00:33:58,490 --> 00:33:55,600
the length of the tube the size of the

749
00:34:01,830 --> 00:33:58,500
mirror was about 48 inches in diameter

750
00:34:03,690 --> 00:34:01,840
this was kind of a tourist attraction it

751
00:34:05,670 --> 00:34:03,700
was actually marked on the map so people

752
00:34:08,310 --> 00:34:05,680
who travel like far and wide to come see

753
00:34:12,750 --> 00:34:08,320
this telescope the only problem was is

754
00:34:14,750 --> 00:34:12,760
that it just wasn't very good and so and

755
00:34:16,310 --> 00:34:14,760
it's quite funny because Herschel

756
00:34:18,710 --> 00:34:16,320
go to give all these presentations about

757
00:34:20,149 --> 00:34:18,720
his observations but he would kind of

758
00:34:21,620 --> 00:34:20,159
gloss over the fact that they were done

759
00:34:23,480 --> 00:34:21,630
with the other telescopes not with this

760
00:34:27,020 --> 00:34:23,490
one because he didn't really want to

761
00:34:29,810 --> 00:34:27,030
admit this but he really hit on the

762
00:34:31,820 --> 00:34:29,820
difficulty of you know building very

763
00:34:34,550 --> 00:34:31,830

large mirrors and very large telescopes

764
00:34:36,440 --> 00:34:34,560
you can see this is an amazingly complex

765
00:34:38,840 --> 00:34:36,450
contraption

766
00:34:40,909 --> 00:34:38,850
it was incredibly heavy it was

767
00:34:44,090 --> 00:34:40,919
completely impractical to actually move

768
00:34:45,680 --> 00:34:44,100
around the sky and so often he could

769
00:34:47,659 --> 00:34:45,690
only observe things for a very short

770
00:34:49,010 --> 00:34:47,669
period of time as they drifted out of

771
00:34:51,620 --> 00:34:49,020
the field because it was far too

772
00:34:58,760 --> 00:34:51,630
difficult to actually move the telescope

773
00:35:01,010 --> 00:34:58,770
around also the the mirror as you make a

774
00:35:03,200 --> 00:35:01,020
mirror bigger it becomes a lot heavier

775
00:35:04,370 --> 00:35:03,210
and it becomes a lot bulkier as well and

776
00:35:08,570 --> 00:35:04,380
so this is where you start getting

777
00:35:11,480 --> 00:35:08,580
problems so if you want to make a mirror

778
00:35:14,090 --> 00:35:11,490
twice as big you also for it for it to

779
00:35:17,330 --> 00:35:14,100
keep its shape and not sort of sag or

780
00:35:20,720 --> 00:35:17,340
flop under gravity you have to make it

781
00:35:22,970 --> 00:35:20,730
four times as thick so you can see as

782
00:35:25,370 --> 00:35:22,980
you scale up in size you're going to end

783
00:35:31,640 --> 00:35:25,380
up with these huge you know bulk sand

784
00:35:33,140 --> 00:35:31,650
material and as your your bulk of your

785
00:35:35,330 --> 00:35:33,150
primary mirror gets bigger and bigger

786
00:35:36,830 --> 00:35:35,340
your the whole support structure also

787
00:35:38,840 --> 00:35:36,840
has to become a lot you know it's

788
00:35:40,700 --> 00:35:38,850

different stronger to actually support

789
00:35:42,350 --> 00:35:40,710
that weight and the whole thing is just

790
00:35:44,960 --> 00:35:42,360
going to very quickly going to become

791
00:35:49,460 --> 00:35:44,970
very cumbersome to use what's more as

792
00:35:51,500 --> 00:35:49,470
well so as you go and this is still an

793
00:35:53,060 --> 00:35:51,510
issue today with mirrors as you go from

794
00:35:55,760 --> 00:35:53,070
day to night there's usually a very

795
00:35:57,890 --> 00:35:55,770
strong drop in temperature and so a

796
00:35:59,720 --> 00:35:57,900
telescope mirror has two kind of thermal

797
00:36:03,640 --> 00:35:59,730
eyes it has its temperature has to

798
00:36:06,050 --> 00:36:03,650
adjust to to the ambient temperature and

799
00:36:07,880 --> 00:36:06,060
that can take a while that settling can

800
00:36:09,950 --> 00:36:07,890
take a while and if you have a mirror

801
00:36:11,540 --> 00:36:09,960
that this is huge bulk of material that

802
00:36:14,120 --> 00:36:11,550
basically could take a very long time

803
00:36:16,160 --> 00:36:14,130
and so Herschel would constantly get

804
00:36:17,930 --> 00:36:16,170
condensation on his mirror which would

805
00:36:21,130 --> 00:36:17,940
then freeze so you'd he'd have like a

806
00:36:24,370 --> 00:36:21,140
layer of frost on it and it wasn't

807
00:36:26,500 --> 00:36:24,380
so Herschel in his you know telescope

808
00:36:31,000 --> 00:36:26,510
building adventures basically came up

809
00:36:33,160 --> 00:36:31,010
against this big problem where you know

810
00:36:34,750 --> 00:36:33,170
this the the primary mirror is you know

811
00:36:36,820 --> 00:36:34,760
kind of the heart of the telescope and

812
00:36:40,060 --> 00:36:36,830
it really drives the costs of other

813
00:36:41,620 --> 00:36:40,070

telescope and it is a very big

814
00:36:43,900 --> 00:36:41,630
engineering challenge how to increase

815
00:36:47,320 --> 00:36:43,910
the size of a telescope without running

816
00:36:49,750 --> 00:36:47,330
into these issues and this continued to

817
00:36:54,550 --> 00:36:49,760
be an issue until you know well into the

818
00:36:57,430 --> 00:36:54,560
nineteenth early twentieth century so a

819
00:37:01,270 --> 00:36:57,440
couple of solutions were this were found

820
00:37:05,470 --> 00:37:01,280
for this so the first is was pioneered

821
00:37:07,690 --> 00:37:05,480
here in the 1940s with the 5-metre Hale

822
00:37:10,420 --> 00:37:07,700
telescope at Mount Palomar Observatory

823
00:37:13,060 --> 00:37:10,430
which is still in operation today and is

824
00:37:16,420 --> 00:37:13,070
actually like an amazing achievement for

825
00:37:19,360 --> 00:37:16,430
its time so this 5 meter mirror was a

826
00:37:23,530 --> 00:37:19,370
huge step up in size from the previous

827
00:37:25,810 --> 00:37:23,540
kind of largest telescope and but it was

828
00:37:28,720 --> 00:37:25,820
clear that too if they had to increase

829
00:37:30,310 --> 00:37:28,730
the thickness of the mirror and to scale

830
00:37:33,760 --> 00:37:30,320
with the diameter that this would be

831
00:37:35,890 --> 00:37:33,770
completely impossible I think even in

832
00:37:37,860 --> 00:37:35,900
the manufacturing process in when the

833
00:37:40,780 --> 00:37:37,870
the glass would come out of the oven

834
00:37:42,490 --> 00:37:40,790
they have to control the cooling because

835
00:37:44,380 --> 00:37:42,500
otherwise the mirror can crack if it

836
00:37:46,180 --> 00:37:44,390
cools too quickly and I think it was

837
00:37:48,370 --> 00:37:46,190
going to have to cool for something like

838
00:37:51,130 --> 00:37:48,380

I don't know it was like many many years

839
00:37:53,440 --> 00:37:51,140
decades basically so this was you know

840
00:37:57,550 --> 00:37:53,450
not going to work so they developed this

841
00:38:01,480 --> 00:37:57,560
technique whereby the glass the molten

842
00:38:03,220 --> 00:38:01,490
glass was kind of poured over this over

843
00:38:06,700 --> 00:38:03,230
over a mold that had this kind of

844
00:38:09,610 --> 00:38:06,710
removable backing structure so that they

845
00:38:12,390 --> 00:38:09,620
could actually remove a huge portion of

846
00:38:15,730 --> 00:38:12,400
the material but keeping these tips ribs

847
00:38:17,380 --> 00:38:15,740
- and that kind of maintained the the

848
00:38:20,410 --> 00:38:17,390
stiffness and the support of the mirror

849
00:38:23,500 --> 00:38:20,420
surface and so by doing this they were

850
00:38:27,640 --> 00:38:23,510
able to cut down the weight of the

851
00:38:29,440 --> 00:38:27,650
mirror by I think to about 65% of the

852
00:38:32,170 --> 00:38:29,450
mass that if it had been you know a

853
00:38:34,030 --> 00:38:32,180
solid block and so this made you know

854
00:38:35,980 --> 00:38:34,040
was kind of key to making this telescope

855
00:38:38,109 --> 00:38:35,990
a success and like I said this is the

856
00:38:40,900 --> 00:38:38,119
telescope is still in operation today

857
00:38:44,410 --> 00:38:40,910
so it's a quiet it was an amazing piece

858
00:38:47,980 --> 00:38:44,420
of engineering a little bit later in the

859
00:38:51,160 --> 00:38:47,990
1980s a technique was developed in

860
00:38:54,790 --> 00:38:51,170
Europe to call kind of active support

861
00:38:58,270 --> 00:38:54,800
active optics so in this technology

862
00:38:59,980 --> 00:38:58,280
rather than you know trying any sort of

863
00:39:03,640 --> 00:38:59,990

clever manufacturing techniques like

864
00:39:07,000 --> 00:39:03,650
this the idea was to not even try to

865
00:39:09,130 --> 00:39:07,010
have the mirror hold its own shape just

866
00:39:11,440 --> 00:39:09,140
create a very thin mirror but fix

867
00:39:13,540 --> 00:39:11,450
actuators on the back that can be you

868
00:39:15,970 --> 00:39:13,550
know electrically controlled that can

869
00:39:18,280 --> 00:39:15,980
basically as the mirror moves around on

870
00:39:20,280 --> 00:39:18,290
the sky and sags under gravity couldn't

871
00:39:23,109 --> 00:39:20,290
just nudge it back into shape

872
00:39:25,180 --> 00:39:23,119
and so this was first demonstrated in

873
00:39:27,970 --> 00:39:25,190
the late 1980s on the three point six

874
00:39:31,630 --> 00:39:27,980
meter new technology telescope this is a

875
00:39:33,160 --> 00:39:31,640
telescope operated by the European

876
00:39:37,140 --> 00:39:33,170
Southern Observatory which is a large

877
00:39:40,000 --> 00:39:37,150
European consortium operating

878
00:39:41,950 --> 00:39:40,010
astronomical telescopes in Chile so this

879
00:39:44,309 --> 00:39:41,960
telescope is still in operation today as

880
00:39:48,460 --> 00:39:44,319
well and this technique is used on many

881
00:39:50,349 --> 00:39:48,470
many large telescopes today so it's

882
00:39:52,930 --> 00:39:50,359
really ingenious and that you can kind

883
00:39:55,750 --> 00:39:52,940
of you know constantly monitor the shape

884
00:39:59,770 --> 00:39:55,760
of the mirror and kind of just nudge it

885
00:40:04,030 --> 00:39:59,780
back into shape as needed the next step

886
00:40:06,760 --> 00:40:04,040
in this was to actually and this is a

887
00:40:10,420 --> 00:40:06,770
technique pioneered on the 10 metre Keck

888
00:40:12,430 --> 00:40:10,430

telescopes in the early 90s is to not

889
00:40:15,460 --> 00:40:12,440
even try to build the mirror as a single

890
00:40:17,700 --> 00:40:15,470
piece but to actually build up the

891
00:40:20,230 --> 00:40:17,710
mirror out of tiles of smaller mirrors

892
00:40:21,789 --> 00:40:20,240
so here you actually see an example this

893
00:40:24,099 --> 00:40:21,799
is actually the southern African Large

894
00:40:27,490 --> 00:40:24,109
Telescope in South Africa which uses

895
00:40:29,859 --> 00:40:27,500
this the same technology so you can see

896
00:40:33,039 --> 00:40:29,869
this is just kind of like lots of

897
00:40:36,670 --> 00:40:33,049
different hexagonal tiles of mirrors and

898
00:40:38,319 --> 00:40:36,680
this is a kind of a drawing of what the

899
00:40:40,599 --> 00:40:38,329
back of one of these segments looks like

900
00:40:43,070 --> 00:40:40,609
so it has these support structures on

901
00:40:45,740 --> 00:40:43,080
the back so that every single

902
00:40:47,600 --> 00:40:45,750
can be adjusted in tip and tilt sorting

903
00:40:49,760 --> 00:40:47,610
and to keep them aligned with their

904
00:40:53,210 --> 00:40:49,770
neighbors so that you can maintain a

905
00:40:55,790 --> 00:40:53,220
beautiful shape for the mirror and as

906
00:40:58,160 --> 00:40:55,800
you may know the James Webb Space

907
00:40:59,810 --> 00:40:58,170
Telescope will marks the first time that

908
00:41:02,840 --> 00:40:59,820
we will launch one of these segmented

909
00:41:05,060 --> 00:41:02,850
mirrors into space and indeed we

910
00:41:07,250 --> 00:41:05,070
wouldn't be able to launch such a large

911
00:41:09,590 --> 00:41:07,260
mirror into space without segmenting it

912
00:41:11,870 --> 00:41:09,600
because it's that technology that lets

913
00:41:14,660 --> 00:41:11,880

us fold it up so that it fits into the

914
00:41:17,750 --> 00:41:14,670
launch vehicle and to then kind of be

915
00:41:24,230 --> 00:41:17,760
deployed and and kind of folded back

916
00:41:27,760 --> 00:41:24,240
into into its full shape after launch so

917
00:41:34,190 --> 00:41:31,520
towards the future this segmentation is

918
00:41:37,370 --> 00:41:34,200
really kind of the path to a huge

919
00:41:39,920 --> 00:41:37,380
scaling up in size of telescopes so here

920
00:41:42,020 --> 00:41:39,930
you see an abused impression of a

921
00:41:45,740 --> 00:41:42,030
next-generation European ground this

922
00:41:49,640 --> 00:41:45,750
telescope called the European extremely

923
00:41:51,260 --> 00:41:49,650
large telescope we do not waste any

924
00:41:56,300 --> 00:41:51,270
money on coming up with good names for

925
00:41:59,210 --> 00:41:56,310
our telescopes and so this the diameter

926
00:42:01,520 --> 00:41:59,220
of this mirror is 39

927
00:42:04,280 --> 00:42:01,530
you can see here these are like these

928
00:42:08,270 --> 00:42:04,290
these tiny specks down here are big

929
00:42:10,310 --> 00:42:08,280
trucks so you can see the size of this

930
00:42:13,520 --> 00:42:10,320
this mirror will have around 800

931
00:42:16,640 --> 00:42:13,530
individual segments that will all have

932
00:42:21,560 --> 00:42:16,650
to be tiled and may and its shape

933
00:42:23,450 --> 00:42:21,570
maintained throughout observations so

934
00:42:25,070 --> 00:42:23,460
the the scenery here this telescope is

935
00:42:28,010 --> 00:42:25,080
under construction in the Atacama Desert

936
00:42:30,880 --> 00:42:28,020
in northern Chile so it is it does it

937
00:42:34,430 --> 00:42:30,890
does actually look like Mars there and

938
00:42:37,910 --> 00:42:34,440

the second kind of technology I wanted

939
00:42:40,310 --> 00:42:37,920
to talk about was the ability to capture

940
00:42:43,910 --> 00:42:40,320
images which led to the birth of

941
00:42:47,540 --> 00:42:43,920
astrophysics and the also the birth of

942
00:42:49,300 --> 00:42:47,550
kind of surveys in astronomy so I put

943
00:42:51,350 --> 00:42:49,310
here a picture of Frederick Douglass

944
00:42:54,230 --> 00:42:51,360
photography was not invented for

945
00:42:55,460 --> 00:42:54,240
astronomy of course it was but

946
00:42:57,880 --> 00:42:55,470
astronomers were very

947
00:43:01,670 --> 00:42:57,890
quick to cut none so the first kind of

948
00:43:06,349 --> 00:43:01,680
photographic technologies were developed

949
00:43:07,880 --> 00:43:06,359
in the kind of 1820s 1830s and these are

950
00:43:10,130 --> 00:43:07,890
some of the very first pictures that

951
00:43:13,430 --> 00:43:10,140
astronomers took with this new you know

952
00:43:16,640 --> 00:43:13,440
with these new techniques there were

953
00:43:18,589 --> 00:43:16,650
lots of really exciting first so in 1840

954
00:43:21,320 --> 00:43:18,599
here astronomer called Draper took

955
00:43:23,330 --> 00:43:21,330
picture this picture of the moon the

956
00:43:26,720 --> 00:43:23,340
first picture of a solar eclipse by

957
00:43:29,510 --> 00:43:26,730
Bukovsky Lewis this was taken in a

958
00:43:31,339 --> 00:43:29,520
European observatory this is from 1851

959
00:43:34,339 --> 00:43:31,349
and so this showed us for the very first

960
00:43:36,260 --> 00:43:34,349
time these and the kind of the solar

961
00:43:39,020 --> 00:43:36,270
picture of the solar corona and these

962
00:43:43,010 --> 00:43:39,030
you know little prominences on the limb

963
00:43:47,180 --> 00:43:43,020

and really importantly as well the first

964
00:43:49,660 --> 00:43:47,190
recorded spectra of stars so here these

965
00:43:53,990 --> 00:43:49,670
are spectra so it's starlight dispersed

966
00:43:55,550 --> 00:43:54,000
we astronomers knew before you know

967
00:43:58,370 --> 00:43:55,560
technically before photography came

968
00:44:00,349 --> 00:43:58,380
along had been able to see these spectra

969
00:44:03,380 --> 00:44:00,359
but a lot of these features are kind of

970
00:44:05,240 --> 00:44:03,390
very faint and you know were very

971
00:44:08,990 --> 00:44:05,250
difficult to study without actually

972
00:44:12,260 --> 00:44:09,000
being able to record them properly so by

973
00:44:14,000 --> 00:44:12,270
with the advent of photography these

974
00:44:18,770 --> 00:44:14,010
could for the first time kind of really

975
00:44:21,010 --> 00:44:18,780
kind of compared and studied and and

976
00:44:23,210 --> 00:44:21,020
this really kind of gave rise to

977
00:44:25,040 --> 00:44:23,220
astrophysics as a science where people

978
00:44:30,470 --> 00:44:25,050
could really study like what the physics

979
00:44:32,480 --> 00:44:30,480
of what was happening inside stars it

980
00:44:34,849 --> 00:44:32,490
was kind of quite a big this is a really

981
00:44:37,550 --> 00:44:34,859
interesting period in in in history of

982
00:44:39,530 --> 00:44:37,560
science this was kind of there was a lot

983
00:44:42,560 --> 00:44:39,540
of enthusiasm about invention and

984
00:44:45,800 --> 00:44:42,570
innovation in Europe as well as in North

985
00:44:47,510 --> 00:44:45,810
America around this time and the fact

986
00:44:50,030 --> 00:44:47,520
also that now these images could be

987
00:44:52,099 --> 00:44:50,040
reproduced and printed meant that they

988
00:44:53,930 --> 00:44:52,109

were you know you did was like the first

989
00:44:55,430 --> 00:44:53,940
time that sort of astronomical images

990
00:44:57,650 --> 00:44:55,440
would appear in in the media in

991
00:45:00,060 --> 00:44:57,660
newspapers and it generated a huge

992
00:45:04,620 --> 00:45:00,070
amount of enthusiasm for astronomy and

993
00:45:07,260 --> 00:45:04,630
in society in general from a scientific

994
00:45:09,420 --> 00:45:07,270
point of view it was also there was this

995
00:45:10,829 --> 00:45:09,430
real feeling that it was the first time

996
00:45:14,880 --> 00:45:10,839
they could really have objective

997
00:45:16,950 --> 00:45:14,890
recordings of what was happening in in

998
00:45:21,030 --> 00:45:16,960
the sky previously it would always

999
00:45:22,800 --> 00:45:21,040
relied on notes and sketches that were

1000
00:45:24,690 --> 00:45:22,810
taken by astronomers which are obviously

1001
00:45:29,250 --> 00:45:24,700
a lot more kind of individual and

1002
00:45:31,680 --> 00:45:29,260
subjective for me this is only a really

1003
00:45:34,880 --> 00:45:31,690
amazing image so this is was taken a

1004
00:45:37,290 --> 00:45:34,890
photograph taken of the Orion Nebula by

1005
00:45:40,859 --> 00:45:37,300
someone called Andrew Inslee common in

1006
00:45:44,730 --> 00:45:40,869
1883 and this was one of the first

1007
00:45:46,829 --> 00:45:44,740
images photographs that showed very

1008
00:45:48,540 --> 00:45:46,839
faint stars that couldn't that work

1009
00:45:51,060 --> 00:45:48,550
couldn't be seen with the naked eye so

1010
00:45:53,550 --> 00:45:51,070
it was kind of the first time that you

1011
00:45:56,069 --> 00:45:53,560
know you could sort of expose for longer

1012
00:45:58,440 --> 00:45:56,079
and then when the photographs were

1013
00:46:01,020 --> 00:45:58,450

processed and it would reveal kind of

1014
00:46:02,460 --> 00:46:01,030
new stars in there that people hadn't

1015
00:46:05,190 --> 00:46:02,470
been able to see before

1016
00:46:07,170 --> 00:46:05,200
so this was kind of really kind of a you

1017
00:46:08,819 --> 00:46:07,180
know must have been a really amazing

1018
00:46:11,520 --> 00:46:08,829
experience you see for the first time

1019
00:46:14,579 --> 00:46:11,530
these things which have been hidden from

1020
00:46:17,309 --> 00:46:14,589
the eye for before and I think

1021
00:46:19,920 --> 00:46:17,319
astronomers were very quick to to

1022
00:46:21,660 --> 00:46:19,930
realize the potential and and the the

1023
00:46:23,760 --> 00:46:21,670
kind of paradigm shift that this

1024
00:46:26,220 --> 00:46:23,770
technology was bringing so here's a

1025
00:46:27,930 --> 00:46:26,230
quote from Charles Pritchard who was the

1026
00:46:32,370 --> 00:46:27,940
civilian professor of astronomy at

1027
00:46:33,440 --> 00:46:32,380
Oxford in the late 1918 80s it's a

1028
00:46:37,410 --> 00:46:33,450
little bit long-winded

1029
00:46:40,440 --> 00:46:37,420
but basically he says oh this is with

1030
00:46:42,750 --> 00:46:40,450
photography we can actually now always

1031
00:46:45,089 --> 00:46:42,760
compare back to you know we have like

1032
00:46:47,400 --> 00:46:45,099
points of comparison like just to be

1033
00:46:48,660 --> 00:46:47,410
able to see if things have changed you

1034
00:46:50,790 --> 00:46:48,670
know because we have that absolute

1035
00:46:53,460 --> 00:46:50,800
recording of what something looked like

1036
00:46:54,930 --> 00:46:53,470
at a particular time so we don't always

1037
00:46:56,430 --> 00:46:54,940
have to like draw sketches and things

1038
00:46:59,069 --> 00:46:56,440

like that it's like very easy to now

1039
00:47:00,660 --> 00:46:59,079
compare and this is still kind of what

1040
00:47:02,430 --> 00:47:00,670
we do you know when we look for for

1041
00:47:05,310 --> 00:47:02,440
things that change in the sky we just

1042
00:47:08,890 --> 00:47:05,320
compare different images

1043
00:47:12,370 --> 00:47:08,900
um photography also kind of paved the

1044
00:47:14,770 --> 00:47:12,380
way for doing astronomy by surveys so

1045
00:47:16,660 --> 00:47:14,780
rather than look surveys is when rather

1046
00:47:19,270 --> 00:47:16,670
than look at a particular object you

1047
00:47:21,700 --> 00:47:19,280
just kind of map the sky into huge parts

1048
00:47:23,770 --> 00:47:21,710
of the sky in one go and then you can

1049
00:47:25,960 --> 00:47:23,780
use those photographs you know to kind

1050
00:47:28,210 --> 00:47:25,970
of pour over them and study what's there

1051
00:47:32,530 --> 00:47:28,220
and catalog all the objects that are

1052
00:47:34,060 --> 00:47:32,540
visible this is something and this is a

1053
00:47:37,560 --> 00:47:34,070
very interesting kind of sociological

1054
00:47:40,750 --> 00:47:37,570
period in astronomy as well because the

1055
00:47:42,430 --> 00:47:40,760
this this work of poring over these

1056
00:47:45,820 --> 00:47:42,440
giant images with you know that

1057
00:47:47,680 --> 00:47:45,830
contained you know thousands of stars or

1058
00:47:49,780 --> 00:47:47,690
lots and lots of stellar spectra was

1059
00:47:51,400 --> 00:47:49,790
considered kind of dull and rote work

1060
00:47:53,980 --> 00:47:51,410
and something that even women could do

1061
00:47:57,880 --> 00:47:53,990
and also you didn't have to pay women as

1062
00:48:00,340 --> 00:47:57,890
much as men to do it and so around this

1063
00:48:04,360 --> 00:48:00,350

era kind of those this entire generation

1064
00:48:06,820 --> 00:48:04,370
of incredibly smart women who did this

1065
00:48:09,610 --> 00:48:06,830
work and who made these incredible

1066
00:48:12,220 --> 00:48:09,620
discoveries basically based on their

1067
00:48:15,130 --> 00:48:12,230
work with these these large-scale

1068
00:48:16,570 --> 00:48:15,140
surveys so here's just a picture of two

1069
00:48:19,480 --> 00:48:16,580
of the you know the best known names

1070
00:48:24,010 --> 00:48:19,490
from that period have Annie jump cannon

1071
00:48:25,540 --> 00:48:24,020
who just classified who looked at three

1072
00:48:30,070 --> 00:48:25,550
hundred and fifty thousand stellar

1073
00:48:32,290 --> 00:48:30,080
spectra by eye and base of stars and

1074
00:48:35,410 --> 00:48:32,300
basically came up with a classification

1075
00:48:36,970 --> 00:48:35,420
scheme based on chemistry and that is

1076
00:48:39,430 --> 00:48:36,980
still the classification scheme we use

1077
00:48:41,640 --> 00:48:39,440
today so that's you know really

1078
00:48:44,410 --> 00:48:41,650
transformative work that she did

1079
00:48:46,060 --> 00:48:44,420
Henrietta Swan Leavitt and similarly

1080
00:48:51,280 --> 00:48:46,070
they both worked at Harvard College

1081
00:48:55,180 --> 00:48:51,290
Observatory just from looking at lots

1082
00:48:56,890 --> 00:48:55,190
and lots of images of stars derived a

1083
00:48:58,480 --> 00:48:56,900
relationship between the period and the

1084
00:49:00,310 --> 00:48:58,490
luminosity of a particular type of

1085
00:49:04,480 --> 00:49:00,320
variable star which we call the Cepheid

1086
00:49:07,300 --> 00:49:04,490
variables which was later used by Hubble

1087
00:49:10,330 --> 00:49:07,310
to derive distances to galaxies and

1088
00:49:13,360 --> 00:49:10,340

which allowed him to discover the you

1089
00:49:15,100 --> 00:49:13,370
know expansion of the universe and again

1090
00:49:16,720 --> 00:49:15,110
this is a relationship we still use

1091
00:49:18,490 --> 00:49:16,730
today we still use these

1092
00:49:21,390 --> 00:49:18,500
variable stars to measure distances to

1093
00:49:25,000 --> 00:49:21,400
things so this is kind of a an amazing

1094
00:49:26,830 --> 00:49:25,010
kind of period this photography and the

1095
00:49:29,680 --> 00:49:26,840
you know these wide field photographic

1096
00:49:33,190 --> 00:49:29,690
surveys were a really amazing period in

1097
00:49:35,740 --> 00:49:33,200
astronomy photography kind of was the

1098
00:49:40,510 --> 00:49:35,750
lay of the land in imaging and well into

1099
00:49:43,450 --> 00:49:40,520
the 20th century the most famous of the

1100
00:49:45,640 --> 00:49:43,460
photographic surveys is probably the

1101
00:49:47,410 --> 00:49:45,650
Palomar optical Sky Survey there was a

1102
00:49:50,080 --> 00:49:47,420
series of these this is an image from

1103
00:49:53,470 --> 00:49:50,090
post one from the first one which was

1104
00:49:56,020 --> 00:49:53,480
executed over a period of a decade so it

1105
00:49:59,350 --> 00:49:56,030
was very long you know over a very long

1106
00:50:01,900 --> 00:49:59,360
period of time and created this an

1107
00:50:04,080 --> 00:50:01,910
absolutely amazing dataset that led to

1108
00:50:06,310 --> 00:50:04,090
the discovery of clusters of galaxies

1109
00:50:08,410 --> 00:50:06,320
thousands of new star clusters in the

1110
00:50:10,390 --> 00:50:08,420
Milky Way galaxy and lots and lots of

1111
00:50:13,600 --> 00:50:10,400
new other interesting objects like

1112
00:50:16,870 --> 00:50:13,610
planetary nebulae but photographic

1113
00:50:18,010 --> 00:50:16,880

plates had had their problems they were

1114
00:50:23,860 --> 00:50:18,020
not you know there were a lot of

1115
00:50:26,620 --> 00:50:23,870
problems with it of using them so there

1116
00:50:27,580 --> 00:50:26,630
were these large glass plates and so you

1117
00:50:29,770 --> 00:50:27,590
know particularly when you're doing

1118
00:50:33,520 --> 00:50:29,780
these huge large-scale surveys you were

1119
00:50:35,730 --> 00:50:33,530
generating a lot of plates and so stuck

1120
00:50:38,230 --> 00:50:35,740
they were kind of cumbersome to store

1121
00:50:42,330 --> 00:50:38,240
you couldn't reuse them so you always

1122
00:50:45,790 --> 00:50:42,340
had you know to get new ones also the

1123
00:50:47,920 --> 00:50:45,800
efficiency with which the photography is

1124
00:50:50,290 --> 00:50:47,930
kind of a chemical process so do you

1125
00:50:53,080 --> 00:50:50,300
have a kind of a photosensitive emulsion

1126
00:50:57,130 --> 00:50:53,090
that goes on this glass plate and then

1127
00:50:58,930 --> 00:50:57,140
reacts to the incoming light but the

1128
00:51:03,820 --> 00:50:58,940
efficiency with which that conversion

1129
00:51:05,110 --> 00:51:03,830
happens is not not very high and it

1130
00:51:07,120 --> 00:51:05,120
could be quite different between

1131
00:51:10,990 --> 00:51:07,130
different parts of the plate or between

1132
00:51:12,700 --> 00:51:11,000
in different plates and the response was

1133
00:51:15,910 --> 00:51:12,710
also not very linear so it was quite

1134
00:51:17,800 --> 00:51:15,920
hard to use the brightness you measure

1135
00:51:19,960 --> 00:51:17,810
in a photograph to really accurately

1136
00:51:22,150 --> 00:51:19,970
measure the actual intrinsic brightness

1137
00:51:26,680 --> 00:51:22,160
of the star so these were kind of you

1138
00:51:28,359 --> 00:51:26,690

know niggly problems that did you know

1139
00:51:30,130 --> 00:51:28,369
really being able to do precision

1140
00:51:34,620 --> 00:51:30,140
science kind of called for a different

1141
00:51:39,040 --> 00:51:34,630
solution um that came in the form of

1142
00:51:42,339 --> 00:51:39,050
electronic imaging using C CDs or

1143
00:51:45,309 --> 00:51:42,349
charge-coupled devices umm what these

1144
00:51:48,400 --> 00:51:45,319
devices do or the the basis of this type

1145
00:51:51,819 --> 00:51:48,410
of energy imaging is to harness what was

1146
00:51:54,160 --> 00:51:51,829
called the photoelectric effect which is

1147
00:51:55,870 --> 00:51:54,170
actually Einstein came up with this

1148
00:51:59,060 --> 00:51:55,880
theory for what happens in the

1149
00:52:01,470 --> 00:51:59,070
photoelectric effect in the early 1900s

1150
00:52:08,790 --> 00:52:01,480
so before that it had been known for

1151
00:52:11,280 --> 00:52:08,800
quite some time that if you if you if

1152
00:52:13,380 --> 00:52:11,290
you irradiate certain materials their

1153
00:52:18,570 --> 00:52:13,390
electrical properties would change so

1154
00:52:20,280 --> 00:52:18,580
which is kind of weird so so then the

1155
00:52:22,440 --> 00:52:20,290
theory behind the photoelectric effect

1156
00:52:25,590 --> 00:52:22,450
that Einstein you know very cleverly

1157
00:52:27,720 --> 00:52:25,600
kind of derived is that the energy of

1158
00:52:31,590 --> 00:52:27,730
the incoming light so when you would

1159
00:52:34,500 --> 00:52:31,600
radiation hits and material releases

1160
00:52:39,600 --> 00:52:34,510
electrons in the kind of substrate of

1161
00:52:40,950 --> 00:52:39,610
the material at the time when Einstein

1162
00:52:42,840 --> 00:52:40,960
came up with the theory we didn't know

1163
00:52:46,140 --> 00:52:42,850

yet what photons were so he framed it

1164
00:52:47,340 --> 00:52:46,150
slightly differently but basically what

1165
00:52:49,470 --> 00:52:47,350
happens is that you know you have

1166
00:52:54,300 --> 00:52:49,480
photons coming in carrying energy and

1167
00:52:57,720 --> 00:52:54,310
they interact with the they're kind of

1168
00:53:00,060 --> 00:52:57,730
with the material of releasing electrons

1169
00:53:01,440 --> 00:53:00,070
and as it turns out this is for a given

1170
00:53:04,980 --> 00:53:01,450
material this is a very predictable

1171
00:53:08,010 --> 00:53:04,990
response and it's it's immediate and

1172
00:53:10,730 --> 00:53:08,020
it's repeatable as well so this

1173
00:53:15,540 --> 00:53:10,740
basically gives a really clever way of

1174
00:53:17,490 --> 00:53:15,550
of using an electrical current to learn

1175
00:53:19,260 --> 00:53:17,500
about the properties of the radiation

1176
00:53:23,370 --> 00:53:19,270
that's coming that's hitting the

1177
00:53:24,930 --> 00:53:23,380
material so so that was you know the

1178
00:53:28,800 --> 00:53:24,940
photoelectric effect was kind of in the

1179
00:53:33,090 --> 00:53:28,810
early 20th century the real breakthrough

1180
00:53:35,790 --> 00:53:33,100
for imaging came when these sutures

1181
00:53:38,180 --> 00:53:35,800
woman here and Smith and Boyle here at

1182
00:53:42,120 --> 00:53:38,190
stirring up their Nobel Prize ceremonies

1183
00:53:44,490 --> 00:53:42,130
they worked at AT&T Bell Labs when they

1184
00:53:48,060 --> 00:53:44,500
figured out a way of sort of

1185
00:53:50,849 --> 00:53:48,070
transferring a charge sort of between

1186
00:53:53,099 --> 00:53:50,859
this is kind of a little book mmm excuse

1187
00:53:57,359 --> 00:53:53,109
me sort of bucket analogy they figured

1188
00:53:59,630 --> 00:53:57,369

out a way of if you had that every

1189
00:54:02,490 --> 00:53:59,640
little element was sort of

1190
00:54:03,870 --> 00:54:02,500
photosensitive element little bit on

1191
00:54:06,240 --> 00:54:03,880
here and then you would collect the

1192
00:54:09,000 --> 00:54:06,250
charge and they figured out how to then

1193
00:54:11,200 --> 00:54:09,010
transfer the charge along kind of row so

1194
00:54:15,460 --> 00:54:11,210
that you could then

1195
00:54:17,980 --> 00:54:15,470
you know I get the signal from the from

1196
00:54:20,490 --> 00:54:17,990
the material and reconstruct a

1197
00:54:23,260 --> 00:54:20,500
2-dimensional image sorry that was clear

1198
00:54:25,210 --> 00:54:23,270
so so basically that you have you know

1199
00:54:27,910 --> 00:54:25,220
this whole array this is what a CCD

1200
00:54:29,620 --> 00:54:27,920
looks like a charge coupled device it's

1201
00:54:34,690 --> 00:54:29,630
got all these little squares which we

1202
00:54:37,630 --> 00:54:34,700
call pixels and and at every one of

1203
00:54:39,280 --> 00:54:37,640
these pixels if you have incident

1204
00:54:42,010 --> 00:54:39,290
radiation it will generate that

1205
00:54:44,710 --> 00:54:42,020
particular charge and then using this

1206
00:54:46,750 --> 00:54:44,720
charge coupling mechanism you can

1207
00:54:48,760 --> 00:54:46,760
actually read that out and reconstruct

1208
00:54:51,850 --> 00:54:48,770
what the image looked like so being able

1209
00:54:53,830 --> 00:54:51,860
to create use this technology and use

1210
00:54:56,050 --> 00:54:53,840
this effects and harness it to produce a

1211
00:54:57,970 --> 00:54:56,060
2-dimensional image that was really kind

1212
00:55:00,730 --> 00:54:57,980
of the key breakthrough for track these

1213
00:55:03,280 --> 00:55:00,740

charged couple devices it Masek the

1214
00:55:05,650 --> 00:55:03,290
great thing about it is that again it's

1215
00:55:09,970 --> 00:55:05,660
very it's a very linear response over a

1216
00:55:12,370 --> 00:55:09,980
very long range of energies and it's

1217
00:55:17,430 --> 00:55:12,380
it's it's very predictable so you can

1218
00:55:20,320 --> 00:55:17,440
basically calibrate it very well and

1219
00:55:22,000 --> 00:55:20,330
then and they have quite high quantum

1220
00:55:24,370 --> 00:55:22,010
efficiency so a very high fraction of

1221
00:55:27,220 --> 00:55:24,380
incident photons will generate that

1222
00:55:29,470 --> 00:55:27,230
current and what's also great is that

1223
00:55:33,700 --> 00:55:29,480
you can actually just mosaic them so and

1224
00:55:36,070 --> 00:55:33,710
one particular CCD devices is quite

1225
00:55:38,530 --> 00:55:36,080
small and can cover only a small portion

1226
00:55:40,180 --> 00:55:38,540
of sky but if you can tile them together

1227
00:55:43,130 --> 00:55:40,190
you can actually get like very wide

1228
00:55:49,260 --> 00:55:47,430
and so firm around so that these were

1229
00:55:52,920 --> 00:55:49,270
these devices were invented sort of in

1230
00:55:54,270 --> 00:55:52,930
them I think in the late 1960s but it

1231
00:55:55,980 --> 00:55:54,280
took quite a while there was a lot of

1232
00:55:57,600 --> 00:55:55,990
early development that needed to happen

1233
00:55:59,340 --> 00:55:57,610
for these to become really useful for

1234
00:56:03,120 --> 00:55:59,350
astronomy but from sort of around the

1235
00:56:05,580 --> 00:56:03,130
1980s see CDs have really been sort of

1236
00:56:12,900 --> 00:56:05,590
the the key technology for imaging in

1237
00:56:14,670 --> 00:56:12,910
visible wavelengths I knew as soon as I

1238
00:56:20,040 --> 00:56:14,680

said it I so I thought I don't know how

1239
00:56:22,350 --> 00:56:20,050
big this is but they can be a few

1240
00:56:27,420 --> 00:56:22,360
centimeters yeah like something like

1241
00:56:31,840 --> 00:56:30,100
what's what's been great as well as that

1242
00:56:33,750 --> 00:56:31,850
theme so a lot of these technologies

1243
00:56:36,850 --> 00:56:33,760
kind of like impact each other as well

1244
00:56:39,280 --> 00:56:36,860
so see CDs have been really critical for

1245
00:56:44,920 --> 00:56:39,290
other types of technological advances

1246
00:56:47,410 --> 00:56:44,930
for manufacturing mirrors for example by

1247
00:56:49,360 --> 00:56:47,420
being able to do electronic imaging we

1248
00:56:51,700 --> 00:56:49,370
were able to develop new measurement

1249
00:56:53,770 --> 00:56:51,710
techniques for optics so to be able to

1250
00:56:55,060 --> 00:56:53,780
actually measure the shapes of mirrors

1251
00:56:58,510 --> 00:56:55,070
better in the lab while we're

1252
00:56:59,860 --> 00:56:58,520
manufacturing them for telescopes so we

1253
00:57:02,620 --> 00:56:59,870
would not be able to build this mirror

1254
00:57:05,910 --> 00:57:02,630
these types of mirrors into that level

1255
00:57:08,560 --> 00:57:05,920
of accuracy without CCD technology

1256
00:57:10,660 --> 00:57:08,570
similarly space astronomy would never

1257
00:57:12,910 --> 00:57:10,670
have been able to flourish to the extent

1258
00:57:15,070 --> 00:57:12,920
that it has without the ability to you

1259
00:57:17,020 --> 00:57:15,080
know record and digitize image record

1260
00:57:18,880 --> 00:57:17,030
images electronically and then digitize

1261
00:57:22,000 --> 00:57:18,890
them so that they could be transmitted

1262
00:57:23,560 --> 00:57:22,010
back to earth and the final technology

1263
00:57:26,410 --> 00:57:23,570

that I'm going to talk about for

1264
00:57:31,930 --> 00:57:26,420
adaptive optics also relies very heavily

1265
00:57:37,040 --> 00:57:35,540
so in the future to kind of highlight

1266
00:57:41,000 --> 00:57:37,050
what's happening with this in the future

1267
00:57:44,210 --> 00:57:41,010
I put an image here of this future

1268
00:57:46,100 --> 00:57:44,220
telescope called the LSST the large

1269
00:57:48,080 --> 00:57:46,110
synoptic survey telescope which is

1270
00:57:52,960 --> 00:57:48,090
basically the biggest digital camera

1271
00:57:57,170 --> 00:57:52,970
that's ever built you can see here the

1272
00:57:59,270 --> 00:57:57,180
what the CCD focal plane looks like for

1273
00:58:00,920 --> 00:57:59,280
this camera so you see here the full

1274
00:58:04,090 --> 00:58:00,930
moon this is the actual size of the full

1275
00:58:08,060 --> 00:58:04,100
moon just for scale then this whole

1276
00:58:10,190 --> 00:58:08,070
mosaic of CCDs has 3.2 billion pixels

1277
00:58:12,800 --> 00:58:10,200
and it covers three and a half square

1278
00:58:14,150 --> 00:58:12,810
degrees field of view so again compare

1279
00:58:17,450 --> 00:58:14,160
that to the you know the size of the

1280
00:58:21,470 --> 00:58:17,460
full moon and it's a mosaic of 189

1281
00:58:23,870 --> 00:58:21,480
individual CCD sensors and this whole

1282
00:58:26,000 --> 00:58:23,880
camera that this is kind of at the heart

1283
00:58:28,880 --> 00:58:26,010
of is like the size of a small car it

1284
00:58:31,460 --> 00:58:28,890
weighs over 6,000 pounds and so this

1285
00:58:34,250 --> 00:58:31,470
telescope is going to absolutely blow

1286
00:58:36,020 --> 00:58:34,260
every other survey out of the water when

1287
00:58:38,660 --> 00:58:36,030
it comes into operation in a few years

1288
00:58:41,660 --> 00:58:38,670

time it's currently under construction

1289
00:58:43,580 --> 00:58:41,670
in Chile and it's going to be able to

1290
00:58:47,990 --> 00:58:43,590
map the sky with that field of view

1291
00:58:49,160 --> 00:58:48,000
whether with at a huge speed so that

1292
00:58:50,720 --> 00:58:49,170
it's going to be able to repeat

1293
00:58:53,750 --> 00:58:50,730
measurements very quickly and measure

1294
00:58:55,160 --> 00:58:53,760
and find things that change I think the

1295
00:58:58,420 --> 00:58:55,170
estimate is that it will discover

1296
00:59:06,650 --> 00:58:58,430
several million supernovae every night

1297
00:59:08,480 --> 00:59:06,660
yeah okay telescopes in space I'm not

1298
00:59:11,930 --> 00:59:08,490
going to talk about this for too long

1299
00:59:13,580 --> 00:59:11,940
but I couldn't really give this talk

1300
00:59:15,920 --> 00:59:13,590
here without talking about telescopes

1301
00:59:18,620 --> 00:59:15,930
going into space this has obviously been

1302
00:59:22,640 --> 00:59:18,630
one of the biggest transformations in

1303
00:59:25,460 --> 00:59:22,650
modern astronomy so why do we want our

1304
00:59:28,670 --> 00:59:25,470
telescopes to go to space well the

1305
00:59:30,760 --> 00:59:28,680
Earth's atmosphere is great for us life

1306
00:59:33,170 --> 00:59:30,770
would as we know it would not be

1307
00:59:35,390 --> 00:59:33,180
sustainable on earth without the

1308
00:59:37,580 --> 00:59:35,400
atmosphere protecting us from harmful

1309
00:59:40,310 --> 00:59:37,590
radiation the kind of maintaining of

1310
00:59:43,010 --> 00:59:40,320
thermal balance kind of balancing out

1311
00:59:44,810 --> 00:59:43,020
the energy that we get from the Sun but

1312
00:59:47,300 --> 00:59:44,820
it's terrible for astronomy and

1313
00:59:49,970 --> 00:59:47,310

this is I think that the thing that

1314
00:59:51,710 --> 00:59:49,980
unifies modern astronomers to those from

1315
00:59:53,420 --> 00:59:51,720
you know 10,000 years ago is that we

1316
00:59:56,900 --> 00:59:53,430
just complain about the weather all the

1317
00:59:58,490 --> 00:59:56,910
time about the clouds this is a very

1318
01:00:00,200 --> 00:59:58,500
kind of crude little sketch of what

1319
01:00:02,780 --> 01:00:00,210
happens when starlight comes through the

1320
01:00:06,910 --> 01:00:02,790
atmosphere the atmosphere is basically

1321
01:00:08,840 --> 01:00:06,920
this layer of thick churning gas

1322
01:00:11,930 --> 01:00:08,850
starlighter's and that pequeños is

1323
01:00:13,630 --> 01:00:11,940
traveling through space and basically

1324
01:00:15,650 --> 01:00:13,640
doesn't really encounter many obstacles

1325
01:00:18,680 --> 01:00:15,660
but then when it hits the atmosphere

1326
01:00:20,930 --> 01:00:18,690
which is this kind of like just gassy

1327
01:00:23,900 --> 01:00:20,940
mess that's you know constantly turning

1328
01:00:25,730 --> 01:00:23,910
constantly changing the light kind of

1329
01:00:27,440 --> 01:00:25,740
gets distorted and then it creates this

1330
01:00:29,870 --> 01:00:27,450
kind of instead of a nice image it

1331
01:00:32,630 --> 01:00:29,880
creates this fuzzy blob and this is

1332
01:00:36,200 --> 01:00:32,640
actually a recording of what you know

1333
01:00:38,600 --> 01:00:36,210
the image of a star looks like you know

1334
01:00:41,330 --> 01:00:38,610
as you you know on a on a CCD chip as

1335
01:00:43,520 --> 01:00:41,340
you see it through the atmosphere so

1336
01:00:47,090 --> 01:00:43,530
instead of like a nice point source like

1337
01:00:48,650 --> 01:00:47,100
a nice point light image you see this

1338
01:00:50,480 --> 01:00:48,660

fuzzy mess here of all these like

1339
01:00:53,410 --> 01:00:50,490
different speckles that are constantly

1340
01:00:55,640 --> 01:00:53,420
moving around and changing in brightness

1341
01:00:57,230 --> 01:00:55,650
so that's kind of what happens when you

1342
01:00:59,720 --> 01:00:57,240
observe you know when you take an image

1343
01:01:02,000 --> 01:00:59,730
of a star through the atmosphere as you

1344
01:01:03,320 --> 01:01:02,010
expose this over time it will just kind

1345
01:01:05,930 --> 01:01:03,330
of build up and it would just be this

1346
01:01:11,300 --> 01:01:05,940
big blurry mess so even the best

1347
01:01:13,010 --> 01:01:11,310
telescopes don't don't ever get to

1348
01:01:15,110 --> 01:01:13,020
achieve what they're theoretically

1349
01:01:17,630 --> 01:01:15,120
capable of because the quality of the

1350
01:01:21,500 --> 01:01:17,640
images is limited by what the atmosphere

1351
01:01:23,270 --> 01:01:21,510
does to them what's more is that some

1352
01:01:25,760 --> 01:01:23,280
light doesn't even get through the

1353
01:01:28,160 --> 01:01:25,770
atmosphere so there's huge parts of this

1354
01:01:30,350 --> 01:01:28,170
electromagnetic spectrum that is

1355
01:01:32,980 --> 01:01:30,360
actually absorbed when the radiation is

1356
01:01:35,630 --> 01:01:32,990
absorbed by molecules in the atmosphere

1357
01:01:38,870 --> 01:01:35,640
we I've just been talking here about

1358
01:01:40,760 --> 01:01:38,880
this visible near infrared portion of

1359
01:01:43,340 --> 01:01:40,770
the spectrum but you see here in the

1360
01:01:45,740 --> 01:01:43,350
infrareds there this is basically this

1361
01:01:48,380 --> 01:01:45,750
is 100% means this the light is

1362
01:01:51,320 --> 01:01:48,390
completely blocked zero is everything

1363
01:01:54,500 --> 01:01:51,330

gets true so you see here in the

1364
01:01:56,210 --> 01:01:54,510
infrared if we want to observe at

1365
01:01:57,529 --> 01:01:56,220
infrared wavelengths from the ground we

1366
01:01:59,539 --> 01:01:57,539
have to do it in these window

1367
01:02:02,779 --> 01:01:59,549
where the atmosphere is actually letting

1368
01:02:04,699 --> 01:02:02,789
it through if we want to be able to

1369
01:02:06,979 --> 01:02:04,709
observe really continuously over this

1370
01:02:11,419 --> 01:02:06,989
whole kind of range we have to go into

1371
01:02:16,009 --> 01:02:11,429
space so the history of space astronomy

1372
01:02:17,899 --> 01:02:16,019
in the space space program in general is

1373
01:02:20,659 --> 01:02:17,909
is obviously a huge subject and has an

1374
01:02:23,899 --> 01:02:20,669
incredibly rich history that I wasn't

1375
01:02:25,519 --> 01:02:23,909
who wasn't really able to do justice but

1376
01:02:27,969 --> 01:02:25,529
just um you know the Hubble Space

1377
01:02:30,889 --> 01:02:27,979
Telescope is the first kind of major

1378
01:02:32,839 --> 01:02:30,899
Observatory that was launched into space

1379
01:02:35,929 --> 01:02:32,849
and has had you know a huge

1380
01:02:38,870 --> 01:02:35,939
transformative impact on astronomy but

1381
01:02:40,399 --> 01:02:38,880
also kind of beyond I think so I just

1382
01:02:43,069 --> 01:02:40,409
wanted to highlight two people who were

1383
01:02:48,789 --> 01:02:43,079
like really seminal in the the Hubble

1384
01:02:51,679 --> 01:02:48,799
Space Telescope coming to being and by

1385
01:02:53,839 --> 01:02:51,689
and as a consequence also like all other

1386
01:02:57,649 --> 01:02:53,849
space telescopes we have a huge range of

1387
01:02:59,479 --> 01:02:57,659
space telescopes in operation today

1388
01:03:01,069 --> 01:02:59,489

the first is Lyman Spitzer who was

1389
01:03:03,199 --> 01:03:01,079
actually the first person to really

1390
01:03:06,409 --> 01:03:03,209
reform early report on the potential of

1391
01:03:08,839 --> 01:03:06,419
a large space-based observatory really

1392
01:03:11,499 --> 01:03:08,849
far back already and this is eventually

1393
01:03:13,849 --> 01:03:11,509
what became the Hubble Space Telescope

1394
01:03:17,749 --> 01:03:13,859
the second person I kind of wanted to

1395
01:03:19,549 --> 01:03:17,759
highlight was Nancy Roman who worked for

1396
01:03:22,489 --> 01:03:19,559
NASA and who played a really critical

1397
01:03:24,379 --> 01:03:22,499
role in kind of rallying the

1398
01:03:26,359 --> 01:03:24,389
astronomical community and organizing

1399
01:03:28,039 --> 01:03:26,369
the astronomical community to maximum

1400
01:03:31,399 --> 01:03:28,049
impact to really kind of be able to

1401
01:03:36,859 --> 01:03:31,409
advocate for this project and to kind of

1402
01:03:39,109 --> 01:03:36,869
make it into reality and so yeah the

1403
01:03:43,159 --> 01:03:39,119
impact of Hubble and of its its fellow

1404
01:03:46,039 --> 01:03:43,169
space telescopes has been completely you

1405
01:03:47,509 --> 01:03:46,049
know transformative as I said this image

1406
01:03:51,289 --> 01:03:47,519
alone which is the Hubble Ultra Deep

1407
01:03:53,629 --> 01:03:51,299
Field kind of has you know completely

1408
01:03:55,879 --> 01:03:53,639
changed astronomy and that's it showed

1409
01:03:57,829 --> 01:03:55,889
so this is the Ultra Deep Field which is

1410
01:04:00,919 --> 01:03:57,839
not the very first generation of this

1411
01:04:07,479 --> 01:04:00,929
image but the very first Hubble Deep

1412
01:04:09,319 --> 01:04:07,489
Field showed so many more galaxies than

1413
01:04:11,029 --> 01:04:09,329

anyone had expected

1414
01:04:15,289 --> 01:04:11,039
really and in so many more different

1415
01:04:17,180 --> 01:04:15,299
shapes and sizes and colors that it kind

1416
01:04:18,709 --> 01:04:17,190
of creates that the whole almost

1417
01:04:21,469 --> 01:04:18,719
instantly created a whole new field of

1418
01:04:22,789 --> 01:04:21,479
galaxy evolution studies and an high

1419
01:04:24,680 --> 01:04:22,799
redshift you know high redshift

1420
01:04:27,019 --> 01:04:24,690
astronomy really being able to study the

1421
01:04:30,199 --> 01:04:27,029
early universe and that was really the

1422
01:04:33,589 --> 01:04:30,209
the Hubble being above the Earth's

1423
01:04:35,449 --> 01:04:33,599
atmosphere not you know being able to

1424
01:04:37,839 --> 01:04:35,459
produce these incredibly sharp images

1425
01:04:41,299 --> 01:04:37,849
even though it's not a huge telescope

1426
01:04:43,519 --> 01:04:41,309
and and having this incredibly kind of

1427
01:04:47,059 --> 01:04:43,529
stable observing environment is really

1428
01:04:49,279 --> 01:04:47,069
what enabled this type of science but

1429
01:04:51,680 --> 01:04:49,289
again it's also good to highlight that

1430
01:04:53,449 --> 01:04:51,690
space astronomy relied on lots of

1431
01:04:55,190 --> 01:04:53,459
several of the other technologies that

1432
01:04:57,440 --> 01:04:55,200
I'm talking about like advances in

1433
01:05:03,109 --> 01:04:57,450
electronic imaging and being able to

1434
01:05:07,609 --> 01:05:03,119
manufacture good quality and lightweight

1435
01:05:10,370 --> 01:05:07,619
mirrors as well again in space astronomy

1436
01:05:15,559 --> 01:05:10,380
this is incredibly condensed down of

1437
01:05:17,239 --> 01:05:15,569
obviously like the overview of space

1438
01:05:19,339 --> 01:05:17,249

astronomy but just here are just some

1439
01:05:21,199 --> 01:05:19,349
cool missions as you know we have the

1440
01:05:24,049 --> 01:05:21,209
James Webb Space Telescope launching it

1441
01:05:26,959 --> 01:05:24,059
a couple of years time and hopefully a

1442
01:05:28,609 --> 01:05:26,969
few years after that there's double your

1443
01:05:30,339 --> 01:05:28,619
first mission as well which people here

1444
01:05:32,900 --> 01:05:30,349
in the building are working very hard on

1445
01:05:35,650 --> 01:05:32,910
and as I work for Lisa I wanted to also

1446
01:05:38,539 --> 01:05:35,660
highlight our next ESO launch which is a

1447
01:05:41,150 --> 01:05:38,549
mission called ke ops which is going to

1448
01:05:45,680 --> 01:05:41,160
study exoplanets and which is actually

1449
01:05:48,000 --> 01:05:45,690
launching later this year the final

1450
01:05:51,030 --> 01:05:48,010
piece of technology

1451
01:05:53,910 --> 01:05:51,040
what to talk about was what we've

1452
01:05:57,510 --> 01:05:53,920
developed to overcome the atmosphere so

1453
01:05:59,190 --> 01:05:57,520
I just mentioned before that's the

1454
01:06:02,339 --> 01:05:59,200
Earth's atmosphere is this barrier that

1455
01:06:04,790 --> 01:06:02,349
we just can't that the introduces a lot

1456
01:06:07,560 --> 01:06:04,800
of problems into astronomical images

1457
01:06:12,150 --> 01:06:07,570
that we can't circumvent well actually

1458
01:06:14,250 --> 01:06:12,160
we can so this is again a kind of a very

1459
01:06:16,319 --> 01:06:14,260
quite a recent technology this is

1460
01:06:19,560 --> 01:06:16,329
actually what I did my PhD in so I have

1461
01:06:21,980 --> 01:06:19,570
a very big soft spot for this for what

1462
01:06:24,750 --> 01:06:21,990
I'm showing in the next few slides just

1463
01:06:27,510 --> 01:06:24,760

repeat that this one here just to remind

1464
01:06:30,000 --> 01:06:27,520
you you know that's atmosphere terrible

1465
01:06:34,579 --> 01:06:30,010
for astronomy so that's what you've what

1466
01:06:38,190 --> 01:06:34,589
we're dealing with so in the 1990s

1467
01:06:41,819 --> 01:06:38,200
largely a going way back before that

1468
01:06:46,710 --> 01:06:41,829
already this is a technology that was

1469
01:06:51,620 --> 01:06:46,720
developed in the military basically here

1470
01:06:55,829 --> 01:06:51,630
in the United States so there was in the

1471
01:06:58,650 --> 01:06:55,839
70s I think mostly 70s 80s there was

1472
01:07:03,059 --> 01:06:58,660
huge interest in being able to take

1473
01:07:05,760 --> 01:07:03,069
images of Soviet satellites from the

1474
01:07:08,099 --> 01:07:05,770
ground to be able to see you know what

1475
01:07:09,540 --> 01:07:08,109
they were doing and everything and but

1476
01:07:11,160 --> 01:07:09,550
they but you're trying to do the same

1477
01:07:13,380 --> 01:07:11,170
thing just in the other direction you

1478
01:07:16,710 --> 01:07:13,390
know they were trying to take images of

1479
01:07:18,210 --> 01:07:16,720
satellites up there but again you were

1480
01:07:20,160 --> 01:07:18,220
going they were trying to take images

1481
01:07:22,500 --> 01:07:20,170
through the atmosphere which would be

1482
01:07:24,030 --> 01:07:22,510
very distorted and couldn't see them at

1483
01:07:27,120 --> 01:07:24,040
the level of detail that there and they

1484
01:07:28,800 --> 01:07:27,130
wanted to see so this whole kind of

1485
01:07:31,050 --> 01:07:28,810
array of technologies was developed

1486
01:07:34,770 --> 01:07:31,060
which we collectively call adaptive

1487
01:07:37,020 --> 01:07:34,780
optics which is where you correct for

1488
01:07:39,359 --> 01:07:37,030

the effects of this Astra

1489
01:07:44,020 --> 01:07:39,369
excuse me atmospheric turbulence in real

1490
01:07:53,560 --> 01:07:47,470
so there are three steps to this process

1491
01:08:02,690 --> 01:07:58,910
there is a sensing step so nope here the

1492
01:08:04,970 --> 01:08:02,700
light comes in bounces off a mirror and

1493
01:08:07,460 --> 01:08:04,980
then at this point this is the scien

1494
01:08:09,380 --> 01:08:07,470
this is a scientist but you split the

1495
01:08:10,670 --> 01:08:09,390
part of the lightest split off towards a

1496
01:08:14,180 --> 01:08:10,680
measurement device which we call a

1497
01:08:16,519 --> 01:08:14,190
wavefront sensor and at this

1498
01:08:18,820 --> 01:08:16,529
measurements that the effects of the

1499
01:08:23,660 --> 01:08:18,830
atmospheric turbulence are characterized

1500
01:08:26,660 --> 01:08:23,670
and then a correction there's basically

1501
01:08:28,640 --> 01:08:26,670
a computation that then calculates how

1502
01:08:31,249 --> 01:08:28,650
to correct for that turbulence at that

1503
01:08:33,829 --> 01:08:31,259
moment and then the commands are sent to

1504
01:08:36,200 --> 01:08:33,839
an optic optic here which is basically a

1505
01:08:38,420 --> 01:08:36,210
bendy mirror so these are small mirrors

1506
01:08:41,539 --> 01:08:38,430
a bit about the size of in original

1507
01:08:43,780 --> 01:08:41,549
systems about this size and have

1508
01:08:46,579 --> 01:08:43,790
actuators mounted on the back of them

1509
01:08:49,519 --> 01:08:46,589
that can respond very very quickly and

1510
01:08:52,099 --> 01:08:49,529
so that this mirror can be shaped in the

1511
01:08:53,840 --> 01:08:52,109
shape that's required exactly to cancel

1512
01:08:55,820 --> 01:08:53,850
out the distortions of the light that's

1513
01:08:58,370 --> 01:08:55,830

coming in to kind of push it back into

1514
01:08:59,990 --> 01:08:58,380
the right shape now the big challenge is

1515
01:09:01,300 --> 01:09:00,000
in so this n forms is sort of

1516
01:09:04,519 --> 01:09:01,310
closed-loop system

1517
01:09:06,650 --> 01:09:04,529
way of constantly measuring constantly

1518
01:09:09,349 --> 01:09:06,660
correcting and sort of to try and

1519
01:09:11,720 --> 01:09:09,359
basically keep the image nice and sharp

1520
01:09:14,360 --> 01:09:11,730
it's still now the problem is is that

1521
01:09:17,090 --> 01:09:14,370
the turbulence in the atmosphere changes

1522
01:09:19,910 --> 01:09:17,100
on timescales of milliseconds so this

1523
01:09:21,740 --> 01:09:19,920
whole loop has to be performed in that

1524
01:09:24,980 --> 01:09:21,750
hundreds of times if not a thousand

1525
01:09:26,660 --> 01:09:24,990
times per second so you can see how this

1526
01:09:31,490 --> 01:09:26,670
could be you know incredibly challenging

1527
01:09:35,570 --> 01:09:31,500
and but you know we the a lot of the the

1528
01:09:37,360 --> 01:09:35,580
basic kind of technological developments

1529
01:09:39,980 --> 01:09:37,370
were done in the military here in the US

1530
01:09:41,329 --> 01:09:39,990
and these results but in parallel there

1531
01:09:43,610 --> 01:09:41,339
was also a lot of research going on in

1532
01:09:47,420 --> 01:09:43,620
Europe and then I think in the late

1533
01:09:49,400 --> 01:09:47,430
1980s it became clear that well the need

1534
01:09:51,050 --> 01:09:49,410
for this in the military had kind of you

1535
01:09:53,210 --> 01:09:51,060
know because the Cold War was kind of

1536
01:09:55,670 --> 01:09:53,220
coming to an end and this was not such a

1537
01:09:57,090 --> 01:09:55,680
high priority but then there was a big

1538
01:09:59,730 --> 01:09:57,100

push to basically deke

1539
01:10:01,980 --> 01:09:59,740
classify all these results and so that

1540
01:10:04,650 --> 01:10:01,990
the astronomical community could benefit

1541
01:10:09,030 --> 01:10:04,660
because the the benefits to astronomy

1542
01:10:10,980 --> 01:10:09,040
were very clear from the start and also

1543
01:10:12,780 --> 01:10:10,990
there were scientists have France who

1544
01:10:14,610 --> 01:10:12,790
were kind of doing research very similar

1545
01:10:16,290 --> 01:10:14,620
research in the same area so they kind

1546
01:10:17,700 --> 01:10:16,300
of realized like we should just be we

1547
01:10:21,350 --> 01:10:17,710
should really just be collaborating on

1548
01:10:25,170 --> 01:10:21,360
this and so this technology has been

1549
01:10:29,730 --> 01:10:25,180
implemented on large telescopes since

1550
01:10:31,230 --> 01:10:29,740
too early since the 90s yeah here you

1551
01:10:33,390 --> 01:10:31,240
can actually see so while I've been

1552
01:10:36,060 --> 01:10:33,400
talking here you can actually see here

1553
01:10:39,300 --> 01:10:36,070
and the effect of switching on the

1554
01:10:41,250 --> 01:10:39,310
adaptive optics system so this is an

1555
01:10:42,570 --> 01:10:41,260
image of a very dense star field towards

1556
01:10:45,720 --> 01:10:42,580
the center of our galaxy in the

1557
01:10:48,450 --> 01:10:45,730
near-infrared and you can see without

1558
01:10:51,000 --> 01:10:48,460
adaptive optics these stars are all very

1559
01:10:54,420 --> 01:10:51,010
blurry and as when you switch the system

1560
01:10:58,650 --> 01:10:54,430
on it takes a while for the system to

1561
01:11:01,440 --> 01:10:58,660
really you know to start working but

1562
01:11:03,270 --> 01:11:01,450
then you can see the improvement in the

1563
01:11:05,430 --> 01:11:03,280

image quality is just amazing and you

1564
01:11:07,170 --> 01:11:05,440
can pick out lots move lots more detail

1565
01:11:10,379 --> 01:11:07,180
lots of small little faint stars that

1566
01:11:12,990 --> 01:11:10,389
were previously just sort of blurred out

1567
01:11:14,939 --> 01:11:13,000
so this has been quite the ground-based

1568
01:11:16,740 --> 01:11:14,949
astronomy has really kind of blown new

1569
01:11:18,689 --> 01:11:16,750
life into ground-based telescopes

1570
01:11:22,020 --> 01:11:18,699
because suddenly this really fundamental

1571
01:11:23,580 --> 01:11:22,030
thing that was causing problems can

1572
01:11:27,479 --> 01:11:23,590
actually now be fixed and so this has

1573
01:11:33,600 --> 01:11:27,489
been a huge area of research really cool

1574
01:11:36,359 --> 01:11:33,610
aspect of adaptive optics is if if you

1575
01:11:38,729 --> 01:11:36,369
don't want to lose light if you use your

1576
01:11:40,709 --> 01:11:38,739
actual science target to perform the

1577
01:11:42,750 --> 01:11:40,719
measurement that's needed to make the

1578
01:11:43,979 --> 01:11:42,760
correction you're kind of losing some of

1579
01:11:47,370 --> 01:11:43,989
your lights because you're having to

1580
01:11:50,399 --> 01:11:47,380
channel it to a different system so the

1581
01:11:54,899 --> 01:11:50,409
way to avoid having to do that is to

1582
01:11:58,229 --> 01:11:54,909
create an artificial star in the sky so

1583
01:11:59,959 --> 01:11:58,239
if say for example you're observing

1584
01:12:02,189 --> 01:11:59,969
something here you can actually kind of

1585
01:12:04,290 --> 01:12:02,199
create an art using a very powerful

1586
01:12:06,540 --> 01:12:04,300
laser you can actually create artificial

1587
01:12:09,720 --> 01:12:06,550
stars so these are very powerful lasers

1588
01:12:11,850 --> 01:12:09,730

that shoot up high into the atmosphere

1589
01:12:19,080 --> 01:12:11,860
and at about 90 kilometers of altitude

1590
01:12:21,090 --> 01:12:19,090
they they cause sodium atoms to to kind

1591
01:12:23,550 --> 01:12:21,100
of jiggle they excite sodium atoms high

1592
01:12:26,850 --> 01:12:23,560
up in the atmosphere which which which

1593
01:12:29,070 --> 01:12:26,860
emits light so they basically create a

1594
01:12:30,870 --> 01:12:29,080
little artificial star and you know you

1595
01:12:33,300 --> 01:12:30,880
can with these lasers you can you could

1596
01:12:35,550 --> 01:12:33,310
put the artificial star wherever you

1597
01:12:38,280 --> 01:12:35,560
know wherever you need it close to where

1598
01:12:39,629 --> 01:12:38,290
you're observing and so now again this

1599
01:12:42,390 --> 01:12:39,639
is something that's very commonly used

1600
01:12:44,609 --> 01:12:42,400
and it allows the correction from the

1601
01:12:46,379 --> 01:12:44,619
adaptive optics systems to be better or

1602
01:12:49,859 --> 01:12:46,389
to perform it over a larger field of

1603
01:12:51,629 --> 01:12:49,869
view and so this is you know this is an

1604
01:12:54,090 --> 01:12:51,639
artist's impression but this is actually

1605
01:12:56,250 --> 01:12:54,100
a real these are real pictures we even

1606
01:12:59,340 --> 01:12:56,260
now are able to use these constellations

1607
01:13:03,399 --> 01:12:59,350
of these laser guide stars to cover a

1608
01:13:10,689 --> 01:13:07,330
this is some these are some first images

1609
01:13:12,490 --> 01:13:10,699
of a system that came into operation a

1610
01:13:15,610 --> 01:13:12,500
couple of years ago three three years

1611
01:13:19,479 --> 01:13:15,620
ago maybe on a telescope in South

1612
01:13:21,430 --> 01:13:19,489
America it shows an object called bien

1613
01:13:24,010 --> 01:13:21,440

que el which is an explosive outflow

1614
01:13:25,660 --> 01:13:24,020
from a very young massive star that's

1615
01:13:28,720 --> 01:13:25,670
forming in the Orion star forming

1616
01:13:30,640 --> 01:13:28,730
complex so these are kind of Hubble

1617
01:13:32,709 --> 01:13:30,650
quality images but these were taken from

1618
01:13:34,990 --> 01:13:32,719
the ground with one of these advanced

1619
01:13:37,450 --> 01:13:35,000
new adaptive optics systems that provide

1620
01:13:41,080 --> 01:13:37,460
this constant correction for the effects

1621
01:13:42,879 --> 01:13:41,090
of turbulence so you can see and this is

1622
01:13:44,260 --> 01:13:42,889
over a fairly large field of view as

1623
01:13:46,990 --> 01:13:44,270
well so you can see like the real

1624
01:13:49,000 --> 01:13:47,000
amazing detail in all these explosion

1625
01:13:52,000 --> 01:13:49,010
fingers that kind of shooting out from

1626
01:13:55,629 --> 01:13:52,010
this central object so that's like you

1627
01:13:58,090 --> 01:13:55,639
know when I was when I was doing my my

1628
01:14:00,250 --> 01:13:58,100
PhD research this was all very much

1629
01:14:04,510 --> 01:14:00,260
still in its infancy so for me these are

1630
01:14:05,860 --> 01:14:04,520
kind of incredible to see so to

1631
01:14:07,419 --> 01:14:05,870
summarize this adaptive optics

1632
01:14:09,689 --> 01:14:07,429
technology has kind of really breathed

1633
01:14:12,879 --> 01:14:09,699
new life into ground-based technologies

1634
01:14:14,410 --> 01:14:12,889
into ground-based telescopes and it's

1635
01:14:16,330 --> 01:14:14,420
kind of paved the way for the next

1636
01:14:19,419 --> 01:14:16,340
generation of big ground-based

1637
01:14:20,649 --> 01:14:19,429
telescopes in the future which can now

1638
01:14:22,240 --> 01:14:20,659

kind of really reach their full

1639
01:14:24,310 --> 01:14:22,250
potential by being able to apply these

1640
01:14:26,290 --> 01:14:24,320
corrections it's a very

1641
01:14:29,560 --> 01:14:26,300
multidisciplinary technology it's a

1642
01:14:31,899 --> 01:14:29,570
combination of optics electronics very

1643
01:14:34,540 --> 01:14:31,909
fast signal processing and powerful

1644
01:14:35,680 --> 01:14:34,550
laser technology and really interesting

1645
01:14:37,540 --> 01:14:35,690
as well as this is something that's

1646
01:14:39,430 --> 01:14:37,550
found application and Industry and

1647
01:14:42,550 --> 01:14:39,440
medicine so this type of technology

1648
01:14:44,379 --> 01:14:42,560
adaptive optics is used for a very high

1649
01:14:49,629 --> 01:14:44,389
resolution imaging of the retina for

1650
01:14:51,879 --> 01:14:49,639
example and and a number of other like

1651
01:14:54,550 --> 01:14:51,889
in microscopy certain types of

1652
01:14:59,290 --> 01:14:54,560
microscopy it's used as well to increase

1653
01:15:01,870 --> 01:14:59,300
the resolution of images okay so kind of

1654
01:15:04,720 --> 01:15:01,880
going to just summarize there very some

1655
01:15:06,459 --> 01:15:04,730
very high-level in some regions for me

1656
01:15:08,350 --> 01:15:06,469
technology and innovation are like

1657
01:15:10,330 --> 01:15:08,360
really key to scientific progress and I

1658
01:15:12,250 --> 01:15:10,340
mean oh this is one of my pet subjects

1659
01:15:13,030 --> 01:15:12,260
is that find it really fascinating how

1660
01:15:17,920 --> 01:15:13,040
they kind of into

1661
01:15:19,930 --> 01:15:17,930
play and we have some amazing new giant

1662
01:15:21,610 --> 01:15:19,940
telescopes coming in the future both in

1663
01:15:24,040 --> 01:15:21,620

space and on the grounds that are really

1664
01:15:25,660 --> 01:15:24,050
going to help us with the aid of all

1665
01:15:27,250 --> 01:15:25,670
this advanced technology are going to

1666
01:15:29,830 --> 01:15:27,260
help us answer these really fundamental

1667
01:15:31,630 --> 01:15:29,840
questions about you know nature of dark

1668
01:15:34,750 --> 01:15:31,640
energy and the formation and evolution

1669
01:15:37,890 --> 01:15:34,760
of galaxies and you know life in the

1670
01:15:53,959 --> 01:15:37,900
universe so thank you very much

1671
01:16:24,209 --> 01:16:18,689
all right we have our speaker see see if

1672
01:16:26,759 --> 01:16:24,219
the projections from the double slit

1673
01:16:29,160 --> 01:16:26,769
experiment are correct that importance

1674
01:16:42,229 --> 01:16:29,170
exists in two places at the same time

1675
01:16:55,500 --> 01:16:49,680
I assume the optics but you got it

1676
01:16:56,489 --> 01:16:55,510
the mass-produced telescope actually I'm

1677
01:17:00,000 --> 01:16:56,499
gonna answer that one first because

1678
01:17:01,589 --> 01:17:00,010
that's easier okay yeah that is actually

1679
01:17:04,919 --> 01:17:01,599
a really big growth area now I think

1680
01:17:07,169 --> 01:17:04,929
there are there are now beginning to be

1681
01:17:10,500 --> 01:17:07,179
some commercial off-the-shelf systems

1682
01:17:13,200 --> 01:17:10,510
that provide some simple advanced optics

1683
01:17:14,939 --> 01:17:13,210
direction not like super advanced but

1684
01:17:17,040 --> 01:17:14,949
and I think you probably need like a

1685
01:17:19,520 --> 01:17:17,050
pretty you know don't think these are

1686
01:17:22,020 --> 01:17:19,530
maybe not like fully like plug-and-play

1687
01:17:23,850 --> 01:17:22,030
but I have heard that this is now they

1688
01:17:28,890 --> 01:17:23,860

are now available to provide some

1689
01:17:37,020 --> 01:17:28,900
correction to improve the images your

1690
01:17:39,540 --> 01:17:37,030
first question about C CDs I think that

1691
01:17:41,729 --> 01:17:39,550
you you you you've hit on something I'm

1692
01:17:44,520 --> 01:17:41,739
not sure - really I mean yeah this it

1693
01:17:48,450 --> 01:17:44,530
really gets into the kind of material

1694
01:17:50,279 --> 01:17:48,460
science of semiconductors I mean yes

1695
01:17:51,720 --> 01:17:50,289
there is always like an uncertainty and

1696
01:17:54,180 --> 01:17:51,730
there are some like weird effects

1697
01:17:59,700 --> 01:17:54,190
sometimes in these food you know these

1698
01:18:01,649 --> 01:17:59,710
materials that we use Percy CDs so there

1699
01:18:05,770 --> 01:18:01,659
is always like some answer

1700
01:18:06,849 --> 01:18:05,780
but yeah I'm not sure I'm answer is that

1701
01:18:12,909 --> 01:18:06,859
does that answer your question a little

1702
01:18:14,529 --> 01:18:12,919
bit a margin of error that you have -

1703
01:18:16,989 --> 01:18:14,539
yeah there were like statistical

1704
01:18:19,259 --> 01:18:16,999
affection and you know there is you know

1705
01:18:23,040 --> 01:18:19,269
the there is sort of quantum nature of

1706
01:18:26,379 --> 01:18:23,050
matter basically that does you know yeah

1707
01:18:30,270 --> 01:18:26,389
there's the probability aspect is in

1708
01:18:34,899 --> 01:18:30,280
there in the responsibility CCD yes

1709
01:18:41,889 --> 01:18:34,909
other questions done there where are we

1710
01:18:44,259 --> 01:18:41,899
grant Oh grant is saying that the

1711
01:18:52,209 --> 01:18:44,269
microphone is not working so to ask your

1712
01:18:53,679 --> 01:18:52,219
question we'll repeat it I'll repeat it

1713
01:19:03,189 --> 01:18:53,689

does adaptive optics have any

1714
01:19:10,959 --> 01:19:03,199
application for Space Telescope's and

1715
01:19:13,029 --> 01:19:10,969
this is in space but there are because

1716
01:19:16,330 --> 01:19:13,039
my PhD was actually sort of a crossover

1717
01:19:18,489 --> 01:19:16,340
between ground in space and so there was

1718
01:19:21,310 --> 01:19:18,499
definitely a kind of application for

1719
01:19:26,199 --> 01:19:21,320
having that ability to live correct

1720
01:19:28,000 --> 01:19:26,209
images in space that's particularly to

1721
01:19:31,149 --> 01:19:28,010
sort of compensate for like thermal

1722
01:19:32,349 --> 01:19:31,159
effects it also it's it reduces you

1723
01:19:34,959 --> 01:19:32,359
don't your mirror doesn't have to be

1724
01:19:36,549 --> 01:19:34,969
fully perfect if you know you can

1725
01:19:38,080 --> 01:19:36,559
actually like nudge it into shape while

1726
01:19:41,169 --> 01:19:38,090
you're observing so in that sense it

1727
01:19:45,279 --> 01:19:41,179
like reduces the risk of it on on the

1728
01:19:47,529 --> 01:19:45,289
optics in space so so there is some

1729
01:19:50,260 --> 01:19:47,539
application for it but it's in a kind of

1730
01:19:54,180 --> 01:19:50,270
slightly different form basically

1731
01:19:57,180 --> 01:19:54,190
hi down front here and this time hold on

1732
01:20:01,660 --> 01:19:57,190
we have the we have the other three now

1733
01:20:06,120 --> 01:20:01,670
how about that question on the James

1734
01:20:10,210 --> 01:20:06,130
Webb how many optical optical

1735
01:20:13,000 --> 01:20:10,220
experiments are onboard how many of yes

1736
01:20:16,480 --> 01:20:13,010
there are full science instruments for

1737
01:20:18,760 --> 01:20:16,490
individual science instruments which

1738
01:20:22,120 --> 01:20:18,770

each but each of these like has a whole

1739
01:20:24,880 --> 01:20:22,130
range of things they could do so the

1740
01:20:28,240 --> 01:20:24,890
instrument I work on for example Mary it

1741
01:20:31,030 --> 01:20:28,250
has a camera on board it has two

1742
01:20:33,640 --> 01:20:31,040
different spectrometers on board and it

1743
01:20:36,190 --> 01:20:33,650
can also do what's called Corona graphic

1744
01:20:38,470 --> 01:20:36,200
imaging so the imaging with the central

1745
01:20:42,280 --> 01:20:38,480
central object locked out so you can see

1746
01:20:44,050 --> 01:20:42,290
faint things around it so there are four

1747
01:20:46,360 --> 01:20:44,060
individual instruments but each of these

1748
01:20:49,210 --> 01:20:46,370
has a number of like different

1749
01:20:51,220 --> 01:20:49,220
functionalities so that they're you know

1750
01:20:53,020 --> 01:20:51,230
for people who want to propose to use it

1751
01:21:00,490 --> 01:20:53,030
they have access to a huge range of

1752
01:21:06,970 --> 01:21:00,500
different capabilities thank you over on

1753
01:21:10,660 --> 01:21:06,980
the left there so I realize it's a lot

1754
01:21:16,379 --> 01:21:10,670
of it's money driven how big could we

1755
01:21:23,350 --> 01:21:21,459
on the grinder in space either or I mean

1756
01:21:31,500 --> 01:21:23,360
seriously I dark side of the moon would

1757
01:21:34,509 --> 01:21:31,510
be awesome very much you talk to and the

1758
01:21:36,669 --> 01:21:34,519
39-metre ground-based telescope I showed

1759
01:21:40,449 --> 01:21:36,679
you the nice artist's conception of that

1760
01:21:42,549 --> 01:21:40,459
was back in the day when I started my

1761
01:21:45,969 --> 01:21:42,559
PhD that was actually a hundred meter

1762
01:21:48,129 --> 01:21:45,979
telescope which but there was already

1763
01:21:49,629 --> 01:21:48,139

then a lot of debate about whether this

1764
01:21:55,310 --> 01:21:49,639
was technically feasible whether we

1765
01:21:59,120 --> 01:21:57,350
again the same questions come up with

1766
01:22:00,980 --> 01:21:59,130
space as well I mean already now we're

1767
01:22:04,850 --> 01:22:00,990
planning the next generation of large

1768
01:22:06,530 --> 01:22:04,860
space observatories that there is

1769
01:22:07,910 --> 01:22:06,540
definitely there are just some things

1770
01:22:10,760 --> 01:22:07,920
that you really just need a bigger

1771
01:22:12,320 --> 01:22:10,770
telescope for that you know a clever

1772
01:22:16,130 --> 01:22:12,330
idea isn't going to help you you really

1773
01:22:18,890 --> 01:22:16,140
need the size but yeah I don't know it's

1774
01:22:20,480 --> 01:22:18,900
very interesting like you say this is

1775
01:22:22,940 --> 01:22:20,490
all very very money driven it's also

1776
01:22:24,410 --> 01:22:22,950
what kind of technical risk you're

1777
01:22:26,420 --> 01:22:24,420
willing to accept and things like that

1778
01:22:27,680 --> 01:22:26,430
right so I mean you said thirty nine

1779
01:22:29,600 --> 01:22:27,690
meters for the ground I think the

1780
01:22:33,530 --> 01:22:29,610
largest space one I've seen proposed to

1781
01:22:36,950 --> 01:22:33,540
16 meters yeah for the Louvre our

1782
01:22:40,840 --> 01:22:36,960
mission well they wanted to be 16 they

1783
01:22:49,930 --> 01:22:45,640
go ahead I think about 20 years ago

1784
01:22:54,140 --> 01:22:49,940
maybe not quite that long ago I saw a

1785
01:22:57,830 --> 01:22:54,150
photograph I think it was using speckle

1786
01:23:02,450 --> 01:22:57,840
interferometry that showed the disc of

1787
01:23:09,350 --> 01:23:02,460
Betelgeuse with sunspots does anybody

1788
01:23:12,170 --> 01:23:09,360

still doing that based on that technique

1789
01:23:20,770 --> 01:23:12,180
there's actually a lot more a lot of new

1790
01:23:23,090 --> 01:23:20,780
types of into describe but yeah

1791
01:23:25,160 --> 01:23:23,100
techniques observational techniques that

1792
01:23:27,440 --> 01:23:25,170
use that the same principle as I

1793
01:23:30,010 --> 01:23:27,450
expected interferometry to really get

1794
01:23:32,240 --> 01:23:30,020
like incredibly high resolution images I

1795
01:23:34,700 --> 01:23:32,250
actually worked on the one instrument

1796
01:23:37,100 --> 01:23:34,710
which has which has recently produced a

1797
01:23:38,630 --> 01:23:37,110
whole lot of results which combines the

1798
01:23:40,490 --> 01:23:38,640
light from different telescopes and

1799
01:23:42,800 --> 01:23:40,500
interferometry in the near-infrared to

1800
01:23:46,820 --> 01:23:42,810
be able to measure extremely high

1801
01:23:48,350 --> 01:23:46,830
precision positions of objects and so

1802
01:23:50,720 --> 01:23:48,360
with that we've been able to measure

1803
01:23:53,030 --> 01:23:50,730
like take direct spectra of exoplanets

1804
01:23:56,809 --> 01:23:53,040
and things like that as well yes that's

1805
01:23:58,639 --> 01:23:56,819
definitely still alive thank you

1806
01:24:01,309 --> 01:23:58,649
yeah I will comment that we here at

1807
01:24:02,959 --> 01:24:01,319
Hubbell constantly see lots of people

1808
01:24:05,419 --> 01:24:02,969
trying to say oh we've got just as good

1809
01:24:07,549 --> 01:24:05,429
resolution as Hubble whether it's using

1810
01:24:09,889 --> 01:24:07,559
adaptive optics or through speckle

1811
01:24:12,049 --> 01:24:09,899
speckle is very fast observations and

1812
01:24:14,479 --> 01:24:12,059
they and they are correct that for very

1813
01:24:17,149 --> 01:24:14,489

short exposure small small field of view

1814
01:24:18,799 --> 01:24:17,159
type things they can get Hubble exposure

1815
01:24:20,719 --> 01:24:18,809
but they can't get Hubble exposure over

1816
01:24:22,789 --> 01:24:20,729
wide field of view you could never do

1817
01:24:24,649 --> 01:24:22,799
like the Orion Nebula image that we have

1818
01:24:26,989 --> 01:24:24,659
you couldn't do that whole Orion Nebula

1819
01:24:29,119 --> 01:24:26,999
via adaptive optics or via speckle or

1820
01:24:30,919 --> 01:24:29,129
anything like that but we're hoping that

1821
01:24:32,899 --> 01:24:30,929
in the future we can start to do that

1822
01:24:34,669 --> 01:24:32,909
from the ground you know

1823
01:24:36,859 --> 01:24:34,679
astronomers well we'll push that the

1824
01:24:49,509 --> 01:24:36,869
technology forward but every every

1825
01:25:00,919 --> 01:24:58,729
other questions I thought I saw I've

1826
01:25:03,589 --> 01:25:00,929
been listening to all this about how

1827
01:25:12,849 --> 01:25:03,599
heavy these mirrors are have gone back

1828
01:25:14,989 --> 01:25:12,859
to the basic mercury they have

1829
01:25:43,299 --> 01:25:14,999
underground which are supposed to be

1830
01:25:49,879 --> 01:25:48,349
thank you and what's really cool is the

1831
01:25:53,319 --> 01:25:49,889
amount of mercury they need to use

1832
01:25:57,679 --> 01:25:53,329
because they can they they can set the

1833
01:26:00,109 --> 01:25:57,689
the substrate to almost the shape they

1834
01:26:02,149 --> 01:26:00,119
need it's a just a tiny bit of mercury

1835
01:26:04,250 --> 01:26:02,159
that they need but unfortunately it's

1836
01:26:05,839 --> 01:26:04,260
also gonna be a just of telescope

1837
01:26:08,089 --> 01:26:05,849
pointing straight up because you're

1838
01:26:09,840 --> 01:26:08,099

rotating it you know it has to have an

1839
01:26:19,130 --> 01:26:09,850
axis so it's a

1840
01:26:27,000 --> 01:26:23,910
one is I work go out with space

1841
01:26:28,950 --> 01:26:27,010
telescopes imaging the earth and we

1842
01:26:31,980 --> 01:26:28,960
don't have an atmospheric problem there

1843
01:26:36,540 --> 01:26:31,990
in fact the loss of resolution decreases

1844
01:26:38,300 --> 01:26:36,550
with altitude now why do we have the

1845
01:26:43,740 --> 01:26:38,310
problem when we look the other way

1846
01:26:46,140 --> 01:26:43,750
that's my first I think it's an

1847
01:26:48,390 --> 01:26:46,150
intriguing question and I do know the

1848
01:26:51,900 --> 01:26:48,400
answer to how I should say the other

1849
01:26:56,400 --> 01:26:51,910
question is on a segmented mirror how

1850
01:26:58,350 --> 01:26:56,410
close does a segmented mirror come to

1851
01:27:01,560 --> 01:26:58,360
matching the resolution of the

1852
01:27:15,510 --> 01:27:01,570
continuous surface say it 1/2 micron

1853
01:27:17,940 --> 01:27:15,520
wavelength from the continuous mirror

1854
01:27:21,450 --> 01:27:17,950
would be is that you get diffraction

1855
01:27:25,320 --> 01:27:21,460
effects from the edges yeah that that

1856
01:27:29,100 --> 01:27:25,330
will degrade the resolution I mean back

1857
01:27:31,260 --> 01:27:29,110
in the 60s I saw the first segment of

1858
01:27:33,600 --> 01:27:31,270
telescopes and was very negative but

1859
01:27:38,000 --> 01:27:33,610
apparently they're working out but they

1860
01:27:41,130 --> 01:27:38,010
still don't match the continuous surface

1861
01:27:45,030 --> 01:27:41,140
maybe 3 to 5 microns they come close

1862
01:27:46,950 --> 01:27:45,040
right right but yes so the shape of the

1863
01:27:48,660 --> 01:27:46,960

point spread function that you get from

1864
01:27:50,400 --> 01:27:48,670
the segmented mirror telescope is you

1865
01:27:52,230 --> 01:27:50,410
know you'll be able to kind of recognize

1866
01:27:55,530 --> 01:27:52,240
the pattern of the segments in that

1867
01:27:58,590 --> 01:27:55,540
basically and then I think your question

1868
01:28:03,750 --> 01:27:58,600
about the Earth Observation images

1869
01:28:08,110 --> 01:28:06,280
but it's just it's about the geometry of

1870
01:28:09,880 --> 01:28:08,120
the system isn't it if you sort your

1871
01:28:12,430 --> 01:28:09,890
tongue your source that you're imaging

1872
01:28:15,640 --> 01:28:12,440
is out infinity it's different different

1873
01:28:17,740 --> 01:28:15,650
geometry of the the light entering the

1874
01:28:20,140 --> 01:28:17,750
telescope than if you if you're imaging

1875
01:28:22,810 --> 01:28:20,150
something on the ground yeah one more

1876
01:28:24,280 --> 01:28:22,820
real quick comment was it Joseph Goodman

1877
01:28:26,560 --> 01:28:24,290
back in the 60s

1878
01:28:31,390 --> 01:28:26,570
used it Cernik a polynomial with the

1879
01:28:34,290 --> 01:28:31,400
analyze the atmospheric and it turns out

1880
01:28:40,479 --> 01:28:34,300
that the dominant Cernik a polynomial is

1881
01:28:44,890 --> 01:28:40,489
a removing prism shifting the image back

1882
01:28:49,690 --> 01:28:44,900
and forth that agree with what you're

1883
01:28:54,130 --> 01:28:49,700
finding okay we're getting towards 9:30

1884
01:28:56,290 --> 01:28:54,140
which is our usual cut off time from

1885
01:28:57,850 --> 01:28:56,300
Maryland's space grant observatory if

1886
01:28:59,950 --> 01:28:57,860
you want to go across the street to look

1887
01:29:01,650 --> 01:28:59,960
through the telescope please come down

1888
01:29:05,160 --> 01:29:01,660

you're going to meet everybody over here

1889
01:29:08,590 --> 01:29:05,170
next month for December we are having

1890
01:29:10,450 --> 01:29:08,600
red dwarfs and brown dwarfs and let us