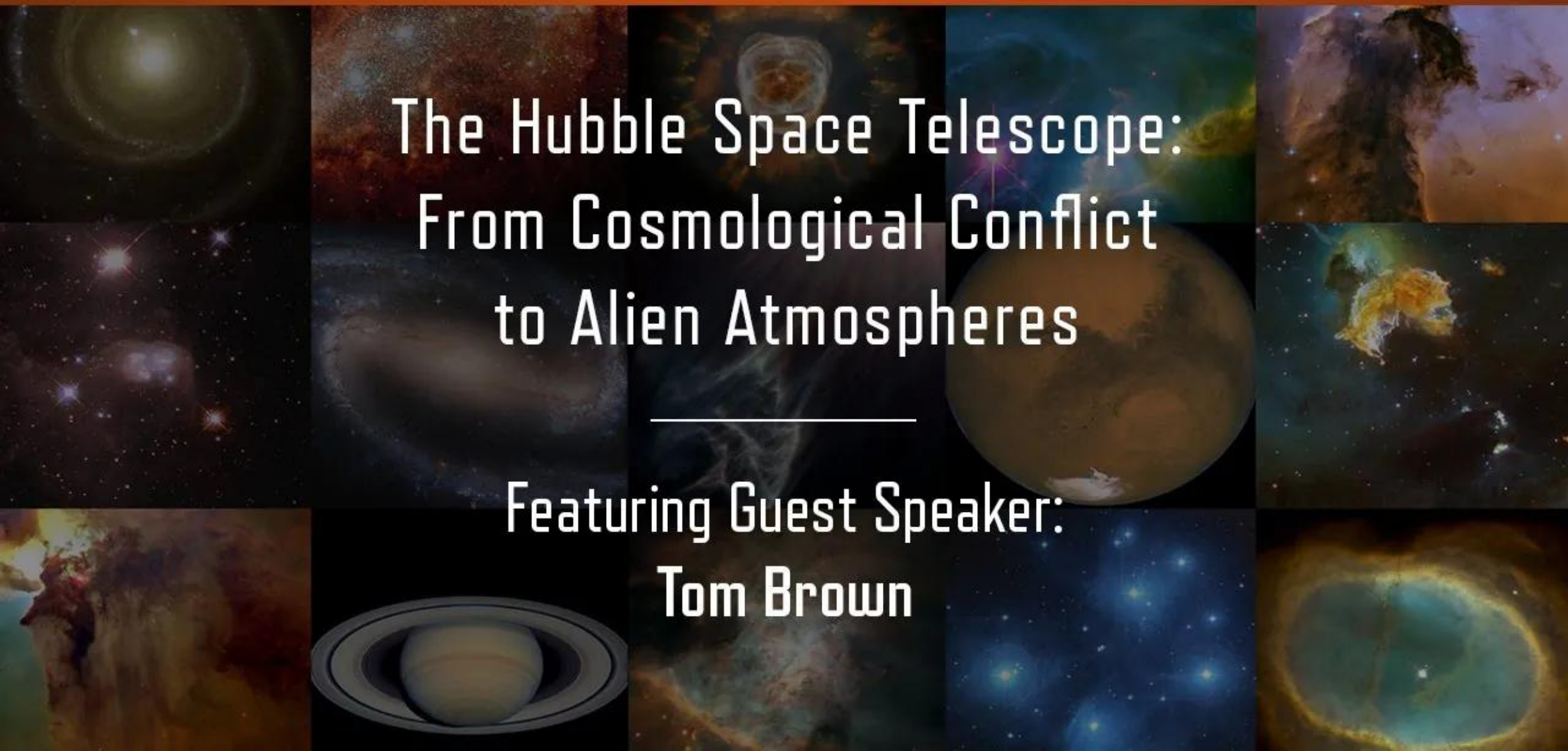
PUBLIC LECTURE SERIES



The Hubble Space Telescope: From Cosmological Conflict to Alien Atmospheres

Featuring Guest Speaker:

Tom Brown

1
00:00:05,510 --> 00:00:03,669
welcome

2
00:00:07,030 --> 00:00:05,520
to the hubble space telescope public

3
00:00:09,830 --> 00:00:07,040
lecture series

4
00:00:11,669 --> 00:00:09,840
today's talk the hubble space telescope

5
00:00:17,670 --> 00:00:11,679
from cosmological conflict

6
00:00:19,349 --> 00:00:17,680
to alien atmospheres by tom brown

7
00:00:21,029 --> 00:00:19,359
we're at the space telescope science

8
00:00:23,349 --> 00:00:21,039
institute and i am dr

9
00:00:25,029 --> 00:00:23,359
frank summers as your host i'd like to

10
00:00:27,589 --> 00:00:25,039
thank our wonderful tech team

11
00:00:29,349 --> 00:00:27,599
thomas marufu and grant justice who help

12
00:00:32,790 --> 00:00:29,359
us bring you this live stream

13
00:00:37,110 --> 00:00:36,229

next month we will have a really special

14
00:00:38,549 --> 00:00:37,120
talk from

15
00:00:40,709 --> 00:00:38,559
christopher our author christopher

16
00:00:41,350 --> 00:00:40,719
wangek who'll be talking about space

17
00:00:44,389 --> 00:00:41,360
fares

18
00:00:45,110 --> 00:00:44,399
how humans will settle the moon mars and

19
00:00:46,950 --> 00:00:45,120
beyond

20
00:00:48,790 --> 00:00:46,960
this is a little different talk for our

21
00:00:50,150 --> 00:00:48,800
series and i know you won't want to miss

22
00:00:53,189 --> 00:00:50,160
that one

23
00:00:55,029 --> 00:00:53,199
in may we have another special talk from

24
00:00:57,910 --> 00:00:55,039
the consonants collective

25
00:00:58,709 --> 00:00:57,920
and the bergamont quartet of the peabody

26
00:01:02,389 --> 00:00:58,719
institute

27
00:01:04,950 --> 00:01:02,399
here in baltimore this is a orchestra

28
00:01:05,590 --> 00:01:04,960
and this is these are music musicians

29
00:01:08,149 --> 00:01:05,600
who have

30
00:01:10,149 --> 00:01:08,159
gonna talk about and play for you

31
00:01:13,429 --> 00:01:10,159
finding the music of the spheres

32
00:01:15,830 --> 00:01:13,439
hearing stars and finally in

33
00:01:17,270 --> 00:01:15,840
june we will have a talk on exoplanets

34
00:01:19,510 --> 00:01:17,280
that's not the final

35
00:01:20,310 --> 00:01:19,520
title uh she promised she would give me

36
00:01:22,950 --> 00:01:20,320
a a

37
00:01:24,830 --> 00:01:22,960
a different title soon by emily rickman

38
00:01:26,310 --> 00:01:24,840

here at the space telescope science

39
00:01:28,230 --> 00:01:26,320
institute

40
00:01:29,670 --> 00:01:28,240
if you'd like to hear learn about it you

41
00:01:34,310 --> 00:01:29,680
can go to our website

42
00:01:37,030 --> 00:01:34,320
just go to www.sdsci.edu

43
00:01:38,789 --> 00:01:37,040
public hyphen lectures and you'll find

44
00:01:42,950 --> 00:01:38,799
this webpage

45
00:01:46,469 --> 00:01:45,910
is uh you can find things about our uh

46
00:01:49,190 --> 00:01:46,479
our

47
00:01:51,190 --> 00:01:49,200
webcasting uh both on the youtube

48
00:01:53,749 --> 00:01:51,200
playlist and the webcast archive from

49
00:01:56,310 --> 00:01:53,759
the space telescope science institute

50
00:01:57,270 --> 00:01:56,320
on the lower right you can see our email

51
00:01:59,510 --> 00:01:57,280
on which you can

52
00:02:00,950 --> 00:01:59,520
enter your email address and subscribe

53
00:02:04,789 --> 00:02:00,960
and get our monthly

54
00:02:05,670 --> 00:02:04,799
our monthly postings also on the website

55
00:02:09,029 --> 00:02:05,680
we have

56
00:02:11,750 --> 00:02:09,039
descriptions of each lecture both in

57
00:02:14,150 --> 00:02:11,760
compact form and if you click on it then

58
00:02:16,710 --> 00:02:14,160
of course you get the full details

59
00:02:17,270 --> 00:02:16,720
along with the title the description as

60
00:02:19,910 --> 00:02:17,280
well as

61
00:02:21,589 --> 00:02:19,920
links to the sdsci webcast and the

62
00:02:24,949 --> 00:02:21,599
youtube version of the webcast

63
00:02:27,510 --> 00:02:24,959

after the after recording

64
00:02:30,070 --> 00:02:27,520
for the email the announcements it's

65
00:02:32,309 --> 00:02:30,080
easiest just to sign up at our website

66
00:02:33,110 --> 00:02:32,319
uh you can also subscribe to our youtube

67
00:02:36,070 --> 00:02:33,120
channel

68
00:02:37,110 --> 00:02:36,080
youtube.com hubble space telescope all

69
00:02:39,030 --> 00:02:37,120
one word

70
00:02:40,790 --> 00:02:39,040
that will give you notices of these live

71
00:02:44,070 --> 00:02:40,800
events as well as

72
00:02:45,750 --> 00:02:44,080
video notices of new videos and finally

73
00:02:46,630 --> 00:02:45,760
if you have comments or questions you

74
00:02:48,830 --> 00:02:46,640
can send them to

75
00:02:51,750 --> 00:02:48,840
the email address public lecture

76
00:02:54,150 --> 00:02:51,760
sdsci.edu

77
00:02:55,589 --> 00:02:54,160
our social media we have social media

78
00:02:57,670 --> 00:02:55,599
for the hubble space telescope

79
00:02:59,990 --> 00:02:57,680
for the james webb space telescope that

80
00:03:02,070 --> 00:03:00,000
launches in october of this year

81
00:03:03,110 --> 00:03:02,080
and for our institute space telescope

82
00:03:05,830 --> 00:03:03,120
science institute

83
00:03:06,869 --> 00:03:05,840
or on facebook twitter youtube and

84
00:03:09,509 --> 00:03:06,879
instagram

85
00:03:10,229 --> 00:03:09,519
as for myself i do a tiny bit of social

86
00:03:14,229 --> 00:03:10,239
media

87
00:03:20,470 --> 00:03:16,710
and now the news from the universe for

88
00:03:24,470 --> 00:03:23,270

our first story for you tonight a comet

89
00:03:27,430 --> 00:03:24,480
amongst the trojan

90
00:03:28,070 --> 00:03:27,440
asteroids now that actually is a lot

91
00:03:30,949 --> 00:03:28,080
more

92
00:03:32,229 --> 00:03:30,959
different uh strange than it may sound

93
00:03:34,470 --> 00:03:32,239
so let me just

94
00:03:35,350 --> 00:03:34,480
break down what we're talking about

95
00:03:38,070 --> 00:03:35,360
first of all

96
00:03:39,509 --> 00:03:38,080
this is a diagram of the inner solar

97
00:03:42,470 --> 00:03:39,519
system okay

98
00:03:44,070 --> 00:03:42,480
and it's out to the orbit of jupiter and

99
00:03:47,110 --> 00:03:44,080
what you can see the main thing

100
00:03:47,430 --> 00:03:47,120
in red is the main asteroid belt there

101
00:03:50,309 --> 00:03:47,440
are

102
00:03:51,110 --> 00:03:50,319
hundreds of thousands 300 400 000

103
00:03:53,270 --> 00:03:51,120
asteroids

104
00:03:55,110 --> 00:03:53,280
in the main asteroid belt and you can

105
00:03:56,149 --> 00:03:55,120
see they stretch mostly from the orbit

106
00:03:58,470 --> 00:03:56,159
of mars

107
00:03:59,990 --> 00:03:58,480
out to the orbit of jupiter and of

108
00:04:02,630 --> 00:04:00,000
course interior to the orbit

109
00:04:04,309 --> 00:04:02,640
of mars are the orbits of venus earth

110
00:04:07,589 --> 00:04:04,319
and mercury

111
00:04:10,149 --> 00:04:07,599
now there's also these blue objects that

112
00:04:12,070 --> 00:04:10,159
are in that in that realm and these are

113
00:04:12,949 --> 00:04:12,080

what were called the mars crossing

114
00:04:14,550 --> 00:04:12,959
asteroids

115
00:04:16,949 --> 00:04:14,560
and they look like they could really

116
00:04:18,629 --> 00:04:16,959
cause havoc to us but really there

117
00:04:20,390 --> 00:04:18,639
aren't that many of them and they're

118
00:04:21,830 --> 00:04:20,400
really really small so they aren't that

119
00:04:24,629 --> 00:04:21,840
much of a threat as it may

120
00:04:26,070 --> 00:04:24,639
appear in this diagram but what i really

121
00:04:28,790 --> 00:04:26,080
want to talk about

122
00:04:30,710 --> 00:04:28,800
are these green blobs in the upper left

123
00:04:32,150 --> 00:04:30,720
and the upper right

124
00:04:33,990 --> 00:04:32,160
these are what's called the trojan

125
00:04:36,150 --> 00:04:34,000
asteroids around jupiter

126
00:04:37,030 --> 00:04:36,160
and i've marked at the top where jupiter

127
00:04:38,790 --> 00:04:37,040
exists

128
00:04:41,189 --> 00:04:38,800
and you'll notice that there's a clump

129
00:04:43,350 --> 00:04:41,199
of asteroids about 60 degrees

130
00:04:45,030 --> 00:04:43,360
in front of jupiter and 60 degrees

131
00:04:47,749 --> 00:04:45,040
behind jupiter

132
00:04:49,110 --> 00:04:47,759
and that's because the gravity of the

133
00:04:51,070 --> 00:04:49,120
sun and jupiter

134
00:04:52,790 --> 00:04:51,080
sort of balance out to create these

135
00:04:55,430 --> 00:04:52,800
semi-stable points

136
00:04:56,070 --> 00:04:55,440
uh 60 degrees in front and 60 degrees

137
00:04:58,710 --> 00:04:56,080
behind

138
00:05:00,629 --> 00:04:58,720

jupiter and the asteroids can sit there

139
00:05:03,749 --> 00:05:00,639
and hang out there

140
00:05:06,710 --> 00:05:03,759
so it was kind of crazy

141
00:05:07,270 --> 00:05:06,720
when hubble took this recent image of a

142
00:05:14,310 --> 00:05:07,280
trojan

143
00:05:15,749 --> 00:05:14,320
2019 ld2

144
00:05:17,270 --> 00:05:15,759
and you may look at that and go wait a

145
00:05:18,230 --> 00:05:17,280
minute that doesn't look like an

146
00:05:21,670 --> 00:05:18,240
asteroid

147
00:05:24,950 --> 00:05:21,680
got a tail

148
00:05:28,629 --> 00:05:24,960
what has tails comets this

149
00:05:31,830 --> 00:05:28,639
isn't an asteroid this is in fact comet

150
00:05:33,909 --> 00:05:31,840
p 2019 ld2

151
00:05:35,350 --> 00:05:33,919
and then you might ask well okay so what

152
00:05:36,950 --> 00:05:35,360
is a comet doing

153
00:05:39,270 --> 00:05:36,960
hanging out in a place where there are

154
00:05:42,070 --> 00:05:39,280
asteroids matter of fact this is the

155
00:05:44,150 --> 00:05:42,080
first comet ever discovered hanging out

156
00:05:46,710 --> 00:05:44,160
in a place where there are asteroids

157
00:05:48,070 --> 00:05:46,720
and to tell you that i gotta go give you

158
00:05:50,870 --> 00:05:48,080
the bigger picture

159
00:05:53,029 --> 00:05:50,880
of the outer solar system so here's a

160
00:05:55,590 --> 00:05:53,039
plot of the outer solar system

161
00:05:57,510 --> 00:05:55,600
and the main feature here is the kuiper

162
00:05:59,830 --> 00:05:57,520
belt all these red and white

163
00:06:01,350 --> 00:05:59,840

objects around the edge outside the

164
00:06:03,510 --> 00:06:01,360
orbit of neptune

165
00:06:04,710 --> 00:06:03,520
that is the kuiper belt now if you

166
00:06:06,309 --> 00:06:04,720
haven't heard of that

167
00:06:08,150 --> 00:06:06,319
this is a region of the solar system

168
00:06:11,189 --> 00:06:08,160
that we only discovered

169
00:06:13,590 --> 00:06:11,199
in the 1990s we know thousands of

170
00:06:14,469 --> 00:06:13,600
objects out in the kuiper belt these are

171
00:06:17,029 --> 00:06:14,479
small

172
00:06:17,749 --> 00:06:17,039
icy bodies out at the edge of the solar

173
00:06:19,830 --> 00:06:17,759
system

174
00:06:22,390 --> 00:06:19,840
and by the way this is the region that

175
00:06:23,510 --> 00:06:22,400
includes pluto this is why pluto is no

176
00:06:25,670 --> 00:06:23,520
longer a planet

177
00:06:26,790 --> 00:06:25,680
because it's actually a member of the

178
00:06:28,710 --> 00:06:26,800
kuiper belt

179
00:06:31,110 --> 00:06:28,720
but let's not get into that because

180
00:06:34,150 --> 00:06:31,120
people can talk your ear off about that

181
00:06:37,670 --> 00:06:34,160
so what happens is the kuiper belt

182
00:06:40,390 --> 00:06:37,680
is repository of these small icy objects

183
00:06:41,590 --> 00:06:40,400
that if they get pulled into the inner

184
00:06:44,790 --> 00:06:41,600
solar system

185
00:06:47,029 --> 00:06:44,800
become comet so they

186
00:06:49,110 --> 00:06:47,039
can have gravitational encounters with

187
00:06:51,670 --> 00:06:49,120
neptune and with saturn

188
00:06:54,070 --> 00:06:51,680

and uranus and jupiter that can bring

189
00:06:56,469 --> 00:06:54,080
them into the inner solar system

190
00:06:57,990 --> 00:06:56,479
and so when they are traversing between

191
00:06:59,990 --> 00:06:58,000
the orbits of neptune

192
00:07:01,189 --> 00:07:00,000
and the orbits of jupiter there's

193
00:07:03,070 --> 00:07:01,199
something known as

194
00:07:05,909 --> 00:07:03,080
centaurs so there's a sort of

195
00:07:09,589 --> 00:07:05,919
gravitational pinball that happens

196
00:07:13,510 --> 00:07:09,599
with these kuiper belt objects so

197
00:07:14,629 --> 00:07:13,520
the significance of seeing comet p-2019

198
00:07:17,909 --> 00:07:14,639
ld2

199
00:07:20,950 --> 00:07:17,919
in the trojan asteroids is that it

200
00:07:23,270 --> 00:07:20,960
is um assuredly a comet that has been

201
00:07:25,430 --> 00:07:23,280
pulled in by this gravitational tug of

202
00:07:27,189 --> 00:07:25,440
war uh sometimes they call it a bucket

203
00:07:28,070 --> 00:07:27,199
brigade as one planet hands it off to

204
00:07:31,110 --> 00:07:28,080
the other planet

205
00:07:33,029 --> 00:07:31,120
and moves it in and it must have had

206
00:07:34,629 --> 00:07:33,039
a close encounter with jupiter

207
00:07:37,909 --> 00:07:34,639
relatively recently

208
00:07:40,309 --> 00:07:37,919
that pulled into a place where it could

209
00:07:42,950 --> 00:07:40,319
be part of the semi-stable pack

210
00:07:44,710 --> 00:07:42,960
at the trojan asteroids but it doesn't

211
00:07:45,110 --> 00:07:44,720
really fit in with the trojan asteroids

212
00:07:48,629 --> 00:07:45,120
within

213
00:07:50,390 --> 00:07:48,639

its orbit the cool thing is they do

214
00:07:51,670 --> 00:07:50,400
simulations of this on how long it will

215
00:07:55,110 --> 00:07:51,680
last there

216
00:07:58,390 --> 00:07:55,120
probably within a few years

217
00:08:01,350 --> 00:07:58,400
we will be able to watch le2

218
00:08:02,710 --> 00:08:01,360
move out of the trojan asteroids and

219
00:08:05,749 --> 00:08:02,720
change its orbit

220
00:08:09,270 --> 00:08:05,759
we can see orbital dynamics happening

221
00:08:11,110 --> 00:08:09,280
on a time scale of several years

222
00:08:12,950 --> 00:08:11,120
now maybe it will come into the inner

223
00:08:15,749 --> 00:08:12,960
solar system and maybe it'll be a bright

224
00:08:18,710 --> 00:08:15,759
comet we can see in the night sky

225
00:08:19,430 --> 00:08:18,720
but actually probably not because they

226
00:08:21,909 --> 00:08:19,440
actually

227
00:08:22,710 --> 00:08:21,919
they predict that within half a million

228
00:08:25,029 --> 00:08:22,720
years

229
00:08:26,629 --> 00:08:25,039
there's a 90 percent chance that it will

230
00:08:27,270 --> 00:08:26,639
have a gravitational encounter with

231
00:08:28,869 --> 00:08:27,280
jupiter

232
00:08:31,350 --> 00:08:28,879
that instead of sending it into the

233
00:08:34,630 --> 00:08:31,360
inner solar system will actually kick it

234
00:08:36,790 --> 00:08:34,640
out of the solar system so this is the

235
00:08:38,310 --> 00:08:36,800
first comet discovered amongst the

236
00:08:41,430 --> 00:08:38,320
trojan asteroids

237
00:08:43,269 --> 00:08:41,440
is it a standard weigh station on the

238
00:08:45,030 --> 00:08:43,279

on the traveling in from the kuiper belt

239
00:08:47,670 --> 00:08:45,040
to the inner solar system

240
00:08:48,470 --> 00:08:47,680
possibly they will continue to look for

241
00:08:50,470 --> 00:08:48,480
more

242
00:08:51,829 --> 00:08:50,480
and will be able to follow the

243
00:08:57,190 --> 00:08:51,839
development of

244
00:09:00,710 --> 00:08:59,190
second story i'm not going to go very

245
00:09:02,630 --> 00:09:00,720
deep into because

246
00:09:05,110 --> 00:09:02,640
many of you have probably seen a lot of

247
00:09:08,389 --> 00:09:05,120
it already this is perseverance

248
00:09:08,870 --> 00:09:08,399
on mars okay if you didn't know if

249
00:09:12,550 --> 00:09:08,880
you're

250
00:09:16,230 --> 00:09:12,560
living under a rock mars 2020 mission

251
00:09:17,829 --> 00:09:16,240
called perseverance has landed on mars

252
00:09:20,389 --> 00:09:17,839
and here are several pictures in the

253
00:09:23,190 --> 00:09:20,399
upper left that is the um

254
00:09:23,990 --> 00:09:23,200
parachute that they use to glide it down

255
00:09:32,150 --> 00:09:24,000
to

256
00:09:32,630 --> 00:09:32,160
thin martian atmosphere and so they

257
00:09:35,110 --> 00:09:32,640
really

258
00:09:36,389 --> 00:09:35,120
couldn't test it on earth with our much

259
00:09:39,030 --> 00:09:36,399
thicker atmosphere

260
00:09:39,430 --> 00:09:39,040
so that's an amazing feat of engineering

261
00:09:41,829 --> 00:09:39,440
because

262
00:09:42,870 --> 00:09:41,839
they really couldn't test it in advance

263
00:09:44,949 --> 00:09:42,880

in the in the

264
00:09:46,230 --> 00:09:44,959
conditions and then you've got the shot

265
00:09:48,310 --> 00:09:46,240
looking down on

266
00:09:50,070 --> 00:09:48,320
the rover as it's heading to the surface

267
00:09:53,509 --> 00:09:50,080
the shot of the rover on the surface

268
00:09:55,910 --> 00:09:53,519
and three cool panoramas there is a

269
00:09:58,070 --> 00:09:55,920
ton of cool information and if you

270
00:09:59,430 --> 00:09:58,080
haven't watched the descent and landing

271
00:10:01,829 --> 00:09:59,440
video

272
00:10:03,269 --> 00:10:01,839
you gotta check it out okay mars

273
00:10:05,829 --> 00:10:03,279
perseverance we're gonna get some

274
00:10:07,829 --> 00:10:05,839
interesting science uh from the crater

275
00:10:09,110 --> 00:10:07,839
uh trying to look for signs of life

276
00:10:11,110 --> 00:10:09,120
could life have developed

277
00:10:13,030 --> 00:10:11,120
in this crater that was once an ancient

278
00:10:15,110 --> 00:10:13,040
ocean that stuff to

279
00:10:16,389 --> 00:10:15,120
stay tuned for but for right now you can

280
00:10:20,630 --> 00:10:16,399
get some really cool

281
00:10:27,110 --> 00:10:24,550
okay to our featured speaker tonight

282
00:10:28,069 --> 00:10:27,120
our featured speaker tonight is tom

283
00:10:30,790 --> 00:10:28,079
brown

284
00:10:31,590 --> 00:10:30,800
and he is extremely important person he

285
00:10:33,509 --> 00:10:31,600
is the head

286
00:10:35,910 --> 00:10:33,519
of the hubble mission office here at the

287
00:10:38,870 --> 00:10:35,920
space telescope science institute

288
00:10:40,150 --> 00:10:38,880

uh he got his undergraduate degree at

289
00:10:42,389 --> 00:10:40,160
penn state

290
00:10:43,269 --> 00:10:42,399
then got his graduate uh did his

291
00:10:45,670 --> 00:10:43,279
graduate work

292
00:10:47,030 --> 00:10:45,680
across the way at johns hopkins

293
00:10:49,030 --> 00:10:47,040
university

294
00:10:50,710 --> 00:10:49,040
he went down to our partner institution

295
00:10:52,550 --> 00:10:50,720
the goddard space flight center

296
00:10:54,310 --> 00:10:52,560
and then came here to space telescope

297
00:10:55,990 --> 00:10:54,320
and it's uh fun that

298
00:10:57,350 --> 00:10:56,000
tom and i learned today that we've both

299
00:10:57,910 --> 00:10:57,360
been at the space telescope science

300
00:10:59,990 --> 00:10:57,920
institute

301
00:11:01,750 --> 00:11:00,000
for 20 years now so we're both

302
00:11:03,509 --> 00:11:01,760
celebrating our 20th anniversary at

303
00:11:05,990 --> 00:11:03,519
space telescope this year

304
00:11:07,910 --> 00:11:06,000
uh he's going to tell you all about what

305
00:11:10,150 --> 00:11:07,920
his functional work is

306
00:11:11,350 --> 00:11:10,160
but he also does research i this is a

307
00:11:12,870 --> 00:11:11,360
guy in a really important position but

308
00:11:14,710 --> 00:11:12,880
he's still doing his research

309
00:11:16,470 --> 00:11:14,720
in fact he was telling me he just got

310
00:11:19,430 --> 00:11:16,480
hubble data last night

311
00:11:20,230 --> 00:11:19,440
on the globular cluster m4 and he's just

312
00:11:23,190 --> 00:11:20,240
itching to pre

313
00:11:25,030 --> 00:11:23,200

to preview that data and study it so

314
00:11:29,269 --> 00:11:25,040
without further ado ladies and gentlemen

315
00:11:33,110 --> 00:11:29,279
dr tom brown thank you frank

316
00:11:35,670 --> 00:11:33,120
all right hello everyone yeah thanks

317
00:11:37,030 --> 00:11:35,680
as you heard my name is tom brown and i

318
00:11:38,630 --> 00:11:37,040
work at the space telescope science

319
00:11:40,550 --> 00:11:38,640
institute and i'll be talking to you

320
00:11:44,230 --> 00:11:40,560
today about the wide range of science

321
00:11:49,269 --> 00:11:46,710
so hubble was launched over 30 years ago

322
00:11:51,990 --> 00:11:49,279
in 1990 as a partnership between

323
00:11:53,590 --> 00:11:52,000
nasa and esa and it's become

324
00:11:55,030 --> 00:11:53,600
increasingly powerful

325
00:11:56,949 --> 00:11:55,040
over the years through a series of

326
00:11:59,269 --> 00:11:56,959
servicing missions

327
00:12:00,870 --> 00:11:59,279
three missions in the 1990s and then

328
00:12:04,069 --> 00:12:00,880
another one in 2002

329
00:12:06,870 --> 00:12:04,079
and another in 2009 and while there are

330
00:12:08,710 --> 00:12:06,880
no additional servicing missions planned

331
00:12:10,150 --> 00:12:08,720
the observatory is expected to be

332
00:12:12,790 --> 00:12:10,160
scientifically operational

333
00:12:16,310 --> 00:12:12,800
through at least 2026 and hopefully the

334
00:12:20,230 --> 00:12:18,310
this is an overview of the physical

335
00:12:22,790 --> 00:12:20,240
characteristics of the observatory it's

336
00:12:26,069 --> 00:12:22,800
about the size of a school bus

337
00:12:27,269 --> 00:12:26,079
it's a little over 13 meters long 4.2

338
00:12:30,550 --> 00:12:27,279

meters wide

339
00:12:32,790 --> 00:12:30,560
a weight of 12 200 kilograms

340
00:12:35,030 --> 00:12:32,800
it's a cassegrain telescope with a

341
00:12:35,910 --> 00:12:35,040
primary mirror 2.4 meters across a

342
00:12:39,750 --> 00:12:35,920
secondary mirror

343
00:12:42,710 --> 00:12:39,760
0.3 meters across it's in orbit

344
00:12:44,629 --> 00:12:42,720
at an altitude of 536 kilometers and

345
00:12:45,269 --> 00:12:44,639
goes around the earth once every 95

346
00:12:47,590 --> 00:12:45,279
minutes

347
00:12:49,670 --> 00:12:47,600
and the orbit is expected to be stable

348
00:12:52,870 --> 00:12:49,680
into the 2040s

349
00:12:54,949 --> 00:12:52,880
the power is provided by solar arrays on

350
00:13:00,310 --> 00:12:54,959
the day side and batteries on the night

351
00:13:03,590 --> 00:13:02,550
the hubble instrument suite which is

352
00:13:05,829 --> 00:13:03,600
shown

353
00:13:07,910 --> 00:13:05,839
in their layout here on the observatory

354
00:13:10,230 --> 00:13:07,920
provides unique capabilities that

355
00:13:11,829 --> 00:13:10,240
keep the telescope in high demand and

356
00:13:13,590 --> 00:13:11,839
also keep it on the cutting edge of

357
00:13:16,069 --> 00:13:13,600
astrophysical research

358
00:13:17,430 --> 00:13:16,079
i'll go through those briefly here first

359
00:13:20,069 --> 00:13:17,440
there's the cosmic origin

360
00:13:22,389 --> 00:13:20,079
spectrograph or cos it was installed in

361
00:13:24,870 --> 00:13:22,399
the last servicing mission 2009

362
00:13:26,069 --> 00:13:24,880
and it's optimized for ultraviolet

363
00:13:28,629 --> 00:13:26,079

spectroscopy of

364
00:13:30,550 --> 00:13:28,639
faint sources complementing those

365
00:13:31,910 --> 00:13:30,560
capabilities is the space telescope

366
00:13:35,110 --> 00:13:31,920
imaging spectrograph

367
00:13:37,110 --> 00:13:35,120
or stis it was installed in the late 90s

368
00:13:38,310 --> 00:13:37,120
and repaired in the last servicing

369
00:13:40,710 --> 00:13:38,320
mission

370
00:13:42,790 --> 00:13:40,720
it provides versatile spectroscopy and

371
00:13:44,069 --> 00:13:42,800
imaging over broad wavelength range in

372
00:13:47,189 --> 00:13:44,079
the optical

373
00:13:50,629 --> 00:13:47,199
ultraviolet and near-infrared next is

374
00:13:54,310 --> 00:13:50,639
the advanced camera for surveys or acs

375
00:13:55,829 --> 00:13:54,320
it was installed in 2002 and repaired in

376
00:13:57,590 --> 00:13:55,839
the last servicing mission

377
00:13:59,509 --> 00:13:57,600
it provides wide field imaging and

378
00:14:01,030 --> 00:13:59,519
spectroscopy with an emphasis on red

379
00:14:02,629 --> 00:14:01,040
sensitivity

380
00:14:05,189 --> 00:14:02,639
and then there's the wide field camera 3

381
00:14:06,870 --> 00:14:05,199
which was installed in 2009

382
00:14:08,470 --> 00:14:06,880
and it provides wide field imaging and

383
00:14:10,389 --> 00:14:08,480
spectroscopy

384
00:14:12,389 --> 00:14:10,399
with a broader wavelength range

385
00:14:13,350 --> 00:14:12,399
extending into the ultraviolet and the

386
00:14:16,550 --> 00:14:13,360
near infrared

387
00:14:18,470 --> 00:14:16,560
and also astrometric capabilities

388
00:14:19,590 --> 00:14:18,480

last there's the fine guidance side

389
00:14:21,829 --> 00:14:19,600
sensor package

390
00:14:23,750 --> 00:14:21,839
or fgs it was launched with the

391
00:14:25,829 --> 00:14:23,760
telescope it has three sensors two of

392
00:14:27,350 --> 00:14:25,839
which were refurbished on subsequent

393
00:14:29,430 --> 00:14:27,360
servicing missions

394
00:14:30,870 --> 00:14:29,440
it's mainly used as part of the pointy

395
00:14:32,629 --> 00:14:30,880
control system

396
00:14:36,870 --> 00:14:32,639
but it can also be used for astrometric

397
00:14:40,949 --> 00:14:38,790
the diagram i'm showing on the right

398
00:14:42,949 --> 00:14:40,959
shows the two main types of data that

399
00:14:45,509 --> 00:14:42,959
you get from these instruments

400
00:14:46,550 --> 00:14:45,519
this is looking at the massive star eta

401
00:14:49,030 --> 00:14:46,560
carina

402
00:14:50,230 --> 00:14:49,040
and this star system is quite violent

403
00:14:52,870 --> 00:14:50,240
it's

404
00:14:53,990 --> 00:14:52,880
shown here as a hubble image on the left

405
00:14:56,230 --> 00:14:54,000
side of the diagram

406
00:14:57,750 --> 00:14:56,240
a high resolution hubble image and then

407
00:15:00,470 --> 00:14:57,760
a spectrum from the center of this

408
00:15:02,790 --> 00:15:00,480
object is shown extending along the

409
00:15:05,590 --> 00:15:02,800
right side of this diagram

410
00:15:07,910 --> 00:15:05,600
and this demonstrates all in one diagram

411
00:15:09,430 --> 00:15:07,920
the power of the hubble space telescope

412
00:15:12,150 --> 00:15:09,440
hubble has powerful imaging and

413
00:15:14,069 --> 00:15:12,160

spectroscopic capabilities they extend

414
00:15:15,750 --> 00:15:14,079
the ultraviolet the optical and the near

415
00:15:17,590 --> 00:15:15,760
infrared and the ultraviolet is

416
00:15:19,269 --> 00:15:17,600
particularly important because you can't

417
00:15:20,949 --> 00:15:19,279
do ultraviolet astronomy from the ground

418
00:15:22,790 --> 00:15:20,959
due to the opacity of the atmosphere and

419
00:15:24,069 --> 00:15:22,800
the atmosphere also blurs light at other

420
00:15:26,790 --> 00:15:24,079
wavelengths and

421
00:15:27,670 --> 00:15:26,800
hubble avoids that by being in orbit and

422
00:15:30,310 --> 00:15:27,680
hubble

423
00:15:32,629 --> 00:15:30,320
has high resolution and contrast in its

424
00:15:36,150 --> 00:15:32,639
imaging and spectroscopy

425
00:15:39,269 --> 00:15:36,160
and these capabilities uh make hubble a

426
00:15:41,110 --> 00:15:39,279
powerful facility still to this day

427
00:15:42,790 --> 00:15:41,120
you can see the spectrum here

428
00:15:45,350 --> 00:15:42,800
complements the information you

429
00:15:46,069 --> 00:15:45,360
obtain with the image because of the

430
00:15:47,509 --> 00:15:46,079
features

431
00:15:51,030 --> 00:15:47,519
in the spectrum corresponding to the

432
00:15:54,870 --> 00:15:52,949
so first i'm going to review how

433
00:15:55,509 --> 00:15:54,880
powerful these two cameras are these

434
00:15:57,509 --> 00:15:55,519
cameras

435
00:15:58,949 --> 00:15:57,519
are far more powerful the ones that are

436
00:16:01,350 --> 00:15:58,959
on there now acs and

437
00:16:02,710 --> 00:16:01,360
wide field camera three they're far more

438
00:16:03,749 --> 00:16:02,720

powerful than those on previous

439
00:16:06,710 --> 00:16:03,759
generations

440
00:16:07,670 --> 00:16:06,720
on the hubble uh so what i'm showing

441
00:16:10,470 --> 00:16:07,680
here on the left

442
00:16:12,629 --> 00:16:10,480
is uh the hubble's 30th anniversary

443
00:16:14,150 --> 00:16:12,639
image of the cosmic reef

444
00:16:15,990 --> 00:16:14,160
this is a beautiful image i'm going to

445
00:16:18,470 --> 00:16:16,000
step through a series of

446
00:16:19,829 --> 00:16:18,480
hubble images of nearby galaxies to make

447
00:16:23,110 --> 00:16:19,839
a point

448
00:16:25,030 --> 00:16:23,120
so these are mostly spiral galaxies like

449
00:16:28,069 --> 00:16:25,040
our own milky way

450
00:16:29,990 --> 00:16:28,079
spiral galaxies in the nearby universe

451
00:16:31,430 --> 00:16:30,000
and all these images are quite beautiful

452
00:16:34,949 --> 00:16:31,440
on the subject of press releases with

453
00:16:38,069 --> 00:16:36,389
some of these are thought to look

454
00:16:39,829 --> 00:16:38,079
somewhat like our own milky way

455
00:16:42,069 --> 00:16:39,839
and there are pairs of galaxies and

456
00:16:44,150 --> 00:16:42,079
interacting galaxies

457
00:16:45,749 --> 00:16:44,160
but i'm going to zoom in here on the

458
00:16:49,509 --> 00:16:45,759
sombrero galaxy

459
00:16:49,990 --> 00:16:49,519
john galaxy here you can see this

460
00:16:52,710 --> 00:16:50,000
prominent

461
00:16:54,069 --> 00:16:52,720
dust lane in the foreground but what's

462
00:16:55,749 --> 00:16:54,079
fascinating is

463
00:16:57,509 --> 00:16:55,759

that you don't just see the sombrero

464
00:16:59,350 --> 00:16:57,519
galaxy you see much of the universe

465
00:17:00,790 --> 00:16:59,360
behind the sombrero galaxy and i can

466
00:17:03,110 --> 00:17:00,800
zoom in here

467
00:17:04,949 --> 00:17:03,120
you can see that there are distant

468
00:17:06,710 --> 00:17:04,959
spiral galaxies in the distant universe

469
00:17:08,870 --> 00:17:06,720
behind the sombrero that are also

470
00:17:09,750 --> 00:17:08,880
in this image and that's something that

471
00:17:11,429 --> 00:17:09,760
really

472
00:17:13,350 --> 00:17:11,439
started to become common with these two

473
00:17:14,870 --> 00:17:13,360
most powerful cameras we have on there

474
00:17:16,549 --> 00:17:14,880
most recently

475
00:17:18,309 --> 00:17:16,559
uh previous generations of cameras

476
00:17:21,669 --> 00:17:18,319
didn't exhibit this behavior but

477
00:17:23,669 --> 00:17:21,679
now when we get a image with hubble

478
00:17:24,949 --> 00:17:23,679
we get not only the object we're looking

479
00:17:26,630 --> 00:17:24,959
at but we tend to get much of the

480
00:17:27,990 --> 00:17:26,640
universe behind that object for free in

481
00:17:30,870 --> 00:17:28,000
the same exposure that's because these

482
00:17:32,390 --> 00:17:30,880
cameras are so powerful

483
00:17:35,270 --> 00:17:32,400
now a lot of the science and hubble

484
00:17:36,870 --> 00:17:35,280
comes from its spectrographs

485
00:17:38,549 --> 00:17:36,880
i mentioned there are two spectrographs

486
00:17:42,310 --> 00:17:38,559
in hubble that complement each other

487
00:17:44,470 --> 00:17:42,320
cos and stis now press releases

488
00:17:46,150 --> 00:17:44,480

on science results involving the

489
00:17:49,190 --> 00:17:46,160
spectrographs often involve

490
00:17:50,630 --> 00:17:49,200
an artist impression because

491
00:17:52,789 --> 00:17:50,640
you don't usually get a pretty picture

492
00:17:54,549 --> 00:17:52,799
with this type of science

493
00:17:56,710 --> 00:17:54,559
i'm going to show you in this talk both

494
00:17:57,990 --> 00:17:56,720
the artist impression for those cases

495
00:18:00,150 --> 00:17:58,000
but i'm also going to show the

496
00:18:02,950 --> 00:18:00,160
spectroscopic data

497
00:18:04,390 --> 00:18:02,960
and i'm doing that just so those viewers

498
00:18:06,150 --> 00:18:04,400
who are interested can see that

499
00:18:07,750 --> 00:18:06,160
the the scientific data alongside the

500
00:18:08,870 --> 00:18:07,760
artist impression

501
00:18:11,110 --> 00:18:08,880
and briefly here i'll show you

502
00:18:12,549 --> 00:18:11,120
schematically how this works you have a

503
00:18:14,150 --> 00:18:12,559
patch of sky

504
00:18:16,070 --> 00:18:14,160
with an object of interest so this

505
00:18:17,029 --> 00:18:16,080
target star here is shown by the blue

506
00:18:19,510 --> 00:18:17,039
box

507
00:18:21,350 --> 00:18:19,520
the light falls down the telescope and

508
00:18:23,430 --> 00:18:21,360
most of it is intercepted but the light

509
00:18:27,270 --> 00:18:23,440
from the object of interest

510
00:18:30,310 --> 00:18:27,280
falls through to a dispersive element

511
00:18:32,070 --> 00:18:30,320
and then or like a greeting or a prism

512
00:18:33,430 --> 00:18:32,080
and then it's spread out on the detector

513
00:18:36,150 --> 00:18:33,440

where you get a pattern of

514
00:18:37,909 --> 00:18:36,160
light and dark corresponding to the

515
00:18:39,029 --> 00:18:37,919
chemist chemistry and temperature in

516
00:18:40,549 --> 00:18:39,039
this object

517
00:18:42,230 --> 00:18:40,559
and that spectrum is then transmitted

518
00:18:44,150 --> 00:18:42,240
back down to earth

519
00:18:46,390 --> 00:18:44,160
so how does this work in practice so

520
00:18:49,510 --> 00:18:46,400
here are the hubble data

521
00:18:51,110 --> 00:18:49,520
for the southern crab nebula this is an

522
00:18:53,270 --> 00:18:51,120
image obtained with hubble as part of

523
00:18:54,310 --> 00:18:53,280
the 29th anniversary

524
00:18:55,750 --> 00:18:54,320
and what i'm going to do here is show

525
00:18:57,909 --> 00:18:55,760
you also the spectrum obtained with

526
00:19:01,029 --> 00:18:57,919
hubble for this object

527
00:19:05,190 --> 00:19:04,150
here is the hubble spectrum the lights

528
00:19:06,870 --> 00:19:05,200
dispersed

529
00:19:08,310 --> 00:19:06,880
with blue wavelengths on the left right

530
00:19:09,590 --> 00:19:08,320
or wavelengths on the right

531
00:19:11,110 --> 00:19:09,600
and then the features you see in the

532
00:19:12,150 --> 00:19:11,120
spectrum correspond to the chemistry of

533
00:19:14,150 --> 00:19:12,160
the object

534
00:19:15,990 --> 00:19:14,160
so on the left here is oxygen and then

535
00:19:19,270 --> 00:19:16,000
you also have hydrogen

536
00:19:22,470 --> 00:19:19,280
nitrogen and sulfur and then those

537
00:19:26,070 --> 00:19:24,390
to give you the colors you see in the

538
00:19:27,990 --> 00:19:26,080

actual image

539
00:19:30,150 --> 00:19:28,000
so this object we obtained both imaging

540
00:19:30,630 --> 00:19:30,160
and spectroscopy and you can see how

541
00:19:32,390 --> 00:19:30,640
those

542
00:19:33,990 --> 00:19:32,400
two types of data complement each other

543
00:19:35,270 --> 00:19:34,000
the image tells us about the structure

544
00:19:37,510 --> 00:19:35,280
of the object but

545
00:19:39,830 --> 00:19:37,520
the spectroscopy tells us about the

546
00:19:42,789 --> 00:19:39,840
temperature and chemistry

547
00:19:44,870 --> 00:19:42,799
now here are those data again the images

548
00:19:46,390 --> 00:19:44,880
and the spectra of this object

549
00:19:48,310 --> 00:19:46,400
now i'm showing along the bottom the

550
00:19:50,070 --> 00:19:48,320
type of plot that

551
00:19:52,390 --> 00:19:50,080
astronomers typically show when they

552
00:19:54,549 --> 00:19:52,400
have a spectrum this is a plot of flux

553
00:19:55,350 --> 00:19:54,559
or energy on the y-axis versus color on

554
00:19:58,470 --> 00:19:55,360
the x-axis

555
00:20:00,150 --> 00:19:58,480
in nanometers from 500 to 700 nanometers

556
00:20:02,549 --> 00:20:00,160
and you can see that the features in

557
00:20:05,430 --> 00:20:02,559
this plot along the black

558
00:20:06,070 --> 00:20:05,440
curve here the spikes correspond to

559
00:20:09,430 --> 00:20:06,080
features

560
00:20:11,430 --> 00:20:09,440
in the beautiful outreach figure so most

561
00:20:12,710 --> 00:20:11,440
of the time when astronomers have

562
00:20:14,950 --> 00:20:12,720
a spectrum they're showing in their

563
00:20:16,310 --> 00:20:14,960

paper they show something like the plot

564
00:20:17,430 --> 00:20:16,320
along the bottom here but you can see

565
00:20:18,630 --> 00:20:17,440
that the information this plot

566
00:20:22,070 --> 00:20:18,640
corresponds to

567
00:20:26,549 --> 00:20:23,590
now hubble science spans the full

568
00:20:28,710 --> 00:20:26,559
breadth of astrophysical phenomena

569
00:20:29,909 --> 00:20:28,720
that's shown here by this pie chart on

570
00:20:31,909 --> 00:20:29,919
the left

571
00:20:33,669 --> 00:20:31,919
this is the breakdown of science topics

572
00:20:35,990 --> 00:20:33,679
in a broad brush

573
00:20:37,669 --> 00:20:36,000
that are being pursued by hubble in the

574
00:20:39,190 --> 00:20:37,679
current observing cycle

575
00:20:41,270 --> 00:20:39,200
observing cycles occur on an annual

576
00:20:44,470 --> 00:20:41,280
basis and you can see hubble

577
00:20:47,110 --> 00:20:44,480
is doing work on black holes he's doing

578
00:20:48,549 --> 00:20:47,120
work on exoplanets and planet formation

579
00:20:50,310 --> 00:20:48,559
about a quarter of the times going into

580
00:20:51,909 --> 00:20:50,320
galaxies a

581
00:20:53,669 --> 00:20:51,919
significant amount of time is going to

582
00:20:54,710 --> 00:20:53,679
studying the dark material between the

583
00:20:57,510 --> 00:20:54,720
galaxies the

584
00:20:59,190 --> 00:20:57,520
intergalactic and circum galactic medium

585
00:21:00,310 --> 00:20:59,200
we have cosmology and large scale

586
00:21:03,510 --> 00:21:00,320
structure

587
00:21:05,510 --> 00:21:03,520
the solar system stellar physics

588
00:21:06,789 --> 00:21:05,520

and stellar populations or groups of

589
00:21:08,390 --> 00:21:06,799
stars

590
00:21:10,950 --> 00:21:08,400
now in the upper right i'm showing a

591
00:21:13,909 --> 00:21:10,960
plot of the number of refereed

592
00:21:15,110 --> 00:21:13,919
publications using hubble data to date

593
00:21:17,270 --> 00:21:15,120
as a function of time

594
00:21:18,470 --> 00:21:17,280
over the history of the mission and you

595
00:21:20,310 --> 00:21:18,480
can see that

596
00:21:21,750 --> 00:21:20,320
this is the scientific productivity of

597
00:21:23,430 --> 00:21:21,760
the telescope has really grown over the

598
00:21:25,190 --> 00:21:23,440
years and now there's roughly a thousand

599
00:21:27,909 --> 00:21:25,200
peer-reviewed papers per

600
00:21:28,870 --> 00:21:27,919
year over eighteen thousand publications

601
00:21:31,750 --> 00:21:28,880
to date

602
00:21:33,270 --> 00:21:31,760
and the bands of color in this plot show

603
00:21:35,029 --> 00:21:33,280
where the paper is drawing the hubble

604
00:21:38,789 --> 00:21:35,039
data from so the lowest

605
00:21:41,510 --> 00:21:38,799
band here in a greenish yellow color

606
00:21:43,750 --> 00:21:41,520
those are papers published by the same

607
00:21:44,310 --> 00:21:43,760
team of astronomers who requested time

608
00:21:47,110 --> 00:21:44,320
on the

609
00:21:47,990 --> 00:21:47,120
telescope so they asked for a time until

610
00:21:49,270 --> 00:21:48,000
on hubble

611
00:21:50,789 --> 00:21:49,280
they got the data and then they

612
00:21:52,630 --> 00:21:50,799
published their results and then the

613
00:21:54,870 --> 00:21:52,640

bands of color above that

614
00:21:56,549 --> 00:21:54,880
are from teams of astronomers who went

615
00:21:57,190 --> 00:21:56,559
back into the archive and at least part

616
00:21:59,990 --> 00:21:57,200
of their

617
00:22:01,029 --> 00:22:00,000
paper is drawing upon archival data uh

618
00:22:02,950 --> 00:22:01,039
collected from

619
00:22:04,390 --> 00:22:02,960
previous observations not observations

620
00:22:05,909 --> 00:22:04,400
they requested themselves so you can see

621
00:22:07,909 --> 00:22:05,919
over half of the data

622
00:22:09,830 --> 00:22:07,919
uh published with hubble these days was

623
00:22:11,430 --> 00:22:09,840
drawn from the archive

624
00:22:14,070 --> 00:22:11,440
now observing time on the telescope is

625
00:22:15,669 --> 00:22:14,080
awarded by a peer review process that's

626
00:22:18,789 --> 00:22:15,679
dual anonymous that was

627
00:22:20,230 --> 00:22:18,799
an innovation that hubble began in the

628
00:22:22,230 --> 00:22:20,240
field a few years ago

629
00:22:23,270 --> 00:22:22,240
this art the hubble telescope was the

630
00:22:25,190 --> 00:22:23,280
first telescope

631
00:22:26,789 --> 00:22:25,200
to use a dual anonymous peer review

632
00:22:27,590 --> 00:22:26,799
systems so the people submitting their

633
00:22:29,110 --> 00:22:27,600
ideas

634
00:22:31,510 --> 00:22:29,120
for peer review don't know who will be

635
00:22:33,830 --> 00:22:31,520
reviewing them and then the people

636
00:22:35,350 --> 00:22:33,840
who are evaluating those ideas don't see

637
00:22:35,990 --> 00:22:35,360
the identities of who submitted the

638
00:22:36,950 --> 00:22:36,000

proposal

639
00:22:39,270 --> 00:22:36,960
those have been stripped from the

640
00:22:39,990 --> 00:22:39,280
proposal and that allows the peer review

641
00:22:42,390 --> 00:22:40,000
to just focus

642
00:22:43,750 --> 00:22:42,400
on the science and it mitigates bias in

643
00:22:46,070 --> 00:22:43,760
the review

644
00:22:47,270 --> 00:22:46,080
the telescope remains in high demand the

645
00:22:48,870 --> 00:22:47,280
over subscription whether you're

646
00:22:49,909 --> 00:22:48,880
measuring that by the number of requests

647
00:22:52,230 --> 00:22:49,919
for time

648
00:22:53,669 --> 00:22:52,240
or the amount of observer time needed

649
00:22:57,669 --> 00:22:53,679
exceeds what's available in any given

650
00:23:01,350 --> 00:22:59,350
now hubble science evolves with the

651
00:23:03,430 --> 00:23:01,360
field

652
00:23:04,870 --> 00:23:03,440
i'm going to show that here through two

653
00:23:06,549 --> 00:23:04,880
science topics that get a lot of

654
00:23:08,549 --> 00:23:06,559
attention these days and the top is

655
00:23:11,270 --> 00:23:08,559
cosmic expansion

656
00:23:13,190 --> 00:23:11,280
now the universe has been known to be

657
00:23:17,110 --> 00:23:13,200
expanding for decades

658
00:23:19,190 --> 00:23:17,120
and when the telescope launched in 1990

659
00:23:21,270 --> 00:23:19,200
astronomers hoped to use the telescope

660
00:23:22,630 --> 00:23:21,280
to accurately characterize the rate of

661
00:23:23,990 --> 00:23:22,640
expansion for the universe

662
00:23:25,750 --> 00:23:24,000
what was not known when the telescope

663
00:23:28,549 --> 00:23:25,760

launched was that that excel

664
00:23:30,070 --> 00:23:28,559
that expansion of the universe had a

665
00:23:32,310 --> 00:23:30,080
period of both deceleration and

666
00:23:33,029 --> 00:23:32,320
acceleration and hublicata played a key

667
00:23:35,190 --> 00:23:33,039
role

668
00:23:36,470 --> 00:23:35,200
in characterizing that variation in the

669
00:23:38,230 --> 00:23:36,480
expansion of the universe

670
00:23:39,590 --> 00:23:38,240
and it was the subject of a nobel prize

671
00:23:40,789 --> 00:23:39,600
along with other telescopes that were

672
00:23:42,789 --> 00:23:40,799
used

673
00:23:44,230 --> 00:23:42,799
we are now in an era of precision

674
00:23:46,390 --> 00:23:44,240
cosmology

675
00:23:47,750 --> 00:23:46,400
where people are measuring the expansion

676
00:23:49,430 --> 00:23:47,760
rate of the universe using different

677
00:23:50,070 --> 00:23:49,440
methods and those methods don't always

678
00:23:52,070 --> 00:23:50,080
give the same

679
00:23:54,549 --> 00:23:52,080
answer within the uncertainties and that

680
00:23:57,590 --> 00:23:54,559
might be implying new physics

681
00:24:00,390 --> 00:23:57,600
and the bottom here i'm showing the work

682
00:24:01,590 --> 00:24:00,400
hubble is doing on exoplanet atmospheres

683
00:24:03,510 --> 00:24:01,600
so the first

684
00:24:04,710 --> 00:24:03,520
exoplanet that is the first planet

685
00:24:06,390 --> 00:24:04,720
outside our own solar system was

686
00:24:08,390 --> 00:24:06,400
discovered after the telescope launched

687
00:24:10,070 --> 00:24:08,400
so this was not a science topic

688
00:24:12,470 --> 00:24:10,080

at the time the telescope was designed

689
00:24:12,950 --> 00:24:12,480
and launched and now hubble spends about

690
00:24:14,789 --> 00:24:12,960
20

691
00:24:16,950 --> 00:24:14,799
of its observing time looking at

692
00:24:19,110 --> 00:24:16,960
exoplanets and hubble is indeed

693
00:24:20,710 --> 00:24:19,120
the premier facility for studying

694
00:24:21,669 --> 00:24:20,720
exoplanets and their atmospheres even

695
00:24:23,669 --> 00:24:21,679
though it's not the premiere

696
00:24:25,669 --> 00:24:23,679
facility for discovering exoplanets

697
00:24:26,950 --> 00:24:25,679
hubble's not a survey telescope but once

698
00:24:29,750 --> 00:24:26,960
other surveys find

699
00:24:31,909 --> 00:24:29,760
exoplanets hubble is used to follow them

700
00:24:33,590 --> 00:24:31,919
up and the way hubble does this work is

701
00:24:34,549 --> 00:24:33,600
shown by the artist impression at the

702
00:24:36,870 --> 00:24:34,559
bottom here

703
00:24:38,470 --> 00:24:36,880
a planet when it passes in front of its

704
00:24:39,590 --> 00:24:38,480
host star when it transits in front of

705
00:24:42,230 --> 00:24:39,600
the host star

706
00:24:42,789 --> 00:24:42,240
the planet and its atmosphere affect the

707
00:24:44,789 --> 00:24:42,799
light

708
00:24:46,710 --> 00:24:44,799
from the system that you see and the

709
00:24:48,470 --> 00:24:46,720
variation that light

710
00:24:50,390 --> 00:24:48,480
is measured with hubble usually through

711
00:24:51,510 --> 00:24:50,400
the spectrum and

712
00:24:56,390 --> 00:24:51,520
that tells us something about the

713
00:25:00,630 --> 00:24:59,350

so another advance with the telescope

714
00:25:02,710 --> 00:25:00,640
that has

715
00:25:04,710 --> 00:25:02,720
changed over time is the way we use the

716
00:25:06,710 --> 00:25:04,720
telescope and that's really making

717
00:25:08,230 --> 00:25:06,720
the pursuit of those two science cases i

718
00:25:10,149 --> 00:25:08,240
just showed you

719
00:25:11,909 --> 00:25:10,159
more powerful and this is called spatial

720
00:25:13,350 --> 00:25:11,919
scanning so normally

721
00:25:15,190 --> 00:25:13,360
it's important to hold a telescope

722
00:25:17,350 --> 00:25:15,200
steady when

723
00:25:18,950 --> 00:25:17,360
obtaining an exposure of an object

724
00:25:21,590 --> 00:25:18,960
whether you're obtaining a spectrum or

725
00:25:22,870 --> 00:25:21,600
you're looking at an image of stars

726
00:25:24,710 --> 00:25:22,880
what we do with spatial scanning is we

727
00:25:26,710 --> 00:25:24,720
intentionally drag the telescope

728
00:25:28,310 --> 00:25:26,720
across the field of view and so if

729
00:25:30,789 --> 00:25:28,320
you're looking at a group of stars

730
00:25:31,430 --> 00:25:30,799
as i'm showing here in the top image the

731
00:25:34,789 --> 00:25:31,440
stars

732
00:25:37,590 --> 00:25:34,799
create streaks during your exposure

733
00:25:39,190 --> 00:25:37,600
but this works to the advantage of of

734
00:25:40,870 --> 00:25:39,200
the astronomer because

735
00:25:42,630 --> 00:25:40,880
now you're getting high precision

736
00:25:43,830 --> 00:25:42,640
astronomers and parallax is for the

737
00:25:45,110 --> 00:25:43,840
objects in the field

738
00:25:46,950 --> 00:25:45,120

because instead of getting one

739
00:25:48,630 --> 00:25:46,960
measurement for the position of each

740
00:25:50,470 --> 00:25:48,640
star you're getting hundreds of

741
00:25:51,830 --> 00:25:50,480
measurements as those stars are dragged

742
00:25:53,909 --> 00:25:51,840
across the field of view

743
00:25:55,510 --> 00:25:53,919
so you can get very high precision

744
00:25:58,549 --> 00:25:55,520
measurements

745
00:26:00,149 --> 00:25:58,559
of their relative positions along the

746
00:26:02,870 --> 00:26:00,159
bottom i'm showing

747
00:26:04,710 --> 00:26:02,880
another way of using spatial scanning

748
00:26:05,110 --> 00:26:04,720
that's with spectroscopic observations

749
00:26:07,430 --> 00:26:05,120
so

750
00:26:09,029 --> 00:26:07,440
this is a exoplanet observation i'm

751
00:26:09,990 --> 00:26:09,039
showing here over the course of the

752
00:26:12,310 --> 00:26:10,000
exposure

753
00:26:13,029 --> 00:26:12,320
wavelength runs from left to right and

754
00:26:15,430 --> 00:26:13,039
then the

755
00:26:17,269 --> 00:26:15,440
spectrum during the exposure is dragged

756
00:26:18,310 --> 00:26:17,279
across the detector from the bottom to

757
00:26:19,350 --> 00:26:18,320
the top

758
00:26:21,830 --> 00:26:19,360
and of course we're spreading the

759
00:26:23,510 --> 00:26:21,840
detector over a larger area more signal

760
00:26:24,630 --> 00:26:23,520
can be detected before we saturate the

761
00:26:26,470 --> 00:26:24,640
detector

762
00:26:28,950 --> 00:26:26,480
and we can average out systematic errors

763
00:26:30,870 --> 00:26:28,960

and that allows a much higher accuracy

764
00:26:33,510 --> 00:26:30,880
to be obtained with the spectroscopic

765
00:26:37,430 --> 00:26:35,269
so next i'm going to explain a little

766
00:26:38,870 --> 00:26:37,440
more detail this cosmic expansion and

767
00:26:39,430 --> 00:26:38,880
how this kind of works pursued with

768
00:26:41,029 --> 00:26:39,440
hubble

769
00:26:42,630 --> 00:26:41,039
and one of the first ways that's being

770
00:26:45,190 --> 00:26:42,640
done is

771
00:26:46,070 --> 00:26:45,200
by combining uh observations of

772
00:26:47,990 --> 00:26:46,080
supernova

773
00:26:49,110 --> 00:26:48,000
explosions so these are exploding star

774
00:26:50,710 --> 00:26:49,120
systems

775
00:26:52,870 --> 00:26:50,720
and the brightnesses of the supernova

776
00:26:55,430 --> 00:26:52,880
are calibrated with cepheid stars

777
00:26:56,630 --> 00:26:55,440
and these are star stars with a known

778
00:26:58,549 --> 00:26:56,640
brightness

779
00:27:00,630 --> 00:26:58,559
so first i need to explain the concept

780
00:27:02,549 --> 00:27:00,640
of the standard candle

781
00:27:05,430 --> 00:27:02,559
so a standard candle is an object with a

782
00:27:09,909 --> 00:27:05,440
known intrinsic luminosity

783
00:27:11,430 --> 00:27:09,919
and then when you observe that object

784
00:27:13,029 --> 00:27:11,440
at a particular brightness that tells

785
00:27:14,710 --> 00:27:13,039
you something about how far away it is

786
00:27:16,310 --> 00:27:14,720
so if i'm standing in front of you with

787
00:27:17,750 --> 00:27:16,320
a candle and you see how bright it is

788
00:27:19,110 --> 00:27:17,760

and then i walk away into the darkness

789
00:27:21,750 --> 00:27:19,120
it looks like it's getting fainter

790
00:27:23,430 --> 00:27:21,760
due to me being further away and you can

791
00:27:27,190 --> 00:27:23,440
use that information to judge how far

792
00:27:28,950 --> 00:27:27,200
away i am so that's a standard candle

793
00:27:30,950 --> 00:27:28,960
parallax is another phenomenon that we

794
00:27:32,310 --> 00:27:30,960
see here on earth in everyday life so if

795
00:27:33,590 --> 00:27:32,320
you're driving your car and you're going

796
00:27:37,110 --> 00:27:33,600
down the road

797
00:27:39,510 --> 00:27:37,120
and you see trees outside the window

798
00:27:40,950 --> 00:27:39,520
nearby they seem to be moving relative

799
00:27:42,789 --> 00:27:40,960
to the background for example about

800
00:27:44,549 --> 00:27:42,799
relative to a distant mountain range

801
00:27:46,710 --> 00:27:44,559
and so as an observer looks at nearby

802
00:27:48,549 --> 00:27:46,720
objects as they're moving

803
00:27:49,909 --> 00:27:48,559
that causes nearby objects to appear

804
00:27:51,909 --> 00:27:49,919
like they're moving against

805
00:27:53,430 --> 00:27:51,919
a screen of distant objects and

806
00:27:55,190 --> 00:27:53,440
astronomers do the same thing with the

807
00:27:57,269 --> 00:27:55,200
earth going around the sun

808
00:27:58,789 --> 00:27:57,279
over the course of the year as the earth

809
00:28:00,149 --> 00:27:58,799
goes around the sun and hubble is going

810
00:28:02,470 --> 00:28:00,159
around the earth

811
00:28:04,070 --> 00:28:02,480
nearby stars appear to move relative to

812
00:28:07,029 --> 00:28:04,080
distant background objects

813
00:28:08,470 --> 00:28:07,039

and that geometry allows astronomers to

814
00:28:09,350 --> 00:28:08,480
measure the distance to those nearby

815
00:28:11,990 --> 00:28:09,360
objects

816
00:28:13,269 --> 00:28:12,000
so the same thing happens here with the

817
00:28:15,430 --> 00:28:13,279
measuring of the expansion of the

818
00:28:16,630 --> 00:28:15,440
universe so this cartoon demonstrates

819
00:28:18,549 --> 00:28:16,640
that on the left-hand side of the

820
00:28:19,510 --> 00:28:18,559
cartoon is a schematic of the milky way

821
00:28:22,149 --> 00:28:19,520
galaxy

822
00:28:24,230 --> 00:28:22,159
and there's the sun with hubble and the

823
00:28:26,789 --> 00:28:24,240
earth going around the sun every year

824
00:28:28,710 --> 00:28:26,799
and it's looking at nearby cepheid stars

825
00:28:30,549 --> 00:28:28,720
and obtaining their parallaxes from the

826
00:28:33,669 --> 00:28:30,559
motion around the sun

827
00:28:35,430 --> 00:28:33,679
so that geometric distance tells us how

828
00:28:37,269 --> 00:28:35,440
far away the cepheid stars are and then

829
00:28:38,950 --> 00:28:37,279
that allows us to calibrate

830
00:28:40,310 --> 00:28:38,960
how bright they are and make them into a

831
00:28:42,630 --> 00:28:40,320
standard candle

832
00:28:44,470 --> 00:28:42,640
those cepheid stars are then observed in

833
00:28:45,430 --> 00:28:44,480
nearby galaxies in the local universe

834
00:28:46,870 --> 00:28:45,440
that's shown in the center of the

835
00:28:48,389 --> 00:28:46,880
cartoon

836
00:28:50,070 --> 00:28:48,399
and that allows us to calibrate the

837
00:28:52,630 --> 00:28:50,080
distances to those

838
00:28:54,310 --> 00:28:52,640

galaxies then when a supernova explodes

839
00:28:55,510 --> 00:28:54,320
in those galaxies we know the distance

840
00:28:57,350 --> 00:28:55,520
to those galaxies so now we know the

841
00:28:57,990 --> 00:28:57,360
brightness of the supernova and now the

842
00:28:59,909 --> 00:28:58,000
supernova

843
00:29:01,510 --> 00:28:59,919
is a standard cannibal candle but it's a

844
00:29:03,110 --> 00:29:01,520
much brighter standard candle than the

845
00:29:04,310 --> 00:29:03,120
sepia it can be used at much greater

846
00:29:07,590 --> 00:29:04,320
distances

847
00:29:10,149 --> 00:29:07,600
and so now the supernova are observed

848
00:29:11,669 --> 00:29:10,159
at extreme distances across the universe

849
00:29:13,830 --> 00:29:11,679
in distant galaxies that's what's shown

850
00:29:15,269 --> 00:29:13,840
on the right-hand side of the cartoon

851
00:29:17,669 --> 00:29:15,279
and that us allows us to measure

852
00:29:19,110 --> 00:29:17,679
distances of galaxies receding away from

853
00:29:21,269 --> 00:29:19,120
us in the distant universe

854
00:29:23,190 --> 00:29:21,279
so it's a chain of evidence here working

855
00:29:25,990 --> 00:29:23,200
your way outward

856
00:29:26,870 --> 00:29:26,000
and just to summarize that so the this

857
00:29:29,269 --> 00:29:26,880
method

858
00:29:31,029 --> 00:29:29,279
combines using two types of standard

859
00:29:33,669 --> 00:29:31,039
candles cepheid variable stars

860
00:29:36,070 --> 00:29:33,679
and then type 1a supernova stellar

861
00:29:38,950 --> 00:29:36,080
explosions

862
00:29:39,669 --> 00:29:38,960
and those are calibrated in turn when

863
00:29:41,110 --> 00:29:39,679

and then you can

864
00:29:43,110 --> 00:29:41,120
measure the expansion of the universe

865
00:29:44,789 --> 00:29:43,120
and for example rhys it all

866
00:29:46,389 --> 00:29:44,799
did this most recently and obtained a

867
00:29:48,310 --> 00:29:46,399
hubble constant

868
00:29:50,710 --> 00:29:48,320
h naught and that's a measure of the

869
00:29:53,909 --> 00:29:50,720
expansion of the universe of 73.2

870
00:29:56,149 --> 00:29:53,919
plus or minus 1.3 kilometers per second

871
00:29:56,710 --> 00:29:56,159
per megaparsec so a mega parsec is a

872
00:29:59,909 --> 00:29:56,720
little over

873
00:30:03,110 --> 00:29:59,919
three million light years so that means

874
00:30:05,269 --> 00:30:03,120
uh for ev every uh

875
00:30:07,750 --> 00:30:05,279
megaparsec out you go the recession

876
00:30:07,990 --> 00:30:07,760
velocity is increasing by 73 kilometers

877
00:30:09,669 --> 00:30:08,000
per

878
00:30:12,389 --> 00:30:09,679
second so as you can see in the

879
00:30:13,909 --> 00:30:12,399
uncertainty there is quite small

880
00:30:16,389 --> 00:30:13,919
now there are other ways of measuring

881
00:30:19,430 --> 00:30:16,399
the expansion of the universe

882
00:30:21,029 --> 00:30:19,440
so the planck satellite for example is a

883
00:30:22,149 --> 00:30:21,039
mission that is mapping the cosmic

884
00:30:24,870 --> 00:30:22,159
microwave background

885
00:30:26,549 --> 00:30:24,880
this is relic radiation left over from

886
00:30:28,310 --> 00:30:26,559
the big bang that is all over the sky

887
00:30:29,830 --> 00:30:28,320
and it makes these all sky maps that are

888
00:30:32,230 --> 00:30:29,840

shown here on the left hand side of the

889
00:30:33,909 --> 00:30:32,240
diagram

890
00:30:35,510 --> 00:30:33,919
when you measure the ripples in the

891
00:30:35,990 --> 00:30:35,520
cosmic microwave background that gives

892
00:30:39,510 --> 00:30:36,000
you

893
00:30:41,430 --> 00:30:39,520
an estimate of how much how fast the

894
00:30:42,310 --> 00:30:41,440
universe is expanding and the planck

895
00:30:45,190 --> 00:30:42,320
team

896
00:30:46,950 --> 00:30:45,200
they measured a hubble constant of h

897
00:30:48,950 --> 00:30:46,960
naught of 67.4

898
00:30:50,310 --> 00:30:48,960
plus or minus 0.5 kilometers per second

899
00:30:51,830 --> 00:30:50,320
per megaparsec

900
00:30:53,430 --> 00:30:51,840
and given the small uncertainty there

901
00:30:55,350 --> 00:30:53,440
that's significantly dif

902
00:30:57,029 --> 00:30:55,360
different than the expansion rate

903
00:30:59,990 --> 00:30:57,039
measured from supernova and cepheus

904
00:31:02,070 --> 00:31:00,000
which is 73.2 plus or minus 1.3

905
00:31:03,430 --> 00:31:02,080
these two measurements are significantly

906
00:31:06,630 --> 00:31:03,440
discrepant with each other

907
00:31:08,870 --> 00:31:06,640
now the planck measurement is looking at

908
00:31:12,070 --> 00:31:08,880
the relics left over from the big bang

909
00:31:13,909 --> 00:31:12,080
and working forward from that the

910
00:31:15,590 --> 00:31:13,919
cepheid and supernova method is looking

911
00:31:17,909 --> 00:31:15,600
in the nearby universe and working

912
00:31:19,350 --> 00:31:17,919
outward so maybe that's the source of

913
00:31:20,950 --> 00:31:19,360

the discrepancy here they're both coming

914
00:31:21,269 --> 00:31:20,960
at the problem from different angles and

915
00:31:23,029 --> 00:31:21,279
and

916
00:31:24,470 --> 00:31:23,039
somewhere along the line there there's

917
00:31:26,149 --> 00:31:24,480
new physics at work that

918
00:31:28,789 --> 00:31:26,159
cause the disconnect and that's still

919
00:31:30,389 --> 00:31:28,799
under investigation

920
00:31:32,950 --> 00:31:30,399
there are complementary programs

921
00:31:36,789 --> 00:31:32,960
exploring the cosmic expansion

922
00:31:39,190 --> 00:31:36,799
using different methods so this is

923
00:31:40,230 --> 00:31:39,200
using what's known as a color magnitude

924
00:31:41,830 --> 00:31:40,240
diagram

925
00:31:44,149 --> 00:31:41,840
if you measure the brightnesses and

926
00:31:47,110 --> 00:31:44,159
colors for a group of stars

927
00:31:49,110 --> 00:31:47,120
those aren't random this is a plot here

928
00:31:50,230 --> 00:31:49,120
of brightness on the y-axis and color on

929
00:31:52,710 --> 00:31:50,240
the x-axis

930
00:31:53,909 --> 00:31:52,720
for a group of stars and you can see

931
00:31:56,230 --> 00:31:53,919
that

932
00:31:57,669 --> 00:31:56,240
it traces out a particular pattern dwarf

933
00:32:00,070 --> 00:31:57,679
stars like our own sun

934
00:32:02,149 --> 00:32:00,080
fall near the bottom of this diagram

935
00:32:04,549 --> 00:32:02,159
those stars like our own sun eventually

936
00:32:06,549 --> 00:32:04,559
swell up and become red giant stars so

937
00:32:07,909 --> 00:32:06,559
towards the upper right of this diagram

938
00:32:09,350 --> 00:32:07,919

until they reach the tip of the red

939
00:32:10,389 --> 00:32:09,360
giant branch the brightest red giant

940
00:32:13,669 --> 00:32:10,399
branch stars

941
00:32:15,590 --> 00:32:13,679
and those are a standard candle

942
00:32:17,190 --> 00:32:15,600
so what wendy friedman's team is doing

943
00:32:18,789 --> 00:32:17,200
here is using hubble these are hubble

944
00:32:20,630 --> 00:32:18,799
images shown on the right here

945
00:32:22,630 --> 00:32:20,640
looking at nearby galaxies and their

946
00:32:23,590 --> 00:32:22,640
outskirts for bright red giant branch

947
00:32:25,430 --> 00:32:23,600
stars and

948
00:32:27,269 --> 00:32:25,440
measuring all the brightnesses of the

949
00:32:29,190 --> 00:32:27,279
red giant branch stars in those

950
00:32:30,789 --> 00:32:29,200
outskirts of those galaxies and because

951
00:32:32,149 --> 00:32:30,799
it's a standard candle the red giant

952
00:32:33,830 --> 00:32:32,159
branch star

953
00:32:36,389 --> 00:32:33,840
that gives you a distance to these

954
00:32:37,509 --> 00:32:36,399
galaxies and then when supernova go off

955
00:32:39,190 --> 00:32:37,519
in those galaxies you have a new

956
00:32:40,630 --> 00:32:39,200
calibration for supernova and now

957
00:32:42,630 --> 00:32:40,640
the rest of the technique is similar to

958
00:32:43,990 --> 00:32:42,640
what i just showed you in the last slide

959
00:32:45,990 --> 00:32:44,000
this is a different way of calibrating

960
00:32:47,750 --> 00:32:46,000
supernova as standard candles

961
00:32:50,149 --> 00:32:47,760
using red giant branch stars instead of

962
00:32:52,070 --> 00:32:50,159
cepheids and using this method

963
00:32:55,029 --> 00:32:52,080

freeman and all found a hubble constant

964
00:32:56,549 --> 00:32:55,039
of 69.8 plus or minus 1.9 kilometers per

965
00:32:58,470 --> 00:32:56,559
second per megaparsec

966
00:33:01,590 --> 00:32:58,480
which falls between the two measurements

967
00:33:03,110 --> 00:33:01,600
i mentioned previously

968
00:33:05,190 --> 00:33:03,120
a completely different way of coming at

969
00:33:06,789 --> 00:33:05,200
this problem is with

970
00:33:08,310 --> 00:33:06,799
gravitational lensing this is a little

971
00:33:10,070 --> 00:33:08,320
bit of a trickier concept

972
00:33:11,590 --> 00:33:10,080
what i'm showing you here on the left

973
00:33:14,310 --> 00:33:11,600
are four

974
00:33:15,830 --> 00:33:14,320
images with hubble of a gravitational

975
00:33:16,470 --> 00:33:15,840
lens system and what a gravitational

976
00:33:19,110 --> 00:33:16,480
lens is

977
00:33:20,549 --> 00:33:19,120
is you have a massive object with a

978
00:33:21,509 --> 00:33:20,559
strong gravitational field in the

979
00:33:23,269 --> 00:33:21,519
foreground

980
00:33:25,110 --> 00:33:23,279
and then some background object that

981
00:33:26,230 --> 00:33:25,120
appears distorted on the sky because the

982
00:33:29,350 --> 00:33:26,240
light is reaching us

983
00:33:31,669 --> 00:33:29,360
through that gravitational lens and so i

984
00:33:33,509 --> 00:33:31,679
can demonstrate this schematically

985
00:33:35,029 --> 00:33:33,519
here's the observer the hubble space

986
00:33:36,310 --> 00:33:35,039
telescope

987
00:33:37,509 --> 00:33:36,320
we're collecting data with that and

988
00:33:39,590 --> 00:33:37,519

we're looking out into the distant

989
00:33:42,549 --> 00:33:39,600
universe at a foreground

990
00:33:43,590 --> 00:33:42,559
lens lensing galaxy so this galaxy acts

991
00:33:45,350 --> 00:33:43,600
like a lens because

992
00:33:47,110 --> 00:33:45,360
its gravitational field is so strong

993
00:33:50,149 --> 00:33:47,120
that the space space time is

994
00:33:52,389 --> 00:33:50,159
significantly curved around that galaxy

995
00:33:53,750 --> 00:33:52,399
you have a distant background object a

996
00:33:56,470 --> 00:33:53,760
lensed quasar

997
00:33:57,669 --> 00:33:56,480
so quasar is a active galaxy in the

998
00:33:59,590 --> 00:33:57,679
distant universe

999
00:34:01,750 --> 00:33:59,600
powered by a supermassive black hole and

1000
00:34:03,590 --> 00:34:01,760
often has variations in its light

1001
00:34:05,750 --> 00:34:03,600
and the light from that quasar can reach

1002
00:34:05,990 --> 00:34:05,760
us to along different paths because of

1003
00:34:08,869 --> 00:34:06,000
the

1004
00:34:10,790 --> 00:34:08,879
lensing here so it can go along this

1005
00:34:13,589 --> 00:34:10,800
path i've shown schematically by path

1006
00:34:15,510 --> 00:34:13,599
a here it bends around the lens because

1007
00:34:17,909 --> 00:34:15,520
of the gravitational field of that

1008
00:34:19,750 --> 00:34:17,919
foreground galaxy and then we're looking

1009
00:34:22,629 --> 00:34:19,760
backwards along that sight line

1010
00:34:26,710 --> 00:34:22,639
so we see the lens quasar image offset

1011
00:34:30,470 --> 00:34:28,869
light can also take path b here along

1012
00:34:32,149 --> 00:34:30,480
this curved path

1013
00:34:34,149 --> 00:34:32,159

and again we look back along the sight

1014
00:34:35,990 --> 00:34:34,159
line and the dotted line says the

1015
00:34:37,430 --> 00:34:36,000
this quasar image appears offset in the

1016
00:34:38,550 --> 00:34:37,440
other direction and this is how you can

1017
00:34:40,950 --> 00:34:38,560
get multiple

1018
00:34:42,389 --> 00:34:40,960
images of the same object on the sky and

1019
00:34:43,109 --> 00:34:42,399
that's what's shown here in the lower

1020
00:34:44,550 --> 00:34:43,119
left

1021
00:34:46,069 --> 00:34:44,560
if you see the hubble images here

1022
00:34:47,190 --> 00:34:46,079
there's a yellow object that's the

1023
00:34:49,270 --> 00:34:47,200
lensing object

1024
00:34:50,470 --> 00:34:49,280
and then the white objects around it are

1025
00:34:52,230 --> 00:34:50,480
all the same object but they're

1026
00:34:53,430 --> 00:34:52,240
appearing offset on the sky because of

1027
00:34:56,550 --> 00:34:53,440
this lensing effect

1028
00:34:59,349 --> 00:34:56,560
and this is just from nature and gravity

1029
00:35:01,270 --> 00:34:59,359
so this actually gives you enough

1030
00:35:02,230 --> 00:35:01,280
information to constrain cosmology

1031
00:35:04,630 --> 00:35:02,240
because the light

1032
00:35:06,710 --> 00:35:04,640
is traveling to us from the quasar along

1033
00:35:09,510 --> 00:35:06,720
those different paths it takes different

1034
00:35:11,190 --> 00:35:09,520
amounts of time to reach the eye because

1035
00:35:12,710 --> 00:35:11,200
those paths are not the same length

1036
00:35:14,829 --> 00:35:12,720
and in this example here that light

1037
00:35:16,150 --> 00:35:14,839
travel time can vary by about 10 days or

1038
00:35:19,670 --> 00:35:16,160

so

1039
00:35:21,430 --> 00:35:19,680
actually

1040
00:35:23,109 --> 00:35:21,440
solve for the cosmology use high

1041
00:35:25,750 --> 00:35:23,119
resolution hubble images

1042
00:35:26,870 --> 00:35:25,760
to model the gravitational lens system

1043
00:35:29,109 --> 00:35:26,880
and then you monitor

1044
00:35:31,589 --> 00:35:29,119
those different images of the quasar on

1045
00:35:34,150 --> 00:35:31,599
the sky and look for flickering

1046
00:35:35,109 --> 00:35:34,160
in those images and variations in the

1047
00:35:37,589 --> 00:35:35,119
light

1048
00:35:38,870 --> 00:35:37,599
and if you see a one change happen in

1049
00:35:40,630 --> 00:35:38,880
the light with one image and then it

1050
00:35:42,870 --> 00:35:40,640
happens ten days later and another

1051
00:35:44,710 --> 00:35:42,880
in the other image of that quasar you

1052
00:35:46,550 --> 00:35:44,720
that gives you a sense of the time delay

1053
00:35:47,990 --> 00:35:46,560
along those two different paths

1054
00:35:50,390 --> 00:35:48,000
you combine that information and

1055
00:35:53,750 --> 00:35:50,400
constrains the geometry of space time

1056
00:35:55,750 --> 00:35:53,760
along and all in this example here

1057
00:35:58,150 --> 00:35:55,760
used such measurements to get a hubble

1058
00:36:00,069 --> 00:35:58,160
constant of 73.3 kilometers per second

1059
00:36:01,510 --> 00:36:00,079
per megaparsec which is very similar to

1060
00:36:03,190 --> 00:36:01,520
the first case i showed you with the

1061
00:36:05,430 --> 00:36:03,200
supernova and the cepheids from reefs at

1062
00:36:09,430 --> 00:36:07,589
now the hubble frontier fields is a

1063
00:36:11,190 --> 00:36:09,440

program with hubble that

1064
00:36:12,630 --> 00:36:11,200
really delved into this gravitational

1065
00:36:14,630 --> 00:36:12,640
lensing effect

1066
00:36:16,310 --> 00:36:14,640
this was a director's discretionary

1067
00:36:18,550 --> 00:36:16,320
program

1068
00:36:20,310 --> 00:36:18,560
of 840 orbits the director of space

1069
00:36:20,950 --> 00:36:20,320
telescope gets a pool of orbits every

1070
00:36:22,630 --> 00:36:20,960
year

1071
00:36:24,390 --> 00:36:22,640
that can be applied towards large

1072
00:36:27,430 --> 00:36:24,400
programs that benefit

1073
00:36:30,310 --> 00:36:27,440
a large area of research in the field

1074
00:36:31,430 --> 00:36:30,320
and that's what was done here i was 840

1075
00:36:34,310 --> 00:36:31,440
orbits and was

1076
00:36:35,750 --> 00:36:34,320
used to observe six massive galaxy

1077
00:36:38,310 --> 00:36:35,760
clusters which are shown in the

1078
00:36:39,670 --> 00:36:38,320
six top panels in this figure here and

1079
00:36:40,790 --> 00:36:39,680
because we have two cameras on hubble

1080
00:36:42,069 --> 00:36:40,800
while one's looking in the galaxy

1081
00:36:43,670 --> 00:36:42,079
cluster the other one

1082
00:36:45,270 --> 00:36:43,680
is looking in a nearby empty field a

1083
00:36:47,910 --> 00:36:45,280
parallel field so those are shown along

1084
00:36:52,310 --> 00:36:50,630
and the research you can do with this uh

1085
00:36:53,670 --> 00:36:52,320
is really amplifying what's possible

1086
00:36:54,710 --> 00:36:53,680
with hubble due to the gravitational

1087
00:36:58,550 --> 00:36:54,720
lensing

1088
00:37:01,430 --> 00:36:58,560

because gravity's

1089
00:37:02,550 --> 00:37:01,440
galaxies can be magnified by up to a

1090
00:37:04,550 --> 00:37:02,560
factor of 50.

1091
00:37:06,550 --> 00:37:04,560
hubble can detect galaxies 10 times

1092
00:37:09,030 --> 00:37:06,560
fainter than otherwise possible

1093
00:37:10,230 --> 00:37:09,040
and in the work here by rachel livermore

1094
00:37:13,750 --> 00:37:10,240
she used this

1095
00:37:14,870 --> 00:37:13,760
lensing to see into the distant universe

1096
00:37:16,550 --> 00:37:14,880
and look at the role of

1097
00:37:18,470 --> 00:37:16,560
faint galaxies in the evolution of the

1098
00:37:19,990 --> 00:37:18,480
early universe and demonstrated that

1099
00:37:23,990 --> 00:37:20,000
they had a significant role in the

1100
00:37:29,589 --> 00:37:27,270
so here are the lens images again

1101
00:37:31,109 --> 00:37:29,599
for all six galaxy clusters as i

1102
00:37:32,550 --> 00:37:31,119
mentioned if something happens if

1103
00:37:34,069 --> 00:37:32,560
there's a variation with one of the

1104
00:37:35,430 --> 00:37:34,079
lensed objects as i was talking about

1105
00:37:37,430 --> 00:37:35,440
the quasar earlier

1106
00:37:39,750 --> 00:37:37,440
because the light takes different paths

1107
00:37:41,430 --> 00:37:39,760
to get here through the lensing system

1108
00:37:43,030 --> 00:37:41,440
you might see the same event happen

1109
00:37:44,630 --> 00:37:43,040
multiple times and we were actually

1110
00:37:47,589 --> 00:37:44,640
lucky enough to have that happen in one

1111
00:37:50,230 --> 00:37:47,599
of these galaxy clusters a supernova

1112
00:37:51,990 --> 00:37:50,240
that was lensed occurred so a star

1113
00:37:54,630 --> 00:37:52,000

system exploded one time but we got to

1114
00:37:57,190 --> 00:37:54,640
see that explosion multiple times

1115
00:37:58,950 --> 00:37:57,200
and so that was in this one system here

1116
00:38:00,150 --> 00:37:58,960
it turns out that the supernova if we

1117
00:38:02,150 --> 00:38:00,160
had been looking would have been first

1118
00:38:03,349 --> 00:38:02,160
visible in 1995 that was the earliest

1119
00:38:05,510 --> 00:38:03,359
the light reached us

1120
00:38:06,630 --> 00:38:05,520
but no one was looking at that time so

1121
00:38:11,030 --> 00:38:06,640
that's shown here

1122
00:38:12,950 --> 00:38:11,040
that happened there but then in 2014

1123
00:38:15,030 --> 00:38:12,960
we saw the supernova occur in a lensed

1124
00:38:16,630 --> 00:38:15,040
image and modeling of the lens system

1125
00:38:17,990 --> 00:38:16,640
implied it would happen again and indeed

1126
00:38:19,430 --> 00:38:18,000
it was observed to happen again in

1127
00:38:22,230 --> 00:38:19,440
december of 2015

1128
00:38:23,270 --> 00:38:22,240
just in line with the predictions and if

1129
00:38:25,750 --> 00:38:23,280
you combine

1130
00:38:27,430 --> 00:38:25,760
the measurements similar to the method i

1131
00:38:30,950 --> 00:38:27,440
showed you before with long and all

1132
00:38:32,630 --> 00:38:30,960
this team who looked at these data first

1133
00:38:34,150 --> 00:38:32,640
shown in the bottom of the slide here

1134
00:38:36,150 --> 00:38:34,160
obtained an expansion rate of the

1135
00:38:37,349 --> 00:38:36,160
universe of 64 kilometers per second

1136
00:38:38,550 --> 00:38:37,359
which is a little lower than some of the

1137
00:38:40,470 --> 00:38:38,560
other measurements i mentioned

1138
00:38:41,670 --> 00:38:40,480

earlier but the uncertainties are

1139
00:38:43,349 --> 00:38:41,680
significantly larger

1140
00:38:47,349 --> 00:38:43,359
it's roughly plus or minus 10 kilometers

1141
00:38:49,829 --> 00:38:47,359
per second so it's still consistent

1142
00:38:50,550 --> 00:38:49,839
now i'm going to switch gears here and

1143
00:38:51,829 --> 00:38:50,560
talk about

1144
00:38:53,990 --> 00:38:51,839
the other topic i mentioned in the

1145
00:38:57,829 --> 00:38:54,000
beginning which is exoplanet science

1146
00:39:00,230 --> 00:38:57,839
so exoplanet science began in the 1980s

1147
00:39:01,910 --> 00:39:00,240
that's with this image here on the left

1148
00:39:04,069 --> 00:39:01,920
the beta pictoris system

1149
00:39:06,230 --> 00:39:04,079
then now in this image from the las

1150
00:39:08,950 --> 00:39:06,240
companus observatory

1151
00:39:10,390 --> 00:39:08,960
what was seen once the telescope was

1152
00:39:12,470 --> 00:39:10,400
used in a way

1153
00:39:13,430 --> 00:39:12,480
employing a coronagraph to block out the

1154
00:39:15,430 --> 00:39:13,440
central light

1155
00:39:16,790 --> 00:39:15,440
and see the objects the fainter objects

1156
00:39:19,589 --> 00:39:16,800
around the bright star

1157
00:39:21,109 --> 00:39:19,599
what was seen was a planetary disk so a

1158
00:39:24,069 --> 00:39:21,119
baby soul system being

1159
00:39:25,430 --> 00:39:24,079
born and so this although this didn't

1160
00:39:26,950 --> 00:39:25,440
show us planets it showed us a

1161
00:39:29,270 --> 00:39:26,960
protoplanetary disk

1162
00:39:31,030 --> 00:39:29,280
being born in this system hubble

1163
00:39:34,150 --> 00:39:31,040

launched in 1990 at the time there were

1164
00:39:35,829 --> 00:39:34,160
no known exoplanets

1165
00:39:38,550 --> 00:39:35,839
the first normal exoplanet that was

1166
00:39:40,310 --> 00:39:38,560
discovered is this system 51 pegasi

1167
00:39:41,829 --> 00:39:40,320
and it wasn't done through imaging it

1168
00:39:43,349 --> 00:39:41,839
was done through what are known as

1169
00:39:45,030 --> 00:39:43,359
radial velocity measurements so what's

1170
00:39:46,630 --> 00:39:45,040
being plotted here is the velocity

1171
00:39:48,710 --> 00:39:46,640
variation in the star

1172
00:39:50,310 --> 00:39:48,720
along our sight line so our radial

1173
00:39:52,870 --> 00:39:50,320
velocity

1174
00:39:55,109 --> 00:39:52,880
as the star is wobbling due to the

1175
00:39:57,589 --> 00:39:55,119
tugging the gravitational pull

1176
00:39:59,030 --> 00:39:57,599
of a planet orbiting that star and so

1177
00:39:59,910 --> 00:39:59,040
this is just the change in radio

1178
00:40:01,589 --> 00:39:59,920
velocity

1179
00:40:03,030 --> 00:40:01,599
as a function of time over and over

1180
00:40:03,349 --> 00:40:03,040
again is what's being shown here over

1181
00:40:06,630 --> 00:40:03,359
the

1182
00:40:08,829 --> 00:40:06,640
its star

1183
00:40:10,309 --> 00:40:08,839
so that was in the mid 90s after hubble

1184
00:40:11,750 --> 00:40:10,319
launched

1185
00:40:14,630 --> 00:40:11,760
hubble did play a role in what's

1186
00:40:17,109 --> 00:40:14,640
currently known as the currently

1187
00:40:18,870 --> 00:40:17,119
the oldest known exoplanet and this is a

1188
00:40:20,309 --> 00:40:18,880

system that has a story that goes back

1189
00:40:22,230 --> 00:40:20,319
over a number of years so what i'm

1190
00:40:25,270 --> 00:40:22,240
showing in the center here is

1191
00:40:25,829 --> 00:40:25,280
an image from hubble of the globular

1192
00:40:34,230 --> 00:40:25,839
cluster

1193
00:40:36,790 --> 00:40:34,240
old stars roughly 13 billion years old

1194
00:40:37,670 --> 00:40:36,800
about a hundred thousand stars or more

1195
00:40:40,710 --> 00:40:37,680
and in

1196
00:40:43,750 --> 00:40:40,720
this globular cluster

1197
00:40:44,550 --> 00:40:43,760
in the late 80s a binary pulsar was

1198
00:40:46,150 --> 00:40:44,560
discovered

1199
00:40:48,150 --> 00:40:46,160
i'm not using hubble this is before

1200
00:40:49,750 --> 00:40:48,160
hubble launched a pulsar is kind of like

1201
00:40:52,069 --> 00:40:49,760
an astronomical light

1202
00:40:53,589 --> 00:40:52,079
house it's a collapsed neutron star

1203
00:40:55,190 --> 00:40:53,599
that's spinning very rapidly and sending

1204
00:40:56,470 --> 00:40:55,200
out a beam of energy into the universe

1205
00:40:57,589 --> 00:40:56,480
over and over again with a repeated

1206
00:41:00,390 --> 00:40:57,599
signal

1207
00:41:02,390 --> 00:41:00,400
in the early 90s multiple papers were

1208
00:41:03,829 --> 00:41:02,400
published showing that this pulsar had a

1209
00:41:05,030 --> 00:41:03,839
timing anomaly and that might be

1210
00:41:07,910 --> 00:41:05,040
indicating the presence

1211
00:41:10,069 --> 00:41:07,920
of a jupiter mass planet in the system

1212
00:41:11,750 --> 00:41:10,079
in the late 90s radio observations

1213
00:41:14,230 --> 00:41:11,760

gave more evidence that there was a

1214
00:41:17,030 --> 00:41:14,240
planet present and then 2003

1215
00:41:19,270 --> 00:41:17,040
astronomers used those data plus several

1216
00:41:19,990 --> 00:41:19,280
years of hubble imaging to conclusively

1217
00:41:21,589 --> 00:41:20,000
demonstrate

1218
00:41:22,950 --> 00:41:21,599
that there was a planet in the system

1219
00:41:24,230 --> 00:41:22,960
and that planet was two and a half times

1220
00:41:25,430 --> 00:41:24,240
the mass of jupiter and it was actually

1221
00:41:27,750 --> 00:41:25,440
a triple system

1222
00:41:29,670 --> 00:41:27,760
and given where this was it's a triple

1223
00:41:30,309 --> 00:41:29,680
system 13 billion years old so this is

1224
00:41:33,510 --> 00:41:30,319
the oldest

1225
00:41:37,910 --> 00:41:35,430
this plot at the bottom i'm showing from

1226
00:41:40,230 --> 00:41:37,920
sarah seeger demonstrates the difficulty

1227
00:41:41,670 --> 00:41:40,240
in doing exoplanet science it's a plot

1228
00:41:45,190 --> 00:41:41,680
of the energy of an object

1229
00:41:46,870 --> 00:41:45,200
versus the wavelength in microns

1230
00:41:49,030 --> 00:41:46,880
for different types of objects at the

1231
00:41:50,870 --> 00:41:49,040
top is in yellow is the spectrum you get

1232
00:41:53,190 --> 00:41:50,880
from a sun-like star

1233
00:41:55,430 --> 00:41:53,200
so star like our own sun the y-axis here

1234
00:41:56,309 --> 00:41:55,440
is logarithmic so as you move down this

1235
00:41:57,589 --> 00:41:56,319
scale

1236
00:41:59,349 --> 00:41:57,599
things are changing by an order of

1237
00:42:02,230 --> 00:41:59,359
magnitude by factors of 10

1238
00:42:04,150 --> 00:42:02,240

and so as you go down to the hot jupiter

1239
00:42:04,710 --> 00:42:04,160
here the next lowest object the dotted

1240
00:42:07,990 --> 00:42:04,720
line

1241
00:42:10,150 --> 00:42:08,000
that's what you would see for a jupiter

1242
00:42:11,750 --> 00:42:10,160
that's orbiting very close to its host

1243
00:42:13,190 --> 00:42:11,760
star so a hot jupiter and you can see

1244
00:42:13,990 --> 00:42:13,200
its orders are magnitude fainter than

1245
00:42:15,990 --> 00:42:14,000
its star

1246
00:42:17,670 --> 00:42:16,000
and then other planets that we see in

1247
00:42:20,150 --> 00:42:17,680
our own solar system like jupiter

1248
00:42:21,829 --> 00:42:20,160
venus earth and mars they're orders of

1249
00:42:23,510 --> 00:42:21,839
magnitude fainter still

1250
00:42:25,190 --> 00:42:23,520
so this is the trickiness of trying to

1251
00:42:28,309 --> 00:42:25,200
do exoplanet science

1252
00:42:31,190 --> 00:42:28,319
which is that exoplanets are

1253
00:42:33,990 --> 00:42:31,200
very faint objects extremely close to

1254
00:42:36,790 --> 00:42:34,000
much brighter objects their host stars

1255
00:42:38,470 --> 00:42:36,800
and so you need to try to mask the light

1256
00:42:39,750 --> 00:42:38,480
from that bright star if you want to see

1257
00:42:41,349 --> 00:42:39,760
the planet

1258
00:42:42,950 --> 00:42:41,359
or you have to look at the effects of

1259
00:42:45,109 --> 00:42:42,960
that planet on its host star

1260
00:42:46,790 --> 00:42:45,119
the light from that host star and that

1261
00:42:48,150 --> 00:42:46,800
it requires a very careful measurement

1262
00:42:50,150 --> 00:42:48,160
since the planets are so much fainter

1263
00:42:52,550 --> 00:42:50,160

than the host star

1264
00:42:54,230 --> 00:42:52,560
this diagram now here in the lower right

1265
00:42:55,670 --> 00:42:54,240
this is a plot of the number of known

1266
00:42:57,670 --> 00:42:55,680
exoplanets

1267
00:42:59,510 --> 00:42:57,680
over the lifetime of hubble going back

1268
00:43:00,790 --> 00:42:59,520
to 1990 to the present and you can see

1269
00:43:02,069 --> 00:43:00,800
when hubble launched there were no known

1270
00:43:03,589 --> 00:43:02,079
exoplanets and today we know of

1271
00:43:05,030 --> 00:43:03,599
thousands of exoplanets

1272
00:43:06,470 --> 00:43:05,040
and the different colors here are the

1273
00:43:08,630 --> 00:43:06,480
different methods for discovering

1274
00:43:10,550 --> 00:43:08,640
exoplanets as i said hubble is not used

1275
00:43:13,990 --> 00:43:10,560
generally to discover exoplanets

1276
00:43:15,270 --> 00:43:14,000
but it is used to follow them up

1277
00:43:17,109 --> 00:43:15,280
so i'll go through some of the

1278
00:43:18,550 --> 00:43:17,119
highlights of hubble's exoplanet work

1279
00:43:21,349 --> 00:43:18,560
here over the years

1280
00:43:23,190 --> 00:43:21,359
so hubble was used at for the first

1281
00:43:24,150 --> 00:43:23,200
detection of an atmosphere around an

1282
00:43:26,710 --> 00:43:24,160
exoplanet

1283
00:43:28,309 --> 00:43:26,720
this was done with this spectrograph

1284
00:43:29,109 --> 00:43:28,319
shown by the artist rendition here in

1285
00:43:31,589 --> 00:43:29,119
the middle

1286
00:43:33,750 --> 00:43:31,599
and what was done here is that stis

1287
00:43:35,750 --> 00:43:33,760
observed this exoplanet system

1288
00:43:37,670 --> 00:43:35,760

during four orbits of the planet around

1289
00:43:40,550 --> 00:43:37,680
its star

1290
00:43:42,710 --> 00:43:40,560
we obtain data like that's shown here on

1291
00:43:44,710 --> 00:43:42,720
the right this is the spectrum

1292
00:43:47,270 --> 00:43:44,720
so variations in energy versus

1293
00:43:49,430 --> 00:43:47,280
wavelength on the x-axis and microns

1294
00:43:51,670 --> 00:43:49,440
those little wiggles in the black data

1295
00:43:53,510 --> 00:43:51,680
points there are from the variations

1296
00:43:54,710 --> 00:43:53,520
in the chemistry of this atmosphere and

1297
00:43:57,430 --> 00:43:54,720
we've highlighted

1298
00:43:58,390 --> 00:43:57,440
the sodium feature in gray there the

1299
00:44:00,069 --> 00:43:58,400
sodium feature

1300
00:44:02,390 --> 00:44:00,079
in this spectrum over the course of

1301
00:44:04,790 --> 00:44:02,400
these observations varied significantly

1302
00:44:06,790 --> 00:44:04,800
due to the fact that the as the planet

1303
00:44:08,630 --> 00:44:06,800
passed in front of the star

1304
00:44:10,150 --> 00:44:08,640
the sodium in the atmosphere that planet

1305
00:44:11,349 --> 00:44:10,160
changed the sodium feature in the

1306
00:44:13,990 --> 00:44:11,359
spectrum

1307
00:44:15,430 --> 00:44:14,000
so this was the first exoplanet

1308
00:44:18,790 --> 00:44:15,440
atmosphere

1309
00:44:20,710 --> 00:44:18,800
found in a another star system

1310
00:44:21,910 --> 00:44:20,720
this star has a spectral type similar to

1311
00:44:25,910 --> 00:44:21,920
the sun and the planet has a mass

1312
00:44:29,349 --> 00:44:27,510
this is the first detection of an

1313
00:44:30,230 --> 00:44:29,359

organic molecule in an exoplanet

1314
00:44:32,790 --> 00:44:30,240
atmosphere

1315
00:44:33,430 --> 00:44:32,800
this was done with the nikmos instrument

1316
00:44:35,030 --> 00:44:33,440
which is still

1317
00:44:37,589 --> 00:44:35,040
on board hubble although it's no longer

1318
00:44:40,550 --> 00:44:37,599
operational what was performed here

1319
00:44:41,190 --> 00:44:40,560
was using nickmas observers watched the

1320
00:44:43,109 --> 00:44:41,200
planet

1321
00:44:45,510 --> 00:44:43,119
transit in front of its star and then go

1322
00:44:47,990 --> 00:44:45,520
behind its star the secondary eclipse

1323
00:44:49,670 --> 00:44:48,000
and the variations seen in the spectrum

1324
00:44:51,829 --> 00:44:49,680
over the course of that time there

1325
00:44:53,670 --> 00:44:51,839
was consistent with methane absorption

1326
00:44:55,750 --> 00:44:53,680
in the exoplanet atmosphere

1327
00:44:57,670 --> 00:44:55,760
so in the center bottom of the diagram

1328
00:44:58,950 --> 00:44:57,680
here you can see the variation in light

1329
00:45:01,349 --> 00:44:58,960
over time

1330
00:45:03,109 --> 00:45:01,359
at different wavelengths as the planet

1331
00:45:04,710 --> 00:45:03,119
passes in front of its star

1332
00:45:06,710 --> 00:45:04,720
and the lower right are the

1333
00:45:08,790 --> 00:45:06,720
spectroscopic data

1334
00:45:11,030 --> 00:45:08,800
this is a plot of absorption versus

1335
00:45:14,309 --> 00:45:11,040
wavelength and microns the black points

1336
00:45:15,990 --> 00:45:14,319
are the hubble data and then the curves

1337
00:45:16,950 --> 00:45:16,000
in orange and blue are different models

1338
00:45:18,390 --> 00:45:16,960

for what could be happening in the

1339
00:45:19,430 --> 00:45:18,400
atmosphere and you can see the orange

1340
00:45:21,109 --> 00:45:19,440
model which has the right amount of

1341
00:45:21,910 --> 00:45:21,119
methane agrees well with the black

1342
00:45:23,910 --> 00:45:21,920
points

1343
00:45:27,829 --> 00:45:23,920
indicating there is methane in the

1344
00:45:32,230 --> 00:45:30,870
this is hubble a few years ago now this

1345
00:45:34,470 --> 00:45:32,240
is more recently

1346
00:45:35,990 --> 00:45:34,480
using the spatial scanning technique i

1347
00:45:36,950 --> 00:45:36,000
mentioned earlier where we intentionally

1348
00:45:39,510 --> 00:45:36,960
drag out

1349
00:45:41,829 --> 00:45:39,520
the spectrum over the detector to obtain

1350
00:45:44,630 --> 00:45:41,839
more signal and get a more refined

1351
00:45:45,670 --> 00:45:44,640
uh signal for the exoplanet so this

1352
00:45:47,829 --> 00:45:45,680
enabled

1353
00:45:49,910 --> 00:45:47,839
the observation of simultaneous transits

1354
00:45:51,190 --> 00:45:49,920
of two earth-sized exoplanets around

1355
00:45:52,790 --> 00:45:51,200
their host star that's what's shown by

1356
00:45:55,829 --> 00:45:52,800
the artist's rendition here

1357
00:45:57,670 --> 00:45:55,839
this planets are trappist 1b and 1c this

1358
00:45:59,109 --> 00:45:57,680
is the trappist system

1359
00:46:01,109 --> 00:45:59,119
the data from hubble are shown on the

1360
00:46:03,349 --> 00:46:01,119
bottom again this is

1361
00:46:04,309 --> 00:46:03,359
changes in energy or flux versus

1362
00:46:05,829 --> 00:46:04,319
wavelength

1363
00:46:07,990 --> 00:46:05,839

so these are the spectra the black

1364
00:46:09,589 --> 00:46:08,000
points are the data points from hubble

1365
00:46:10,710 --> 00:46:09,599
and then the different colored curves

1366
00:46:12,550 --> 00:46:10,720
are different models for what's

1367
00:46:14,550 --> 00:46:12,560
happening in the atmosphere

1368
00:46:15,670 --> 00:46:14,560
and the best agreement comes when you

1369
00:46:17,670 --> 00:46:15,680
minimize the amount of

1370
00:46:19,990 --> 00:46:17,680
helium and hydrogen in the envelopes for

1371
00:46:21,109 --> 00:46:20,000
this exoplanet these exoplanets

1372
00:46:23,270 --> 00:46:21,119
and so that means these exoplanet

1373
00:46:23,510 --> 00:46:23,280
atmospheres have little hydrogen helium

1374
00:46:26,829 --> 00:46:23,520
and

1375
00:46:28,870 --> 00:46:26,839
increases the odds that they're

1376
00:46:30,550 --> 00:46:28,880
habitable

1377
00:46:32,790 --> 00:46:30,560
finally i'm showing you here a more

1378
00:46:34,790 --> 00:46:32,800
recent result from hannah wakeford

1379
00:46:36,390 --> 00:46:34,800
this is the most detailed look at an

1380
00:46:38,790 --> 00:46:36,400
exoplanet atmosphere

1381
00:46:40,550 --> 00:46:38,800
to date it combines data from three

1382
00:46:42,230 --> 00:46:40,560
different telescopes hubble

1383
00:46:43,910 --> 00:46:42,240
in space two of its instruments the very

1384
00:46:45,670 --> 00:46:43,920
large telescope on the ground one of its

1385
00:46:47,910 --> 00:46:45,680
instruments and then the spitzer space

1386
00:46:49,190 --> 00:46:47,920
space telescope one of its instruments

1387
00:46:50,069 --> 00:46:49,200
and you combine all those together you

1388
00:46:51,990 --> 00:46:50,079

get the spectrum

1389
00:46:53,829 --> 00:46:52,000
the composite spectrum on the upper

1390
00:46:55,589 --> 00:46:53,839
right there shown

1391
00:46:57,990 --> 00:46:55,599
on top of an artist rendition of the

1392
00:46:59,910 --> 00:46:58,000
planet this is a plot of

1393
00:47:01,510 --> 00:46:59,920
the signal strength on the y-axis versus

1394
00:47:06,150 --> 00:47:01,520
microns on the x-axis

1395
00:47:07,910 --> 00:47:06,160
and the different wiggles in that

1396
00:47:09,589 --> 00:47:07,920
spectrum are due to the chemistry of the

1397
00:47:12,870 --> 00:47:09,599
exoplanet so you can see

1398
00:47:15,349 --> 00:47:12,880
hydrogen helium sodium potassium water

1399
00:47:17,670 --> 00:47:15,359
and carbon dioxide

1400
00:47:19,349 --> 00:47:17,680
so this system uh the planet here is

1401
00:47:21,589 --> 00:47:19,359
called wasp 39b

1402
00:47:23,430 --> 00:47:21,599
it's thought to be a hot saturn orbiting

1403
00:47:25,510 --> 00:47:23,440
a sun-like star

1404
00:47:27,270 --> 00:47:25,520
the spectrum shows clear evidence of

1405
00:47:27,990 --> 00:47:27,280
water in the atmosphere at triple the

1406
00:47:30,230 --> 00:47:28,000
abundance

1407
00:47:31,910 --> 00:47:30,240
of that in the saturn of our own solar

1408
00:47:33,510 --> 00:47:31,920
system

1409
00:47:35,990 --> 00:47:33,520
along the bottom here now i'm going to

1410
00:47:37,430 --> 00:47:36,000
demonstrate why combining data from all

1411
00:47:40,309 --> 00:47:37,440
these different wavelengths

1412
00:47:42,710 --> 00:47:40,319
and different facilities is so powerful

1413
00:47:45,910 --> 00:47:42,720

so first we're showing you here

1414
00:47:47,910 --> 00:47:45,920
in purple just an analysis done on the

1415
00:47:50,069 --> 00:47:47,920
near infrared data alone so

1416
00:47:51,990 --> 00:47:50,079
on the bottom right here is a spectrum

1417
00:47:53,829 --> 00:47:52,000
showing the the absorption

1418
00:47:55,349 --> 00:47:53,839
on the y-axis versus wavelength on the

1419
00:47:56,710 --> 00:47:55,359
x-axis and microns

1420
00:47:59,430 --> 00:47:56,720
and the black data points are just the

1421
00:48:01,030 --> 00:47:59,440
infrared data the purple curves that are

1422
00:48:03,270 --> 00:48:01,040
passing through the black points

1423
00:48:05,589 --> 00:48:03,280
that's the full range of models that is

1424
00:48:07,990 --> 00:48:05,599
consistent with those data

1425
00:48:09,430 --> 00:48:08,000
on the lower left are four panels

1426
00:48:11,510 --> 00:48:09,440
showing the properties of

1427
00:48:13,190 --> 00:48:11,520
interest for this exoplanet system we'd

1428
00:48:13,910 --> 00:48:13,200
like to know its temperature the metals

1429
00:48:15,750 --> 00:48:13,920
present

1430
00:48:16,950 --> 00:48:15,760
the radius of the planet and the haze in

1431
00:48:18,710 --> 00:48:16,960
the atmosphere

1432
00:48:20,069 --> 00:48:18,720
and there are a lot of values that are

1433
00:48:21,190 --> 00:48:20,079
consistent with the data it's why

1434
00:48:24,549 --> 00:48:21,200
there's a distribution

1435
00:48:27,190 --> 00:48:24,559
in each of those plots if we however

1436
00:48:28,710 --> 00:48:27,200
combine now all the data available to us

1437
00:48:29,589 --> 00:48:28,720
from the ultraviolet the optical and the

1438
00:48:31,990 --> 00:48:29,599

infrared

1439
00:48:32,870 --> 00:48:32,000
that's what's shown now in green so the

1440
00:48:35,030 --> 00:48:32,880
black points

1441
00:48:36,630 --> 00:48:35,040
on the spectrum at the bottom right here

1442
00:48:37,670 --> 00:48:36,640
now the black points are the

1443
00:48:39,670 --> 00:48:37,680
the data from all the different

1444
00:48:41,349 --> 00:48:39,680
telescopes being combined over a wide

1445
00:48:43,349 --> 00:48:41,359
wavelength range

1446
00:48:45,829 --> 00:48:43,359
and because we have more data points in

1447
00:48:47,430 --> 00:48:45,839
black the the curves now for the model

1448
00:48:49,430 --> 00:48:47,440
which are now shown in green

1449
00:48:51,750 --> 00:48:49,440
are much tighter there are far fewer

1450
00:48:53,589 --> 00:48:51,760
models that are consistent with the data

1451
00:48:54,950 --> 00:48:53,599
and that's shown here by the constraints

1452
00:48:56,390 --> 00:48:54,960
on the left so now here are the four

1453
00:48:57,589 --> 00:48:56,400
properties again of the exoplanet

1454
00:49:00,069 --> 00:48:57,599
atmosphere we're interested in

1455
00:49:01,910 --> 00:49:00,079
temperature metals radius and haze and

1456
00:49:03,030 --> 00:49:01,920
now the distribution is much tighter and

1457
00:49:05,430 --> 00:49:03,040
if you see if i blink

1458
00:49:06,230 --> 00:49:05,440
back and forth and purple here's the

1459
00:49:07,990 --> 00:49:06,240
wide

1460
00:49:09,430 --> 00:49:08,000
where we don't have as good a handle on

1461
00:49:10,309 --> 00:49:09,440
things because we're not using all the

1462
00:49:12,710 --> 00:49:10,319
data

1463
00:49:14,230 --> 00:49:12,720

and now things are narrower because we

1464
00:49:16,549 --> 00:49:14,240
are using all the data available we get

1465
00:49:17,670 --> 00:49:16,559
much better constraints and so looking

1466
00:49:19,829 --> 00:49:17,680
ahead

1467
00:49:21,589 --> 00:49:19,839
this is giving us a lot of hope for work

1468
00:49:22,069 --> 00:49:21,599
the two telescopes working together when

1469
00:49:24,870 --> 00:49:22,079
when

1470
00:49:26,950 --> 00:49:24,880
james webb is up in space james the

1471
00:49:27,750 --> 00:49:26,960
james webb space telescope is launching

1472
00:49:29,910 --> 00:49:27,760
later this year

1473
00:49:30,790 --> 00:49:29,920
it's primarily an infrared telescope and

1474
00:49:32,069 --> 00:49:30,800
when it's working

1475
00:49:33,750 --> 00:49:32,079
in tandem with the hubble space

1476
00:49:35,270 --> 00:49:33,760
telescope when those two telescopes are

1477
00:49:36,790 --> 00:49:35,280
working together looking at exoplanets

1478
00:49:40,230 --> 00:49:36,800
we're going to get amazing constraints

1479
00:49:45,510 --> 00:49:43,349
now it's not just other solar systems

1480
00:49:46,870 --> 00:49:45,520
that hubble observes hubble spends a

1481
00:49:48,630 --> 00:49:46,880
significant amount of time looking at

1482
00:49:49,270 --> 00:49:48,640
our own solar system in particular

1483
00:49:51,670 --> 00:49:49,280
supporting

1484
00:49:53,109 --> 00:49:51,680
other dedicated missions throughout our

1485
00:49:55,670 --> 00:49:53,119
solar system

1486
00:49:57,670 --> 00:49:55,680
so for example the new horizons mission

1487
00:49:59,910 --> 00:49:57,680
navigated to pluto and hubble played a

1488
00:50:02,630 --> 00:49:59,920

key role in navigating to pluto

1489
00:50:04,150 --> 00:50:02,640
identifying four new pluto moons and

1490
00:50:05,910 --> 00:50:04,160
also confirming that the navigation

1491
00:50:07,109 --> 00:50:05,920
pathway for new horizons was safe from

1492
00:50:08,950 --> 00:50:07,119
debris

1493
00:50:11,589 --> 00:50:08,960
and then once new horizons arrived at

1494
00:50:13,109 --> 00:50:11,599
pluto hubble was used to identify a

1495
00:50:15,030 --> 00:50:13,119
target for an extended mission

1496
00:50:16,309 --> 00:50:15,040
for the new horizons mission ultimate

1497
00:50:18,470 --> 00:50:16,319
duel and

1498
00:50:20,630 --> 00:50:18,480
provided navigation assistance to

1499
00:50:21,430 --> 00:50:20,640
proceed to that target and so the center

1500
00:50:24,069 --> 00:50:21,440
image shown

1501
00:50:25,589 --> 00:50:24,079
here from hubble is the extended mission

1502
00:50:27,990 --> 00:50:25,599
target and on right

1503
00:50:28,790 --> 00:50:28,000
is the image obtained from new horizons

1504
00:50:32,950 --> 00:50:28,800
as it

1505
00:50:36,630 --> 00:50:34,710
hubble has looked at jupiter over the

1506
00:50:38,309 --> 00:50:36,640
years this is a relatively recent image

1507
00:50:41,109 --> 00:50:38,319
from 2020 of jupiter

1508
00:50:43,030 --> 00:50:41,119
beautiful color image and there are also

1509
00:50:45,829 --> 00:50:43,040
missions to jupiter

1510
00:50:46,390 --> 00:50:45,839
so for example the juno spacecraft which

1511
00:50:49,030 --> 00:50:46,400
is shown

1512
00:50:51,030 --> 00:50:49,040
not to scale in the upper left there has

1513
00:50:53,030 --> 00:50:51,040

been orbiting jupiter with a period once

1514
00:50:56,069 --> 00:50:53,040
every 53 days of approaching

1515
00:50:58,710 --> 00:50:56,079
jupiter's closest approach and when

1516
00:50:59,270 --> 00:50:58,720
the juno satellite orbiting jupiter

1517
00:51:01,510 --> 00:50:59,280
reaches

1518
00:51:02,309 --> 00:51:01,520
closest approach to jupiter at those

1519
00:51:03,670 --> 00:51:02,319
times hubble

1520
00:51:05,910 --> 00:51:03,680
is looking at the same time

1521
00:51:08,230 --> 00:51:05,920
contemporaneously to provide

1522
00:51:09,510 --> 00:51:08,240
data alongside the juno data as are

1523
00:51:10,870 --> 00:51:09,520
telescopes on the ground such as the

1524
00:51:12,870 --> 00:51:10,880
gemini telescope

1525
00:51:14,870 --> 00:51:12,880
and so working with multiple facilities

1526
00:51:17,430 --> 00:51:14,880
together we get

1527
00:51:18,470 --> 00:51:17,440
new insight into the physics of what's

1528
00:51:20,069 --> 00:51:18,480
happening in jupiter and

1529
00:51:23,109 --> 00:51:20,079
for example here the storm systems on

1530
00:51:23,990 --> 00:51:23,119
jupiter so the juno satellite is peering

1531
00:51:26,470 --> 00:51:24,000
into those so

1532
00:51:27,990 --> 00:51:26,480
those storm systems in radio waves the

1533
00:51:30,309 --> 00:51:28,000
gemini telescope

1534
00:51:31,190 --> 00:51:30,319
is looking in the thermal infrared and

1535
00:51:33,910 --> 00:51:31,200
hubble is

1536
00:51:35,430 --> 00:51:33,920
looking in reflected light but combining

1537
00:51:37,670 --> 00:51:35,440
data from all of those

1538
00:51:42,069 --> 00:51:37,680

facilities working together we can get

1539
00:51:45,670 --> 00:51:43,990
and we also besides looking at other

1540
00:51:46,069 --> 00:51:45,680
star systems for their exoplanets we

1541
00:51:48,230 --> 00:51:46,079
look at

1542
00:51:50,150 --> 00:51:48,240
other stars to understand star formation

1543
00:51:51,349 --> 00:51:50,160
history in the universe

1544
00:51:53,349 --> 00:51:51,359
this is something called stellar

1545
00:51:53,829 --> 00:51:53,359
archaeology when you look at a group of

1546
00:51:55,190 --> 00:51:53,839
stars

1547
00:51:56,870 --> 00:51:55,200
such as that shown here this is a

1548
00:51:57,510 --> 00:51:56,880
beautiful hubble image of a crowded star

1549
00:51:59,349 --> 00:51:57,520
field

1550
00:52:00,630 --> 00:51:59,359
you see a distribution of colors and

1551
00:52:02,549 --> 00:52:00,640
brightnesses

1552
00:52:04,069 --> 00:52:02,559
the colors reflect the temperatures of

1553
00:52:05,829 --> 00:52:04,079
those stars and the brightnesses reflect

1554
00:52:08,390 --> 00:52:05,839
the luminosities of those stars

1555
00:52:09,990 --> 00:52:08,400
but that distribution is not random the

1556
00:52:12,150 --> 00:52:10,000
the distribution you see

1557
00:52:13,349 --> 00:52:12,160
traces the life cycle of a star traces

1558
00:52:15,190 --> 00:52:13,359
stellar evolution

1559
00:52:17,670 --> 00:52:15,200
and the picture you see here will change

1560
00:52:18,150 --> 00:52:17,680
with age and hubble can use this kind of

1561
00:52:20,549 --> 00:52:18,160
information

1562
00:52:21,430 --> 00:52:20,559
to probe the detailed history of star

1563
00:52:23,829 --> 00:52:21,440

formation

1564
00:52:25,270 --> 00:52:23,839
in both nearby galaxies and nearby star

1565
00:52:27,829 --> 00:52:25,280
clusters where we can

1566
00:52:28,630 --> 00:52:27,839
resolve the individual stars like this

1567
00:52:30,549 --> 00:52:28,640
and so i'm going to show you an

1568
00:52:32,230 --> 00:52:30,559
animation put together by some folks

1569
00:52:33,910 --> 00:52:32,240
showing at the bottom there their names

1570
00:52:35,430 --> 00:52:33,920
at space telescope we put together this

1571
00:52:36,710 --> 00:52:35,440
animation of this hubble image we're

1572
00:52:38,710 --> 00:52:36,720
first going to sort

1573
00:52:40,470 --> 00:52:38,720
the stars in color left to right with

1574
00:52:42,549 --> 00:52:40,480
the hottest bluest stars

1575
00:52:44,710 --> 00:52:42,559
on the left and the coolest reddest

1576
00:52:45,829 --> 00:52:44,720
stars on the right

1577
00:52:47,670 --> 00:52:45,839
then we're going to sort the stars in

1578
00:52:48,950 --> 00:52:47,680
luminosity with the brightest stars at

1579
00:52:49,910 --> 00:52:48,960
the top and the faintest stars at the

1580
00:52:52,710 --> 00:52:49,920
bottom

1581
00:52:53,990 --> 00:52:52,720
and when you get here sorting the stars

1582
00:52:55,510 --> 00:52:54,000
in that hubble image is a color

1583
00:52:56,710 --> 00:52:55,520
magnitude diagram such as the one i

1584
00:52:58,630 --> 00:52:56,720
showed earlier in the talk when i was

1585
00:53:00,549 --> 00:52:58,640
talking about the red giant branch as

1586
00:53:02,470 --> 00:53:00,559
a distance indicator with the

1587
00:53:04,069 --> 00:53:02,480
cosmological measurements

1588
00:53:05,750 --> 00:53:04,079

so you can see here there's uh the

1589
00:53:06,390 --> 00:53:05,760
distribution is not random there's this

1590
00:53:09,109 --> 00:53:06,400
pattern

1591
00:53:11,349 --> 00:53:09,119
and dwarf stars are near the bottom of

1592
00:53:13,190 --> 00:53:11,359
this diagram the sun is a dwarf star

1593
00:53:15,270 --> 00:53:13,200
and dwarf stars will swell up and become

1594
00:53:16,710 --> 00:53:15,280
red giant stars towards the upper right

1595
00:53:18,470 --> 00:53:16,720
and the tip of the red giant branch are

1596
00:53:20,150 --> 00:53:18,480
the brightest red giant brain stars up

1597
00:53:22,630 --> 00:53:20,160
there at the upper right

1598
00:53:23,510 --> 00:53:22,640
those stars then ignite helium in their

1599
00:53:26,150 --> 00:53:23,520
cores

1600
00:53:28,069 --> 00:53:26,160
and become much hotter so they move over

1601
00:53:30,470 --> 00:53:28,079
to the upper left part of this picture

1602
00:53:31,510 --> 00:53:30,480
here where you see the bright blue stars

1603
00:53:33,910 --> 00:53:31,520
they're hotter and blue

1604
00:53:35,589 --> 00:53:33,920
blue bright stars and then when they

1605
00:53:38,470 --> 00:53:35,599
exhaust their fuel they fade as white

1606
00:53:40,710 --> 00:53:38,480
dwarfs to the lower left

1607
00:53:42,549 --> 00:53:40,720
so that's the the story that's told by

1608
00:53:44,309 --> 00:53:42,559
the distribution of color and brightness

1609
00:53:46,950 --> 00:53:44,319
in a hubble picture

1610
00:53:48,230 --> 00:53:46,960
and elene tolstoy demonstrates this well

1611
00:53:49,030 --> 00:53:48,240
here in this figure she's done a lot of

1612
00:53:51,430 --> 00:53:49,040
work in this area

1613
00:53:52,710 --> 00:53:51,440

with a variety of telescopes and what's

1614
00:53:54,630 --> 00:53:52,720
plotted here in her plot

1615
00:53:56,230 --> 00:53:54,640
is brightness on the y-axis versus color

1616
00:53:58,390 --> 00:53:56,240
or temperature on the x-axis

1617
00:53:59,910 --> 00:53:58,400
for different evolutionary phases in the

1618
00:54:01,349 --> 00:53:59,920
life cycle of a star

1619
00:54:02,950 --> 00:54:01,359
for stars of different masses and

1620
00:54:05,510 --> 00:54:02,960
they're color-coded here according to

1621
00:54:07,430 --> 00:54:05,520
the table alongside on the right

1622
00:54:08,950 --> 00:54:07,440
so for the most massive stars we call

1623
00:54:10,870 --> 00:54:08,960
those o stars they have a mass

1624
00:54:12,309 --> 00:54:10,880
more than 100 times the mass of the sun

1625
00:54:14,069 --> 00:54:12,319
they go whipping through this diagram

1626
00:54:15,670 --> 00:54:14,079
very quickly on a time scale of just a

1627
00:54:18,870 --> 00:54:15,680
few million years

1628
00:54:21,030 --> 00:54:18,880
and then for low mass stars such as an m

1629
00:54:22,630 --> 00:54:21,040
dwarf star at half the mass of the sun

1630
00:54:24,309 --> 00:54:22,640
it takes billions of years to go through

1631
00:54:25,109 --> 00:54:24,319
this diagram to evolve through this

1632
00:54:28,069 --> 00:54:25,119
diagram

1633
00:54:28,710 --> 00:54:28,079
and and so all the different masses of

1634
00:54:32,630 --> 00:54:28,720
stars

1635
00:54:34,390 --> 00:54:32,640
rates and we can trace their evolution

1636
00:54:36,630 --> 00:54:34,400
in this distribution of brightness and

1637
00:54:38,549 --> 00:54:36,640
temperature

1638
00:54:40,230 --> 00:54:38,559

now to give you a specific example of

1639
00:54:43,670 --> 00:54:40,240
this type of research

1640
00:54:45,430 --> 00:54:43,680
this is an image a photograph taken from

1641
00:54:46,630 --> 00:54:45,440
the surface of the earth of the dark

1642
00:54:48,390 --> 00:54:46,640
night sky

1643
00:54:50,549 --> 00:54:48,400
and for those of you who've been able to

1644
00:54:52,470 --> 00:54:50,559
look at the sky away from the cities

1645
00:54:54,630 --> 00:54:52,480
out in the out in the woods or out where

1646
00:54:56,309 --> 00:54:54,640
it's quite dark you can see the strip of

1647
00:54:57,190 --> 00:54:56,319
stars going across the sky it's called

1648
00:54:59,030 --> 00:54:57,200
the milky way

1649
00:55:01,030 --> 00:54:59,040
that's our own milky way galaxy we live

1650
00:55:03,589 --> 00:55:01,040
in a spiral galaxy in the disk of that

1651
00:55:06,309 --> 00:55:03,599
spiral galaxy is where the sun resides

1652
00:55:07,910 --> 00:55:06,319
and because we're in that disc it forms

1653
00:55:08,390 --> 00:55:07,920
a stripe of stars that goes across the

1654
00:55:09,750 --> 00:55:08,400
sky

1655
00:55:11,589 --> 00:55:09,760
if you're out someplace where it's dark

1656
00:55:13,670 --> 00:55:11,599
enough to see it

1657
00:55:14,950 --> 00:55:13,680
what's shown by the inset is the center

1658
00:55:17,910 --> 00:55:14,960
of the milky way where

1659
00:55:19,670 --> 00:55:17,920
we pointed with hubble and so that inset

1660
00:55:19,990 --> 00:55:19,680
there is the high resolution hubble

1661
00:55:22,390 --> 00:55:20,000
image

1662
00:55:23,589 --> 00:55:22,400
of just one tiny piece of this much

1663
00:55:25,349 --> 00:55:23,599

larger photograph

1664
00:55:27,750 --> 00:55:25,359
zoomed in on the center of the milky way

1665
00:55:30,309 --> 00:55:27,760
that field is called the sweeps field

1666
00:55:32,470 --> 00:55:30,319
the acronym is the sagittarius window

1667
00:55:34,549 --> 00:55:32,480
eclipsing extrasolar planet search

1668
00:55:35,910 --> 00:55:34,559
this is a program led by kyler sahu

1669
00:55:37,829 --> 00:55:35,920
nearly 20 years ago

1670
00:55:39,030 --> 00:55:37,839
he pointed hubble at this star field

1671
00:55:42,069 --> 00:55:39,040
this crowded star field

1672
00:55:43,430 --> 00:55:42,079
for a week to look for exoplanets and he

1673
00:55:44,789 --> 00:55:43,440
successfully found the most distant

1674
00:55:47,349 --> 00:55:44,799
exoplanets found

1675
00:55:48,470 --> 00:55:47,359
by transit when those exoplanets passed

1676
00:55:50,549 --> 00:55:48,480
in front of these crowdeds

1677
00:55:52,150 --> 00:55:50,559
this crowded field of stars it affected

1678
00:55:53,190 --> 00:55:52,160
the starlight from those stars that we

1679
00:55:55,510 --> 00:55:53,200
measured

1680
00:55:56,390 --> 00:55:55,520
and we were able to find exoplanets

1681
00:55:58,630 --> 00:55:56,400
however this

1682
00:56:00,309 --> 00:55:58,640
star field is itself interesting because

1683
00:56:02,630 --> 00:56:00,319
it gives insight into the formation of

1684
00:56:03,910 --> 00:56:02,640
the center of the milky way our galaxy

1685
00:56:05,829 --> 00:56:03,920
and this field has been imaged

1686
00:56:09,109 --> 00:56:05,839
repeatedly by hubble over the years

1687
00:56:10,390 --> 00:56:09,119
and because it has both excellent detail

1688
00:56:12,309 --> 00:56:10,400

in terms of the colors and brightnesses

1689
00:56:13,030 --> 00:56:12,319
we measure but also a time series of

1690
00:56:15,109 --> 00:56:13,040
being looked at

1691
00:56:17,030 --> 00:56:15,119
repeatedly over the years this gives us

1692
00:56:18,710 --> 00:56:17,040
both insight into the star formation

1693
00:56:20,390 --> 00:56:18,720
history but also the motions in the

1694
00:56:22,630 --> 00:56:20,400
center of the milky way

1695
00:56:26,150 --> 00:56:22,640
and so just to demonstrate that here's

1696
00:56:28,309 --> 00:56:26,160
the high resolution image from hubble

1697
00:56:30,549 --> 00:56:28,319
the again this distribution of color and

1698
00:56:34,309 --> 00:56:30,559
brightness is not random in here

1699
00:56:36,309 --> 00:56:34,319
and i'm going to zoom in on one patch

1700
00:56:37,910 --> 00:56:36,319
in the upper left here pull that over to

1701
00:56:38,789 --> 00:56:37,920
the side and if you look very carefully

1702
00:56:40,309 --> 00:56:38,799
at your screen

1703
00:56:42,309 --> 00:56:40,319
you can see that the stars are moving

1704
00:56:43,829 --> 00:56:42,319
this is two years of hubble data

1705
00:56:45,270 --> 00:56:43,839
turned into a time lapse it's just

1706
00:56:45,750 --> 00:56:45,280
playing back and forth over the light

1707
00:56:47,510 --> 00:56:45,760
loop

1708
00:56:49,510 --> 00:56:47,520
frontwards and backwards so you can see

1709
00:56:50,870 --> 00:56:49,520
the motion of stars so this is not an

1710
00:56:51,910 --> 00:56:50,880
animation or an artist's rendition

1711
00:56:54,950 --> 00:56:51,920
that's the actual

1712
00:56:56,789 --> 00:56:54,960
series of hubble images in one at one

1713
00:56:59,190 --> 00:56:56,799

wavelength and one filter on hubble

1714
00:57:00,950 --> 00:56:59,200
at that patch of the field and so you

1715
00:57:01,510 --> 00:57:00,960
can see the motions of the stars and you

1716
00:57:03,750 --> 00:57:01,520
can see

1717
00:57:05,349 --> 00:57:03,760
the ages of the stars and so will

1718
00:57:07,190 --> 00:57:05,359
clarkson recently had

1719
00:57:09,030 --> 00:57:07,200
a press release on these results where

1720
00:57:09,829 --> 00:57:09,040
he found two distinct populations of

1721
00:57:11,910 --> 00:57:09,839
stars

1722
00:57:14,069 --> 00:57:11,920
based on these data in the center of our

1723
00:57:15,670 --> 00:57:14,079
milky way he found an older population

1724
00:57:17,190 --> 00:57:15,680
that was less chemically enriched

1725
00:57:18,710 --> 00:57:17,200
and these stars were moving more slowly

1726
00:57:19,349 --> 00:57:18,720
and they were probably there in the

1727
00:57:21,030 --> 00:57:19,359
early

1728
00:57:22,630 --> 00:57:21,040
part of the milky way history and then

1729
00:57:23,990 --> 00:57:22,640
he found a younger population of stars

1730
00:57:26,150 --> 00:57:24,000
that was more enriched moving more

1731
00:57:27,589 --> 00:57:26,160
quickly these were probably

1732
00:57:29,270 --> 00:57:27,599
in smaller galaxies that were

1733
00:57:31,510 --> 00:57:29,280
cannibalized as they fell into the milky

1734
00:57:33,430 --> 00:57:31,520
way

1735
00:57:35,270 --> 00:57:33,440
now hubble's also has a very large

1736
00:57:38,390 --> 00:57:35,280
program underway right now

1737
00:57:39,109 --> 00:57:38,400
to to produce a library of stars for the

1738
00:57:41,190 --> 00:57:39,119

future

1739
00:57:42,630 --> 00:57:41,200
this is another director's discretionary

1740
00:57:44,390 --> 00:57:42,640
program like the frontier fields i

1741
00:57:44,950 --> 00:57:44,400
mentioned earlier this is a thousand

1742
00:57:46,549 --> 00:57:44,960
orbits

1743
00:57:48,549 --> 00:57:46,559
spread over three years it's called the

1744
00:57:50,309 --> 00:57:48,559
ulysses program the ultraviolet legacy

1745
00:57:51,270 --> 00:57:50,319
library of young stars as essential

1746
00:57:53,589 --> 00:57:51,280
standards

1747
00:57:55,190 --> 00:57:53,599
and what this program is doing is

1748
00:57:58,230 --> 00:57:55,200
creating a spectroscopic

1749
00:58:00,069 --> 00:57:58,240
library of ultraviolet spectroscopy

1750
00:58:01,670 --> 00:58:00,079
that can be used by other telescopes now

1751
00:58:04,230 --> 00:58:01,680
and in the future because this is

1752
00:58:05,670 --> 00:58:04,240
a unique hubble ability and it's going

1753
00:58:07,829 --> 00:58:05,680
to be a legacy for hubble

1754
00:58:10,230 --> 00:58:07,839
so the library is going to be looking at

1755
00:58:12,549 --> 00:58:10,240
young stars at a variety of masses

1756
00:58:14,470 --> 00:58:12,559
sampling different parameters for stars

1757
00:58:16,390 --> 00:58:14,480
the survey was put together

1758
00:58:18,150 --> 00:58:16,400
with the the participation of the

1759
00:58:20,309 --> 00:58:18,160
scientific community

1760
00:58:21,430 --> 00:58:20,319
they provided initial input for the

1761
00:58:23,270 --> 00:58:21,440
design of the survey and then they

1762
00:58:25,510 --> 00:58:23,280
continue to provide advice

1763
00:58:27,030 --> 00:58:25,520

the implementation team at the space

1764
00:58:29,829 --> 00:58:27,040
telescope science institute is led by

1765
00:58:31,030 --> 00:58:29,839
julia roman duvall

1766
00:58:32,549 --> 00:58:31,040
and so this is another one of these

1767
00:58:33,349 --> 00:58:32,559
stellar diagrams with brightness on the

1768
00:58:35,910 --> 00:58:33,359
y-axis

1769
00:58:37,670 --> 00:58:35,920
and color temperature on the x-axis and

1770
00:58:39,270 --> 00:58:37,680
showing the evolution of young stars at

1771
00:58:41,109 --> 00:58:39,280
different masses ranging from half

1772
00:58:42,390 --> 00:58:41,119
the mass of the sun to 15 times the mass

1773
00:58:45,750 --> 00:58:42,400
of the sun and they take

1774
00:58:47,349 --> 00:58:45,760
different tracks through that diagram

1775
00:58:49,030 --> 00:58:47,359
the ulysses program is spending about

1776
00:58:50,150 --> 00:58:49,040
500 orbits looking at the most massive

1777
00:58:53,030 --> 00:58:50,160
stars

1778
00:58:54,390 --> 00:58:53,040
in this diagram produce and this is a

1779
00:58:57,750 --> 00:58:54,400
beautiful hubble image of

1780
00:58:58,470 --> 00:58:57,760
such massive star formation and then

1781
00:59:00,150 --> 00:58:58,480
it's also

1782
00:59:02,230 --> 00:59:00,160
looking at the low-mass stars in this

1783
00:59:03,270 --> 00:59:02,240
diagram and this is a hubble image of

1784
00:59:04,950 --> 00:59:03,280
such a star

1785
00:59:06,710 --> 00:59:04,960
now this program though is producing

1786
00:59:08,069 --> 00:59:06,720
spectroscopy not images so it's

1787
00:59:09,910 --> 00:59:08,079
producing spectral like what's shown

1788
00:59:11,750 --> 00:59:09,920

here in the middle of your screen

1789
00:59:13,589 --> 00:59:11,760
this is the ultraviolet spectrum so

1790
00:59:14,870 --> 00:59:13,599
energy versus wavelength and angstroms

1791
00:59:17,270 --> 00:59:14,880
for a high mass star

1792
00:59:18,710 --> 00:59:17,280
and it's showing features from different

1793
00:59:19,430 --> 00:59:18,720
aspects of the chemistry and physics

1794
00:59:21,990 --> 00:59:19,440
involved

1795
00:59:22,630 --> 00:59:22,000
in blue is highlighted an absorption

1796
00:59:24,309 --> 00:59:22,640
feature

1797
00:59:25,670 --> 00:59:24,319
from the dark interstellar medium

1798
00:59:27,430 --> 00:59:25,680
between the stars

1799
00:59:29,030 --> 00:59:27,440
in green there's a feature from the

1800
00:59:31,510 --> 00:59:29,040
stellar wind in the star

1801
00:59:33,349 --> 00:59:31,520
and then red is highlighted a feature

1802
00:59:34,870 --> 00:59:33,359
from the dark circum galactic medium

1803
00:59:36,470 --> 00:59:34,880
between the galaxies

1804
00:59:38,069 --> 00:59:36,480
so for high mass stars we're going to be

1805
00:59:39,670 --> 00:59:38,079
doing the

1806
00:59:41,910 --> 00:59:39,680
giving a look into the winds chemistry

1807
00:59:43,670 --> 00:59:41,920
and radiation for stellar astrophysics

1808
00:59:45,670 --> 00:59:43,680
and we'll be looking at the interstellar

1809
00:59:47,589 --> 00:59:45,680
and circum galactic medium between the

1810
00:59:48,789 --> 00:59:47,599
stars and between the galaxies

1811
00:59:50,230 --> 00:59:48,799
and then for low-mass stars we're going

1812
00:59:51,910 --> 00:59:50,240
to be looking at the physics of those

1813
00:59:53,589 --> 00:59:51,920

low-mass stars the accretion that

1814
00:59:55,990 --> 00:59:53,599
happens the shocks flows

1815
00:59:58,549 --> 00:59:56,000
discs and jets and their transient

1816
01:00:01,990 --> 00:59:59,990
now as i mentioned the dark material

1817
01:00:02,710 --> 01:00:02,000
between the stars is also an area of

1818
01:00:04,950 --> 01:00:02,720
study and

1819
01:00:06,390 --> 01:00:04,960
it was actually the that kind of science

1820
01:00:09,030 --> 01:00:06,400
was a prime motivation

1821
01:00:10,630 --> 01:00:09,040
for the cosmic origin spectrograph uh

1822
01:00:11,430 --> 01:00:10,640
one of the two spectrographs on hubble

1823
01:00:13,109 --> 01:00:11,440
and

1824
01:00:14,870 --> 01:00:13,119
the way this science works is shown

1825
01:00:16,789 --> 01:00:14,880
schematically in the lower left here

1826
01:00:18,150 --> 01:00:16,799
the material between the stars is dark

1827
01:00:20,710 --> 01:00:18,160
it's gas and dust

1828
01:00:22,549 --> 01:00:20,720
it's not luminous and so the way you

1829
01:00:24,390 --> 01:00:22,559
measure that material is look along a

1830
01:00:26,950 --> 01:00:24,400
sight line through the universe at some

1831
01:00:28,789 --> 01:00:26,960
background illumination basically a

1832
01:00:31,190 --> 01:00:28,799
flashlight that nature provides

1833
01:00:32,390 --> 01:00:31,200
and you look back towards a quasar is

1834
01:00:33,670 --> 01:00:32,400
what's commonly done so that's what's

1835
01:00:35,190 --> 01:00:33,680
shown in the schematic here hubble is

1836
01:00:35,990 --> 01:00:35,200
looking through the dark material in the

1837
01:00:38,710 --> 01:00:36,000
universe

1838
01:00:40,390 --> 01:00:38,720

back towards a quasar a quasar is a

1839
01:00:42,870 --> 01:00:40,400
quasi-stellar object

1840
01:00:45,030 --> 01:00:42,880
it's an active galaxy nucleus powered by

1841
01:00:46,710 --> 01:00:45,040
a super massive black hole

1842
01:00:47,750 --> 01:00:46,720
these are bright as they give off the

1843
01:00:49,510 --> 01:00:47,760
light the light passes through the

1844
01:00:50,870 --> 01:00:49,520
universe comes back to hubble and then

1845
01:00:52,870 --> 01:00:50,880
some of that light is absorbed on the

1846
01:00:54,309 --> 01:00:52,880
way to hubble because of the circum

1847
01:00:56,390 --> 01:00:54,319
galactic medium

1848
01:00:58,069 --> 01:00:56,400
two recent examples of large hubble

1849
01:01:00,150 --> 01:00:58,079
surveys in this kind of work

1850
01:01:01,349 --> 01:01:00,160
uh there's the cubs survey led by

1851
01:01:03,270 --> 01:01:01,359
chennada

1852
01:01:04,630 --> 01:01:03,280
this is the cosmic ultraviolet barrion

1853
01:01:08,470 --> 01:01:04,640
survey uh

1854
01:01:10,230 --> 01:01:08,480
chen is looking here her and her team

1855
01:01:11,670 --> 01:01:10,240
are probing the circum galactic medium

1856
01:01:12,950 --> 01:01:11,680
toward distance galaxies and

1857
01:01:14,789 --> 01:01:12,960
intermediate redshift

1858
01:01:16,470 --> 01:01:14,799
looking back in time roughly four to ten

1859
01:01:18,870 --> 01:01:16,480
billion years into the past

1860
01:01:20,789 --> 01:01:18,880
to probe the chemistry of the circum

1861
01:01:21,670 --> 01:01:20,799
galactic medium over a fairly large

1862
01:01:23,109 --> 01:01:21,680
distance here

1863
01:01:25,109 --> 01:01:23,119

then there's the amiga program

1864
01:01:26,470 --> 01:01:25,119
absorption maps in the gas of andromeda

1865
01:01:29,030 --> 01:01:26,480
this is led by

1866
01:01:31,109 --> 01:01:29,040
leonardo this is probing the environment

1867
01:01:33,430 --> 01:01:31,119
around the nearby andromeda galaxy

1868
01:01:34,950 --> 01:01:33,440
that's a giant spiral galaxy like our

1869
01:01:36,630 --> 01:01:34,960
own galaxy it's the nearest spiral

1870
01:01:37,670 --> 01:01:36,640
galaxy to our own in the local

1871
01:01:39,349 --> 01:01:37,680
neighborhood

1872
01:01:41,030 --> 01:01:39,359
and this program is intended to

1873
01:01:42,710 --> 01:01:41,040
investigate the vast halo of gas around

1874
01:01:44,390 --> 01:01:42,720
andromeda now andromeda because it's the

1875
01:01:45,670 --> 01:01:44,400
nearest spiral galaxy and it's similar

1876
01:01:48,470 --> 01:01:45,680
to our own in many ways

1877
01:01:49,589 --> 01:01:48,480
it's been the subject of study to to

1878
01:01:51,670 --> 01:01:49,599
many astronomers over the years and

1879
01:01:53,349 --> 01:01:51,680
hubble spent a lot of time looking at it

1880
01:01:55,349 --> 01:01:53,359
and just to give you some background on

1881
01:01:57,430 --> 01:01:55,359
that there is the pan

1882
01:01:59,109 --> 01:01:57,440
chromatic hubble andromeda treasury led

1883
01:02:00,470 --> 01:01:59,119
by julianne del canton this was a very

1884
01:02:01,510 --> 01:02:00,480
large program spending hundreds of

1885
01:02:03,589 --> 01:02:01,520
orbits mapping

1886
01:02:05,029 --> 01:02:03,599
a significant part of andromeda so it's

1887
01:02:07,109 --> 01:02:05,039
shown here on the right

1888
01:02:08,870 --> 01:02:07,119

now is a ground-based image of the

1889
01:02:10,950 --> 01:02:08,880
andromeda galaxy the entire andromeda

1890
01:02:13,029 --> 01:02:10,960
galaxy which is quite large on the sky

1891
01:02:15,109 --> 01:02:13,039
again it's a spiral galaxy like our own

1892
01:02:16,150 --> 01:02:15,119
it's it's it's somewhat edge on not

1893
01:02:17,430 --> 01:02:16,160
entirely edge on

1894
01:02:19,990 --> 01:02:17,440
and then the section that's highlighted

1895
01:02:23,109 --> 01:02:20,000
where it says hst fat that's the map

1896
01:02:24,549 --> 01:02:23,119
that julianne del canton performed that

1897
01:02:27,910 --> 01:02:24,559
she obtained with hubble

1898
01:02:29,430 --> 01:02:27,920
taking hubble and tiling out in great

1899
01:02:32,230 --> 01:02:29,440
detail with hubble's

1900
01:02:33,510 --> 01:02:32,240
cameras a significant chunk of the

1901
01:02:34,950 --> 01:02:33,520
andromeda galaxy

1902
01:02:37,029 --> 01:02:34,960
in the ultraviolet optical and near

1903
01:02:37,910 --> 01:02:37,039
infrared making a high resolution map of

1904
01:02:41,270 --> 01:02:37,920
that part of the

1905
01:02:44,549 --> 01:02:41,280
galaxy i'll zoom in here

1906
01:02:46,150 --> 01:02:44,559
here's a more detailed look at the map

1907
01:02:47,589 --> 01:02:46,160
that's the fat program obtained and just

1908
01:02:48,950 --> 01:02:47,599
to give you a sense of scale

1909
01:02:51,270 --> 01:02:48,960
everyone knows what the full moon looks

1910
01:02:52,950 --> 01:02:51,280
like on the sky so this is how big

1911
01:02:54,789 --> 01:02:52,960
that patch of sky looks like compared to

1912
01:02:56,470 --> 01:02:54,799
the full moon when you go outside

1913
01:02:57,910 --> 01:02:56,480

and i'll zoom in on one section here

1914
01:03:00,789 --> 01:02:57,920
just so you can see that we

1915
01:03:03,029 --> 01:03:00,799
hubble is able to to resolve individual

1916
01:03:04,950 --> 01:03:03,039
stars in the disk of andromeda here and

1917
01:03:06,470 --> 01:03:04,960
disentangle the star formation history

1918
01:03:08,230 --> 01:03:06,480
of andromeda

1919
01:03:09,510 --> 01:03:08,240
so now i'm going to pull back out like i

1920
01:03:11,190 --> 01:03:09,520
said a lot of work has been done on the

1921
01:03:12,470 --> 01:03:11,200
stars of andromeda what this amiga

1922
01:03:16,230 --> 01:03:12,480
program has done though

1923
01:03:18,630 --> 01:03:16,240
is zoom much further out than this so

1924
01:03:20,069 --> 01:03:18,640
i'm going to pull much further out this

1925
01:03:22,549 --> 01:03:20,079
is to scale now the full moon would be

1926
01:03:26,069 --> 01:03:22,559
tiny on this scale hard to see

1927
01:03:27,589 --> 01:03:26,079
and the amiga program probed various

1928
01:03:30,390 --> 01:03:27,599
sight lines through the vast

1929
01:03:31,430 --> 01:03:30,400
plasma halo of andromeda around

1930
01:03:34,309 --> 01:03:31,440
andromeda

1931
01:03:35,990 --> 01:03:34,319
looking at background quasars so these

1932
01:03:37,109 --> 01:03:36,000
orange circles that are shown here are

1933
01:03:39,349 --> 01:03:37,119
each a sight line

1934
01:03:40,950 --> 01:03:39,359
to a background quasar behind andromeda

1935
01:03:42,150 --> 01:03:40,960
and looking through that sight line at

1936
01:03:43,829 --> 01:03:42,160
each of those quasars to see the

1937
01:03:44,789 --> 01:03:43,839
absorption from the halo of gas around

1938
01:03:46,630 --> 01:03:44,799

andromeda

1939
01:03:48,470 --> 01:03:46,640
and the results demonstrated that this

1940
01:03:51,750 --> 01:03:48,480
halo of gas on andromeda

1941
01:03:53,910 --> 01:03:51,760
extends at least 1.3 million light years

1942
01:03:55,670 --> 01:03:53,920
in all directions from andromeda and

1943
01:03:56,390 --> 01:03:55,680
what's amazing about that is andromeda

1944
01:03:57,990 --> 01:03:56,400
itself

1945
01:03:59,670 --> 01:03:58,000
is about two and a half million light

1946
01:04:00,390 --> 01:03:59,680
years away from the milky way our own

1947
01:04:02,309 --> 01:04:00,400
galaxy

1948
01:04:03,510 --> 01:04:02,319
so the fact that this halo extends 1.3

1949
01:04:04,390 --> 01:04:03,520
million light years in all directions

1950
01:04:06,789 --> 01:04:04,400
means it extends

1951
01:04:08,390 --> 01:04:06,799
more than halfway back towards us and

1952
01:04:10,230 --> 01:04:08,400
there are at least two distinct shells

1953
01:04:12,870 --> 01:04:10,240
of complex gas

1954
01:04:14,150 --> 01:04:12,880
in the halo of andromeda in this gas as

1955
01:04:16,230 --> 01:04:14,160
can be seen here by

1956
01:04:18,309 --> 01:04:16,240
features of carbon and silicon in the

1957
01:04:21,190 --> 01:04:18,319
spectra that are obtained

1958
01:04:22,150 --> 01:04:21,200
so the these halos are quite complex the

1959
01:04:25,190 --> 01:04:22,160
the shells

1960
01:04:26,309 --> 01:04:25,200
around this galaxy now as i said each of

1961
01:04:28,870 --> 01:04:26,319
these sight lines

1962
01:04:30,630 --> 01:04:28,880
is illuminated by a background quasar a

1963
01:04:32,950 --> 01:04:30,640

quasar is a distant

1964
01:04:34,630 --> 01:04:32,960
active galaxy nucleus powered by a black

1965
01:04:36,230 --> 01:04:34,640
hole and black holes are

1966
01:04:38,230 --> 01:04:36,240
also the subject of intense study with

1967
01:04:40,470 --> 01:04:38,240
hubble so i'll show

1968
01:04:42,230 --> 01:04:40,480
what really got this kicked off was an

1969
01:04:44,309 --> 01:04:42,240
observation of m84 in the late

1970
01:04:46,069 --> 01:04:44,319
90s with the space telescope imaging

1971
01:04:48,309 --> 01:04:46,079
spectrograph

1972
01:04:49,910 --> 01:04:48,319
stis is able to provide spatially

1973
01:04:51,190 --> 01:04:49,920
resolved spectroscopy so it's shown on

1974
01:04:54,069 --> 01:04:51,200
the far left here

1975
01:04:55,510 --> 01:04:54,079
is an image of the galaxy m84 with one

1976
01:04:57,029 --> 01:04:55,520
of the earlier cameras earlier

1977
01:04:58,630 --> 01:04:57,039
generation cameras on hubble wide field

1978
01:05:00,710 --> 01:04:58,640
planetary camera two

1979
01:05:02,549 --> 01:05:00,720
and then stis placed its slit in the

1980
01:05:03,589 --> 01:05:02,559
center of this galaxy along where the

1981
01:05:06,710 --> 01:05:03,599
black hole is

1982
01:05:08,390 --> 01:05:06,720
and produce the spectrum you see here so

1983
01:05:10,549 --> 01:05:08,400
what is being plotted

1984
01:05:11,750 --> 01:05:10,559
is the velocities implied by that

1985
01:05:13,349 --> 01:05:11,760
spectrum

1986
01:05:15,430 --> 01:05:13,359
as a function of position along the slit

1987
01:05:16,710 --> 01:05:15,440
so green is a velocity similar to the

1988
01:05:19,349 --> 01:05:16,720

velocity of the galaxy

1989
01:05:21,190 --> 01:05:19,359
and as you move along the slit the

1990
01:05:22,309 --> 01:05:21,200
velocity shifts dramatically over to the

1991
01:05:23,910 --> 01:05:22,319
blue

1992
01:05:25,750 --> 01:05:23,920
and then they move and that's a doppler

1993
01:05:27,109 --> 01:05:25,760
shift because things are blue shifted

1994
01:05:28,870 --> 01:05:27,119
and then they shift all the way back to

1995
01:05:30,150 --> 01:05:28,880
the red again before returning to the

1996
01:05:33,029 --> 01:05:30,160
velocity of the galaxy

1997
01:05:33,670 --> 01:05:33,039
so the blue is material that's falling

1998
01:05:36,150 --> 01:05:33,680
towards us

1999
01:05:37,670 --> 01:05:36,160
it's material on the far side of the

2000
01:05:39,510 --> 01:05:37,680
black hole falling into the black hole

2001
01:05:41,589 --> 01:05:39,520
towards us so it's blue shifted

2002
01:05:43,270 --> 01:05:41,599
and then the red is material on the near

2003
01:05:44,470 --> 01:05:43,280
side of the black hole falling away from

2004
01:05:46,390 --> 01:05:44,480
us into the black hole

2005
01:05:48,230 --> 01:05:46,400
and so it's shifted to the red and that

2006
01:05:49,990 --> 01:05:48,240
velocity that is implied by

2007
01:05:51,990 --> 01:05:50,000
this motion is a velocity of 400

2008
01:05:53,190 --> 01:05:52,000
kilometers per second at a point 26

2009
01:05:53,910 --> 01:05:53,200
light years out from the center of the

2010
01:05:58,230 --> 01:05:53,920
black hole

2011
01:05:59,349 --> 01:05:58,240
than 300 million times the mass of the

2012
01:06:01,589 --> 01:05:59,359
sun

2013
01:06:03,109 --> 01:06:01,599

and once hubble did this hubble

2014
01:06:05,190 --> 01:06:03,119
continued to look at many

2015
01:06:06,710 --> 01:06:05,200
black holes in the nearby universe over

2016
01:06:08,390 --> 01:06:06,720
the years since then

2017
01:06:09,990 --> 01:06:08,400
so for example here's a much more recent

2018
01:06:13,589 --> 01:06:10,000
result in 2019

2019
01:06:15,270 --> 01:06:13,599
looking at a spiral galaxy ngc 3147

2020
01:06:16,789 --> 01:06:15,280
the hubble image is shown on the left in

2021
01:06:19,109 --> 01:06:16,799
the center is an artist's rendition of

2022
01:06:19,750 --> 01:06:19,119
its black hole and on the right is a

2023
01:06:21,349 --> 01:06:19,760
spectrum

2024
01:06:22,789 --> 01:06:21,359
of the material in the vicinity of the

2025
01:06:25,990 --> 01:06:22,799
black hole

2026
01:06:26,549 --> 01:06:26,000
the black curve is the hubble spectrum

2027
01:06:28,549 --> 01:06:26,559
and in red

2028
01:06:30,230 --> 01:06:28,559
is the model of the material falling

2029
01:06:33,270 --> 01:06:30,240
into the black hole

2030
01:06:35,670 --> 01:06:33,280
the data shown here imply that that the

2031
01:06:37,670 --> 01:06:35,680
there is a supermassive black hole of

2032
01:06:38,309 --> 01:06:37,680
around 250 million times the mass of the

2033
01:06:40,390 --> 01:06:38,319
sun

2034
01:06:41,430 --> 01:06:40,400
and also shows that this material around

2035
01:06:43,829 --> 01:06:41,440
the black hole

2036
01:06:45,510 --> 01:06:43,839
is in an accretion disk that's moving at

2037
01:06:46,630 --> 01:06:45,520
relativistic speeds at about 10 percent

2038
01:06:48,630 --> 01:06:46,640

the speed of light

2039
01:06:50,390 --> 01:06:48,640
and the increasion disc encroaches

2040
01:06:51,750 --> 01:06:50,400
closer to the black hole or event

2041
01:06:56,309 --> 01:06:51,760
horizon than what's predicted from

2042
01:06:59,750 --> 01:06:58,230
now as i said hubble has looked at many

2043
01:07:01,349 --> 01:06:59,760
black holes over the years and if you

2044
01:07:02,069 --> 01:07:01,359
look at the ensemble of black hole

2045
01:07:03,829 --> 01:07:02,079
measurements

2046
01:07:06,470 --> 01:07:03,839
made to date you can see that black

2047
01:07:07,829 --> 01:07:06,480
holes are intimately related to their

2048
01:07:09,589 --> 01:07:07,839
host galaxies

2049
01:07:11,109 --> 01:07:09,599
so what's shown here in the upper right

2050
01:07:14,309 --> 01:07:11,119
in this plot is

2051
01:07:16,470 --> 01:07:14,319
the mass of various black holes

2052
01:07:18,309 --> 01:07:16,480
in units of masses of the sun on a

2053
01:07:20,309 --> 01:07:18,319
logarithmic scale there

2054
01:07:21,750 --> 01:07:20,319
and then on the x-axis is the galaxy

2055
01:07:22,710 --> 01:07:21,760
mass for the galaxy where those black

2056
01:07:25,430 --> 01:07:22,720
holes reside

2057
01:07:26,230 --> 01:07:25,440
again on a logarithm logarithmic scale

2058
01:07:27,910 --> 01:07:26,240
in units of

2059
01:07:29,349 --> 01:07:27,920
the mass of the sun and you can see that

2060
01:07:31,190 --> 01:07:29,359
the two are correlated

2061
01:07:33,109 --> 01:07:31,200
uh they're tightly correlated there and

2062
01:07:33,910 --> 01:07:33,119
thus the black hole mass tends to go up

2063
01:07:36,870 --> 01:07:33,920

when they live

2064
01:07:38,630 --> 01:07:36,880
within a galaxy of higher mass and so

2065
01:07:42,789 --> 01:07:38,640
black holes are tied to the evolution

2066
01:07:44,870 --> 01:07:42,799
of the galaxy within which they live

2067
01:07:46,630 --> 01:07:44,880
hubble more recently is starting to look

2068
01:07:47,589 --> 01:07:46,640
at other explosive phenomena in the

2069
01:07:50,710 --> 01:07:47,599
universe like

2070
01:07:53,750 --> 01:07:50,720
gravitational wave events

2071
01:07:55,109 --> 01:07:53,760
which these are our ripples in the space

2072
01:07:57,589 --> 01:07:55,119
time continuum

2073
01:07:59,190 --> 01:07:57,599
caused by the merger of massive objects

2074
01:07:59,750 --> 01:07:59,200
and one that got a lot of attention with

2075
01:08:02,549 --> 01:07:59,760
the press

2076
01:08:04,950 --> 01:08:02,559
several years ago is this merger of a

2077
01:08:05,990 --> 01:08:04,960
binary neutron star system so neutron

2078
01:08:08,789 --> 01:08:06,000
star is a collapsed

2079
01:08:10,630 --> 01:08:08,799
dense star near the end of its life and

2080
01:08:13,430 --> 01:08:10,640
there's a binary neutron

2081
01:08:14,710 --> 01:08:13,440
neutron star system where the stars were

2082
01:08:16,070 --> 01:08:14,720
spiraling around each other and

2083
01:08:17,669 --> 01:08:16,080
eventually merged

2084
01:08:19,430 --> 01:08:17,679
and that caused a gravitational wave

2085
01:08:20,070 --> 01:08:19,440
event that rippled out throughout the

2086
01:08:22,070 --> 01:08:20,080
universe

2087
01:08:23,349 --> 01:08:22,080
and was detected by two gravitational

2088
01:08:24,630 --> 01:08:23,359

wave experiments

2089
01:08:27,430 --> 01:08:24,640
the advanced ligo experiment and the

2090
01:08:29,349 --> 01:08:27,440
virgo experiment in august of 2017

2091
01:08:31,189 --> 01:08:29,359
there was a gamma-ray burst detected

2092
01:08:32,709 --> 01:08:31,199
from this event also at the same time by

2093
01:08:35,269 --> 01:08:32,719
two experiments

2094
01:08:36,870 --> 01:08:35,279
and a bunch of facilities overall

2095
01:08:40,390 --> 01:08:36,880
following up on this and the event was

2096
01:08:43,510 --> 01:08:40,400
localized to the galaxy ngc 4993

2097
01:08:43,990 --> 01:08:43,520
at a distance of 40 megaparsecs hubble

2098
01:08:46,070 --> 01:08:44,000
and other

2099
01:08:48,229 --> 01:08:46,080
observatories provided follow-up in the

2100
01:08:50,149 --> 01:08:48,239
days and weeks afterwards

2101
01:08:51,349 --> 01:08:50,159
and that's what's shown here on the left

2102
01:08:53,349 --> 01:08:51,359
is the hubble imaging

2103
01:08:54,789 --> 01:08:53,359
of this event in the aftermath over the

2104
01:08:55,590 --> 01:08:54,799
course of several days or what the

2105
01:08:58,229 --> 01:08:55,600
insets that are

2106
01:08:59,110 --> 01:08:58,239
shown there and then also hubble by

2107
01:09:02,229 --> 01:08:59,120
chance happened to

2108
01:09:04,070 --> 01:09:02,239
observe this same galaxy by by luck

2109
01:09:05,510 --> 01:09:04,080
several months before the event in april

2110
01:09:06,870 --> 01:09:05,520
2017

2111
01:09:08,229 --> 01:09:06,880
so we also got to see what this galaxy

2112
01:09:09,110 --> 01:09:08,239
looked like before the explosion

2113
01:09:11,269 --> 01:09:09,120

happened

2114
01:09:12,470 --> 01:09:11,279
now hubble will play a critical role in

2115
01:09:14,870 --> 01:09:12,480
this type of science in the

2116
01:09:15,510 --> 01:09:14,880
2020s as more gravitational wave

2117
01:09:17,110 --> 01:09:15,520
experiments

2118
01:09:18,709 --> 01:09:17,120
come online and they become more

2119
01:09:19,349 --> 01:09:18,719
sensitive and there are additional

2120
01:09:22,789 --> 01:09:19,359
all-sky

2121
01:09:24,630 --> 01:09:22,799
surveys with a variety of facilities

2122
01:09:27,189 --> 01:09:24,640
all these surveys both gravitational

2123
01:09:28,870 --> 01:09:27,199
waves experiments and all sky surveys at

2124
01:09:30,550 --> 01:09:28,880
other wavelengths

2125
01:09:32,390 --> 01:09:30,560
then hubble are going to be scanning the

2126
01:09:34,309 --> 01:09:32,400
sky and finding new explosive transient

2127
01:09:36,950 --> 01:09:34,319
phenomena and uv optical

2128
01:09:37,990 --> 01:09:36,960
follow-up data with hubble will be key

2129
01:09:40,950 --> 01:09:38,000
because hubble

2130
01:09:43,030 --> 01:09:40,960
has unique capabilities and it'll help

2131
01:09:43,829 --> 01:09:43,040
provide a localization within the host

2132
01:09:45,749 --> 01:09:43,839
galaxy

2133
01:09:47,590 --> 01:09:45,759
for these events it'll provide high

2134
01:09:49,189 --> 01:09:47,600
position precision positions and

2135
01:09:50,550 --> 01:09:49,199
luminosities

2136
01:09:52,229 --> 01:09:50,560
it'll also provide discrimination

2137
01:09:53,510 --> 01:09:52,239
between competing models of the

2138
01:09:55,990 --> 01:09:53,520

transient event

2139
01:09:57,750 --> 01:09:56,000
and just to show you how it can do that

2140
01:09:59,750 --> 01:09:57,760
what's plotted here is from this

2141
01:10:02,229 --> 01:09:59,760
gravitational wave event 2017

2142
01:10:03,430 --> 01:10:02,239
is a plot of the brightness versus time

2143
01:10:07,030 --> 01:10:03,440
in days

2144
01:10:09,110 --> 01:10:07,040
at different wavelengths so in the

2145
01:10:10,790 --> 01:10:09,120
purple colors that's ultraviolet light

2146
01:10:11,910 --> 01:10:10,800
and then the red colors that's infrared

2147
01:10:15,990 --> 01:10:11,920
light

2148
01:10:17,910 --> 01:10:16,000
and this is from a variety of data sets

2149
01:10:19,669 --> 01:10:17,920
looking at this gravitational wave event

2150
01:10:20,950 --> 01:10:19,679
over the course of several days

2151
01:10:23,110 --> 01:10:20,960
and weeks and you can see in the

2152
01:10:24,470 --> 01:10:23,120
ultraviolet the gravitational wave event

2153
01:10:26,390 --> 01:10:24,480
fades quite quickly

2154
01:10:28,950 --> 01:10:26,400
whereas it takes weeks to fade in the

2155
01:10:32,070 --> 01:10:28,960
infrared and so this strong

2156
01:10:34,390 --> 01:10:32,080
wavelength dependence to the decay will

2157
01:10:37,189 --> 01:10:34,400
give us insight into competing models of

2158
01:10:39,830 --> 01:10:37,199
the physics of what's happening here

2159
01:10:41,830 --> 01:10:39,840
so hubble's outlook for the 2020s hubble

2160
01:10:44,709 --> 01:10:41,840
will play an exciting role in the next

2161
01:10:45,990 --> 01:10:44,719
decade of astrophysics hubble and webb

2162
01:10:48,310 --> 01:10:46,000
working together

2163
01:10:51,189 --> 01:10:48,320

will give us amazing insight into

2164
01:10:52,870 --> 01:10:51,199
exoplanets and their atmospheres

2165
01:10:55,110 --> 01:10:52,880
hubble will continue to probe the

2166
01:10:57,189 --> 01:10:55,120
expansion of the universe and the dark

2167
01:10:59,189 --> 01:10:57,199
energy responsible for it

2168
01:11:01,830 --> 01:10:59,199
hubble will work with solar system

2169
01:11:03,590 --> 01:11:01,840
missions exploring our own solar system

2170
01:11:05,030 --> 01:11:03,600
and hubble data will be key to

2171
01:11:07,590 --> 01:11:05,040
understanding

2172
01:11:09,110 --> 01:11:07,600
the data obtained of other upcoming

2173
01:11:12,709 --> 01:11:09,120
survey facilities

2174
01:11:14,310 --> 01:11:12,719
exploring transient explosive phenomena

2175
01:11:16,470 --> 01:11:14,320
we're going to have a new decade of all

2176
01:11:17,350 --> 01:11:16,480
sky surveys and also gravitational wave

2177
01:11:19,189 --> 01:11:17,360
astronomy

2178
01:11:21,750 --> 01:11:19,199
and hubble will be involved in all that

2179
01:11:28,229 --> 01:11:24,870
ah thank you tom that was great i mean

2180
01:11:29,030 --> 01:11:28,239
that is yeah i mean it takes a lot to

2181
01:11:30,709 --> 01:11:29,040
cram into an

2182
01:11:32,870 --> 01:11:30,719
hour all the things that hubble's done

2183
01:11:34,790 --> 01:11:32,880
for 30 years

2184
01:11:36,070 --> 01:11:34,800
how long have you been the uh hst

2185
01:11:38,790 --> 01:11:36,080
mission head

2186
01:11:40,070 --> 01:11:38,800
since 2016. i worked on james webb for

2187
01:11:40,950 --> 01:11:40,080
eight years before that and hubble

2188
01:11:43,510 --> 01:11:40,960

before that

2189
01:11:44,870 --> 01:11:43,520
right so you've seen uh you know quite

2190
01:11:46,390 --> 01:11:44,880
quite a bit of

2191
01:11:47,910 --> 01:11:46,400
some of the new stuff that we've done

2192
01:11:50,229 --> 01:11:47,920
we've been able to do

2193
01:11:51,189 --> 01:11:50,239
and so i i guess one of the questions i

2194
01:11:53,030 --> 01:11:51,199
would ask is

2195
01:11:55,030 --> 01:11:53,040
in looking at how hubble has changed

2196
01:11:55,669 --> 01:11:55,040
over how we've used hubble over the over

2197
01:11:58,310 --> 01:11:55,679
the years

2198
01:11:59,669 --> 01:11:58,320
you showcase the the drift scanning are

2199
01:12:00,870 --> 01:11:59,679
there other really cool things that

2200
01:12:02,390 --> 01:12:00,880
we've been able to do with hubble that

2201
01:12:03,350 --> 01:12:02,400
we didn't really imagine

2202
01:12:05,990 --> 01:12:03,360
that we were going to do from the

2203
01:12:07,270 --> 01:12:06,000
beginning i mean the actual planets is

2204
01:12:08,630 --> 01:12:07,280
the most obvious thing it really

2205
01:12:10,229 --> 01:12:08,640
captures the imagination because the

2206
01:12:11,350 --> 01:12:10,239
whole search for life it's really laying

2207
01:12:13,430 --> 01:12:11,360
the groundwork

2208
01:12:14,790 --> 01:12:13,440
for the eventual discovery of life and

2209
01:12:16,630 --> 01:12:14,800
other systems you know that's that's

2210
01:12:18,149 --> 01:12:16,640
one of the holy grails of astronomy so i

2211
01:12:20,229 --> 01:12:18,159
would say that uh

2212
01:12:21,990 --> 01:12:20,239
the high precision measurements that

2213
01:12:23,430 --> 01:12:22,000

we're doing with astrometry that

2214
01:12:25,510 --> 01:12:23,440
again i highlighted this early in the

2215
01:12:27,830 --> 01:12:25,520
talk that was not really foreseen

2216
01:12:29,270 --> 01:12:27,840
at this level uh when hubble launched we

2217
01:12:30,070 --> 01:12:29,280
knew that hubble was going to give us

2218
01:12:32,470 --> 01:12:30,080
really

2219
01:12:33,510 --> 01:12:32,480
amazing detail and high contrast high

2220
01:12:35,189 --> 01:12:33,520
resolution imaging

2221
01:12:36,630 --> 01:12:35,199
that would allow us to measure positions

2222
01:12:38,229 --> 01:12:36,640
and motions of stars

2223
01:12:40,229 --> 01:12:38,239
but with this drift scanning as we said

2224
01:12:42,470 --> 01:12:40,239
now that we can do its orders of

2225
01:12:43,830 --> 01:12:42,480
magnitude more powerful than we

2226
01:12:45,350 --> 01:12:43,840
thought we would be able to do at launch

2227
01:12:46,870 --> 01:12:45,360
and it's competitive with dedicated

2228
01:12:49,110 --> 01:12:46,880
missions i mean the gaia mission

2229
01:12:51,030 --> 01:12:49,120
is doing amazing work in this area over

2230
01:12:52,310 --> 01:12:51,040
the vast area you know sky but hubble

2231
01:12:53,510 --> 01:12:52,320
gets measurements that are competitive

2232
01:12:55,110 --> 01:12:53,520
with gaia in this area

2233
01:12:56,950 --> 01:12:55,120
and is actually you know used for

2234
01:12:57,669 --> 01:12:56,960
specific ways to complement what gaia is

2235
01:12:59,750 --> 01:12:57,679
doing so

2236
01:13:01,030 --> 01:12:59,760
i mean as the field changes hubble gets

2237
01:13:01,669 --> 01:13:01,040
used in new innovative ways to

2238
01:13:04,790 --> 01:13:01,679

complement

2239
01:13:06,870 --> 01:13:04,800
with other facilities

2240
01:13:08,630 --> 01:13:06,880
right and that's one of the benefits of

2241
01:13:11,189 --> 01:13:08,640
having a telescope that you

2242
01:13:11,830 --> 01:13:11,199
learn and re-learn and adjust for 30

2243
01:13:13,510 --> 01:13:11,840
years

2244
01:13:15,430 --> 01:13:13,520
right so we actually had a question

2245
01:13:18,390 --> 01:13:15,440
about that in our chat

2246
01:13:19,189 --> 01:13:18,400
um and it said how do you line up

2247
01:13:21,590 --> 01:13:19,199
multiple

2248
01:13:22,950 --> 01:13:21,600
exposures so precisely i mean hubble's

2249
01:13:24,149 --> 01:13:22,960
orbiting and it's got to be wiggling and

2250
01:13:25,669 --> 01:13:24,159
wobbling and such and

2251
01:13:27,910 --> 01:13:25,679
can you explain a bit about the uh the

2252
01:13:29,189 --> 01:13:27,920
fts stuff sure yeah so the pointing

2253
01:13:32,229 --> 01:13:29,199
control system

2254
01:13:33,750 --> 01:13:32,239
involves multiple components that are

2255
01:13:34,229 --> 01:13:33,760
all working together and when we're

2256
01:13:36,310 --> 01:13:34,239
actually

2257
01:13:38,149 --> 01:13:36,320
looking at an object we have three

2258
01:13:39,750 --> 01:13:38,159
operational gyroscopes

2259
01:13:40,950 --> 01:13:39,760
that are helping to orient the telescope

2260
01:13:43,110 --> 01:13:40,960
and then we also have what we said that

2261
01:13:44,950 --> 01:13:43,120
was the fine guidance sensor package

2262
01:13:47,189 --> 01:13:44,960
and these are three fine guidance

2263
01:13:48,950 --> 01:13:47,199

sensors that we also call the pickles

2264
01:13:50,149 --> 01:13:48,960
they have sort of a pickle shaped view

2265
01:13:52,149 --> 01:13:50,159
on the sky that

2266
01:13:53,990 --> 01:13:52,159
extends a much wider field of view than

2267
01:13:56,310 --> 01:13:54,000
you get on the normal cameras on hubble

2268
01:13:57,750 --> 01:13:56,320
and you can look on the web i don't have

2269
01:13:59,590 --> 01:13:57,760
one handy in the slides here but

2270
01:14:00,709 --> 01:13:59,600
you can see the the focal plane of

2271
01:14:02,149 --> 01:14:00,719
hubble and where all the different

2272
01:14:03,430 --> 01:14:02,159
cameras look and then the pickles are

2273
01:14:05,189 --> 01:14:03,440
these very obvious three

2274
01:14:06,630 --> 01:14:05,199
pickle-shaped fields of view and what

2275
01:14:08,310 --> 01:14:06,640
they do is they look at a big

2276
01:14:09,910 --> 01:14:08,320
group of stars and that fall into the

2277
01:14:11,990 --> 01:14:09,920
pickles and just track

2278
01:14:13,590 --> 01:14:12,000
where those stars are within the field

2279
01:14:13,990 --> 01:14:13,600
of view to find guidance sensors and you

2280
01:14:16,550 --> 01:14:14,000
have those

2281
01:14:17,590 --> 01:14:16,560
working in tandem with the the

2282
01:14:19,510 --> 01:14:17,600
gyroscopes

2283
01:14:20,870 --> 01:14:19,520
and then the reaction wheels can orient

2284
01:14:22,310 --> 01:14:20,880
the telescope and all those work

2285
01:14:24,229 --> 01:14:22,320
together very carefully

2286
01:14:26,070 --> 01:14:24,239
to hold things steady at the level of

2287
01:14:27,830 --> 01:14:26,080
milliarc seconds i mean so that's it's a

2288
01:14:29,669 --> 01:14:27,840

system that all works together dovetails

2289
01:14:31,430 --> 01:14:29,679
together very precisely

2290
01:14:32,709 --> 01:14:31,440
right i don't think people recognize

2291
01:14:34,310 --> 01:14:32,719
that they sort of think it's just the

2292
01:14:36,630 --> 01:14:34,320
gyroscopes doing it all

2293
01:14:38,229 --> 01:14:36,640
right and getting getting getting that

2294
01:14:39,590 --> 01:14:38,239
feedback loop between

2295
01:14:41,830 --> 01:14:39,600
all the different systems is so

2296
01:14:42,550 --> 01:14:41,840
important right okay so we got some

2297
01:14:43,910 --> 01:14:42,560
basic uh

2298
01:14:46,149 --> 01:14:43,920
uh questions that we always get about

2299
01:14:49,030 --> 01:14:46,159
hubble so i'll hit those first of all

2300
01:14:49,350 --> 01:14:49,040
sure um would another servicing mission

2301
01:14:51,510 --> 01:14:49,360
be

2302
01:14:52,709 --> 01:14:51,520
possible with for example the falcon

2303
01:14:54,630 --> 01:14:52,719
heavy

2304
01:14:56,070 --> 01:14:54,640
um right now there are no servicing

2305
01:14:59,350 --> 01:14:56,080
missions planned

2306
01:15:01,110 --> 01:14:59,360
but it is intriguing to watch the the

2307
01:15:02,070 --> 01:15:01,120
new variety of launch services coming

2308
01:15:04,550 --> 01:15:02,080
online as the

2309
01:15:05,189 --> 01:15:04,560
as the you know cooperation between uh

2310
01:15:07,430 --> 01:15:05,199
both

2311
01:15:08,709 --> 01:15:07,440
government space programs and commercial

2312
01:15:09,990 --> 01:15:08,719
space programs prior you know like

2313
01:15:13,510 --> 01:15:10,000

spacex and blue origin

2314
01:15:14,630 --> 01:15:13,520
and so forth uh so it's possible that

2315
01:15:16,550 --> 01:15:14,640
someday someone could

2316
01:15:18,310 --> 01:15:16,560
service hubble i mean right now no one

2317
01:15:20,070 --> 01:15:18,320
has mapped that out in detail but yes

2318
01:15:20,870 --> 01:15:20,080
there are heavy lift capabilities coming

2319
01:15:22,870 --> 01:15:20,880
into play

2320
01:15:24,149 --> 01:15:22,880
people have looked in the past at ways

2321
01:15:26,950 --> 01:15:24,159
we could have you know in the

2322
01:15:28,630 --> 01:15:26,960
at the in the early 2000s uh when the

2323
01:15:29,430 --> 01:15:28,640
servicing the last service admission to

2324
01:15:31,430 --> 01:15:29,440
hubble

2325
01:15:32,630 --> 01:15:31,440
was in danger of being uh canceled and

2326
01:15:33,910 --> 01:15:32,640
not proceeding people were looking at

2327
01:15:35,350 --> 01:15:33,920
ways of doing hubble servicing

2328
01:15:37,270 --> 01:15:35,360
robotically for example

2329
01:15:38,870 --> 01:15:37,280
so people have looked at innovative ways

2330
01:15:40,550 --> 01:15:38,880
to service hubble

2331
01:15:41,910 --> 01:15:40,560
and these new launch facilities coming

2332
01:15:45,030 --> 01:15:41,920
online could certainly

2333
01:15:47,750 --> 01:15:45,040
you know revisit that question good so

2334
01:15:49,350 --> 01:15:47,760
the obvious question then is without a

2335
01:15:52,709 --> 01:15:49,360
service commission how long do

2336
01:15:55,189 --> 01:15:52,719
do we expect hubble to last so hubble

2337
01:15:56,950 --> 01:15:55,199
is has already lasted much longer than

2338
01:15:58,470 --> 01:15:56,960

we expected and that's good news so i'm

2339
01:15:59,270 --> 01:15:58,480
not saying that uh oh that means it can

2340
01:16:01,510 --> 01:15:59,280
go any day

2341
01:16:02,870 --> 01:16:01,520
this is really a a positive story

2342
01:16:04,790 --> 01:16:02,880
because during the last service in

2343
01:16:06,229 --> 01:16:04,800
mission 2009

2344
01:16:07,510 --> 01:16:06,239
and i worked on one of the instruments

2345
01:16:08,630 --> 01:16:07,520
that whitefield camera three that's what

2346
01:16:09,510 --> 01:16:08,640
i was working on right before i switched

2347
01:16:11,270 --> 01:16:09,520
to james webb

2348
01:16:12,470 --> 01:16:11,280
we were hopeful that hubble at that time

2349
01:16:14,310 --> 01:16:12,480
after the last servicing mission would

2350
01:16:16,070 --> 01:16:14,320
last till about 2016 or so

2351
01:16:17,510 --> 01:16:16,080
that was really what we were looking for

2352
01:16:19,030 --> 01:16:17,520
but what happened was

2353
01:16:20,390 --> 01:16:19,040
after everything was up there we saw how

2354
01:16:22,070 --> 01:16:20,400
well everything was working and we were

2355
01:16:24,070 --> 01:16:22,080
able to track everything and watch the

2356
01:16:26,070 --> 01:16:24,080
evolution of it as it was up there and

2357
01:16:28,070 --> 01:16:26,080
in the harsh environment of space we had

2358
01:16:29,350 --> 01:16:28,080
to re-evaluate those reliability

2359
01:16:30,790 --> 01:16:29,360
estimates because we said oh hey you

2360
01:16:32,310 --> 01:16:30,800
know a lot of the things that

2361
01:16:33,990 --> 01:16:32,320
that look like they could be wearing out

2362
01:16:34,790 --> 01:16:34,000
it's actually working much better than

2363
01:16:36,709 --> 01:16:34,800

we thought and so

2364
01:16:38,070 --> 01:16:36,719
the engineers at nasa gave that all

2365
01:16:39,910 --> 01:16:38,080
another look and they

2366
01:16:41,510 --> 01:16:39,920
continuously update the estimates for

2367
01:16:42,470 --> 01:16:41,520
how reliable the different subsystems

2368
01:16:44,149 --> 01:16:42,480
and instruments are

2369
01:16:45,750 --> 01:16:44,159
and right now there's an excellent

2370
01:16:47,110 --> 01:16:45,760
chance that we are operational through

2371
01:16:48,709 --> 01:16:47,120
2026

2372
01:16:50,630 --> 01:16:48,719
and every year operational things look

2373
01:16:51,750 --> 01:16:50,640
better and better and so there's still a

2374
01:16:52,790 --> 01:16:51,760
good chance it lasts throughout the

2375
01:16:55,270 --> 01:16:52,800
2020s so

2376
01:16:55,990 --> 01:16:55,280
you know we'll see all right so that

2377
01:16:57,350 --> 01:16:56,000
leads to

2378
01:16:59,110 --> 01:16:57,360
the other the other question that was

2379
01:17:01,590 --> 01:16:59,120
asked is

2380
01:17:02,950 --> 01:17:01,600
about the capabilities of hst versus

2381
01:17:04,950 --> 01:17:02,960
jwst

2382
01:17:07,430 --> 01:17:04,960
and then we just got a recent question

2383
01:17:09,590 --> 01:17:07,440
about jjsd and hsd working together

2384
01:17:10,870 --> 01:17:09,600
so some people don't understand the the

2385
01:17:12,149 --> 01:17:10,880
different capabilities the two

2386
01:17:13,270 --> 01:17:12,159
telescopes have can you just go into

2387
01:17:15,510 --> 01:17:13,280
that for a little bit sure

2388
01:17:17,750 --> 01:17:15,520

so first of all james webb is much

2389
01:17:19,750 --> 01:17:17,760
larger than hubble it has a much bigger

2390
01:17:21,270 --> 01:17:19,760
aperture the width of its primary mirror

2391
01:17:22,790 --> 01:17:21,280
is six and a half meters across whereas

2392
01:17:24,070 --> 01:17:22,800
hubble is 2.4 meters across

2393
01:17:25,430 --> 01:17:24,080
so there's a lot more collecting area

2394
01:17:26,470 --> 01:17:25,440
for james webb and james webb was

2395
01:17:29,510 --> 01:17:26,480
designed

2396
01:17:32,470 --> 01:17:29,520
primarily to look at very faint

2397
01:17:34,149 --> 01:17:32,480
red objects in the far distant universe

2398
01:17:35,189 --> 01:17:34,159
looking way back in time looking all the

2399
01:17:37,750 --> 01:17:35,199
way across the universe

2400
01:17:38,630 --> 01:17:37,760
and so it's an infrared telescope uh it

2401
01:17:40,470 --> 01:17:38,640
has a

2402
01:17:42,709 --> 01:17:40,480
large segmented primary mirror to

2403
01:17:44,550 --> 01:17:42,719
collect this very faint infrared light

2404
01:17:45,910 --> 01:17:44,560
uh it doesn't really operate at short

2405
01:17:47,030 --> 01:17:45,920
wavelengths into the optical and

2406
01:17:49,590 --> 01:17:47,040
ultraviolet

2407
01:17:50,709 --> 01:17:49,600
and that's where hubble really shines

2408
01:17:52,149 --> 01:17:50,719
and because

2409
01:17:53,669 --> 01:17:52,159
it's one of the only facilities that

2410
01:17:54,950 --> 01:17:53,679
really you know it's the largest

2411
01:17:55,590 --> 01:17:54,960
telescope working the ultraviolet

2412
01:17:58,149 --> 01:17:55,600
optical

2413
01:17:58,950 --> 01:17:58,159

in space and so what we're going to see

2414
01:18:01,270 --> 01:17:58,960
is a shift

2415
01:18:02,950 --> 01:18:01,280
i think after james webb launches where

2416
01:18:04,630 --> 01:18:02,960
james webb is really going to be pushing

2417
01:18:05,990 --> 01:18:04,640
the envelope in the infrared

2418
01:18:07,350 --> 01:18:06,000
i think we'll still do infrared science

2419
01:18:08,950 --> 01:18:07,360
with hubble but we'll shift what we're

2420
01:18:10,390 --> 01:18:08,960
doing with uh on in the infrared hubble

2421
01:18:11,510 --> 01:18:10,400
given the presence of james webb

2422
01:18:13,350 --> 01:18:11,520
and then you're going to see things

2423
01:18:14,950 --> 01:18:13,360
working in tandem where looking at the

2424
01:18:16,550 --> 01:18:14,960
same object like an exoplanet

2425
01:18:17,910 --> 01:18:16,560
james webb will get the infrared data

2426
01:18:19,590 --> 01:18:17,920
hubble will get the ultrabon optical

2427
01:18:20,229 --> 01:18:19,600
data and you'll combine those to really

2428
01:18:21,510 --> 01:18:20,239
learn

2429
01:18:23,750 --> 01:18:21,520
everything about that object that you

2430
01:18:24,390 --> 01:18:23,760
can and the exoplanets is a great

2431
01:18:25,910 --> 01:18:24,400
example

2432
01:18:27,590 --> 01:18:25,920
of where that really works well but

2433
01:18:29,110 --> 01:18:27,600
there are other areas as well

2434
01:18:30,950 --> 01:18:29,120
exactly because you know your

2435
01:18:33,510 --> 01:18:30,960
demonstration in your slides

2436
01:18:34,950 --> 01:18:33,520
of why we need multiple telescopes in

2437
01:18:37,189 --> 01:18:34,960
multiple wavelengths

2438
01:18:39,030 --> 01:18:37,199

really show you know nasa doesn't need

2439
01:18:40,790 --> 01:18:39,040
just one telescope it needs a fleet of

2440
01:18:42,790 --> 01:18:40,800
telescopes to cover as much of the

2441
01:18:44,470 --> 01:18:42,800
electromagnetic spectrum as we can

2442
01:18:45,669 --> 01:18:44,480
yeah and hannah wakeford that was her

2443
01:18:47,350 --> 01:18:45,679
research there i had her name on the

2444
01:18:49,270 --> 01:18:47,360
slide but she's really given

2445
01:18:50,550 --> 01:18:49,280
stupendous talks if you look out there

2446
01:18:51,669 --> 01:18:50,560
on this subject about how

2447
01:18:53,350 --> 01:18:51,679
synergistically

2448
01:18:55,189 --> 01:18:53,360
combining exoplanet data from different

2449
01:18:57,830 --> 01:18:55,199
facilities really breaks open you know

2450
01:19:00,149 --> 01:18:57,840
what you can learn

2451
01:19:02,709 --> 01:19:00,159
um somebody asked uh has hubble ever

2452
01:19:05,110 --> 01:19:02,719
been hit by space debris

2453
01:19:06,830 --> 01:19:05,120
uh yes so it gets hit by microbes i like

2454
01:19:10,310 --> 01:19:06,840
the movie gravity by the way

2455
01:19:11,830 --> 01:19:10,320
yeah right so so it does

2456
01:19:13,510 --> 01:19:11,840
you know there's the environment of

2457
01:19:15,110 --> 01:19:13,520
space is pretty harsh so there are both

2458
01:19:16,229 --> 01:19:15,120
cosmic rays passing through hubble and

2459
01:19:18,470 --> 01:19:16,239
bouncing around

2460
01:19:20,390 --> 01:19:18,480
uh and causing scattering uh radiation

2461
01:19:21,910 --> 01:19:20,400
scattering uh and then there's also

2462
01:19:23,510 --> 01:19:21,920
micro meteorites and so when the

2463
01:19:24,229 --> 01:19:23,520

astronauts go up there every servicing

2464
01:19:26,149 --> 01:19:24,239
mission

2465
01:19:27,830 --> 01:19:26,159
they've refurbished the outside of

2466
01:19:29,750 --> 01:19:27,840
hubble and the blankets and

2467
01:19:31,430 --> 01:19:29,760
the surface of hubble and you can see

2468
01:19:32,630 --> 01:19:31,440
impacts from hubble but it's not like

2469
01:19:34,229 --> 01:19:32,640
something you know

2470
01:19:36,310 --> 01:19:34,239
has gone clear through it and you know

2471
01:19:38,070 --> 01:19:36,320
done damage that uh is catastrophic in

2472
01:19:39,590 --> 01:19:38,080
any way or anything like that it's just

2473
01:19:42,149 --> 01:19:39,600
uh you can see the impacts from

2474
01:19:45,350 --> 01:19:42,159
micrometeorites et cetera yeah

2475
01:19:45,669 --> 01:19:45,360
okay and then we get um a question that

2476
01:19:49,430 --> 01:19:45,679
i'm

2477
01:19:51,430 --> 01:19:49,440
to answer this one

2478
01:19:53,110 --> 01:19:51,440
uh do you think faint gravitational

2479
01:19:55,750 --> 01:19:53,120
waves from the early universe

2480
01:19:56,870 --> 01:19:55,760
will contribute to the cosmological

2481
01:19:59,030 --> 01:19:56,880
constant or understanding of the

2482
01:20:01,910 --> 01:19:59,040
cosmological constant and such

2483
01:20:03,830 --> 01:20:01,920
uh they're trying to take these

2484
01:20:05,510 --> 01:20:03,840
gravitational wave discoveries and see

2485
01:20:06,870 --> 01:20:05,520
does this affect the universe on large

2486
01:20:10,709 --> 01:20:06,880
scale with this

2487
01:20:13,590 --> 01:20:10,719
uh the dark energy i mean dark energy

2488
01:20:15,030 --> 01:20:13,600

still remains a mystery and as as these

2489
01:20:17,990 --> 01:20:15,040
as the uncertainties shrink

2490
01:20:18,790 --> 01:20:18,000
on the measurement of this expansion we

2491
01:20:20,149 --> 01:20:18,800
begin to

2492
01:20:22,070 --> 01:20:20,159
these groups who are doing this research

2493
01:20:23,430 --> 01:20:22,080
begin to rule out some of the possible

2494
01:20:24,629 --> 01:20:23,440
explanations for dark energy and the

2495
01:20:27,669 --> 01:20:24,639
expansion of the universe

2496
01:20:29,350 --> 01:20:27,679
uh given the the variety of answers

2497
01:20:31,110 --> 01:20:29,360
still on the table

2498
01:20:33,590 --> 01:20:31,120
i guess it's not unthinkable that the

2499
01:20:35,430 --> 01:20:33,600
gravitational wave astronomy could help

2500
01:20:37,510 --> 01:20:35,440
uh shed more light on that on that

2501
01:20:38,390 --> 01:20:37,520
problem uh no pun intended there because

2502
01:20:39,350 --> 01:20:38,400
there's really no light with the

2503
01:20:42,070 --> 01:20:39,360
gravitational waves but

2504
01:20:43,669 --> 01:20:42,080
but uh but i i you know i suppose it

2505
01:20:44,870 --> 01:20:43,679
could help narrow down what's going on

2506
01:20:46,790 --> 01:20:44,880
but i'm not a gravitational wave

2507
01:20:47,590 --> 01:20:46,800
astronomer either uh so i could just

2508
01:20:49,030 --> 01:20:47,600
tell you that

2509
01:20:51,110 --> 01:20:49,040
you know i've seen people looking at it

2510
01:20:53,030 --> 01:20:51,120
in cosmic microwave background radiation

2511
01:20:54,790 --> 01:20:53,040
and through these different uh chains of

2512
01:20:55,510 --> 01:20:54,800
evidence of the expansion from local

2513
01:20:57,750 --> 01:20:55,520

objects

2514
01:21:00,149 --> 01:20:57,760
gravitational wave astronomy might have

2515
01:21:03,189 --> 01:21:00,159
a role to play

2516
01:21:04,629 --> 01:21:03,199
it's um it's such a cool that we're

2517
01:21:06,950 --> 01:21:04,639
getting these new

2518
01:21:08,390 --> 01:21:06,960
ways of seeing the universe popping up

2519
01:21:10,629 --> 01:21:08,400
in our lifetime

2520
01:21:13,350 --> 01:21:10,639
okay last question i i gleaned from the

2521
01:21:15,030 --> 01:21:13,360
chat was about gravitational lensing

2522
01:21:16,470 --> 01:21:15,040
and it appears that this person is used

2523
01:21:16,950 --> 01:21:16,480
to seeing gravitational lensing as

2524
01:21:19,189 --> 01:21:16,960
forming

2525
01:21:20,870 --> 01:21:19,199
rings but when you showed them that they

2526
01:21:22,390 --> 01:21:20,880
were the point sources

2527
01:21:23,990 --> 01:21:22,400
right can you just go in a little bit

2528
01:21:25,669 --> 01:21:24,000
about that and how

2529
01:21:27,110 --> 01:21:25,679
gravitational lens can produce different

2530
01:21:30,229 --> 01:21:27,120
imaging sure

2531
01:21:31,669 --> 01:21:30,239
so if you actually make a map uh and i

2532
01:21:32,070 --> 01:21:31,679
showed in that one slide where that's

2533
01:21:33,189 --> 01:21:32,080
where

2534
01:21:34,149 --> 01:21:33,199
it looked like the video went off the

2535
01:21:35,590 --> 01:21:34,159
rails for a little bit and then i

2536
01:21:37,910 --> 01:21:35,600
brought it back so i guess people still

2537
01:21:39,830 --> 01:21:37,920
saw those images right

2538
01:21:41,270 --> 01:21:39,840

so there's actually a great paper on

2539
01:21:43,270 --> 01:21:41,280
this recently that i just saw in the

2540
01:21:45,430 --> 01:21:43,280
literature that explains this but

2541
01:21:46,950 --> 01:21:45,440
basically the gravitational lens is the

2542
01:21:49,830 --> 01:21:46,960
foreground object

2543
01:21:50,550 --> 01:21:49,840
and depending on how far away you are on

2544
01:21:53,510 --> 01:21:50,560
the sky

2545
01:21:54,470 --> 01:21:53,520
far away but you know just the

2546
01:21:56,709 --> 01:21:54,480
background object

2547
01:21:57,830 --> 01:21:56,719
where it falls on the sky relative to

2548
01:21:59,510 --> 01:21:57,840
that massive lens

2549
01:22:01,669 --> 01:21:59,520
you get dramatically different effects

2550
01:22:03,189 --> 01:22:01,679
and so there are places where you can go

2551
01:22:04,629 --> 01:22:03,199
and the geometry is quite complex where

2552
01:22:04,950 --> 01:22:04,639
you get something like a ring like you

2553
01:22:06,070 --> 01:22:04,960
said

2554
01:22:08,149 --> 01:22:06,080
but then there are other places you can

2555
01:22:09,510 --> 01:22:08,159
go where the light really is focused on

2556
01:22:11,110 --> 01:22:09,520
one side or the other

2557
01:22:13,030 --> 01:22:11,120
of the lens and that's when you get

2558
01:22:14,709 --> 01:22:13,040
these multiple images and

2559
01:22:16,470 --> 01:22:14,719
depending upon the structure of the

2560
01:22:18,310 --> 01:22:16,480
gravitational lens itself because often

2561
01:22:20,709 --> 01:22:18,320
it's not just a single

2562
01:22:22,310 --> 01:22:20,719
massive galaxy it can also be a galaxy

2563
01:22:23,189 --> 01:22:22,320

cluster with a complicated mass

2564
01:22:24,950 --> 01:22:23,199
distribution in there

2565
01:22:26,629 --> 01:22:24,960
you can get quite complex patterns in

2566
01:22:27,110 --> 01:22:26,639
the frontier fields so great examples of

2567
01:22:29,430 --> 01:22:27,120
that

2568
01:22:30,870 --> 01:22:29,440
where it's not just you know one lens

2569
01:22:32,790 --> 01:22:30,880
it's all these arcs and and

2570
01:22:33,990 --> 01:22:32,800
and you know a supernova exploded

2571
01:22:34,629 --> 01:22:34,000
multiple times even though it's just one

2572
01:22:36,229 --> 01:22:34,639
supernova

2573
01:22:37,590 --> 01:22:36,239
which blew people's minds when they saw

2574
01:22:38,950 --> 01:22:37,600
that i mean that was i mean you know you

2575
01:22:40,070 --> 01:22:38,960
knew it was possible but to have that

2576
01:22:41,189 --> 01:22:40,080
happen was like you know get out the

2577
01:22:42,870 --> 01:22:41,199
party hats because

2578
01:22:44,709 --> 01:22:42,880
uh because it was really an amazing

2579
01:22:46,950 --> 01:22:44,719
demonstration of both lensing and the

2580
01:22:49,669 --> 01:22:46,960
time delays involved right

2581
01:22:51,590 --> 01:22:49,679
so yeah uh gravitational lensing always

2582
01:22:54,229 --> 01:22:51,600
attracts the public's fascination

2583
01:22:55,430 --> 01:22:54,239
and it uh the the number of ways for it

2584
01:22:57,830 --> 01:22:55,440
to be complex

2585
01:22:59,030 --> 01:22:57,840
has just multiplied with hubble and i

2586
01:23:00,950 --> 01:22:59,040
remember when i was

2587
01:23:03,030 --> 01:23:00,960
just starting with hubble and we got the

2588
01:23:04,950 --> 01:23:03,040

image of abell 1689

2589
01:23:06,629 --> 01:23:04,960
and seeing the tremendous lensing that

2590
01:23:09,669 --> 01:23:06,639
hubble could see

2591
01:23:11,910 --> 01:23:09,679
that high resolution really has has has

2592
01:23:15,510 --> 01:23:11,920
made that field just jump

2593
01:23:18,830 --> 01:23:15,520
right right okay well tom uh

2594
01:23:20,950 --> 01:23:18,840
that was fantastic a really great great

2595
01:23:21,990 --> 01:23:20,960
overview i want to say to everybody

2596
01:23:24,790 --> 01:23:22,000
please join us

2597
01:23:26,149 --> 01:23:24,800
next month uh april 6th christopher

2598
01:23:28,629 --> 01:23:26,159
wanzak will be talking about

2599
01:23:29,430 --> 01:23:28,639
space fares how humans will settle the

2600
01:23:32,470 --> 01:23:29,440
moon

2601
01:23:33,350 --> 01:23:32,480
mars and beyond and thank you very much