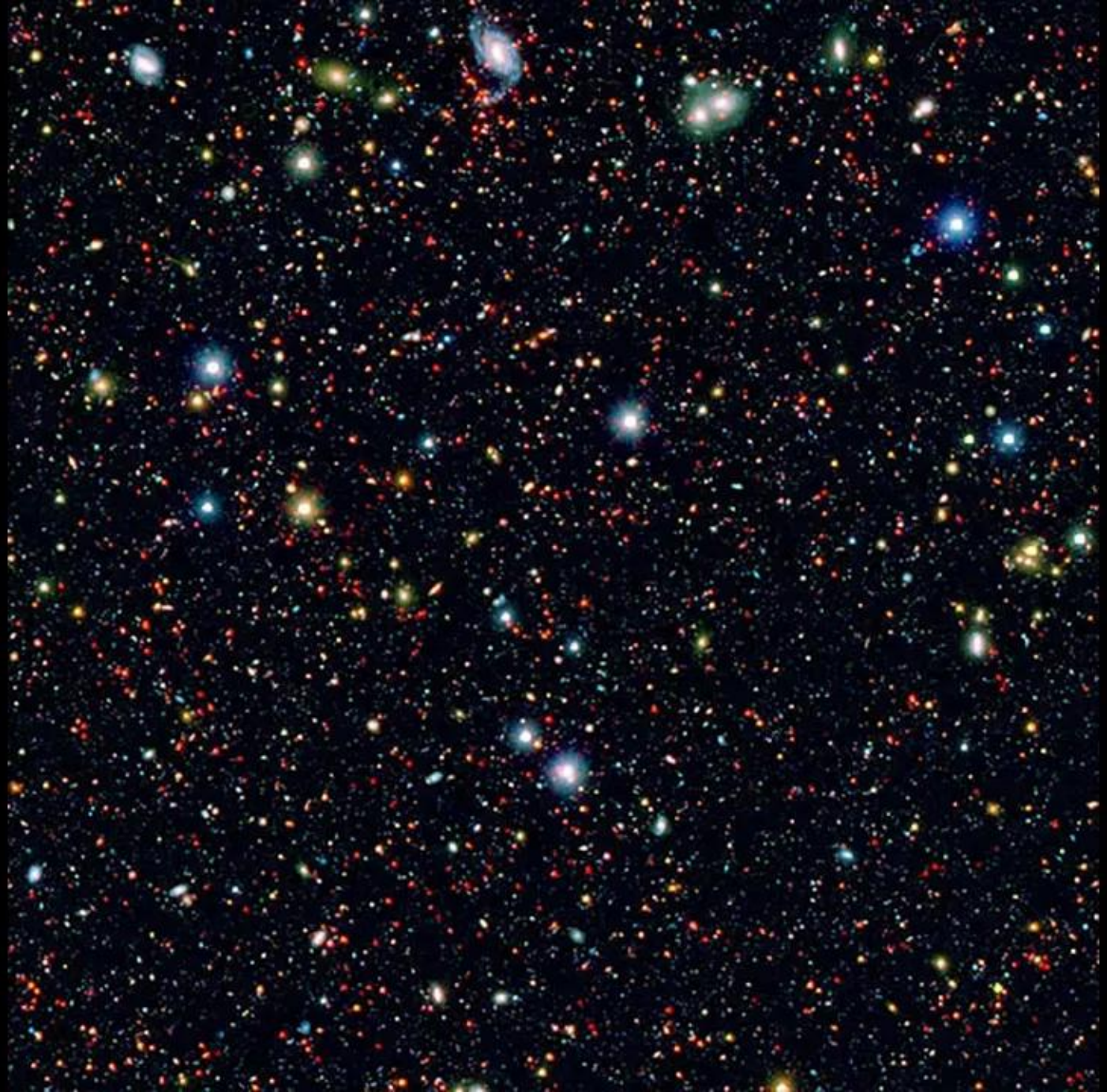

1
00:00:03,750 --> 00:00:01,829
[Music]

2
00:00:05,349 --> 00:00:03,760
nasa's jet propulsion laboratory

3
00:00:07,990 --> 00:00:05,359
presents

4
00:00:10,070 --> 00:00:08,000
the von carmen lecture a series of talks

5
00:00:13,350 --> 00:00:10,080
by scientists and engineers who are

6
00:00:18,350 --> 00:00:13,360
exploring our planet our solar system

7
00:00:25,269 --> 00:00:22,790
[Music]

8
00:00:26,790 --> 00:00:25,279
good evening everybody

9
00:00:28,550 --> 00:00:26,800
thank you for joining us tonight my name

10
00:00:30,710 --> 00:00:28,560
is mark razzie from the public services

11
00:00:32,229 --> 00:00:30,720
office at jpl and again want to thank

12
00:00:34,709 --> 00:00:32,239
you so much for joining us for this

13
00:00:35,670 --> 00:00:34,719

edition of the von carmen series

14
00:00:37,190 --> 00:00:35,680
tonight

15
00:00:39,670 --> 00:00:37,200
we're going to explore the infrared

16
00:00:41,430 --> 00:00:39,680
spectrum or at least some of it

17
00:00:43,830 --> 00:00:41,440
now william herschel first discovered

18
00:00:46,790 --> 00:00:43,840
the infrared in 1800 but it wasn't until

19
00:00:49,029 --> 00:00:46,800
the mid-20th century that real research

20
00:00:51,270 --> 00:00:49,039
into that part of the spectrum began but

21
00:00:53,270 --> 00:00:51,280
when it did it began in earnest there

22
00:00:55,189 --> 00:00:53,280
have been many instruments telescopes

23
00:00:57,430 --> 00:00:55,199
and spacecraft that have all worked to

24
00:00:59,110 --> 00:00:57,440
reveal mysteries hidden in the infrared

25
00:01:00,310 --> 00:00:59,120
but there are still plenty of unanswered

26
00:01:03,270 --> 00:01:00,320
questions

27
00:01:05,109 --> 00:01:03,280
tonight our guests who are but two

28
00:01:07,030 --> 00:01:05,119
of very many people working on these

29
00:01:09,030 --> 00:01:07,040
projects by the way are going to talk

30
00:01:11,030 --> 00:01:09,040
about two upcoming missions that hope to

31
00:01:13,910 --> 00:01:11,040
deepen our understanding of our universe

32
00:01:16,310 --> 00:01:13,920
by continuing to delve into the infrared

33
00:01:18,550 --> 00:01:16,320
helping me out tonight with the q a is

34
00:01:22,710 --> 00:01:18,560
our co-host jpl public outreach

35
00:01:24,870 --> 00:01:22,720
specialist caitlin soares hi caitlin

36
00:01:26,550 --> 00:01:24,880
hello and welcome everyone as mark

37
00:01:29,429 --> 00:01:26,560
mentioned my name is caitlin and i work

38
00:01:31,270 --> 00:01:29,439

in public outreach at jpl we have a

39
00:01:32,630 --> 00:01:31,280
fascinating program for you tonight and

40
00:01:35,590 --> 00:01:32,640
we want you to be involved in the

41
00:01:37,350 --> 00:01:35,600
conversation so please ask questions in

42
00:01:38,789 --> 00:01:37,360
the chat and we'll try to address as

43
00:01:40,870 --> 00:01:38,799
many of them as possible tonight

44
00:01:42,789 --> 00:01:40,880
throughout our discussion if you don't

45
00:01:44,230 --> 00:01:42,799
see the chat for some reason please

46
00:01:46,069 --> 00:01:44,240
refresh your browser and it should

47
00:01:47,510 --> 00:01:46,079
appear and i'll turn it back over to

48
00:01:50,069 --> 00:01:47,520
mark now so he can introduce our

49
00:01:51,990 --> 00:01:50,079
brilliant speakers for tonight's program

50
00:01:55,109 --> 00:01:52,000
thank you very much caitlin so our

51
00:01:57,590 --> 00:01:55,119
guests tonight are dr dita markovic who

52
00:01:59,990 --> 00:01:57,600
is a research scientist at jpl

53
00:02:01,990 --> 00:02:00,000
working on the euclid mission and dr

54
00:02:04,389 --> 00:02:02,000
phil corngut who is a research scientist

55
00:02:06,709 --> 00:02:04,399
at caltech and the instrument scientist

56
00:02:08,790 --> 00:02:06,719
on the spherex mission good evening my

57
00:02:11,830 --> 00:02:08,800
friends how are you guys

58
00:02:14,550 --> 00:02:11,840
all right it's super happy to be here

59
00:02:15,830 --> 00:02:14,560
thanks our pleasure so phil to set the

60
00:02:17,350 --> 00:02:15,840
stage

61
00:02:18,550 --> 00:02:17,360
uh would you be so kind to give us a

62
00:02:21,430 --> 00:02:18,560
little bit of a primer on the

63
00:02:23,990 --> 00:02:21,440

electromagnetic spectrum

64
00:02:26,390 --> 00:02:24,000
sure be happy to all right well uh when

65
00:02:28,470 --> 00:02:26,400
you think about fundamental measurements

66
00:02:29,910 --> 00:02:28,480
in astronomy there's really one

67
00:02:33,430 --> 00:02:29,920
observable we're talking about and

68
00:02:35,750 --> 00:02:33,440
that's electromagnetic radiation now

69
00:02:37,670 --> 00:02:35,760
you're more familiar with that term by

70
00:02:38,710 --> 00:02:37,680
its colloquial term

71
00:02:39,830 --> 00:02:38,720
light

72
00:02:42,390 --> 00:02:39,840
and

73
00:02:44,790 --> 00:02:42,400
all the signals that we're measuring

74
00:02:46,550 --> 00:02:44,800
from the gamma ray through x-ray and all

75
00:02:48,869 --> 00:02:46,560
the way to the radio those are all just

76
00:02:50,949 --> 00:02:48,879
different flavors of light and the

77
00:02:53,190 --> 00:02:50,959
parameter which which governs that

78
00:02:54,710 --> 00:02:53,200
flavor is what we call wavelength so

79
00:02:57,030 --> 00:02:54,720
what you're looking at here in this in

80
00:02:58,790 --> 00:02:57,040
this plot is the electromagnetic

81
00:03:00,070 --> 00:02:58,800
spectrum that is accessible to

82
00:03:02,630 --> 00:03:00,080
astronomers

83
00:03:05,830 --> 00:03:02,640
that x-axis there in wavelength is a

84
00:03:07,190 --> 00:03:05,840
logarithmic scale and it spans 15 orders

85
00:03:09,430 --> 00:03:07,200
of magnitude

86
00:03:12,550 --> 00:03:09,440
so that's literally a factor of a

87
00:03:14,070 --> 00:03:12,560
million times a billion in the available

88
00:03:15,589 --> 00:03:14,080

light that's out there

89
00:03:18,630 --> 00:03:15,599
the way you think about those different

90
00:03:20,630 --> 00:03:18,640
flavors in in terms of your real world

91
00:03:23,509 --> 00:03:20,640
is is in color

92
00:03:25,110 --> 00:03:23,519
except uh it's far outreaching from what

93
00:03:26,550 --> 00:03:25,120
your eyeballs are used to if we go to

94
00:03:29,350 --> 00:03:26,560
the next slide

95
00:03:30,550 --> 00:03:29,360
you can see in context the optical which

96
00:03:32,070 --> 00:03:30,560
is every

97
00:03:34,869 --> 00:03:32,080
you know piece of light that you've ever

98
00:03:37,190 --> 00:03:34,879
seen in your life from blue to red which

99
00:03:39,990 --> 00:03:37,200
spans only about you know less than a

100
00:03:42,710 --> 00:03:40,000
factor of two in wavelength so that's a

101
00:03:44,789 --> 00:03:42,720
pretty wild concept to to think about

102
00:03:46,470 --> 00:03:44,799
there's a million billion colors out

103
00:03:48,070 --> 00:03:46,480
there you could see

104
00:03:49,830 --> 00:03:48,080
you know just over a factor of two of

105
00:03:51,910 --> 00:03:49,840
them so there's all sorts of uh

106
00:03:53,670 --> 00:03:51,920
observables which which

107
00:03:55,350 --> 00:03:53,680
can trace all sorts of stuff from

108
00:03:57,589 --> 00:03:55,360
astronomical objects

109
00:03:59,509 --> 00:03:57,599
it's not a surprise why your eyeballs

110
00:04:01,350 --> 00:03:59,519
work in that wavelength range called the

111
00:04:02,949 --> 00:04:01,360
optical if you click on the next slide

112
00:04:03,990 --> 00:04:02,959
we'll show the spectrum the emission

113
00:04:06,229 --> 00:04:04,000

spectrum

114
00:04:08,309 --> 00:04:06,239
of your very favorite source or at least

115
00:04:10,149 --> 00:04:08,319
the one that is most common

116
00:04:13,509 --> 00:04:10,159
here on earth which is

117
00:04:15,190 --> 00:04:13,519
the star that is our hometown or the sun

118
00:04:18,390 --> 00:04:15,200
which is about

119
00:04:20,629 --> 00:04:18,400
on the order of 5700 degrees kelvin and

120
00:04:22,230 --> 00:04:20,639
its spectrum looks like that which peaks

121
00:04:23,990 --> 00:04:22,240
in the optical

122
00:04:26,230 --> 00:04:24,000
on the next slide we'll kind of zoom in

123
00:04:28,390 --> 00:04:26,240
on on that neighborhood

124
00:04:30,469 --> 00:04:28,400
and uh you know the the peak of the sun

125
00:04:33,110 --> 00:04:30,479
which is right there around green at a

126
00:04:35,909 --> 00:04:33,120
few hundred nanometers wavelength

127
00:04:38,070 --> 00:04:35,919
just redder than red so at longer

128
00:04:40,070 --> 00:04:38,080
wavelengths than your eyeballs work at

129
00:04:42,070 --> 00:04:40,080
is the near infrared and that's that's

130
00:04:43,510 --> 00:04:42,080
the the region that we're interested in

131
00:04:46,150 --> 00:04:43,520
discussing today

132
00:04:47,830 --> 00:04:46,160
and there's all sorts of interesting uh

133
00:04:50,070 --> 00:04:47,840
sources out there

134
00:04:52,469 --> 00:04:50,080
nominally things which are emitting

135
00:04:54,870 --> 00:04:52,479
thermally in the infrared so things that

136
00:04:56,950 --> 00:04:54,880
are not quite as hot as the sun that go

137
00:04:59,110 --> 00:04:56,960
down to thousands to even you know

138
00:05:01,990 --> 00:04:59,120

hundreds of degrees kelvin

139
00:05:04,550 --> 00:05:02,000
now there's a problem while with uh you

140
00:05:06,710 --> 00:05:04,560
know doing that kind of observation here

141
00:05:08,390 --> 00:05:06,720
on our hometown of the earth if you

142
00:05:10,469 --> 00:05:08,400
click to the next slide

143
00:05:12,310 --> 00:05:10,479
you can see what our

144
00:05:14,230 --> 00:05:12,320
atmosphere does so

145
00:05:17,029 --> 00:05:14,240
while earth's atmosphere is great for

146
00:05:19,350 --> 00:05:17,039
things like breathing and living on it's

147
00:05:20,950 --> 00:05:19,360
not so great for looking through so all

148
00:05:22,870 --> 00:05:20,960
of those magenta lines that you're

149
00:05:24,870 --> 00:05:22,880
seeing there that's absorption features

150
00:05:27,670 --> 00:05:24,880
in our earth's atmosphere

151
00:05:29,430 --> 00:05:27,680
so um you know while air looks clear to

152
00:05:31,270 --> 00:05:29,440
you in the optical if you look in the

153
00:05:33,110 --> 00:05:31,280
near infrared it's not really clear at

154
00:05:35,749 --> 00:05:33,120
all there's all sorts of stuff uh

155
00:05:37,670 --> 00:05:35,759
absorbing not to mention that everything

156
00:05:39,189 --> 00:05:37,680
you know that's here on earth that's uh

157
00:05:40,710 --> 00:05:39,199
you know kind of room temperature is

158
00:05:43,189 --> 00:05:40,720
actually glowing

159
00:05:44,469 --> 00:05:43,199
in in light and emitting so it really

160
00:05:47,430 --> 00:05:44,479
makes sense

161
00:05:50,070 --> 00:05:47,440
when you're doing astronomy in the near

162
00:05:53,110 --> 00:05:50,080
infrared to get off of this planet and

163
00:05:53,909 --> 00:05:53,120

go up into space

164
00:05:59,909 --> 00:05:53,919
so

165
00:06:02,309 --> 00:05:59,919
astronomy

166
00:06:03,909 --> 00:06:02,319
yeah i'm happy to do that so i guess

167
00:06:06,790 --> 00:06:03,919
what i should say first is that

168
00:06:09,189 --> 00:06:06,800
astronomy is kind of like detective work

169
00:06:10,870 --> 00:06:09,199
it's not quite like other science where

170
00:06:12,390 --> 00:06:10,880
you can you know put something in a lab

171
00:06:14,790 --> 00:06:12,400
and poke it and see what happens and

172
00:06:15,990 --> 00:06:14,800
then you know figure out the laws of

173
00:06:17,510 --> 00:06:16,000
nature that way

174
00:06:18,790 --> 00:06:17,520
in astronomy

175
00:06:21,029 --> 00:06:18,800
the things that we're interested in are

176
00:06:22,950 --> 00:06:21,039
really really far away so all we can do

177
00:06:25,029 --> 00:06:22,960
is kind of sit here and hope that

178
00:06:27,029 --> 00:06:25,039
information will you know on its own

179
00:06:29,270 --> 00:06:27,039
come to reach us and so things that we

180
00:06:31,110 --> 00:06:29,280
observe you know we look at stars and if

181
00:06:32,390 --> 00:06:31,120
you're cosmologists like phil and i you

182
00:06:34,870 --> 00:06:32,400
look at things that are much much

183
00:06:37,110 --> 00:06:34,880
further away than stars like galaxies

184
00:06:38,870 --> 00:06:37,120
and so what we do is we sit here and we

185
00:06:40,629 --> 00:06:38,880
collect the information that's coming to

186
00:06:43,029 --> 00:06:40,639
us from from those galaxies and the most

187
00:06:45,029 --> 00:06:43,039
common way this information reaches us

188
00:06:47,270 --> 00:06:45,039

is through light and we're talking about

189
00:06:49,029 --> 00:06:47,280
the electromagnetic spectrum today so so

190
00:06:51,350 --> 00:06:49,039
that's of course uh what i'm talking

191
00:06:53,029 --> 00:06:51,360
about here and so so this light comes

192
00:06:55,110 --> 00:06:53,039
from these really distant galaxies to us

193
00:06:57,909 --> 00:06:55,120
and we built these huge collectors of

194
00:06:59,990 --> 00:06:57,919
light or telescopes to to capture it and

195
00:07:01,270 --> 00:07:00,000
then of course we examine all the

196
00:07:02,790 --> 00:07:01,280
information we try to get all the

197
00:07:04,469 --> 00:07:02,800
information that's in this light and one

198
00:07:06,150 --> 00:07:04,479
of the things that we do is we break it

199
00:07:07,830 --> 00:07:06,160
up into its component wavelengths or

200
00:07:09,350 --> 00:07:07,840
frequencies or energies

201
00:07:11,350 --> 00:07:09,360
which is basically the spectrum that

202
00:07:14,070 --> 00:07:11,360
phil has been telling you about and

203
00:07:15,990 --> 00:07:14,080
these spectra they contain

204
00:07:19,350 --> 00:07:16,000
basically a fingerprint a really

205
00:07:21,510 --> 00:07:19,360
specific pattern that tells us a lot

206
00:07:23,189 --> 00:07:21,520
about the chemical properties the

207
00:07:25,350 --> 00:07:23,199
thermal properties and the kinematic

208
00:07:27,029 --> 00:07:25,360
properties of the thing that's emitting

209
00:07:29,749 --> 00:07:27,039
that light so the light source so the

210
00:07:31,909 --> 00:07:29,759
properties of the stars and the galaxies

211
00:07:34,710 --> 00:07:31,919
and so we can have you know we can have

212
00:07:36,309 --> 00:07:34,720
like uh very small ranges in in in

213
00:07:38,070 --> 00:07:36,319

wavelength or frequency where there's a

214
00:07:40,390 --> 00:07:38,080
bit of extra light in there and those

215
00:07:41,830 --> 00:07:40,400
are called emission lines or we can have

216
00:07:43,749 --> 00:07:41,840
part of the spectrum where there's a

217
00:07:45,510 --> 00:07:43,759
little bit less light so if you if you

218
00:07:47,510 --> 00:07:45,520
show the next picture you can see um

219
00:07:49,830 --> 00:07:47,520
i've sort of made a little a picture

220
00:07:51,430 --> 00:07:49,840
that shows a kind of a pattern of these

221
00:07:52,710 --> 00:07:51,440
uh absorption lines where there's a

222
00:07:54,150 --> 00:07:52,720
little bit less light and there's an

223
00:07:56,230 --> 00:07:54,160
emission light with a little bit more

224
00:07:58,469 --> 00:07:56,240
light and this is specific pattern we

225
00:08:00,790 --> 00:07:58,479
can that we can understand really well

226
00:08:03,029 --> 00:08:00,800
because it the exact pattern of the

227
00:08:04,629 --> 00:08:03,039
emission absorption lines uh comes out

228
00:08:06,469 --> 00:08:04,639
of quantum physics and we can play

229
00:08:08,070 --> 00:08:06,479
around with this in the lab and and

230
00:08:10,150 --> 00:08:08,080
actually calculate exactly what these

231
00:08:11,670 --> 00:08:10,160
lights might appear might appear for you

232
00:08:13,510 --> 00:08:11,680
know in different if you have different

233
00:08:14,790 --> 00:08:13,520
types of stuff that's emitting the light

234
00:08:16,070 --> 00:08:14,800
the light different gases at different

235
00:08:18,070 --> 00:08:16,080
temperatures

236
00:08:19,830 --> 00:08:18,080
and what's also really cool is that

237
00:08:21,270 --> 00:08:19,840
something really interesting happens to

238
00:08:23,990 --> 00:08:21,280

this pattern

239
00:08:26,070 --> 00:08:24,000
and uh if if there's some kind of motion

240
00:08:28,150 --> 00:08:26,080
of the emitter of this light so let me

241
00:08:29,589 --> 00:08:28,160
first um tell you about the doppler

242
00:08:31,350 --> 00:08:29,599
effect so you might have heard of it

243
00:08:33,909 --> 00:08:31,360
before and it's an effect that happens

244
00:08:35,029 --> 00:08:33,919
in sound um and it's it's i'm sure

245
00:08:36,709 --> 00:08:35,039
you've all even if you don't know the

246
00:08:39,269 --> 00:08:36,719
expression doppler effect you would have

247
00:08:40,949 --> 00:08:39,279
experienced it because an example of it

248
00:08:43,509 --> 00:08:40,959
is if you have an emergency vehicle that

249
00:08:45,269 --> 00:08:43,519
has a siren that's moving towards you

250
00:08:47,750 --> 00:08:45,279
and if the emergency vehicle is moving

251
00:08:49,750 --> 00:08:47,760
towards you it's as if as if the waves

252
00:08:52,310 --> 00:08:49,760
the sound waves are getting squished

253
00:08:54,389 --> 00:08:52,320
together and so the pitch of the siren

254
00:08:56,310 --> 00:08:54,399
you know is higher than usual

255
00:08:58,710 --> 00:08:56,320
and if it's if the emergency vehicle is

256
00:09:00,550 --> 00:08:58,720
hopefully moving away from you um then

257
00:09:02,870 --> 00:09:00,560
it's as if the sound waves get stretched

258
00:09:04,949 --> 00:09:02,880
out and the pitch falls so the siren as

259
00:09:06,949 --> 00:09:04,959
it approaches you it is high pitched and

260
00:09:09,110 --> 00:09:06,959
then as it moves past you and goes away

261
00:09:10,710 --> 00:09:09,120
from you the pitch falls and something

262
00:09:12,949 --> 00:09:10,720
kind of similar happens in light and

263
00:09:14,710 --> 00:09:12,959

it's really interesting but the the big

264
00:09:16,630 --> 00:09:14,720
difference is uh one of the big

265
00:09:18,949 --> 00:09:16,640
differences is that the thing that is

266
00:09:21,269 --> 00:09:18,959
emitting this light needs to be moving

267
00:09:23,110 --> 00:09:21,279
with respect to the observer so its

268
00:09:24,790 --> 00:09:23,120
speed with respect to you has to be a

269
00:09:27,269 --> 00:09:24,800
lot higher than of that emergency

270
00:09:28,949 --> 00:09:27,279
vehicle in fact this light emitter needs

271
00:09:30,630 --> 00:09:28,959
to be traveling at a significant

272
00:09:32,470 --> 00:09:30,640
fraction of the speed of light so you

273
00:09:34,790 --> 00:09:32,480
might say close to the speed of light

274
00:09:36,870 --> 00:09:34,800
for this kind of shifting effect to be

275
00:09:38,870 --> 00:09:36,880
observable so what happens is if you

276
00:09:41,750 --> 00:09:38,880
have a distant galaxy that is for some

277
00:09:43,350 --> 00:09:41,760
mysterious reason moving away from you

278
00:09:45,350 --> 00:09:43,360
the wavelength it's as if the wavelength

279
00:09:49,430 --> 00:09:45,360
of light gets stretched out

280
00:09:51,509 --> 00:09:49,440
um it gets red-shifted and uh so the the

281
00:09:52,870 --> 00:09:51,519
the any the pattern

282
00:09:55,269 --> 00:09:52,880
moves towards the red part of the

283
00:09:57,509 --> 00:09:55,279
spectrum and if the galaxy was moving

284
00:09:59,509 --> 00:09:57,519
towards you the light would get blue

285
00:10:01,910 --> 00:09:59,519
shifted so this specific pattern this

286
00:10:04,389 --> 00:10:01,920
fingerprint that we can understand moves

287
00:10:07,110 --> 00:10:04,399
towards the blue and so you can measure

288
00:10:08,550 --> 00:10:07,120

this red shift or blue shift and about a

289
00:10:11,030 --> 00:10:08,560
hundred years ago there was somebody

290
00:10:12,949 --> 00:10:11,040
called vesto schleifer who tried to

291
00:10:15,509 --> 00:10:12,959
measure uh you know he looked at a bunch

292
00:10:17,269 --> 00:10:15,519
of things that he called nebulae but we

293
00:10:19,910 --> 00:10:17,279
now call galaxies because we know that

294
00:10:23,190 --> 00:10:19,920
they're outside of our own milky way so

295
00:10:25,829 --> 00:10:23,200
he measured a bunch of redshifts and uh

296
00:10:27,350 --> 00:10:25,839
and he noticed that in fact there were

297
00:10:29,190 --> 00:10:27,360
mostly redshifts and there was only a

298
00:10:31,030 --> 00:10:29,200
handful of galaxies that where he

299
00:10:33,269 --> 00:10:31,040
actually found blue shifts and then

300
00:10:35,350 --> 00:10:33,279
sometime later somebody called hubble

301
00:10:37,590 --> 00:10:35,360
came along and he looked at this data

302
00:10:39,750 --> 00:10:37,600
and he supplemented it with other data

303
00:10:41,590 --> 00:10:39,760
and he looked at it and he said okay

304
00:10:42,949 --> 00:10:41,600
let's measure the distances to these

305
00:10:44,790 --> 00:10:42,959
galaxies and see if there's a

306
00:10:47,750 --> 00:10:44,800
relationship between redshift and

307
00:10:49,430 --> 00:10:47,760
distance and so if we if we look at the

308
00:10:51,030 --> 00:10:49,440
sky and we look at all of these galaxies

309
00:10:53,269 --> 00:10:51,040
and we measure redshift so we might get

310
00:10:54,790 --> 00:10:53,279
a picture uh like like the next picture

311
00:10:57,030 --> 00:10:54,800
that i have here for you this was this

312
00:10:59,750 --> 00:10:57,040
picture was actually made a lot after

313
00:11:03,190 --> 00:10:59,760

after um slifer and hubble this was from

314
00:11:04,790 --> 00:11:03,200
a an experiment called two mass um so

315
00:11:05,829 --> 00:11:04,800
here you have lots of little dots and

316
00:11:07,350 --> 00:11:05,839
they have different colors and the

317
00:11:08,790 --> 00:11:07,360
different colors correspond to different

318
00:11:10,710 --> 00:11:08,800
measurements a red shift so this is what

319
00:11:11,829 --> 00:11:10,720
this would look like on the sky

320
00:11:13,750 --> 00:11:11,839
and but

321
00:11:15,030 --> 00:11:13,760
what if so so as i said before what if

322
00:11:16,710 --> 00:11:15,040
hubble said what if we can measure

323
00:11:18,550 --> 00:11:16,720
distances to all of these galaxies and

324
00:11:21,190 --> 00:11:18,560
see if there's a relationship in fact

325
00:11:23,269 --> 00:11:21,200
there is a relationship and i have an

326
00:11:24,949 --> 00:11:23,279
equation for you now so brace yourselves

327
00:11:26,790 --> 00:11:24,959
so if you show the next picture it's the

328
00:11:28,470 --> 00:11:26,800
only equation i promise and it's just to

329
00:11:29,829 --> 00:11:28,480
illustrate the importance of the

330
00:11:31,670 --> 00:11:29,839
redshift distance relation so what

331
00:11:33,670 --> 00:11:31,680
you're seeing here on the left hand side

332
00:11:35,350 --> 00:11:33,680
there's a d with a subscript a and

333
00:11:37,509 --> 00:11:35,360
that's the angular diameter distance as

334
00:11:39,430 --> 00:11:37,519
we call it and on the right hand side

335
00:11:41,350 --> 00:11:39,440
there's the letter c which is the speed

336
00:11:43,030 --> 00:11:41,360
of light as the speed of light we have

337
00:11:44,470 --> 00:11:43,040
the letter z which is the red shift and

338
00:11:46,710 --> 00:11:44,480

then an integral

339
00:11:49,190 --> 00:11:46,720
of one over a function called h that's

340
00:11:51,670 --> 00:11:49,200
called the hubble function and that

341
00:11:53,350 --> 00:11:51,680
function contains all the information

342
00:11:55,190 --> 00:11:53,360
well a lot of the information about what

343
00:11:57,910 --> 00:11:55,200
the universe is made of

344
00:11:59,829 --> 00:11:57,920
and it tells you a lot about the history

345
00:12:01,430 --> 00:11:59,839
of our cosmos so if you can measure the

346
00:12:03,509 --> 00:12:01,440
d the distance and if you if you can

347
00:12:05,750 --> 00:12:03,519
measure the z the red shift so this is

348
00:12:07,190 --> 00:12:05,760
the distance redshift relation then you

349
00:12:09,750 --> 00:12:07,200
can infer

350
00:12:11,509 --> 00:12:09,760
so much about our cosmology about this h

351
00:12:14,310 --> 00:12:11,519
function about what the universe is made

352
00:12:16,310 --> 00:12:14,320
of and it's causing history and so now

353
00:12:18,310 --> 00:12:16,320
if i can show you a picture of what

354
00:12:20,870 --> 00:12:18,320
happens if you plo if you

355
00:12:22,710 --> 00:12:20,880
connect distances and redships together

356
00:12:23,910 --> 00:12:22,720
so these dots on this picture this is

357
00:12:26,389 --> 00:12:23,920
again from two masks they're all

358
00:12:29,829 --> 00:12:26,399
different galaxies and the colors denote

359
00:12:31,350 --> 00:12:29,839
uh the red shifts and of course distance

360
00:12:33,509 --> 00:12:31,360
is distance and we sit in the center

361
00:12:36,870 --> 00:12:33,519
we're the observer and you can see that

362
00:12:38,389 --> 00:12:36,880
redshift increases with distance and so

363
00:12:39,590 --> 00:12:38,399

when hubble realized this of course he

364
00:12:41,509 --> 00:12:39,600
didn't have a picture as nice as this

365
00:12:42,870 --> 00:12:41,519
but he had something like that when he

366
00:12:45,030 --> 00:12:42,880
realized he when he saw this

367
00:12:47,030 --> 00:12:45,040
relationship he said oh wait a minute

368
00:12:49,269 --> 00:12:47,040
that must mean that the universe itself

369
00:12:51,269 --> 00:12:49,279
is expanding space itself is pulling

370
00:12:53,829 --> 00:12:51,279
these galaxies apart so that those that

371
00:12:56,550 --> 00:12:53,839
are the furthest away from us are seem

372
00:12:58,870 --> 00:12:56,560
to be moving away from us at the highest

373
00:13:01,829 --> 00:12:58,880
speed and so this way if we can make

374
00:13:04,389 --> 00:13:01,839
these kinds of three-dimensional

375
00:13:06,069 --> 00:13:04,399
maps of the universe or the of the expan

376
00:13:07,430 --> 00:13:06,079
of the distribution of galaxies in the

377
00:13:10,790 --> 00:13:07,440
universe

378
00:13:13,829 --> 00:13:10,800
we can look both far away into space but

379
00:13:16,230 --> 00:13:13,839
we can also look far away into the past

380
00:13:17,269 --> 00:13:16,240
and that's because light has a finite

381
00:13:19,509 --> 00:13:17,279
speed

382
00:13:21,350 --> 00:13:19,519
so that if i'm receiving if i'm looking

383
00:13:23,750 --> 00:13:21,360
at a galaxy with of course a big

384
00:13:25,670 --> 00:13:23,760
telescope it's very very far away what

385
00:13:28,310 --> 00:13:25,680
i'm seeing is not the galaxy as it is

386
00:13:30,870 --> 00:13:28,320
today but a galaxy the galaxy as it was

387
00:13:32,550 --> 00:13:30,880
when light left this galaxy which may

388
00:13:34,310 --> 00:13:32,560

well have been billions and billions of

389
00:13:36,069 --> 00:13:34,320
years ago and so this way as we look

390
00:13:38,629 --> 00:13:36,079
into the distance we looked into the

391
00:13:40,389 --> 00:13:38,639
cosmic past and phil i think has a nice

392
00:13:42,710 --> 00:13:40,399
picture to show you what happens if you

393
00:13:44,230 --> 00:13:42,720
look through you well you might what you

394
00:13:46,310 --> 00:13:44,240
might see if you look through the cosmic

395
00:13:48,710 --> 00:13:46,320
past

396
00:13:51,590 --> 00:13:48,720
right yeah so uh if we bring up the next

397
00:13:53,110 --> 00:13:51,600
slide uh let's uh you know look at some

398
00:13:55,750 --> 00:13:53,120
of the implications of those concepts

399
00:13:58,710 --> 00:13:55,760
that did just introduced right so this

400
00:14:00,550 --> 00:13:58,720
figure is is a cartoon of

401
00:14:02,790 --> 00:14:00,560
the history and the evolution of the

402
00:14:05,829 --> 00:14:02,800
universe that arrow that goes from left

403
00:14:07,509 --> 00:14:05,839
to right represents uh time from the

404
00:14:09,829 --> 00:14:07,519
very beginning until today which is all

405
00:14:12,470 --> 00:14:09,839
the way on the right side where you see

406
00:14:14,550 --> 00:14:12,480
today the structure of the universe as

407
00:14:17,910 --> 00:14:14,560
as we know it that has all sorts of

408
00:14:19,110 --> 00:14:17,920
galaxies populating this cosmic web of

409
00:14:21,670 --> 00:14:19,120
structure

410
00:14:23,509 --> 00:14:21,680
and you know this diffuse light that's

411
00:14:25,269 --> 00:14:23,519
that's uh that's out there today that

412
00:14:27,189 --> 00:14:25,279
came from all sorts of tidal

413
00:14:30,710 --> 00:14:27,199

interactions in the history of uh the

414
00:14:33,509 --> 00:14:30,720
evolution of galaxies where you know fly

415
00:14:34,949 --> 00:14:33,519
stars get flung out way into their um

416
00:14:36,310 --> 00:14:34,959
excerpts

417
00:14:39,509 --> 00:14:36,320
so if we think about

418
00:14:41,430 --> 00:14:39,519
observing today in the near infrared all

419
00:14:42,949 --> 00:14:41,440
of those galaxies in their what's called

420
00:14:45,990 --> 00:14:42,959
a rest frame so

421
00:14:48,949 --> 00:14:46,000
in in today's uh unread shifted

422
00:14:50,550 --> 00:14:48,959
wavelengths they're emitting in the in

423
00:14:52,310 --> 00:14:50,560
the near infrared and they they peak

424
00:14:54,629 --> 00:14:52,320
there because they have a bunch of stars

425
00:14:56,949 --> 00:14:54,639
which are you know cooler than than than

426
00:14:59,829 --> 00:14:56,959
our sun but if we think about now

427
00:15:02,310 --> 00:14:59,839
looking further away hence further back

428
00:15:06,069 --> 00:15:02,320
in time also since the universe is

429
00:15:09,430 --> 00:15:06,079
expanding we're looking at sources that

430
00:15:12,550 --> 00:15:09,440
are redshifted far away so if you go all

431
00:15:15,110 --> 00:15:12,560
the way back to about you know only

432
00:15:16,470 --> 00:15:15,120
um you know ten to tens of billions of

433
00:15:18,710 --> 00:15:16,480
years ago

434
00:15:22,069 --> 00:15:18,720
uh the first stars in galaxies which

435
00:15:24,389 --> 00:15:22,079
were forming out of the the the neutral

436
00:15:27,350 --> 00:15:24,399
hydrogen which cooled and and condensed

437
00:15:29,670 --> 00:15:27,360
and those first stars turned on emitting

438
00:15:31,829 --> 00:15:29,680

in their rest frame ultraviolet so

439
00:15:36,150 --> 00:15:31,839
really blue and really hot that's now

440
00:15:38,230 --> 00:15:36,160
red shifted into into our uh observation

441
00:15:39,509 --> 00:15:38,240
so um when we talk about the infrared

442
00:15:41,509 --> 00:15:39,519
background another term that we use is

443
00:15:43,350 --> 00:15:41,519
the extra galactic background light

444
00:15:45,670 --> 00:15:43,360
we're thinking about the integral we're

445
00:15:48,710 --> 00:15:45,680
measuring the integrated light

446
00:15:51,430 --> 00:15:48,720
production in all of cosmic history

447
00:15:52,150 --> 00:15:51,440
and it turns out that the

448
00:15:54,150 --> 00:15:52,160
uh

449
00:15:55,990 --> 00:15:54,160
when we look at the structure today in

450
00:15:57,990 --> 00:15:56,000
galaxies the way they're populating in

451
00:16:00,949 --> 00:15:58,000
this web

452
00:16:03,829 --> 00:16:00,959
all of that structure was seeded at the

453
00:16:05,910 --> 00:16:03,839
very earliest epochs

454
00:16:07,670 --> 00:16:05,920
right after the big bang in an epic

455
00:16:08,790 --> 00:16:07,680
called inflation so there are these two

456
00:16:10,629 --> 00:16:08,800
epics

457
00:16:13,269 --> 00:16:10,639
in in in

458
00:16:15,430 --> 00:16:13,279
of of rapid expansion in cosmic history

459
00:16:18,470 --> 00:16:15,440
that early epic of inflation and then

460
00:16:21,990 --> 00:16:18,480
today where dark energy uh is taking

461
00:16:24,150 --> 00:16:22,000
over and is expanding our universe uh

462
00:16:26,150 --> 00:16:24,160
rapidly so the large-scale structure

463
00:16:28,629 --> 00:16:26,160

today is tied to those

464
00:16:30,710 --> 00:16:28,639
earliest epics through what was seated

465
00:16:32,629 --> 00:16:30,720
as quantum fluctuations which i'm going

466
00:16:33,910 --> 00:16:32,639
to pass it back to uh deeda to tell you

467
00:16:35,670 --> 00:16:33,920
a bit about

468
00:16:37,829 --> 00:16:35,680
yeah if you would be so kind can you

469
00:16:40,230 --> 00:16:37,839
elaborate on those a bit

470
00:16:42,310 --> 00:16:40,240
yes i'm happy to in fact i can even show

471
00:16:43,749 --> 00:16:42,320
an animation so if you show the next

472
00:16:45,430 --> 00:16:43,759
thing that we have to show

473
00:16:47,670 --> 00:16:45,440
thank you so

474
00:16:49,749 --> 00:16:47,680
there's something really strange

475
00:16:52,069 --> 00:16:49,759
happening if you look at empty vacuum of

476
00:16:53,350 --> 00:16:52,079
space so if you were able to go into the

477
00:16:55,430 --> 00:16:53,360
vacuum and see what it looks like it

478
00:16:57,030 --> 00:16:55,440
might look pretty boring to you but if

479
00:17:00,069 --> 00:16:57,040
you could zoom in and look on the

480
00:17:02,069 --> 00:17:00,079
tiniest microscopic quantum scales you

481
00:17:03,910 --> 00:17:02,079
would see that it's anything but boring

482
00:17:05,590 --> 00:17:03,920
now of course we can't do that we can't

483
00:17:07,750 --> 00:17:05,600
see these scales even with the best

484
00:17:10,150 --> 00:17:07,760
microscopes we can only see hints of it

485
00:17:12,150 --> 00:17:10,160
and we certainly can't observe what we

486
00:17:13,590 --> 00:17:12,160
um you know this this kind of thing that

487
00:17:14,949 --> 00:17:13,600
i'm showing you here and what i'm

488
00:17:16,630 --> 00:17:14,959

showing you here is called quantum

489
00:17:19,110 --> 00:17:16,640
fluctuation it's kind of like this

490
00:17:21,350 --> 00:17:19,120
bubbling on quantum scales and what's

491
00:17:24,069 --> 00:17:21,360
happening is that basically out of

492
00:17:25,990 --> 00:17:24,079
nowhere uh pairs of particles and

493
00:17:28,069 --> 00:17:26,000
anti-particles are as if they're

494
00:17:30,070 --> 00:17:28,079
borrowing energy from empty space and

495
00:17:31,270 --> 00:17:30,080
coming into existence and then a small

496
00:17:33,110 --> 00:17:31,280
fraction of a second later they're

497
00:17:35,270 --> 00:17:33,120
annihilating each other and returning

498
00:17:37,270 --> 00:17:35,280
this energy back into space

499
00:17:39,750 --> 00:17:37,280
and this was actually also happening at

500
00:17:41,750 --> 00:17:39,760
the very very beginning of the universe

501
00:17:44,310 --> 00:17:41,760
except that back then things were even

502
00:17:46,070 --> 00:17:44,320
stranger at the very very first moments

503
00:17:48,390 --> 00:17:46,080
of our universe the universe was really

504
00:17:49,590 --> 00:17:48,400
dense and really hot and then these

505
00:17:51,350 --> 00:17:49,600
things were bubbling the quantum

506
00:17:52,789 --> 00:17:51,360
fluctuations were happening

507
00:17:55,990 --> 00:17:52,799
and suddenly

508
00:17:58,390 --> 00:17:56,000
space itself started to expand

509
00:17:59,750 --> 00:17:58,400
in a really really dramatic way not just

510
00:18:01,990 --> 00:17:59,760
expand but

511
00:18:03,590 --> 00:18:02,000
accelerate so it was speeding up the

512
00:18:05,669 --> 00:18:03,600
expansion was speeding up as as phil

513
00:18:07,909 --> 00:18:05,679

mentioned and we called this process in

514
00:18:10,549 --> 00:18:07,919
the early universe we call it inflation

515
00:18:12,150 --> 00:18:10,559
and we don't really understand what

516
00:18:13,190 --> 00:18:12,160
drove it and why it happened and we

517
00:18:14,390 --> 00:18:13,200
don't understand the thing that's

518
00:18:17,510 --> 00:18:14,400
powering it

519
00:18:19,669 --> 00:18:17,520
but as the universe expanded it also the

520
00:18:20,549 --> 00:18:19,679
density dropped and it cooled

521
00:18:22,630 --> 00:18:20,559
and

522
00:18:24,950 --> 00:18:22,640
this thing that was powering this

523
00:18:26,710 --> 00:18:24,960
inflation it underwent something that we

524
00:18:29,029 --> 00:18:26,720
call you could call a phase transition

525
00:18:31,909 --> 00:18:29,039
so what happened was that the cooling

526
00:18:34,310 --> 00:18:31,919
pushed this strange stuff to decay into

527
00:18:36,310 --> 00:18:34,320
more familiar particles of you know that

528
00:18:38,710 --> 00:18:36,320
make us up and you know that we can

529
00:18:40,870 --> 00:18:38,720
interact with also a bunch of other

530
00:18:43,270 --> 00:18:40,880
weird stuff on the side but that's too

531
00:18:45,990 --> 00:18:43,280
and so the universe was expanding and

532
00:18:47,990 --> 00:18:46,000
and as inflation was over very quickly a

533
00:18:50,789 --> 00:18:48,000
very small fraction of a second

534
00:18:52,630 --> 00:18:50,799
um it it what it had done is it pulled

535
00:18:55,669 --> 00:18:52,640
these quantum fluctuations from these

536
00:18:58,310 --> 00:18:55,679
tiny microscopic scales to macroscopic

537
00:19:01,190 --> 00:18:58,320
observable scales and so these this

538
00:19:03,590 --> 00:19:01,200

these little these little uh bumps they

539
00:19:05,510 --> 00:19:03,600
were kind of small and big bumps on all

540
00:19:07,510 --> 00:19:05,520
scales were frozen in so they didn't

541
00:19:10,390 --> 00:19:07,520
bubble anymore but they were there also

542
00:19:12,789 --> 00:19:10,400
on observable microscopic scales and so

543
00:19:14,870 --> 00:19:12,799
in and so what we had now after a very

544
00:19:16,710 --> 00:19:14,880
maybe a very small amount of time at the

545
00:19:19,430 --> 00:19:16,720
beginning of the universe we had this

546
00:19:21,190 --> 00:19:19,440
this lumpy soup that was made up of you

547
00:19:23,750 --> 00:19:21,200
know particles of normal matter but also

548
00:19:25,190 --> 00:19:23,760
of dark matter and this lumpy soup of

549
00:19:28,070 --> 00:19:25,200
course was being governed by the laws of

550
00:19:29,909 --> 00:19:28,080
physics so it felt gravity and it felt

551
00:19:31,430 --> 00:19:29,919
pressure so these little lumps in the

552
00:19:33,750 --> 00:19:31,440
soup felt pressure and they certainly

553
00:19:35,430 --> 00:19:33,760
started inflating into these

554
00:19:36,710 --> 00:19:35,440
bubbles of sound so sound was

555
00:19:38,470 --> 00:19:36,720
propagating through

556
00:19:40,390 --> 00:19:38,480
this early universe

557
00:19:42,470 --> 00:19:40,400
and so and now

558
00:19:44,390 --> 00:19:42,480
you know this situation kind of lasted

559
00:19:45,510 --> 00:19:44,400
for hundreds of thousands of years so

560
00:19:46,870 --> 00:19:45,520
we're going we've gone from a fraction

561
00:19:48,549 --> 00:19:46,880
of a second to hundreds of thousands of

562
00:19:50,789 --> 00:19:48,559
years and after some hundreds of

563
00:19:52,390 --> 00:19:50,799

thousands of years the this sounds

564
00:19:55,669 --> 00:19:52,400
stopped propagating because the density

565
00:19:57,590 --> 00:19:55,679
dropped so much and these these bubbles

566
00:19:59,669 --> 00:19:57,600
of sound that were propagating through

567
00:20:01,430 --> 00:19:59,679
they got frozen in so i'm gonna have an

568
00:20:04,070 --> 00:20:01,440
animation for you to show these bubbles

569
00:20:05,990 --> 00:20:04,080
of sound and what happened afterwards so

570
00:20:08,230 --> 00:20:06,000
the bubbles of sound uh so if you go to

571
00:20:10,789 --> 00:20:08,240
the next animation please um the bubbles

572
00:20:13,110 --> 00:20:10,799
of sound were also um you know uh

573
00:20:15,110 --> 00:20:13,120
influenced by gravity so the the shells

574
00:20:17,750 --> 00:20:15,120
of these bubbles fragmented under

575
00:20:19,830 --> 00:20:17,760
gravity and collapsed into galaxies

576
00:20:22,070 --> 00:20:19,840
but galaxies also formed at the centers

577
00:20:23,430 --> 00:20:22,080
of the bubbles and that was because of

578
00:20:26,630 --> 00:20:23,440
dark matter

579
00:20:28,149 --> 00:20:26,640
didn't feel this pressure at the

580
00:20:29,590 --> 00:20:28,159
beginning of the universe it didn't you

581
00:20:31,750 --> 00:20:29,600
know sound wasn't propagating through it

582
00:20:34,230 --> 00:20:31,760
so it kind of remained in the locations

583
00:20:36,070 --> 00:20:34,240
of those original lumps and then it also

584
00:20:38,549 --> 00:20:36,080
attracted lots of normal matter towards

585
00:20:40,390 --> 00:20:38,559
them and that's what that normal matter

586
00:20:42,149 --> 00:20:40,400
then fragmented under gravity into

587
00:20:43,669 --> 00:20:42,159
galaxies and collapsed

588
00:20:46,070 --> 00:20:43,679

and the really cool thing about thing

589
00:20:47,590 --> 00:20:46,080
about these bubbles is that the physics

590
00:20:49,590 --> 00:20:47,600
to calculate their size is pretty

591
00:20:51,990 --> 00:20:49,600
straightforward so we can actually

592
00:20:55,669 --> 00:20:52,000
calculate how big we expect them to be

593
00:20:57,510 --> 00:20:55,679
today so this is 150 megaparsecs and

594
00:20:59,350 --> 00:20:57,520
and so if we look at the sky and we know

595
00:21:01,430 --> 00:20:59,360
how big these bubbles are supposed to be

596
00:21:03,029 --> 00:21:01,440
if we can see them and measure how big

597
00:21:05,029 --> 00:21:03,039
they appear then we could measure

598
00:21:07,270 --> 00:21:05,039
distances so it turns out that these

599
00:21:09,909 --> 00:21:07,280
bubbles were discovered

600
00:21:12,149 --> 00:21:09,919
in astronomy about 15 years ago they're

601
00:21:14,470 --> 00:21:12,159
called baryonic acoustic oscillations

602
00:21:16,710 --> 00:21:14,480
formally and they are an amazing measure

603
00:21:18,149 --> 00:21:16,720
of distance throughout a huge amount of

604
00:21:19,990 --> 00:21:18,159
the universe so looking back into the

605
00:21:22,390 --> 00:21:20,000
past you can measure distances to really

606
00:21:24,630 --> 00:21:22,400
distant galaxies but you can only do it

607
00:21:27,669 --> 00:21:24,640
statistically so

608
00:21:30,310 --> 00:21:27,679
using this this measurement of of this

609
00:21:31,990 --> 00:21:30,320
of distance that is that works so well

610
00:21:34,870 --> 00:21:32,000
and then measuring the redshifts of the

611
00:21:36,789 --> 00:21:34,880
galaxies that make up these bubbles um

612
00:21:38,710 --> 00:21:36,799
then you can calculate this distance

613
00:21:41,110 --> 00:21:38,720

redshift relation and you can see this

614
00:21:43,190 --> 00:21:41,120
effect you can see the effect that the

615
00:21:45,750 --> 00:21:43,200
unit as phil mentioned that the universe

616
00:21:47,029 --> 00:21:45,760
started accelerating uh

617
00:21:49,270 --> 00:21:47,039
as to the expansion of the universe

618
00:21:51,029 --> 00:21:49,280
started accelerating again billions of

619
00:21:53,430 --> 00:21:51,039
years after inflation and this

620
00:21:54,950 --> 00:21:53,440
accelerated expansion uh is we say that

621
00:21:56,549 --> 00:21:54,960
it's fueled by dark energy as phil

622
00:21:59,830 --> 00:21:56,559
mentioned and we don't really know what

623
00:22:02,390 --> 00:21:59,840
dark energy is and so in fact dark

624
00:22:05,190 --> 00:22:02,400
energy and inflation are two of the

625
00:22:08,149 --> 00:22:05,200
biggest mysteries of modern physics and

626
00:22:10,149 --> 00:22:08,159
that's really exciting too to work on

627
00:22:11,990 --> 00:22:10,159
that's really really cool

628
00:22:13,430 --> 00:22:12,000
um so let me call for the next slide and

629
00:22:14,950 --> 00:22:13,440
kind of summarize what you two have

630
00:22:16,630 --> 00:22:14,960
talked about so far so there have been

631
00:22:18,470 --> 00:22:16,640
two epochs where the expansion of the

632
00:22:21,190 --> 00:22:18,480
universe was speeding up

633
00:22:22,870 --> 00:22:21,200
uh the first epic was called inflation

634
00:22:24,870 --> 00:22:22,880
and then the current expansion which is

635
00:22:26,470 --> 00:22:24,880
due to dark energy

636
00:22:28,230 --> 00:22:26,480
there's a wealth of information related

637
00:22:29,750 --> 00:22:28,240
to both of these phenomena buried in the

638
00:22:30,870 --> 00:22:29,760

large scale structure of the universe

639
00:22:32,390 --> 00:22:30,880
and these two missions are going to help

640
00:22:33,669 --> 00:22:32,400
us you know pull some of that out so the

641
00:22:35,270 --> 00:22:33,679
euclid mission

642
00:22:36,710 --> 00:22:35,280
will probe the structure at about half

643
00:22:38,470 --> 00:22:36,720
the age of the universe if i got that

644
00:22:40,549 --> 00:22:38,480
right and from that we'll infer what

645
00:22:42,870 --> 00:22:40,559
dark energy is doing

646
00:22:44,789 --> 00:22:42,880
to the universe's expansion today

647
00:22:47,270 --> 00:22:44,799
and then the spherex mission

648
00:22:49,590 --> 00:22:47,280
will survey a huge volume of large scale

649
00:22:51,190 --> 00:22:49,600
structure in the nearby universe and

650
00:22:53,750 --> 00:22:51,200
from that will teach us about the energy

651
00:22:56,870 --> 00:22:53,760
field or fields that drove inflation in

652
00:22:59,270 --> 00:22:56,880
the first instance of cosmic history

653
00:23:01,270 --> 00:22:59,280
so phil let's bring you back um if you

654
00:23:03,590 --> 00:23:01,280
please tell us about the spherics

655
00:23:05,669 --> 00:23:03,600
mission that you're working on

656
00:23:07,029 --> 00:23:05,679
all right yeah well i've got an overview

657
00:23:10,549 --> 00:23:07,039
on the next slide

658
00:23:12,950 --> 00:23:10,559
and so spherex is uh is indeed another

659
00:23:14,789 --> 00:23:12,960
it's a tortured acronym it stands for

660
00:23:17,590 --> 00:23:14,799
the spectrophotometer for the history of

661
00:23:19,110 --> 00:23:17,600
the universe epic of reionization

662
00:23:22,950 --> 00:23:19,120
explorer

663
00:23:25,590 --> 00:23:22,960

and um it's designed really as as one of

664
00:23:27,909 --> 00:23:25,600
the first uh missions where not only are

665
00:23:30,390 --> 00:23:27,919
we gonna make a map of the whole sky in

666
00:23:32,630 --> 00:23:30,400
imaging but we're gonna take a spectrum

667
00:23:35,029 --> 00:23:32,640
towards every single pointing at a

668
00:23:36,630 --> 00:23:35,039
resolution of six arc seconds in the

669
00:23:38,789 --> 00:23:36,640
entire universe

670
00:23:41,510 --> 00:23:38,799
and from that huge data set we've

671
00:23:44,230 --> 00:23:41,520
optimized further to really get at these

672
00:23:46,149 --> 00:23:44,240
three main science themes the first is

673
00:23:48,470 --> 00:23:46,159
as we've been discussing to measure the

674
00:23:51,350 --> 00:23:48,480
large scale structure in today's

675
00:23:53,990 --> 00:23:51,360
universe so tracing all the galaxies as

676
00:23:56,710 --> 00:23:54,000
they populate this cosmic web and by

677
00:23:58,870 --> 00:23:56,720
doing statistics on the relations and

678
00:24:00,390 --> 00:23:58,880
how clumpy and clustered they are to tie

679
00:24:03,029 --> 00:24:00,400
that back to those

680
00:24:04,549 --> 00:24:03,039
quantum fluctuations at the at the real

681
00:24:06,470 --> 00:24:04,559
dawn

682
00:24:08,630 --> 00:24:06,480
during inflation

683
00:24:10,630 --> 00:24:08,640
but also we're going to measure that

684
00:24:12,470 --> 00:24:10,640
integrated light field in the extra

685
00:24:15,029 --> 00:24:12,480
galactic background light

686
00:24:16,710 --> 00:24:15,039
and from that to disentangle the various

687
00:24:19,190 --> 00:24:16,720
components which came from that epoch of

688
00:24:21,430 --> 00:24:19,200

realization the or the the time when the

689
00:24:24,230 --> 00:24:21,440
those first stars and galaxies were

690
00:24:26,549 --> 00:24:24,240
turning on and and evolving through

691
00:24:28,230 --> 00:24:26,559
cosmic time till today where there's all

692
00:24:30,630 --> 00:24:28,240
sorts of diffuse light that's gotten

693
00:24:32,789 --> 00:24:30,640
flung out to the far reaches of excerpts

694
00:24:34,310 --> 00:24:32,799
but also at our

695
00:24:37,350 --> 00:24:34,320
more close to home in our own

696
00:24:39,590 --> 00:24:37,360
neighborhood of the milky way so our

697
00:24:43,269 --> 00:24:39,600
parent galaxy that we live in

698
00:24:49,430 --> 00:24:46,789
this significant feature of absorption

699
00:24:51,350 --> 00:24:49,440
that comes from ice so just water ice

700
00:24:53,750 --> 00:24:51,360
and we're going to survey

701
00:24:56,870 --> 00:24:53,760
our galactic plane in our neighborhood

702
00:24:58,470 --> 00:24:56,880
for water ice absorption and as we know

703
00:25:01,190 --> 00:24:58,480
at least on earth

704
00:25:03,990 --> 00:25:01,200
where we're looking for life uh we're

705
00:25:05,669 --> 00:25:04,000
looking for water and so most of the ice

706
00:25:07,669 --> 00:25:05,679
most of the water in the universe is

707
00:25:09,750 --> 00:25:07,679
actually not liquid it's in ice form so

708
00:25:10,789 --> 00:25:09,760
spherics is going to survey the galactic

709
00:25:13,190 --> 00:25:10,799
plane

710
00:25:14,789 --> 00:25:13,200
for water ice absorption

711
00:25:17,350 --> 00:25:14,799
uh on the next slide i'll show you a

712
00:25:20,630 --> 00:25:17,360
movie of how we implement this so

713
00:25:22,630 --> 00:25:20,640

spherex it it lives in what we call a

714
00:25:25,269 --> 00:25:22,640
sun synchronous low earth

715
00:25:27,269 --> 00:25:25,279
polar orbit so at about 700 kilometers

716
00:25:28,870 --> 00:25:27,279
over the earth we're going around on

717
00:25:31,350 --> 00:25:28,880
this terminator line so it's always

718
00:25:33,750 --> 00:25:31,360
sunrise or sunset for spherex and we

719
00:25:35,750 --> 00:25:33,760
keep our solar panels there to the our

720
00:25:37,430 --> 00:25:35,760
back to the sun to keep us nice and

721
00:25:40,390 --> 00:25:37,440
charged up and powered

722
00:25:43,029 --> 00:25:40,400
now you can see as we pan up spherex has

723
00:25:45,190 --> 00:25:43,039
the set of three nestled shields we call

724
00:25:47,430 --> 00:25:45,200
them photon shields

725
00:25:49,269 --> 00:25:47,440
their job is to block the radiation

726
00:25:51,510 --> 00:25:49,279
which is coming up off the earth the

727
00:25:53,430 --> 00:25:51,520
thermal radiation from the earth as well

728
00:25:55,190 --> 00:25:53,440
as the sunlight from getting to the core

729
00:25:56,549 --> 00:25:55,200
of spherex which is that telescope you

730
00:25:58,230 --> 00:25:56,559
can see there

731
00:26:00,149 --> 00:25:58,240
this telescope because we're working in

732
00:26:02,710 --> 00:26:00,159
the near infrared has to be cooled to

733
00:26:05,510 --> 00:26:02,720
really low temperatures and we do so

734
00:26:06,789 --> 00:26:05,520
passively using the actual cold of deep

735
00:26:08,870 --> 00:26:06,799
space

736
00:26:13,110 --> 00:26:08,880
doing that we can cool this telescope

737
00:26:14,870 --> 00:26:13,120
down to 40 kelvin uh you know most of us

738
00:26:16,710 --> 00:26:14,880

at least in america think in terms of

739
00:26:20,149 --> 00:26:16,720
fahrenheit that's the equivalent of

740
00:26:22,830 --> 00:26:20,159
minus 387 fahrenheit and we need to get

741
00:26:25,430 --> 00:26:22,840
down that that low to control the

742
00:26:27,110 --> 00:26:25,440
emission actually the light emitted from

743
00:26:29,029 --> 00:26:27,120
our telescope

744
00:26:30,470 --> 00:26:29,039
at the core of sphere x

745
00:26:32,390 --> 00:26:30,480
is uh

746
00:26:34,070 --> 00:26:32,400
what we call a linear variable filter an

747
00:26:35,510 --> 00:26:34,080
lvf and i've got a picture of one on the

748
00:26:37,110 --> 00:26:35,520
next slide

749
00:26:39,269 --> 00:26:37,120
and this is where we get all of our

750
00:26:41,430 --> 00:26:39,279
spectroscopic power it's a really

751
00:26:43,190 --> 00:26:41,440
efficient way of doing this in space

752
00:26:45,430 --> 00:26:43,200
it's a little piece of actually of

753
00:26:47,990 --> 00:26:45,440
sapphire which has a very special

754
00:26:51,029 --> 00:26:48,000
optical coating on it which only

755
00:26:53,669 --> 00:26:51,039
transmits selected wavelengths depending

756
00:26:55,350 --> 00:26:53,679
on where you land on the filter so in

757
00:26:57,029 --> 00:26:55,360
that picture you're looking at you could

758
00:26:58,149 --> 00:26:57,039
think of on the left

759
00:27:00,390 --> 00:26:58,159
um

760
00:27:02,230 --> 00:27:00,400
it would only let through blue or light

761
00:27:03,750 --> 00:27:02,240
and then towards the the right it would

762
00:27:06,390 --> 00:27:03,760
let through the redder light so

763
00:27:09,110 --> 00:27:06,400

depending on where a source or galaxy

764
00:27:11,190 --> 00:27:09,120
lands on our filter we're measuring it

765
00:27:13,510 --> 00:27:11,200
at a different wavelength now we use

766
00:27:15,510 --> 00:27:13,520
these linear variable filters in concert

767
00:27:17,350 --> 00:27:15,520
with a wide field telescope and if you

768
00:27:20,789 --> 00:27:17,360
go to the next slide

769
00:27:22,549 --> 00:27:20,799
i'll show you how how that looks so the

770
00:27:24,549 --> 00:27:22,559
telescope is made entirely out of

771
00:27:26,950 --> 00:27:24,559
aluminum and it's actually a pretty

772
00:27:29,029 --> 00:27:26,960
modest size the aperture or the primary

773
00:27:31,669 --> 00:27:29,039
mirror is only about 20 centimeters so

774
00:27:32,870 --> 00:27:31,679
kind of kind of basketball sized and if

775
00:27:34,950 --> 00:27:32,880
we cut it in half there you can see

776
00:27:37,110 --> 00:27:34,960
we've got three mirrors now a

777
00:27:38,950 --> 00:27:37,120
telescope's job is to is to take light

778
00:27:41,750 --> 00:27:38,960
from the other side of the universe so

779
00:27:44,310 --> 00:27:41,760
collimated light that has parallel rays

780
00:27:45,830 --> 00:27:44,320
and it brings it to a focus at what we

781
00:27:48,389 --> 00:27:45,840
call the focal plane that's highlighted

782
00:27:51,029 --> 00:27:48,399
and that's in that square there at that

783
00:27:54,389 --> 00:27:51,039
focal plane we place an assembly of

784
00:27:56,470 --> 00:27:54,399
three detectors each of which has their

785
00:27:58,470 --> 00:27:56,480
own linear variable filters so depending

786
00:27:59,830 --> 00:27:58,480
on where the light hits we're measuring

787
00:28:01,029 --> 00:27:59,840
it at a certain wavelength so you can

788
00:28:03,269 --> 00:28:01,039

see that light

789
00:28:04,950 --> 00:28:03,279
going through at a certain position

790
00:28:06,310 --> 00:28:04,960
we'll make an image and it might look

791
00:28:07,269 --> 00:28:06,320
something like what you see on the left

792
00:28:09,269 --> 00:28:07,279
there

793
00:28:11,430 --> 00:28:09,279
we tally up all the light that got

794
00:28:14,230 --> 00:28:11,440
detected there and from that we've now

795
00:28:17,029 --> 00:28:14,240
made a single point on the spectrum

796
00:28:18,870 --> 00:28:17,039
if we move our telescope so that that

797
00:28:21,190 --> 00:28:18,880
same source lands at a different

798
00:28:22,789 --> 00:28:21,200
position so we dithered it now we're

799
00:28:24,870 --> 00:28:22,799
measuring it at a different wavelength

800
00:28:26,789 --> 00:28:24,880
we make another image we add up all the

801
00:28:28,870 --> 00:28:26,799
photons that we detected and then we've

802
00:28:30,950 --> 00:28:28,880
got another point on our spectrum

803
00:28:33,110 --> 00:28:30,960
if you go ahead and repeat that about 50

804
00:28:36,470 --> 00:28:33,120
times we'll build up an entire

805
00:28:38,789 --> 00:28:36,480
near-infrared spectrum for that source

806
00:28:40,789 --> 00:28:38,799
um if you go to the next slide so so if

807
00:28:43,029 --> 00:28:40,799
we were if we were

808
00:28:44,950 --> 00:28:43,039
to do this only for an individual source

809
00:28:47,190 --> 00:28:44,960
that'd be really inefficient but the

810
00:28:49,190 --> 00:28:47,200
beauty of spherex is that we we're

811
00:28:51,669 --> 00:28:49,200
multiplexing heavily so in this

812
00:28:52,710 --> 00:28:51,679
animation i've hid that center lvf and

813
00:28:55,590 --> 00:28:52,720

instead

814
00:28:59,029 --> 00:28:55,600
we're placing a simulated image of what

815
00:29:01,029 --> 00:28:59,039
spherex's sky looks like put it to scale

816
00:29:01,750 --> 00:29:01,039
on that detector so now that we've flown

817
00:29:05,669 --> 00:29:01,760
in

818
00:29:08,389 --> 00:29:05,679
simultaneously

819
00:29:11,510 --> 00:29:08,399
a spectroscopic sample for hundreds of

820
00:29:13,669 --> 00:29:11,520
thousands of sources at every moment so

821
00:29:17,110 --> 00:29:13,679
we measure hundreds of thousands of

822
00:29:19,430 --> 00:29:17,120
sources at each time we take about 600

823
00:29:22,310 --> 00:29:19,440
exposures per day and then we do that

824
00:29:24,830 --> 00:29:22,320
relentlessly for two years building up

825
00:29:27,669 --> 00:29:24,840
spectroscopic data set for billions of

826
00:29:29,750 --> 00:29:27,679
objects on the next slide

827
00:29:32,310 --> 00:29:29,760
we show you how we do that

828
00:29:34,870 --> 00:29:32,320
so again we're going around the earth

829
00:29:36,950 --> 00:29:34,880
around that day night boundary

830
00:29:39,830 --> 00:29:36,960
and we dither our linear variable

831
00:29:43,029 --> 00:29:39,840
filters around as we as we fill in those

832
00:29:45,269 --> 00:29:43,039
gaps and so we put every single position

833
00:29:47,510 --> 00:29:45,279
on the celestial sphere to every

834
00:29:49,750 --> 00:29:47,520
position on our focal plane and then

835
00:29:52,070 --> 00:29:49,760
we're measuring it at all the wavelength

836
00:29:54,149 --> 00:29:52,080
so as the sphere x goes around the earth

837
00:29:56,470 --> 00:29:54,159
and the earth goes around the sun it

838
00:29:59,110 --> 00:29:56,480

gets modulated and moves around and in

839
00:30:02,389 --> 00:29:59,120
six months time we've built up a

840
00:30:05,029 --> 00:30:02,399
spectrum towards every point in the sky

841
00:30:07,590 --> 00:30:05,039
we do this four times and to build up a

842
00:30:08,549 --> 00:30:07,600
redundant spectroscopic sample

843
00:30:12,070 --> 00:30:08,559
to

844
00:30:16,389 --> 00:30:14,389
so on the next slide i'll show you a

845
00:30:18,710 --> 00:30:16,399
simulation of what we might expect from

846
00:30:21,510 --> 00:30:18,720
the sphere x data set and this is super

847
00:30:23,590 --> 00:30:21,520
exciting we're flying through now

848
00:30:26,070 --> 00:30:23,600
i think it's important to convey to you

849
00:30:28,310 --> 00:30:26,080
that this is actually it's it's not an

850
00:30:30,230 --> 00:30:28,320
artist representation this comes from an

851
00:30:33,190 --> 00:30:30,240
actual simulation that was done by our

852
00:30:35,110 --> 00:30:33,200
colleagues at argonne national labs

853
00:30:36,789 --> 00:30:35,120
who using what we know about the

854
00:30:38,789 --> 00:30:36,799
contents of the universe and the large

855
00:30:40,870 --> 00:30:38,799
scale structure

856
00:30:41,909 --> 00:30:40,880
simulate with a trillion particles in a

857
00:30:43,110 --> 00:30:41,919
computer

858
00:30:57,190 --> 00:30:43,120
that

859
00:30:59,909 --> 00:30:57,200
and so this kind of gives you a scale of

860
00:31:01,350 --> 00:30:59,919
just the the vastness of the data set i

861
00:31:03,669 --> 00:31:01,360
should also mention that what we're

862
00:31:06,230 --> 00:31:03,679
flying through right now is about 1

863
00:31:07,830 --> 00:31:06,240

200th of what the sphere x data set is

864
00:31:09,350 --> 00:31:07,840
going to look like

865
00:31:11,590 --> 00:31:09,360
and from

866
00:31:13,590 --> 00:31:11,600
once we have this three-dimensional map

867
00:31:16,149 --> 00:31:13,600
that has all of these galaxies spread

868
00:31:17,430 --> 00:31:16,159
out in space we'll do all our statistics

869
00:31:19,750 --> 00:31:17,440
on their clumpiness how they're

870
00:31:21,269 --> 00:31:19,760
associated with their neighbors on all

871
00:31:24,789 --> 00:31:21,279
sorts of scales including the large

872
00:31:26,789 --> 00:31:24,799
scales and from that to learn to tie

873
00:31:28,789 --> 00:31:26,799
that all the way back to the quantum

874
00:31:31,190 --> 00:31:28,799
fluctuations which seeded that large

875
00:31:32,950 --> 00:31:31,200
scale structure at the very earliest

876
00:31:34,950 --> 00:31:32,960
epics of the universe

877
00:31:36,549 --> 00:31:34,960
so as we're flying through we're flying

878
00:31:38,470 --> 00:31:36,559
away from the observer so we're looking

879
00:31:40,230 --> 00:31:38,480
back in time

880
00:31:42,470 --> 00:31:40,240
earlier and earlier in the universe's

881
00:31:44,389 --> 00:31:42,480
history and you can see as we as we

882
00:31:47,029 --> 00:31:44,399
start getting out here the number of

883
00:31:48,870 --> 00:31:47,039
galaxies is going down now that's not

884
00:31:50,870 --> 00:31:48,880
because the number of galaxies in the

885
00:31:53,669 --> 00:31:50,880
universe goes down there it's because

886
00:31:56,230 --> 00:31:53,679
this is a simulation of the selection

887
00:31:58,870 --> 00:31:56,240
function of sphere x so it's it's tuned

888
00:32:02,070 --> 00:31:58,880

to our sensitivity and our wavelengths

889
00:32:04,310 --> 00:32:02,080
and what we've optimized our survey for

890
00:32:06,950 --> 00:32:04,320
so now as it's getting sparser out here

891
00:32:09,750 --> 00:32:06,960
is a good time for me to turn back over

892
00:32:11,909 --> 00:32:09,760
to dita and euclid because that's where

893
00:32:13,350 --> 00:32:11,919
they start to shine and pick up where we

894
00:32:15,110 --> 00:32:13,360
left off

895
00:32:16,389 --> 00:32:15,120
yeah dina if you could hop back in here

896
00:32:17,590 --> 00:32:16,399
yeah and tell us about the euclid

897
00:32:19,750 --> 00:32:17,600
mission that you're working on this

898
00:32:22,070 --> 00:32:19,760
flyby is so cool

899
00:32:24,710 --> 00:32:22,080
yeah i'm really happy to yeah so

900
00:32:27,750 --> 00:32:24,720
basically euclid takes over about just

901
00:32:29,909 --> 00:32:27,760
about now at a redshift 0.8 and it's

902
00:32:34,389 --> 00:32:29,919
aiming to find galaxies between redshift

903
00:32:36,789 --> 00:32:34,399
about 0.8 to 1.8 and that um that that

904
00:32:38,470 --> 00:32:36,799
redshift range corresponds roughly to

905
00:32:39,909 --> 00:32:38,480
the time where dark energy was really

906
00:32:42,789 --> 00:32:39,919
just starting to become important

907
00:32:44,310 --> 00:32:42,799
kicking and kicking in and the universe

908
00:32:46,710 --> 00:32:44,320
was starting to re-accelerate its

909
00:32:49,269 --> 00:32:46,720
expansion and so euclid will be we'll be

910
00:32:51,350 --> 00:32:49,279
aiming at this range and and uh by and

911
00:32:53,430 --> 00:32:51,360
we will be looking at uh basically

912
00:32:54,230 --> 00:32:53,440
emission lines that correspond to a

913
00:32:57,029 --> 00:32:54,240

certain

914
00:32:59,190 --> 00:32:57,039
quantum transition in hydrogen and that

915
00:33:01,110 --> 00:32:59,200
happens to fall in the lab it falls into

916
00:33:02,789 --> 00:33:01,120
the visible part of the spectrum but

917
00:33:04,230 --> 00:33:02,799
when once you get redshift once you get

918
00:33:07,029 --> 00:33:04,240
the universe expanding and looking at

919
00:33:08,389 --> 00:33:07,039
these galaxies these this this feature

920
00:33:10,470 --> 00:33:08,399
this part of the fingerprint in the

921
00:33:12,310 --> 00:33:10,480
spectrum of galaxies gets redshifted

922
00:33:14,950 --> 00:33:12,320
into into the near infrared and that's

923
00:33:17,430 --> 00:33:14,960
why euclid um has one of the two

924
00:33:19,350 --> 00:33:17,440
instruments is an infrared uh instrument

925
00:33:21,669 --> 00:33:19,360
but generally euclid looks a little bit

926
00:33:23,029 --> 00:33:21,679
different to spherics uh the

927
00:33:26,549 --> 00:33:23,039
configuration is a little bit more

928
00:33:29,269 --> 00:33:26,559
familiar um and it will also be orbiting

929
00:33:31,750 --> 00:33:29,279
uh much further away from earth so if

930
00:33:35,190 --> 00:33:31,760
you show the next graphic that we have

931
00:33:37,990 --> 00:33:35,200
you'll see that the uh the the euclid's

932
00:33:39,430 --> 00:33:38,000
spacecraft will we will be sending it uh

933
00:33:42,149 --> 00:33:39,440
to something called the second

934
00:33:44,710 --> 00:33:42,159
lagrangian point of the sun earth system

935
00:33:46,710 --> 00:33:44,720
uh which is about uh just under a

936
00:33:48,710 --> 00:33:46,720
million miles away from earth so far

937
00:33:51,590 --> 00:33:48,720
outside the moon's orbit around the

938
00:33:53,350 --> 00:33:51,600

earth and it will be will be orbiting um

939
00:33:55,590 --> 00:33:53,360
the earth and the sun simultaneously at

940
00:33:57,110 --> 00:33:55,600
that point and the point the reason why

941
00:33:58,950 --> 00:33:57,120
we want to go to the second lagrangian

942
00:34:00,070 --> 00:33:58,960
point is it's it's a particularly stable

943
00:34:02,630 --> 00:34:00,080
point

944
00:34:03,750 --> 00:34:02,640
in the sun earth system uh and

945
00:34:05,830 --> 00:34:03,760
the reason why that's important is

946
00:34:08,629 --> 00:34:05,840
because you need if you go there you

947
00:34:10,149 --> 00:34:08,639
need less fuel um to to correct your

948
00:34:11,589 --> 00:34:10,159
orbit because obviously the amount of

949
00:34:13,190 --> 00:34:11,599
fuel is limited because this thing is

950
00:34:16,069 --> 00:34:13,200
very far away so like there's a gas

951
00:34:17,589 --> 00:34:16,079
station there a hydrazine gas station so

952
00:34:18,950 --> 00:34:17,599
so of course we want to conserve fuel

953
00:34:21,430 --> 00:34:18,960
and that's why it's important to go to

954
00:34:24,470 --> 00:34:21,440
one of these stable points um and so the

955
00:34:26,149 --> 00:34:24,480
spacecraft itself um will look i have a

956
00:34:27,589 --> 00:34:26,159
little graphic that will show you what

957
00:34:29,990 --> 00:34:27,599
the spacecraft will look like this is

958
00:34:32,470 --> 00:34:30,000
cgi but it almost already looks like

959
00:34:34,389 --> 00:34:32,480
this in fact the um the payload module

960
00:34:35,909 --> 00:34:34,399
just arrived to italy this week

961
00:34:37,589 --> 00:34:35,919
where it's being assembled together into

962
00:34:39,909 --> 00:34:37,599
the full spacecraft that you see

963
00:34:41,109 --> 00:34:39,919

spinning on your screen so this is what

964
00:34:43,109 --> 00:34:41,119
you could look like so you have this

965
00:34:44,550 --> 00:34:43,119
cylindrical part on that's on top now

966
00:34:46,710 --> 00:34:44,560
that's the telescope part it's a

967
00:34:50,629 --> 00:34:46,720
reflector telescope it has three mirrors

968
00:34:53,030 --> 00:34:50,639
and the primary mirror um is 1.2 meters

969
00:34:55,589 --> 00:34:53,040
in in width which i guess is about four

970
00:34:57,510 --> 00:34:55,599
foot um and so so there's a telescope

971
00:34:59,829 --> 00:34:57,520
part and then the middle part is a

972
00:35:01,589 --> 00:34:59,839
so-called focal plane where the light

973
00:35:03,670 --> 00:35:01,599
from the telescope will focus and it

974
00:35:05,109 --> 00:35:03,680
contains two instruments one is a

975
00:35:07,349 --> 00:35:05,119
visible light instrument that i'm not

976
00:35:09,750 --> 00:35:07,359
talking about today and it's just it's a

977
00:35:11,270 --> 00:35:09,760
made up of similar chips to um the

978
00:35:13,349 --> 00:35:11,280
detector chips that you might have in

979
00:35:15,190 --> 00:35:13,359
your in your camera phone and then you

980
00:35:17,829 --> 00:35:15,200
have a near infrared detector it's also

981
00:35:19,670 --> 00:35:17,839
just an array of 4x4 chips

982
00:35:21,750 --> 00:35:19,680
and then at the very bottom

983
00:35:22,870 --> 00:35:21,760
or at the very top right now is the

984
00:35:25,349 --> 00:35:22,880
so-called

985
00:35:27,349 --> 00:35:25,359
service module which contains a computer

986
00:35:29,109 --> 00:35:27,359
and the fuel tanks and that computer

987
00:35:30,790 --> 00:35:29,119
basically controls where the telescope

988
00:35:33,750 --> 00:35:30,800

is pointing and it's also talking to

989
00:35:36,470 --> 00:35:33,760
earth it's talking uh through um three

990
00:35:39,270 --> 00:35:36,480
main really big antennas in argentina

991
00:35:40,790 --> 00:35:39,280
australia and and spain so that you know

992
00:35:42,310 --> 00:35:40,800
as the earth spins we can stay in

993
00:35:44,550 --> 00:35:42,320
contact if we need to and then you have

994
00:35:46,710 --> 00:35:44,560
of course this flat bit on the side i

995
00:35:48,230 --> 00:35:46,720
guess on that side for you where that's

996
00:35:49,430 --> 00:35:48,240
the solar panels basically which and

997
00:35:52,230 --> 00:35:49,440
it's also a

998
00:35:53,829 --> 00:35:52,240
shield that shields um the telescope and

999
00:35:55,670 --> 00:35:53,839
electronics from solar radiation which

1000
00:35:57,750 --> 00:35:55,680
might heat it up but it also of course

1001
00:35:59,829 --> 00:35:57,760
powers some of the electronics so the

1002
00:36:01,670 --> 00:35:59,839
two instruments in the focal plane will

1003
00:36:02,790 --> 00:36:01,680
be taking images of the sky through the

1004
00:36:05,030 --> 00:36:02,800
by collecting the light through the

1005
00:36:06,310 --> 00:36:05,040
telescope and let me show you what those

1006
00:36:08,790 --> 00:36:06,320
images might look like so if you show

1007
00:36:10,390 --> 00:36:08,800
the next picture that i have for you so

1008
00:36:12,550 --> 00:36:10,400
in the near infrared instrument we'll be

1009
00:36:13,990 --> 00:36:12,560
taking you know images in the infrared

1010
00:36:16,150 --> 00:36:14,000
with three different filters will just

1011
00:36:18,069 --> 00:36:16,160
be fields of galaxies but then there

1012
00:36:20,069 --> 00:36:18,079
will also be a spectroscopic explosion

1013
00:36:22,069 --> 00:36:20,079

this is called slitless spectroscopy

1014
00:36:23,910 --> 00:36:22,079
where the light from all the sources in

1015
00:36:26,310 --> 00:36:23,920
the field of view will be going through

1016
00:36:27,510 --> 00:36:26,320
kind of a glorified prism and these

1017
00:36:29,829 --> 00:36:27,520
little lines that you see in this

1018
00:36:31,270 --> 00:36:29,839
picture are basically the spectra of

1019
00:36:33,430 --> 00:36:31,280
distant galaxies which are the little

1020
00:36:35,270 --> 00:36:33,440
ones and then the very saturated spectra

1021
00:36:36,950 --> 00:36:35,280
of the of the stars in our milky way

1022
00:36:40,390 --> 00:36:36,960
galaxy which we don't care about in this

1023
00:36:41,750 --> 00:36:40,400
particular uh context um and so and so

1024
00:36:43,349 --> 00:36:41,760
the really tricky thing here is that

1025
00:36:45,349 --> 00:36:43,359
your field of view is going to be full

1026
00:36:48,230 --> 00:36:45,359
of all these overlapping spectra and

1027
00:36:49,750 --> 00:36:48,240
that's that will create you know a trick

1028
00:36:51,990 --> 00:36:49,760
it means that we need to use very

1029
00:36:54,710 --> 00:36:52,000
sophisticated data analysis methods to

1030
00:36:56,870 --> 00:36:54,720
extract those spectra those emission

1031
00:36:58,069 --> 00:36:56,880
lines and those redshifts and so one of

1032
00:37:00,230 --> 00:36:58,079
the ways we're going to do that which is

1033
00:37:01,030 --> 00:37:00,240
basically the simplest way is to have um

1034
00:37:05,270 --> 00:37:01,040
these

1035
00:37:06,870 --> 00:37:05,280
we're going to mount them in the

1036
00:37:08,230 --> 00:37:06,880
telescope several different ones at

1037
00:37:10,230 --> 00:37:08,240
different angles so that this picture

1038
00:37:12,230 --> 00:37:10,240

will be rotated and it will be easier to

1039
00:37:13,670 --> 00:37:12,240
disentangle this different spectra but

1040
00:37:15,910 --> 00:37:13,680
also we've been building you know for

1041
00:37:17,589 --> 00:37:15,920
years uh tens and hundreds of people

1042
00:37:19,430 --> 00:37:17,599
have been building this sophisticated

1043
00:37:21,990 --> 00:37:19,440
software pipeline to extract all of

1044
00:37:24,710 --> 00:37:22,000
these really tricky things and so we'll

1045
00:37:26,870 --> 00:37:24,720
get spectra we'll get spectra

1046
00:37:29,270 --> 00:37:26,880
of tens of millions of galaxies all

1047
00:37:31,430 --> 00:37:29,280
across the extra galactic sky

1048
00:37:33,349 --> 00:37:31,440
and we will also make three-dimensional

1049
00:37:35,349 --> 00:37:33,359
maps using this spectra and we will

1050
00:37:37,510 --> 00:37:35,359
statistically statistically extract

1051
00:37:40,230 --> 00:37:37,520
those acoustic bubbles and and connect

1052
00:37:42,630 --> 00:37:40,240
redshift to distances that way and so we

1053
00:37:44,950 --> 00:37:42,640
will make we will try to reproduce

1054
00:37:47,190 --> 00:37:44,960
um what hubble did a hundred years ago

1055
00:37:48,950 --> 00:37:47,200
and hopefully do something a little bit

1056
00:37:50,630 --> 00:37:48,960
better than that and so let me show you

1057
00:37:52,470 --> 00:37:50,640
what hubble did 100 years ago if you see

1058
00:37:54,150 --> 00:37:52,480
that if you look at the next

1059
00:37:56,069 --> 00:37:54,160
picture that's actually hubble's plot

1060
00:37:57,430 --> 00:37:56,079
from his paper where he plotted velocity

1061
00:37:59,589 --> 00:37:57,440
against distance and velocity

1062
00:38:01,510 --> 00:37:59,599
corresponds to redshift and you see this

1063
00:38:03,349 --> 00:38:01,520

line of increasing velocity with

1064
00:38:05,430 --> 00:38:03,359
distance of course he

1065
00:38:06,790 --> 00:38:05,440
got the numbers quite wrong but the

1066
00:38:08,790 --> 00:38:06,800
trend was still there we know the

1067
00:38:10,550 --> 00:38:08,800
universe is expanding and so if you zoom

1068
00:38:12,150 --> 00:38:10,560
out massively now you get a plot like

1069
00:38:14,710 --> 00:38:12,160
this which is what we're doing nowadays

1070
00:38:15,990 --> 00:38:14,720
in cosmology and so it's not just euclid

1071
00:38:17,430 --> 00:38:16,000
there's been several experiments that

1072
00:38:19,670 --> 00:38:17,440
have been trying to to make this

1073
00:38:21,349 --> 00:38:19,680
connection and so there's been several

1074
00:38:22,790 --> 00:38:21,359
ground-based experiments and their

1075
00:38:24,069 --> 00:38:22,800
results um

1076
00:38:26,150 --> 00:38:24,079
specifically to do with redshift

1077
00:38:28,630 --> 00:38:26,160
distance relation uh i've put on this

1078
00:38:30,630 --> 00:38:28,640
plot with the colorful single dots and

1079
00:38:32,710 --> 00:38:30,640
then i've shown you what we think euclid

1080
00:38:34,950 --> 00:38:32,720
will do and how it will fill this gap in

1081
00:38:36,710 --> 00:38:34,960
distance and redshift with very very

1082
00:38:38,470 --> 00:38:36,720
small error bars that you can't even see

1083
00:38:40,470 --> 00:38:38,480
because they're hiding behind the points

1084
00:38:42,470 --> 00:38:40,480
and so this is what you will do and so

1085
00:38:44,310 --> 00:38:42,480
i've put on here what

1086
00:38:46,550 --> 00:38:44,320
what experiments have done so far and

1087
00:38:48,870 --> 00:38:46,560
what euclid will might do and but i've

1088
00:38:50,470 --> 00:38:48,880

also put four four lines on here and

1089
00:38:52,310 --> 00:38:50,480
these lines they correspond to different

1090
00:38:53,670 --> 00:38:52,320
universes different types of universe

1091
00:38:55,510 --> 00:38:53,680
that we might live in

1092
00:38:57,510 --> 00:38:55,520
and you can see that even already all

1093
00:39:00,390 --> 00:38:57,520
the data that exist is lying very close

1094
00:39:03,030 --> 00:39:00,400
to this solid line and this solid line

1095
00:39:05,589 --> 00:39:03,040
corresponds to a universe that is only

1096
00:39:07,829 --> 00:39:05,599
five percent made of regular matter that

1097
00:39:12,390 --> 00:39:07,839
we're made of so called baryonic matter

1098
00:39:15,589 --> 00:39:12,400
25 of it is made of dark matter and 70

1099
00:39:17,829 --> 00:39:15,599
of the universe is made of dark energy

1100
00:39:19,670 --> 00:39:17,839
and that's what all the data is pointing

1101
00:39:21,349 --> 00:39:19,680
at and we that's what we're trying to do

1102
00:39:23,589 --> 00:39:21,359
we're trying to to do with euclid and

1103
00:39:25,670 --> 00:39:23,599
with spherics and with with all these

1104
00:39:28,310 --> 00:39:25,680
different experiments is try to

1105
00:39:30,310 --> 00:39:28,320
really um get this data really really

1106
00:39:32,630 --> 00:39:30,320
precisely make these lines really really

1107
00:39:35,030 --> 00:39:32,640
precisely and try to understand

1108
00:39:36,550 --> 00:39:35,040
all the properties of dark energy and

1109
00:39:38,230 --> 00:39:36,560
how it impacts the

1110
00:39:39,910 --> 00:39:38,240
accelerated expansion in the universe

1111
00:39:41,990 --> 00:39:39,920
and of course of inflation in the case

1112
00:39:44,150 --> 00:39:42,000
of spherex and try to understand what

1113
00:39:45,750 --> 00:39:44,160

that implies about fundamental physics

1114
00:39:48,069 --> 00:39:45,760
and i personally am really excited about

1115
00:39:50,870 --> 00:39:49,910
thank you so much dita that is just so

1116
00:39:53,190 --> 00:39:50,880
cool

1117
00:39:54,950 --> 00:39:53,200
um so let's bring phil back and then

1118
00:39:56,950 --> 00:39:54,960
just let me mention

1119
00:39:59,190 --> 00:39:56,960
as of now euclid's scheduled to launch

1120
00:40:01,109 --> 00:39:59,200
in a little over a year at spherex in

1121
00:40:03,990 --> 00:40:01,119
just a few years and i also wanted to

1122
00:40:06,150 --> 00:40:04,000
note that as many of you that uh are

1123
00:40:07,750 --> 00:40:06,160
familiar with nasa may already know all

1124
00:40:11,670 --> 00:40:07,760
of this data is

1125
00:40:15,270 --> 00:40:11,680
will be publicly available

1126
00:40:16,710 --> 00:40:15,280
yeah so uh yeah i mean i think um

1127
00:40:19,109 --> 00:40:16,720
i hope we conveyed some of our

1128
00:40:20,309 --> 00:40:19,119
excitement for this upcoming uh you know

1129
00:40:22,550 --> 00:40:20,319
missions

1130
00:40:24,069 --> 00:40:22,560
and uh you know we've concentrated data

1131
00:40:27,109 --> 00:40:24,079
and i are cosmologists and so that's

1132
00:40:28,950 --> 00:40:27,119
that's kind of our area but i think

1133
00:40:31,109 --> 00:40:28,960
what's really going to be exciting is

1134
00:40:32,630 --> 00:40:31,119
that we're shoveling all of this data

1135
00:40:34,950 --> 00:40:32,640
just out into the community the

1136
00:40:36,550 --> 00:40:34,960
astronomical community but also just the

1137
00:40:38,550 --> 00:40:36,560
the general public

1138
00:40:40,470 --> 00:40:38,560

and those data sets are going to have so

1139
00:40:42,710 --> 00:40:40,480
much information just in in the case of

1140
00:40:46,150 --> 00:40:42,720
spherex there's going to be billions of

1141
00:40:47,190 --> 00:40:46,160
galaxies with spectroscopic uh

1142
00:40:48,870 --> 00:40:47,200
data

1143
00:40:52,309 --> 00:40:48,880
hundreds of millions of main secret

1144
00:40:54,390 --> 00:40:52,319
stars hundreds of brown dwarfs and all

1145
00:40:56,230 --> 00:40:54,400
sorts of other stuff

1146
00:40:57,430 --> 00:40:56,240
euclid is going to cover supernovae

1147
00:40:59,349 --> 00:40:57,440
they're going to do gravitational

1148
00:41:03,510 --> 00:40:59,359
lensing there's going to be

1149
00:41:05,750 --> 00:41:03,520
you know millions of galaxy mergers and

1150
00:41:07,829 --> 00:41:05,760
perhaps the most exciting stuff is just

1151
00:41:09,750 --> 00:41:07,839
what we haven't even thought of yet the

1152
00:41:12,630 --> 00:41:09,760
discovery space when you do these kinds

1153
00:41:13,829 --> 00:41:12,640
of huge surveys and just you know

1154
00:41:17,190 --> 00:41:13,839
deliver

1155
00:41:20,630 --> 00:41:17,200
a really big data set out into the

1156
00:41:22,710 --> 00:41:20,640
the world of astronomers to to mine and

1157
00:41:23,910 --> 00:41:22,720
glean as much information as possible

1158
00:41:25,510 --> 00:41:23,920
out of there

1159
00:41:27,270 --> 00:41:25,520
if i had to bet right now i'd say the

1160
00:41:29,030 --> 00:41:27,280
most exciting thing

1161
00:41:30,309 --> 00:41:29,040
to come out of spherex is really

1162
00:41:31,750 --> 00:41:30,319
something that we haven't thought about

1163
00:41:34,470 --> 00:41:31,760

right now so

1164
00:41:36,470 --> 00:41:34,480
i'm really excited and i hope we we

1165
00:41:37,670 --> 00:41:36,480
conveyed our uh some of that excitement

1166
00:41:39,829 --> 00:41:37,680
to you today

1167
00:41:41,750 --> 00:41:39,839
oh yeah very cool you guys both of you

1168
00:41:43,430 --> 00:41:41,760
thank you so much um yeah it's gonna be

1169
00:41:45,829 --> 00:41:43,440
great to see like just what becomes of

1170
00:41:47,430 --> 00:41:45,839
all this great data so i think this is a

1171
00:41:49,030 --> 00:41:47,440
great time to see what kind of questions

1172
00:41:50,710 --> 00:41:49,040
we have out there so caitlin uh what are

1173
00:41:52,309 --> 00:41:50,720
you seeing out there in the in the media

1174
00:41:55,430 --> 00:41:52,319
world

1175
00:41:58,069 --> 00:41:55,440
sure um so this one is for phil

1176
00:42:01,190 --> 00:41:58,079
musical wolves on youtube asks can

1177
00:42:03,030 --> 00:42:01,200
spheric see a galaxy behind a galaxy

1178
00:42:06,550 --> 00:42:03,040
does anything block its view is it

1179
00:42:08,790 --> 00:42:06,560
possible for it to see through

1180
00:42:11,270 --> 00:42:08,800
well so it's it's uh it's it's it's an

1181
00:42:13,589 --> 00:42:11,280
interesting question and it depends on

1182
00:42:15,270 --> 00:42:13,599
the contents of the different two

1183
00:42:16,470 --> 00:42:15,280
different galaxies

1184
00:42:19,270 --> 00:42:16,480
and uh

1185
00:42:21,190 --> 00:42:19,280
and what you know what the line of sight

1186
00:42:24,470 --> 00:42:21,200
that goes through it so you know that

1187
00:42:26,150 --> 00:42:24,480
absorption features those will imprint

1188
00:42:29,030 --> 00:42:26,160

different features so if you have like a

1189
00:42:30,630 --> 00:42:29,040
background illuminating galaxy and let's

1190
00:42:32,230 --> 00:42:30,640
say you know really

1191
00:42:33,349 --> 00:42:32,240
you know young and has lots of star

1192
00:42:36,470 --> 00:42:33,359
formation

1193
00:42:38,710 --> 00:42:36,480
and um you know lots of uv so really

1194
00:42:39,750 --> 00:42:38,720
blue and then the the galaxy that's in

1195
00:42:42,069 --> 00:42:39,760
front of it

1196
00:42:44,630 --> 00:42:42,079
um you know could have lots of molecular

1197
00:42:47,030 --> 00:42:44,640
clouds and dust and stuff what you would

1198
00:42:49,670 --> 00:42:47,040
see from the background source would

1199
00:42:51,750 --> 00:42:49,680
have an absorption fingerprint from the

1200
00:42:54,390 --> 00:42:51,760
foreground source so

1201
00:42:56,829 --> 00:42:54,400
you know it's hard to disentangle those

1202
00:42:59,190 --> 00:42:56,839
we always have to deal with the

1203
00:43:01,430 --> 00:42:59,200
resolution of our you know we can only

1204
00:43:03,030 --> 00:43:01,440
measure so fine of a thing we use the

1205
00:43:06,230 --> 00:43:03,040
word confusion

1206
00:43:07,829 --> 00:43:06,240
in uh in um in astronomy but mean it

1207
00:43:10,069 --> 00:43:07,839
literally but the beauty of

1208
00:43:11,990 --> 00:43:10,079
spectroscopic is that you know if you

1209
00:43:13,750 --> 00:43:12,000
have two spectra that are on top of each

1210
00:43:16,470 --> 00:43:13,760
other and if you have a high redshift

1211
00:43:18,309 --> 00:43:16,480
galaxy and a low redshift galaxies you

1212
00:43:23,430 --> 00:43:18,319
can see by separating out the colors the

1213
00:43:27,589 --> 00:43:25,109

great

1214
00:43:29,910 --> 00:43:27,599
thank you um we have another one this

1215
00:43:31,589 --> 00:43:29,920
one's for dita um this is a good

1216
00:43:35,190 --> 00:43:31,599
question how far away does something

1217
00:43:37,430 --> 00:43:35,200
have to be for it to redshift

1218
00:43:39,430 --> 00:43:37,440
um it's not about distance really it's

1219
00:43:40,950 --> 00:43:39,440
about the

1220
00:43:43,190 --> 00:43:40,960
apparent motion of it with respect to

1221
00:43:45,750 --> 00:43:43,200
the observer but i guess you could also

1222
00:43:47,990 --> 00:43:45,760
you could be asking actually about how

1223
00:43:49,990 --> 00:43:48,000
far does the galaxy have to be in order

1224
00:43:52,230 --> 00:43:50,000
for the expansion of space to red-shift

1225
00:43:55,030 --> 00:43:52,240
it and i mean in principle that's not

1226
00:43:58,150 --> 00:43:55,040
it's not a hard limit you know it's just

1227
00:44:00,230 --> 00:43:58,160
becomes more and more red-shifted so it

1228
00:44:02,470 --> 00:44:00,240
is really about the apparent velocity

1229
00:44:04,470 --> 00:44:02,480
but uh yeah it's just that the more the

1230
00:44:06,470 --> 00:44:04,480
further you look the more it seems

1231
00:44:08,309 --> 00:44:06,480
red-shifted which has to do with the

1232
00:44:10,309 --> 00:44:08,319
expansion of the universe but of course

1233
00:44:11,910 --> 00:44:10,319
you know there are also galaxies do

1234
00:44:14,069 --> 00:44:11,920
actually move around because of gravity

1235
00:44:16,150 --> 00:44:14,079
as well so there this is actually a

1236
00:44:17,589 --> 00:44:16,160
really interesting topic that i i work

1237
00:44:18,550 --> 00:44:17,599
on but i definitely don't have time to

1238
00:44:20,470 --> 00:44:18,560

talk about it but there's something

1239
00:44:21,990 --> 00:44:20,480
called redshift space distortions which

1240
00:44:23,750 --> 00:44:22,000
means that galaxies are moving around a

1241
00:44:25,670 --> 00:44:23,760
little bit as they're kind of going with

1242
00:44:27,270 --> 00:44:25,680
the expanding space and those redshift

1243
00:44:28,790 --> 00:44:27,280
space distortions actually can tell us a

1244
00:44:30,630 --> 00:44:28,800
lot about our theories of gravity and

1245
00:44:31,829 --> 00:44:30,640
they can we can test einstein's theory

1246
00:44:34,150 --> 00:44:31,839
with that and that's also really

1247
00:44:38,870 --> 00:44:34,160
exciting

1248
00:44:41,829 --> 00:44:38,880
um i think we have time for one more

1249
00:44:44,870 --> 00:44:41,839
question um this one i i think would be

1250
00:44:46,790 --> 00:44:44,880
for phil so rey on linkedin asks how

1251
00:44:48,829 --> 00:44:46,800
fast is the universe expanding does it

1252
00:44:50,470 --> 00:44:48,839
expand at the speed of

1253
00:44:52,790 --> 00:44:50,480
light

1254
00:44:54,950 --> 00:44:52,800
so okay when we talk about so that that

1255
00:44:56,470 --> 00:44:54,960
plot that that data showed we call that

1256
00:44:59,750 --> 00:44:56,480
the hubble flow

1257
00:45:02,390 --> 00:44:59,760
and if you look at what we call h naught

1258
00:45:04,710 --> 00:45:02,400
or how fast it's expanding today

1259
00:45:08,230 --> 00:45:04,720
um it's around

1260
00:45:10,790 --> 00:45:08,240
so 67 to 70 ish

1261
00:45:11,990 --> 00:45:10,800
kilometers per second per megaparsec

1262
00:45:13,510 --> 00:45:12,000
okay so let's

1263
00:45:15,750 --> 00:45:13,520

let's let's think about that for a

1264
00:45:18,550 --> 00:45:15,760
second um it's actually a very

1265
00:45:20,630 --> 00:45:18,560
convenient unit because we think about

1266
00:45:23,030 --> 00:45:20,640
okay a megaparsec that's a huge distance

1267
00:45:26,069 --> 00:45:23,040
so let's let's just answer that question

1268
00:45:27,510 --> 00:45:26,079
at a megaparsec which is a you know a

1269
00:45:28,390 --> 00:45:27,520
distance

1270
00:45:30,630 --> 00:45:28,400
that's

1271
00:45:32,870 --> 00:45:30,640
you know pretty cosmologically far away

1272
00:45:34,710 --> 00:45:32,880
from us but that means that those

1273
00:45:38,790 --> 00:45:34,720
galaxies are basically moving away from

1274
00:45:40,470 --> 00:45:38,800
us at 70 kilometers per second at that

1275
00:45:42,309 --> 00:45:40,480
at that distance so

1276
00:45:44,390 --> 00:45:42,319
that's how far away

1277
00:45:46,470 --> 00:45:44,400
also interesting about that expansion

1278
00:45:49,109 --> 00:45:46,480
rate if we now think okay kilometers per

1279
00:45:51,270 --> 00:45:49,119
second per megaparsec okay kilometers a

1280
00:45:53,109 --> 00:45:51,280
unit of distance megaparsec is a unit of

1281
00:45:55,510 --> 00:45:53,119
distance so you can convert things

1282
00:45:57,910 --> 00:45:55,520
around and those distance cancel out and

1283
00:45:59,750 --> 00:45:57,920
then you're left with one over seconds

1284
00:46:02,069 --> 00:45:59,760
so it's an inverse time

1285
00:46:04,390 --> 00:46:02,079
if we invert that time

1286
00:46:07,109 --> 00:46:04,400
you'll get something around 14 billion

1287
00:46:10,790 --> 00:46:07,119
or 13.8 billion and that's the age of

1288
00:46:14,790 --> 00:46:12,870

wow

1289
00:46:18,390 --> 00:46:14,800
well thank you very much phil thank you

1290
00:46:20,230 --> 00:46:18,400
very much dida so folks that's about all

1291
00:46:22,309 --> 00:46:20,240
the time we have tonight so i want to

1292
00:46:23,910 --> 00:46:22,319
thank both of you dita phil thank you so

1293
00:46:25,589 --> 00:46:23,920
much caitlyn of course

1294
00:46:27,589 --> 00:46:25,599
all the folks behind the scenes and of

1295
00:46:29,910 --> 00:46:27,599
course all of you out there for tuning

1296
00:46:32,230 --> 00:46:29,920
in as caitlyn said earlier you know this

1297
00:46:33,829 --> 00:46:32,240
is your space program and this is one

1298
00:46:35,910 --> 00:46:33,839
way for you to participate in it and we

1299
00:46:37,990 --> 00:46:35,920
appreciate that so thank you

1300
00:46:40,790 --> 00:46:38,000
so please join us next month when we'll

1301
00:46:42,790 --> 00:46:40,800
talk with jpl scientist josh willis

1302
00:46:45,109 --> 00:46:42,800
about the sentinel 6 michael freilix

1303
00:46:47,990 --> 00:46:45,119
satellite's first year in space that'll

1304
00:46:53,150 --> 00:46:48,000
be a good one until then be safe and